HEUN

OFF GRID PROJECT

Engr. 333A

Prof. Heun

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Goal

The goal of the project was to construct a *realistic* plan to get Calvin *off the grid*. This means that Calvin would own and operate on–site facilities that generate all the electricity consumed by the campus. Current peak load for the college is approximately three megawatts. Upon completion of the new recreation center and dining hall renovation, future load will climb to roughly five megawatts. As a result, the desired system to remove the college from the grid would provide five megawatts.

Method of Approach

Three technology groups were presented with a variety of energy producing technologies for utilization in an off-grid proposal. The technologies included geothermal, solar photovoltaic, solar thermal, cogeneration, fuel cells and wind power. After some initial research, the technology groups concluded the three most promising systems were solar photovoltaic, cogeneration, and fuel cells.

After selecting a technology to pursue, each group attempted to research a system large enough to supply all of the college's energy needs. Shortly thereafter, it became apparent that getting off the grid using some of the technologies was not feasible. Solar panels are so large that Calvin does not have enough space to contain the number of panels necessary to produce five, or even three, megawatts. In addition, current panel cost is prohibitive for large scale implementation on campus or anywhere in the Midwest. Similarly, the cogeneration and fuel cell groups found that systems as large as three or five megawatts were not economically feasible. At this point, each group was directed to focus on the largest system that might be economically feasible. This introduced the possibility of combining technologies later to produce the total desired output or using small systems to reduce energy dependence as well as cost, although not providing energy independence.

Analysis

Solar Photovoltaic

After determining that large scale solar PV was not feasible, several ideas were proposed. First, the group decided to research small solar arrays which could attach to light posts and power the lights at night. Second, the group sought to investigate smaller scale systems to mount on existing as well as future buildings. These systems would be of the same magnitude as the existing twenty kilowatt Bunker Center array.

The individual solar arrays for light posts proved too expensive for consideration. Instead, the solar group's final proposal consisted of a seventy-five kilowatt array which would be tied to Calvin's main grid. Seventy-five kilowatts is the load required to power all of the lights at night, so this was the reference number used for the new system.

Electricity is most expensive to purchase from the grid between the hours of 11 AM and 7 PM. Energy purchased during this time period is referred to as "on-peak". Electricity purchased any other time is "off-peak" and costs roughly one third of on-peak prices. Although the proposed solar array is not large enough to lessen the college's dependency on the electric company, it can be used for "peak shaving", which is the practice of producing energy during the times when it is most expensive to buy from the electric company. This is exactly what the proposed solar system would do.

Fuel Cells

Because data for specific fuel cells is difficult and time consuming to obtain, the group asked companies for information on one megawatt, three megawatt, and five megawatt systems simultaneously. Before cost information was known, the group found many non-economic advantages associated with fuel cells. Upon hearing back from fuel cell manufacturers, it was clear that no fuel cell system is currently economically viable. The high initial system cost and the high fuel and maintenance costs yield losses each year after implementation.

Cogeneration

Cogeneration is a term referring to any type of power generation which produces both electricity and heat. The co-gen group focused on both reciprocating and turbine engines for their analysis. As previously mentioned, a five megawatt cogeneration system is not economically viable for the college. Knowing this, the group investigated six different turbine engine sizes and two reciprocating engines in order to select the largest system that is financially beneficial. These systems ranged in size from **1.2** megawatts to **5** megawatts.

An in depth study of reciprocating engines revealed that no current model exists which yields a profit. With natural gas costs at current levels, these engines can never pay themselves off and the buyer could suffer significant losses if gas prices increase further. Turbine engines produce significantly more steam than reciprocating engines, and this steam gives turbines much more potential economic payback if the steam can be used. However, utilizing all of the steam from large turbines proved difficult. Small turbine engines were the only option which had economic potential, so the group focused their efforts on an in depth analysis for these systems.

Conclusion

It was evident early on in the project that removing Calvin College completely from the grid is not economically feasible at this time. Although this is true, implementing a cogeneration system on campus will help lessen the college's demand on the power company and could save millions of dollars over time. The only researched technology capable of such cost savings is a turbine system. The ideal turbine engine for the college is a 1.2 MW Saturn 20.

The Saturn 20 is an ideal system because it provides **1.2** MW of electricity and Calvin's steam demand is large enough to utilize all the heat produced by the turbine. Any larger turbine produces more steam than the college's demand and some would be wasted. This turbine will be accompanied by two chillers which utilize steam for cooling purposes. The complete system (engine room, chillers, and vapor phase) occupy roughly a **50' x 56'** rectangle. Potential locations for the system are adjacent to the renovated Knollcrest dining hall or next to the Prince power plant, as seen in Figure D.3 in Appendix D.

Funding for a turbine would not be available up front. The college would have to borrow money and pay it back over a four year period. One benefit is that the college can "borrow" money from its endowment fund and pay it back without interest. Doing this would mean other improvements to campus could not be made until the money was paid back, but it would be cheaper than borrowing from a bank.

APPENDIX A:
Cogeneration Analysis

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Introduction

This report is to allow the integration group to examine the application of optimized gas turbine and reciprocating engine systems. We investigated a variety of different factors to find the optimum solution. Some factors were: the addition of absorption chillers, different lengths of loans, different sizes of systems, different prices of natural gas, etc to see which system would be the best fit for the college and provide the quickest return on capital investment.

Technology Choice – Gas Turbine Cogeneration

In today's society energy usage is becoming an increasing concern. Calvin College is actively seeking ways to conserve energy for two major reasons. First, they wish to be a steward in their usage of the environment. Second, they want to keep energy cost low so that subsequent costs are not passed on to students. To accomplish these goals research was done on the installation of cogeneration systems.

There are two major types of cogeneration systems gas turbines and reciprocating engines. Both of these systems provide a reliable source of electric and steam power for campus. However when costs are concerned the gas turbine provides a much higher return on investment than the reciprocating engine.

For our analysis we calculated on and off peak rates for each month. These rates show both the amounts of steam and electricity used and produced for the campus. On peak times may be times while classes our in session whereas off peak times may be during holidays such as Christmas break.

The monthly steam and energy usage was calculated because it will show how the amounts necessary to heat and power campus change on a monthly basis.

The effect that temperature has on the steam output is that as the average monthly temperature drops the amount of steam the system will produce also drops. The effect that temperature has on electrical output is that as temperature drops more electricity will be produced from the system.

When supplemental firing takes place more fuel is added to the system which in turn produces more steam. The worksheet has been optimized so that the optimum amount of fuel has been added to the system and we receive the best output.

The best case situation found can be seen below in Table A.1. Appendix A shows the optimized gas turbine system and the savings it will provide the college.

Appendix B shows the amount of time it will take to break even on the optimal gas turbine system and how much the return on the investment will be for different loan lengths.

Other Design Aspects

Aesthetics

Co-generation systems are not generally aesthetically pleasing. These systems need to be fully enclosed in a building. The building also needs to be able to dampen the noise produced by the engines.

Expandability

Cogeneration systems are expandable if there is sufficient space for turbines and piping. Expandability is also dependent on how easy it is to tie the system into the steam loop.

Reliability

Gas turbine cogeneration systems are a proven and effective way to efficiently generate electric power, heat, and cooling. Turbine cogeneration systems are very reliable in terms of power availability. This technology has had a lot of time to develop and be refined. With proper maintenance these systems have an uptime of approximately 96%.

Pollution

This system runs on natural gas and other gaseous fuels. Gas turbines produce virtually no sulfur dioxide (SO_2), particulates, or air toxins. However more power and thermal efficiency through high firing temperatures and air compression ratios, has translated into increased and uncontrolled emissions of NOx gases.

Fuel

Natural gas is a non-renewable resource, but this system can be operated on other fuels such as methane, which is renewable. Currently the supply of natural gas is not in danger of running out, but the price fluctuates unpredictably. Best and worst-case scenarios for the price of gas were calculated in our analysis. These calculations show that co-generation systems are very sensitive to the price of natural gas.

Funding

After an extensive search of Michigan government and environmental programs no grants were found for co-generation energy. Our financial analysis includes several loan options for purchasing this system. The costs of cogeneration systems have leveled off, and do not promise to be come cheaper in the future.

Maintenance and Repair

The cost of maintenance and repair for a gas turbine system was estimated in two ways. An estimated rate quoted from engine suppliers was obtained. Then the actual costs from our current co-generation system were used to find the current rate Calvin College is paying. These rates as well as the rate we used in our analysis are presented in Table A.2.

Space Requirements

The space requirements will depend greatly on the size of the system. Several different system sizes were analyzed in our model.

Reciprocating IC Engine

Based on our analysis we found the reciprocating engine system not feasible for Calvin College. The first reason that the reciprocating engine will not works is that it is very sensitive to the cost of natural gas. Part of the reason that the engines are much more sensitive to the cost of gas is that they are less efficient than the gas turbines; the reciprocating engines we chose range in efficiency from 68-72%. The graph below (Figure A.1) shows that no matter what the cost of gas is, there is no point at which the reciprocating engine will provide a greater return than the gas turbines.

The graph shows the cost that gas must be in order for the college not to be losing money on the system. Calvin currently pays around $7.00 for gas which means that if the price continues to increase the college is not far off from being at a price where they would start losing money on the system.

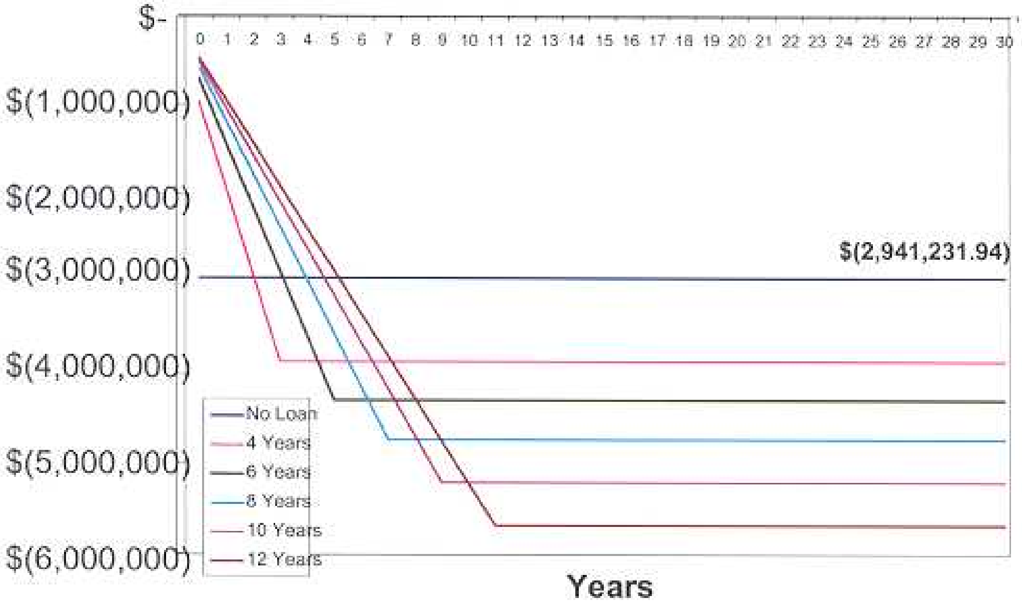

Figure A.1: Reciprocating Engine Financial Status Next 30 Years

$7.74 Gas Price

Further explanation of this case

It was assumed that all necessary equipment could be purchased without the need for loans. Also assumptions were made about Calvin's current heating and cooling needs. Calvin was helpful in providing actuate information regarding the heating requirements but little information is know about the day to day cooling requirements. First calculations were done to show that at Calvin's peek heating loads would utilize 100% of the steam energy received from the turbine. Second, during the summer time steam from the turbine would be vented to the atmosphere. This was a very inefficient option and not cost effective. Alternatively absorption chillers could be purchased to replace the cooling received from electric driven compressors. This creates a use for the steam during the summer time and also a savings of electricity from not running the compressors. The currently the air conditioners are load sensing (in other words the hotter it becomes the harder the compressor works). To compensate for this unknown variable it was assumed that the average load while operating the absorption chillers is 15%. This takes into account the lower cooling load required at night and during the spring and fall. It was assumed that cooling systems would be needed for 5 months of the year. Also the cost analysis for steam savings was updated to reflect the changes in seasons. During the winter months it was shown that all steam could be used for heating. During the spring and fall 80% of the steam will be wasted because both the heating and cooling loads don't require it. In the summer it is estimated that during peak loading the absorption chillers will need to utilize 90% of the steam.

Conclusion

To take the college off the grid is a feasible option however we recommend not to do so right away. Whether the system will pay for itself is still heavily determined by the cost of natural gas. With continued uncertainty in the fossil fuel industry the best thing to do right now may be to wait to determine whether the cost of natural gas escalates significantly or levels off.

Table A.1: Optimized System Selection and Annual Savings

	Turbine #	Fuel Volume (1000ft^3/hr)	range	Steam Outputs (1000-lb/hr)	kW-hr	Fuel for steam	Energy required kW-hr found in s	Steam costs per hr	Turbine Op. Costs Yearly
Saturn 20	1	19	16.3 to 46.386	11592	1174	14	4271	106	$1,198,368
Centuar 40	2	41.4	41.4 to 132.17	19210	3419	23	7077	176	$2,611,181
Centuar 50	3	51.53	51.53 to 139.5	25238	4483	31	9297	231	$3,250,100
Mercury 50	4	39.14	39.14 to 130.8	13009	4506	16	4792	119	$2,468,638
Taurus 60	5	58	30.3 to 160	87575	5376	107	32262	801	$3,658,176
Saturn 20 2X	6	38		23185	2348	28	8541		$2,396,736
none of the above	7	0		0	0	0	0		$0

Select the turbine #

1

Total Annual savings

$580,046.71

Figure A.2: Financial Status For Next 30 Years
$7.50 For Gas

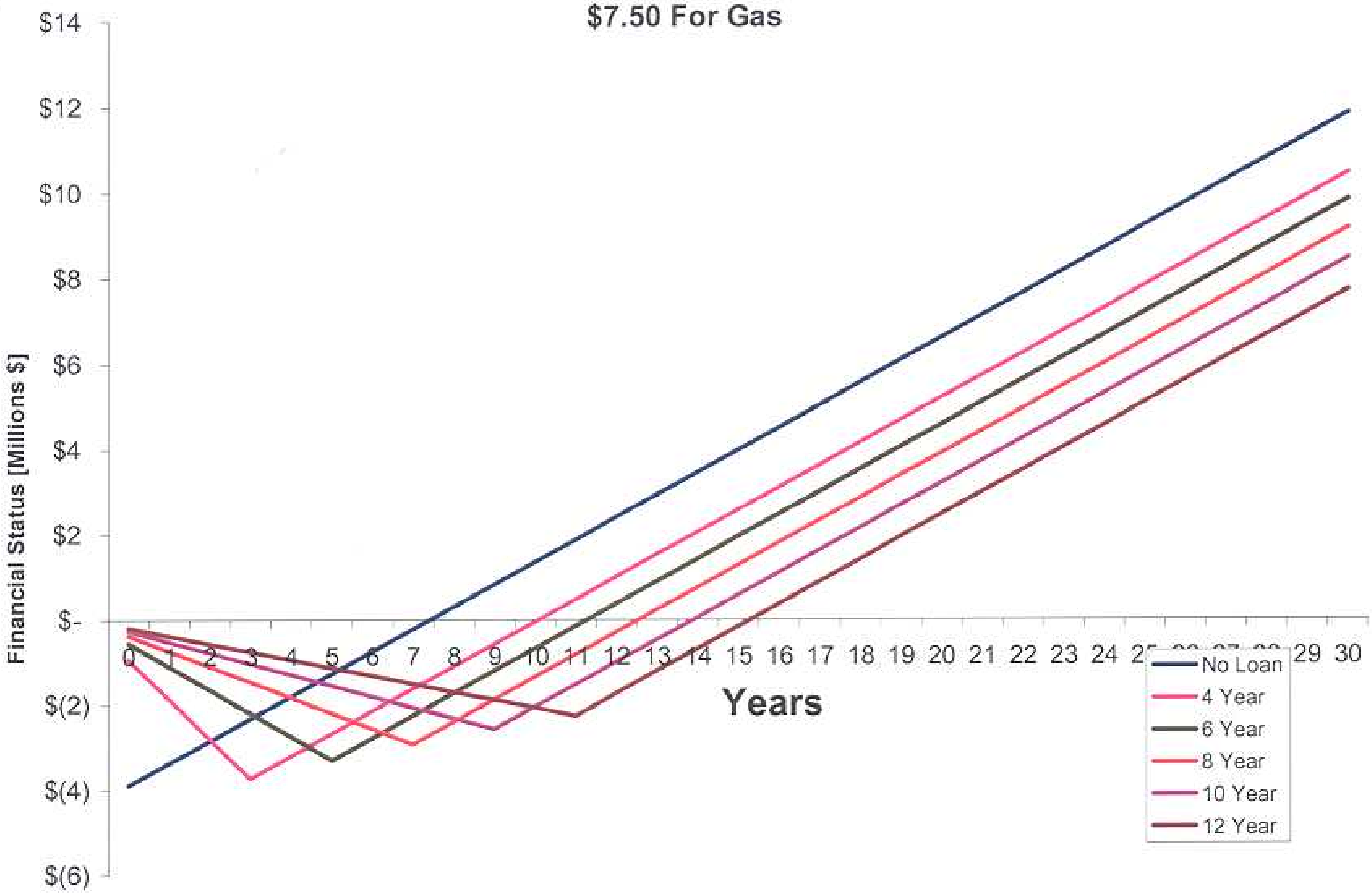

Table A.2: Operations and Maintenace Costs

Capital Costs considered for this analysis

	Saturn	Centaur 40	Centaur 50	Mercury	Taurus 60
Turbine Engine	828000	1470000	1884000	1960000	2640000
Heat recovery system	437500	625000	750000	750000	875000
Switch gear	125000	187500	187500	250000	250000
Installation and slab	600000	1750000	1750000	1750000	1750000
Engineering	312500	500000	500000	500000	625000
Contingency	187500	468750	493750	493750	525000
Totals	**$ 2,490,500**	**$ 5,001,250**	**$ 5,565,250**	**$ 5,703,750**	**$ 6,665,000**

Capital Costs considered for this analysis to date

	7042-GL	16V-AT27GL	Case 1	Case 2	Case 3
Engine	400000	1300000	1200000	1300000	2100000
Equipment	200000	650000	600000	650000	1050000
Installation and slab	400000	1000000	1200000	1000000	1800000
Engineering	100000	500000	300000	500000	700000
Totals	**$ 1,100,000**	**$ 3,450,000**	**$ 3,300,000**	**$ 3,450,000**	**$ 5,650,000**

CSI 15-675, Absorption chillers					**Total install costs**	Total Costs
	Material	Labor	Equip		**Cost CAP Absorbsion Chiller**	
100 ton	51600	1280	127	53007	$ 132,800.00	**$ 185,807.00**
150 ton	66600	1500	149	68249	$ 167,200.00	**$ 235,449.00**
200 ton	74300	1640	163	76103	$ 201,600.00	**$ 277,703.00**
250 ton	83500	1710	170	85380	$ 236,000.00	**$ 321,380.00**
350 ton	102000	2070	205	104275	$ 304,800.00	**$ 409,075.00**
750 ton	182000	3030	301	185331	$ 580,000.00	**$ 765,331.00**
850 ton	195000	3210	319	198529	$ 648,800.00	**$ 847,329.00**
950 ton	209000	3570	354	212924	$ 717,600.00	**$ 930,524.00**
1125 ton	241000	3920	389	245309	$ 838,000.00	**$ 1,083,309.00**

cost of electric	$	0.06
Eff Electric Comp		95%
Average Load %		12%

12000 btu/cool ton
0.000293071 convert btu to kW hours

	Current syste	Cooling load (kW)	Annual costs	
Science BL	850	2989.324946	$ 15,768.53	$ 117,800.21
Library	1100	3868.538165	$ 102,031.68	$ 23,560.04
AB chiller	850	2989.324946	$ 78,842.66	
Total used	2800	9847.188056	$ 196,642.87	

Cost Alternatives

	Sizes neede	Total Cost	Steam Require	Steam Requirements
New Chiller	850	$ 847,329.00	15895	1907.4
New Chiller	1125	$ 1,083,309.00	21037.5	2524.5
Current Chiller	850	Currently used (free)	15895	1907.4
Total	2825	$ 1,930,638.00	52,827.50	6,339.30

18.7 steam to ton refrigeration

Table A.3: Steam and Electrical Outputs as a Function of Average Temperature

Steam outputs as function of yearly temperature

			1		2	3	4	6	7
	Temp F		Saturn 20		Centaur 40	Centaur 50	Mercury 50	Saturn 20	NONE
Jan	21.8		9012		22209	28564	16894	18025	0
Feb	23.7		9087		22060	28470	17079	18173	0
Mar	34.1		9628		21397	28121	18905	19255	0
Apr	46		10586		21175	27993	23594	21172	0
May	57.5		11944		21845	28025	32317	23889	0
Jun	67		13451		23330	28082	43981	26902	0
Jul	71.6		14321		24428	28097	51469	28643	0
Aug	69.5		13912		23893	28092	47886	27824	0
Sep	61		12456		22280	28047	36074	24912	0
Oct	49.5		10950		21269	27992	25730	21900	0
Nov	38		9897		21245	28053	20067	19795	0
Dec	27		9233		21818	28329	17494	18465	0

Electrical outputs as function of yearly temperature

			1		2	3	4	6	7
	Temp F		Saturn 20		Centaur 40	Centaur 50	Mercury 50	Saturn 20	NONE
Jan	21.8		1213		4030	5176	5176	2426	0
Feb	23.7		1215		3997	5142	5142	2430	0
Mar	34.1		1221		3821	4968	4968	2442	0
Apr	46		1214		3647	4786	4786	2427	0
May	62		1177		3471	4562	4562	2355	0
Jun	71		1145		3400	4436	4436	2291	0
Jul	74.6		1131		3376	4384	4384	2262	0
Aug	72.5		1139		3390	4414	4414	2279	0
Sep	61		1180		3480	4576	4576	2361	0
Oct	49.5		1208		3603	4736	4736	2417	0
Nov	38		1220		3761	4906	4906	2441	0
Dec	27		1218		3939	5085	5085	2436	0

APPENDIX B:
Solar Photovoltaic Analysis

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Aaron Svacha

Abstract

To coordinate Calvin College with its future expansion and goal of getting off the electricity grid, a medium-sized solar photovoltaic (PV) system was proposed. The initial target energy loads were the parking lot and path lights located throughout the entire campus. The current system utilizes electricity from Consumer's Energy, through three separate lighting loops. Switching the energy source from the grid to the PV cell attains the desired goal. While the initial goal was to store electricity and use it for the lights, due to battery costs as well as the increased cost of electricity during the day, it became apparent that it would be better to dump the power directly into the grid, and pull from the grid at night to power the lights.

Objective

The objective of this appendix is to outline a plan for purchasing and maintaining a solar PV system that would replace the current supply of electricity from the grid. The information required to meet the stated proposal consists of a detailed layout of component data, a financial summary throughout the implementation process, and a location for the system(s).

Array Panels

Currently, the power required to operate all of the **490** parking lot, roadway, and path lights is **75kW**. To generate this amount of electricity from a PV array, 28,000ft^2 of amorphous panels are required. Alternatively, crystalline panels could be used, taking up about 12,600ft^2. The question arises as to which type of panel to use. At first glance, the crystalline seems better because it produces the same power as the amorphous in less space; however, due to the ease of installation and capability of producing power at lower light levels, amorphous panels give crystalline a run for its money. Installation of amorphous panels is much more simplistic than for crystalline as it is an adhesive backed roll that is durable enough to walk on. These factors alone provide for ideal installation and maintenance. A more in depth lest of the technical details of these panels is located in Table B.2.

Location

Because of the large physical space required by photovoltaic panels, and their need for direct sunlight, the location of the array and its components is an important factor in the process. Additionally, the system must maintain aesthetic appeal. With this in mind, there are a number of feasible roof locations on Calvin's campus. Buildings that appear to fit this description are the Hekman Library, all dormitories, and North Hall. The college is including a new Physical Education (PE) building and Knollcrest Dining Hall in its future expansion plans, thus these would be the best buildings to target for PV. The panels are most efficient when they are facing South at an angle of 44° to the ground. By designing these two buildings with PV in mind, not only will the buildings be more efficient sources of PV electricity, but it will also look better as the building and PV were designed together as one unit. Also, by integrating the PV into the roof, you can easily extend the life of your roof thus saving the college even more money in the long run.

While amorphous panels tie nicely into future projects and sloped roofs, the crystalline works very nicely on flat roofs because extra mounts will be needed anyways. The drawback for crystalline panels is that their mounting often requires holes to be drilled in the roof top to secure the panel system. This idea does not go well with the maintenance of buildings. The flat surfaces of North Hall and the Hekman Library are ideal for crystalline panels, but only if a mounting system that does not involve drilling holes in the roof can be found.

Financial Plan

While a portion of the implemented photovoltaic system will be paid for by way of a grant, not all of it is capable of being paid in this fashion. Most grants will only cover the materials such as the PV panels and the batteries, but installation costs must all be absorbed by the recipient of the grant. While this is how grants are generally set up, the installation cost does not appear to be the only costs that Calvin College will be left with, at this time the only grant that we found was for $60,000 from the Michigan Energy Office, thus covering only 6% of the initial cost of the system. Because of this, a loan must be taken out to cover the remaining costs. Assuming a 12% interest rate and a desire to pay off the loan in 7 years, produces annual payments of $207,000 bringing the total pay that Calvin College must cover up to 1.45M$; costing Calvin paying nearly 1.5 times the cost of the system. While this is all happening, the PV system is producing electricity, thus saving the college money on the order of $23,000 per year, if a 75kW system is implemented. If this is the case, over the next 30 years, Calvin will have saved a total of about $720,000. While this is a nice savings it still does not come close to paying off the entire system, or for that matter buying an additional one. Even if Calvin College were to pay for the proposed PV system upfront with "out-of-pocket" money, it would take almost 23 years for Calvin to get the money back out of their investment.[1] Figure 1 shows this concept graphically.

A final note on financing solar panels is that payback rate or the economic efficiency does not change with the size of the system. This is different than many investments where a larger upfront capital yields higher economic efficiency.

Non-Fiscal Benefits

Due to the operating simplicity of PV and the ongoing reliability of the sun, PV electricity is very reliable and is 100% pollutant-free. This type of environmentally friendly energy generation is great for the College's public image. It represents both Calvin's concern for God's creation and the school's insistence of staying on the cutting edge of developing technologies. Additionally, the panels have a long guaranteed life of 20-25 years and continue to work well beyond that, thus providing years of educational value.

Conclusion

While PV is a very green energy, in the form of energy conservation, it is also very green in the price tag that it comes with. Because of the extreme upfront cost, strictly from a financial viewpoint, PV won't pay for itself under current values and probably will not in the near future either. However, because the financial 'green' is not the only green that matters, it would be good to reiterate the simplicity and pollutant-free operation that photovoltaic cells provide. Due to all of the benefits of green energy it seems that if larger grants are found it would be very wise to implement Calvin with more PV focusing the crystalline atop flat roofs and building the amorphous panels into the new roofs and even attaching it to some of the older ones.

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[1] This does not include interest made on yearly savings.

Table B.1: Outdoor Lighting Power Requirements

		Large Lights	Small Lights		
	Wattage (W/bulb)	175	100		
	Quantity (# bulbs/Calvin)	343	150		
	Pole Cost ($/pole)	200	200		
	Fixture Cost ($/light)	495	495		
	Life (hrs/bulb)	7500	10000		
	On Time (hrs/day)	16	16	**Max / 'Worst Case'**	**10-16 hrs/day**
	On Time (hrs/day)	10	10	**Min / 'Best Case'**	**10-16 hrs/day**
	Maintenance (hr/light-year)	1	1		
	Electric Demand (kW/Calvin)	60.025	15	**75.025**	**PV size requirement**
Max	**Power Demand (kW-hr/day-Calvin)**	960.4	240	**1200.4**	**Battery Power Required**
Max	**Power Demand (kW-hr/year-Calvin)**	350546	87600	**438146**	
Medium	**Power Demand (kW-hr/year-Calvin)**	284819	71175	**355993.6**	
Min	**Power Demand (kW-hr/year-Calvin)**	219091	54750	**273841.3**	
?	**Bulb Replacement (bulb/yr-Calvin)**	217.0046667	71.175	**# of bulbs being replaced each year**	
	Maintenance Wage ($/hr)	50	40	won't change w/ changes	
	Electric Cost ($/kW-hr)	0.065	0.065		
	Bulb Cost ($/bulb)	5	5	doesn't matter b/c won't change w/ changes	
lights	**Maintenance Bill ($/yr-Calvin)**	17150	6000	**23150**	won't be changed by modifications
	Bulb Bill ($/yr-Calvin)	1085.023333	355.875	**1440.898**	won't be changed by modifications
medium	**Current Electric Bill ($/yr-Calvin)**	18513.21063	4626.375	**23139.59**	

Table B.2: Photovoltaic Specifications

	PV System		Need 75 kW		
	Amorphous	**Crystalline**			
www.	OkSolar.com	solardepot.com			
Panel Type	PVL 87	PV/BP-3160B			
Life (yrs)	20	25			
Length (ft)	12.5	5.2			
Width (ft)	1.3	2.6			
SA (ft^2/panel)	16.1	13.5			
Panel Cost ($/panel)	480	779			
Mounting Materials ($/panel)	50	50			
Instalation Labor Cost ($/panel)	*50*	*250*	*estimated*	Labor	
Sum ($/panel)	**580**	**1079**	**1659**		
Maintenance Cost ($/yr-panel)	*0*	*0*	*estimated*		
Max Output (W/panel)	87	160			
Average Output (W/panel)	73.95	142			
Expected Output (W/panel)	43.5	80	Efficiency Expectation		0.5
Number of Panels	862.0689655	468.75			
Power Output (kW/Calvin)	37.5	37.5	**75**		
Equipment Cost ($/Calvin)	456896.5517	388593.75	**845490.302**		
Initial Labor ($/Calvin)	43103.44828	117187.5	**160290.948**		
Initial Cost ($/Calvin)	500000	505781.25	**1005781.25**		
SA requirements (ft^2/Calvin)	13918.82184	6327.148438	**20245.9703**		
Maintenance Cost ($/yr-Calvin)	0	0	**0**		

Table B.3: Additional Components

	Batteries	Inverter
Life (yrs)	8	*20*
Cost ($/unit)	155	1045
Capacity (W/unit)		3600
Capacity (A-hr/unit)	100	
Efficiency ($/W)		0.290278
Efficiency ($/A-hr)	1.55	
Voltage (V)	24	24
Power (kW-hr/unit)	2.4	
Energy (kW/unit)		3.6
Units Required	0	21
Equip Cost ($/Calvin)	0	21945
Labor Cost ($/Calvin)		
Maintenance Cost ($/yr-Calvin)		

Note: While batteries would be needed for being completely independent from the grid, using batteries would not make sense in this proposed case because we are going to tie directly into the grid. By tying into the grid, peak shaving is performed saving the college more money in batteries as well as in electricity as electricity costs are higher during peak load times and cheaper during off peak times.

Table B.4: Flow of Money Calculations

	Labor Cost ($/Calvin)	Initial Cost ($/Calvin)	Life (yrs)
Current Electricity			
Crystalline PV System	$43,103	$456,897	50
Amorphous PV System	$117,188	$388,594	50
Batteries		$0	8
Inverter		$21,945	20

Note: Batteries were not needed in our system thus have no initial cost.

	Annual Money Flow ($/yr-Calvin)
Electrical Savings	$23,140
Maintenance Cost	$0

Grant Rules:
Not Labor, Installation
Equipment, Materials, Supplies

Grant	$60,000
Loan	$967,726
Length of Loan (yr)	$7
Interest Rate	$0
Annual Payment ($/yr-Calvin)	$212,046
Total Payback for Loan ($)	$1,484,322
Interest Paid on Loan ($)	$516,596
Sum Total of Electric Savings ($)	$717,327

		Taking a Loan		Future Savings	
Year	PV System Cost ($)	Loan Payments ($)	Remainder of Loan to Pay ($)	Electric Cost Saved ($)	Summed Savings ($)
0	-$1,027,726	-$212,046	-$1,484,322	$23,140	$23,140
1	$0	-$212,046	-$1,272,276	$23,140	$46,279
2	$0	-$212,046	-$1,060,230	$23,140	$69,419
3	$0	-$212,046	-$848,184	$23,140	$92,558
4	$0	-$212,046	-$636,138	$23,140	$115,698
5	$0	-$212,046	-$424,092	$23,140	$138,838
6	$0	-$212,046	-$212,046	$23,140	$161,977
7	$0	-$212,046	$0	$23,140	$185,117
8	$0	$0	$0	$23,140	$208,256
9	$0	$0	$0	$23,140	$231,396
10	$0	$0	$0	$23,140	$254,535
11	$0	$0	$0	$23,140	$277,675
12	$0	$0	$0	$23,140	$300,815
13	$0	$0	$0	$23,140	$323,954
14	$0	$0	$0	$23,140	$347,094
15	$0	$0	$0	$23,140	$370,233
16	$0	$0	$0	$23,140	$393,373
17	$0	$0	$0	$23,140	$416,513
18	$0	$0	$0	$23,140	$439,652
19	$0	$0	$0	$23,140	$462,792
20	-$21,945	$0	$0	$23,140	$485,931
21	$0	$0	$0	$23,140	$509,071
22	$0	$0	$0	$23,140	$532,210
23	$0	$0	$0	$23,140	$555,350
24	$0	$0	$0	$23,140	$578,490
25	$0	$0	$0	$23,140	$601,629
26	$0	$0	$0	$23,140	$624,769
27	$0	$0	$0	$23,140	$647,908
28	$0	$0	$0	$23,140	$671,048
29	$0	$0	$0	$23,140	$694,188
30	$0	$0	$0	$23,140	$717,327

Total Future Savings = $717,327

Table B.5: System Details

						Over 30 Year Time Frame with No Loan Taken		
Goal	Size (kW)	Fraction Power Amorphous	Total Foot Print (ft^2)	Installed Cost ($)	Grant ($)	Total Spendings ($)	Total Electrical Savings ($)	Overall Spending ($)
Power Outdoor Lights	75	0	12654	$1,011,563	$60,000	$951,563	$693,956	$257,606
	75	0.5	20246	$1,005,781	$60,000	$945,781	$693,956	$251,825
	75	1	27838	$1,000,000	$60,000	$940,000	$693,956	$246,044
150 kW	150	0	25309	$2,023,125	$60,000	$1,963,125	$1,387,913	$575,213
	150	0.5	40492	$2,011,563	$60,000	$1,951,563	$1,387,913	$563,650
	150	1	55675	$2,000,000	$60,000	$1,940,000	$1,387,912	$552,087
250 kW	250	0	42181	$3,371,875	$60,000	$3,311,875	$2,313,188	$998,688
	250	0.5	67487	$3,352,604	$60,000	$3,292,604	$2,313,188	$979,417
	250	1	92792	$3,333,333	$60,000	$3,273,333	$2,313,188	$960,146
Cover Roofs	740	0	124856	$9,980,750	$60,000	$9,920,750	$6,847,035	$3,073,715
	463	0.5	124985	$6,209,023	$60,000	$6,149,023	$4,284,023	$1,865,000
	336	1	124713	$4,480,000	$60,000	$4,420,000	$3,108,924	$1,311,076

Assumptions: Constant values for money and electricity

	30 Year Break-Even Analysis			Installed Price	
Changes Needed	Factor of Current	New Value ($)	Electrical Cost (¢/kW-hr)	Amorphous ($/panel)	Crystaline ($/panel)
Increased Electrical Cost	1.36	$945,781	8.9		
Reduced Photovoltaic Cost	0.69	$693,956		$400	$744

Note: Data used is 37.5kW Amorphous / 37.5kW Crystaline

Calculation Description: 'Factor of Current' indicates the factor that the electrical cost or photovoltaic cost would need to change by in order to breakeven right at 30 years.

Table B.6: Breakeven Analysis

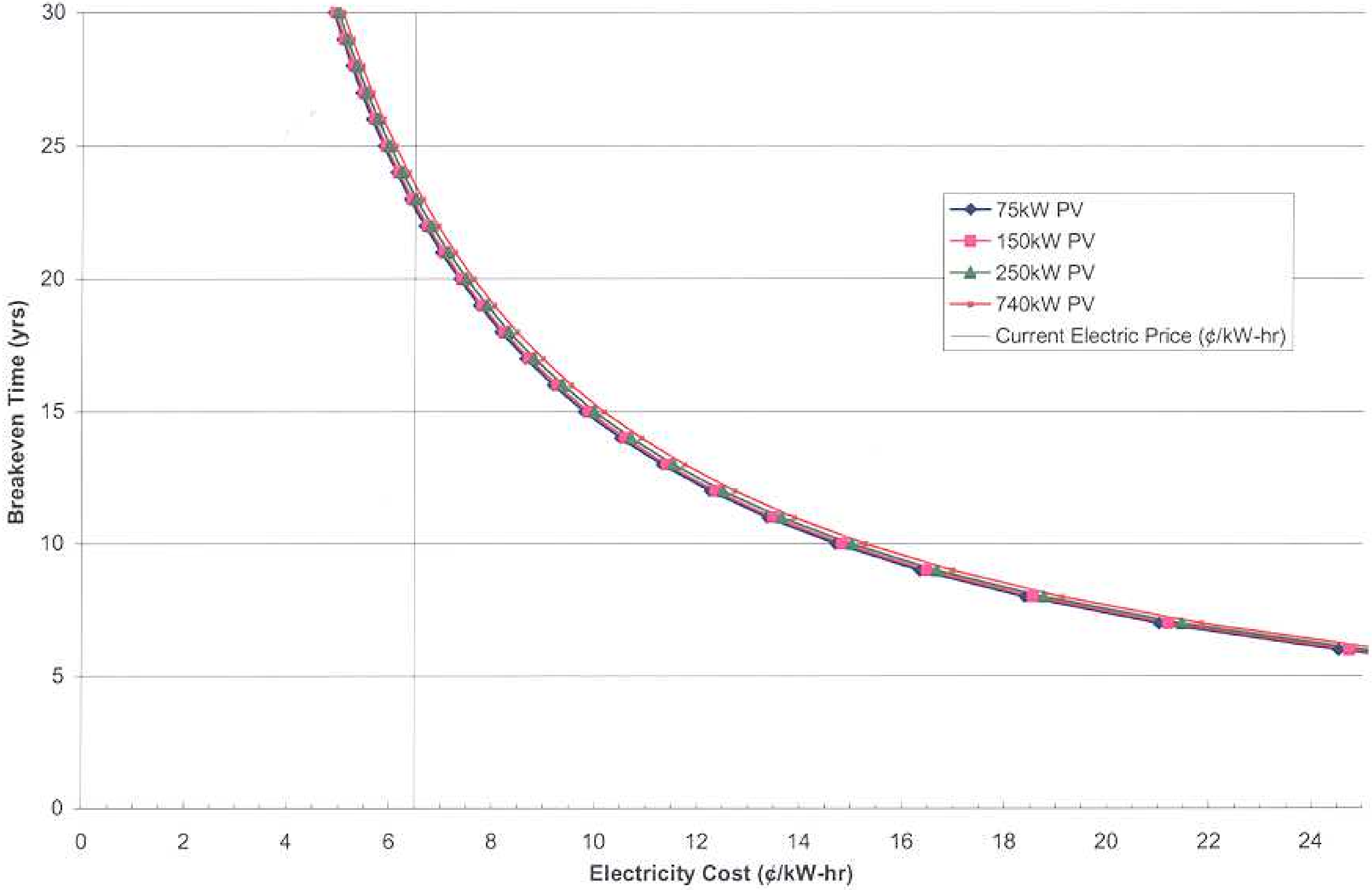
Loan Length (yrs) 0
Interest Rate 0.12

hrs/yr 8765.8

	(¢/kW-hr)	yrs
Current Electric	6.5	0
Current Electric	6.5	30

	Photo Voltaic	Sizing Goal	Photo Voltaic	Sizing Goal	Photo Voltaic	Sizing Goal	Photo Voltaic	Sizing Goal
System Size (kW)	75	Power Outdoor Lights	150	Peak Shaving	250	Peak Shaving	740	Max Roof Tops
Initial cost ($)	967726		1951563		3292604		9920750	
Years for BE	Electric Cost ($/yr)	Electricity Cost (¢/kW-hr)	Electric Cost ($/yr)	Electricity Cost (¢/kW-hr)	Electric Cost ($/yr)	Electricity Cost (¢/kW-hr)	Electric Cost ($/yr)	Electricity Cost (¢/kW-hr)
1	$967,726	147	$1,951,563	148	$3,292,604.17	150	$9,920,750	152.9
2	$483,863	74	$975,781	74	$1,646,302.08	75	$4,960,375	76.5
3	$322,575	49	$650,521	49	$1,097,534.72	50	$3,306,917	51.0
4	$241,932	37	$487,891	37	$823,151.04	38	$2,480,188	38.2
5	$193,545	29	$390,313	30	$658,520.83	30	$1,984,150	30.6
6	$161,288	25	$325,260	25	$548,767.36	25	$1,653,458	25.5
7	$138,247	21	$278,795	21	$470,372.02	21	$1,417,250	21.8
8	$120,966	18	$243,945	19	$411,575.52	19	$1,240,094	19.1
9	$107,525	16	$216,840	16	$365,844.91	17	$1,102,306	17.0
10	$96,773	15	$195,156	15	$329,260.42	15	$992,075	15.3
11	$87,975	13	$177,415	13	$299,327.65	14	$901,886	13.9
12	$80,644	12	$162,630	12	$274,383.68	13	$826,729	12.7
13	$74,440	11	$150,120	11	$253,277.24	12	$763,135	11.8
14	$69,123	11	$139,397	11	$235,186.01	11	$708,625	10.9
15	$64,515	10	$130,104	10	$219,506.94	10	$661,383	10.2
16	$60,483	9	$121,973	9	$205,787.76	9	$620,047	9.6
17	$56,925	9	$114,798	9	$193,682.60	9	$583,574	9.0
18	$53,763	8	$108,420	8	$182,922.45	8	$551,153	8.5
19	$50,933	8	$102,714	8	$173,294.96	8	$522,145	8.0
20	$48,386	7	$97,578	7	$164,630.21	8	$496,038	7.6
21	$46,082	7	$92,932	7	$156,790.67	7	$472,417	7.3
22	$43,988	7	$88,707	7	$149,663.83	7	$450,943	7.0
23	$42,075	6	$84,851	6	$143,156.70	7	$431,337	6.6
24	$40,322	6	$81,315	6	$137,191.84	6	$413,365	6.4
25	$38,709	6	$78,063	6	$131,704.17	6	$396,830	6.1
26	$37,220	6	$75,060	6	$126,638.62	6	$381,567	5.9
27	$35,842	5	$72,280	5	$121,948.30	6	$367,435	5.7
28	$34,562	5	$69,699	5	$117,593.01	5	$354,313	5.5
29	$33,370	5	$67,295	5	$113,538.07	5	$342,095	5.3
30	$32,258	5	$65,052	5	$109,753.47	5	$330,692	5.1

Figure B.1: Electrical Breakeven Analysis
Assuming No Loans Taken



Contacts/Links

Contacts:

Henry DeVries- VP of Administration, Finance, and Information Services.

Paul Pennock- Mechanical Projects Technician

Chuck Howlerda- Electronics Shop Technician

Marc Huizinga- Mechanical Assistant Director

Dan Slager- Energy Management Technician

Links:

$60,000 Grant-
http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=MI12F&state=MI&CurrentPageID=1

Crystalline Panel-
www.solardepotcom

Amorphous Panel-
www.OkSolar.com

Appendix C:
Fuel Cell Analysis

Aaron Buys
Josh Blocker
Matt Vredevoogd

Objectives:

To study fuel cells as an alternative energy option, and determine if they are a feasible solution to Calvin College's attempts to become energy independent.

Methods

In order to determine whether or not fuel cells were a viable option, we looked into what requirements Calvin has for energy usage. Once we had estimates of current energy usage on campus as well as predictions for the future, we researched different types of fuel cells and determined which model was the best to meet the requirements on campus both now and a number of years down the line.

From our research, we were able to come up with many advantages and disadvantages for fuel cells. These were weighed against the advantages and disadvantages of the current systems from which Calvin gets their electricity in order to determine if fuel cells would be a good replacement for the current system.

One factor that has been important for on campus projects in the past is aesthetics. For this reason, we looked into the appearance of a fuel system and the size constraints when trying to determine if one could be placed on Calvin's campus without becoming an eyesore. Probably the main criteria for determining whether or not a fuel cell system would be an option for Calvin College was the cost of the system. In order to get cost data that could be compared to current electricity cost data, we put together a spreadsheet which looks at three different scenarios: Best Case, Worst Case, and Future Case.

In the end, we also looked at the future of fuel cells and tried to determine if the prospects for using them would improve in the future.

Results

Currently, a 3-MegaWatt fuel cell would be enough to provide power for our campus. We found that multiple fuel cells could be easily linked together if more capacity was needed in the future, so we based all of our studies on a 3-MW plant that is currently produced by Fuel Cell Energy.

There were a few advantages to using fuel cells rather than buying electricity from the grid. They are very efficient; when waste heat is used the efficiency can be as much as 80%. When tied in with the grid, fuel cells are over 97% reliable. They are very quiet and provide a consistent voltage output. Tying new cells to the old ones is easy, making expansion simple. They also emit much less pollution than power plants that produce the electricity that we buy from the grid.

There are also some disadvantages to using fuel cells as Calvin's power source. Currently, the only easily attainable fuel source for the cells is natural gas, which is not very cost effective in the present and most likely will not be in the future. They are not load-following, so variations in energy usage will mean that excess energy will be wasted or not enough energy will be produced at certain times. Furthermore, the largest disadvantage to using fuel cells comes with their costs.

A fuel cell does not need to be placed inside an enclosed structure. It can be placed outside on a concrete pad, which would save a lot of money on construction costs. However, Calvin's restrictions on what types of things can be placed on campus would likely prohibit this from taking place for visual reasons. If that is the case, we have made a rough estimate of about two million dollars for a simple building in which to place the fuel cell. The building would be approximately 10,000 square feet.

Tables C.1 (a)-(c) on the following pages are economic analyses of fuel cells based on a 12% interest rate, a life of 30 years, and a six cent per kilowatt-hour price of electricity under three different scenarios. Even in the best case scenario, with the current natural gas price, using fuel cells rather than buying electricity from the grid would cost the college over two million dollars each year. The future case shows that even if the up-front costs go down and natural gas prices stay where they currently are, Calvin would still be losing over one million dollars each year. Large maintenance costs due to overhauling the system make up a large portion of these costs. Unfortunately, there are currently few, if any, grants or incentives for installing fuel cells; initial costs would have to be covered with donations or huge loans, which would make the costs even greater. The price of natural gas appears to be the driving force for the fuel cell system, so unless prices go down or another fuel source becomes more readily available, fuel cells will not be an economically viable option for Calvin College in the near future.

Table C.1 (a) : Best Case Scenario

Size	3000	kW
Initial cost	$4,000.00	per kW
Maintenance	$130.00	per kW-year
Gas consumption	80	million Btu/kW-yr
Installation cost	$250.00	per kW
Water usage	1275	gal/kW-yr
Price of water	$0.0025	per gal
Average Price of nat. gas	$7.00	per million Btu
	Total Costs	
Initial Cost	$12,000,000.00	
Installation	$750,000.00	
Annualized Initial Costs	$1,582,831.63	per year
Gas	$1,680,000.00	per year
Maintenance	$390,000.00	per year
Water	$9,562.50	per year
Total	**$3,662,394.13**	**per year**
If bought from the grid	$1,530,000.00	per year
"Savings"	**-$2,132,394.13**	**per year**

Table C.1 [b] : Worst Case Scenario

Size	3000	kW
Initial cost	$4,000.00	per kW
Maintenance	$130.00	per kW-year
Gas consumption	80	million Btu/kW-yr
Installation cost	$500.00	per kW
Water usage	1275	gal/kW-yr
Price of water	$0.0025	per gal
Average Price of nat. gas	$17.50	per million Btu
	Total Costs	
Initial Cost	$12,000,000.00	
Installation	$1,500,000.00	
Annualized Initial Costs	$1,675,939.38	per year
Gas	$4,200,000.00	per year
Maintenance	$390,000.00	per year
Water	$9,562.50	per year
Total	**$6,275,501.88**	**per year**
If bought from the grid	$1,530,000.00	per year
"Savings"	**-$4,745,501.88**	**per year**

Table C.1 [c] : Future Case Scenario

Size	3000	kW
Initial cost	$1,500.00	per kW
Maintenance	$130.00	per kW-year
Gas consumption	80	million Btu/kW-yr
Installation cost	$250.00	per kW
Water usage	1275	gal/kW-yr
Price of water	$0.0025	per gal
Average Price of nat. gas	$7.00	per million Btu
	Total Costs	
Initial Cost	$4,500,000.00	
Installation	$750,000.00	
Annualized Initial Costs	$651,754.20	per year
Gas	$1,680,000.00	per year
Maintenance	$390,000.00	per year
Water	$9,562.50	per year
Total	**$2,731,316.70**	**per year**
If bought from the grid	$1,530,000.00	per year
"Savings"	**-$1,201,316.70**	**per year**

Figure C.1 summarizes the major costs involved with the fuel cell system

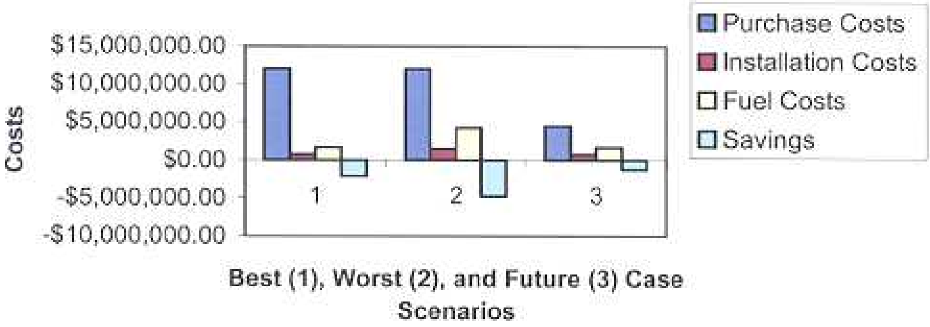


Figure C.1 - Cost Analysis for Fuel Cells

Conclusions

The very large purchase, installation, and maintenance costs for fuel cells, as well as the increasing prices of natural gas, led us to determine that fuel cells are not currently a viable option for Calvin College's energy needs. Even if initial costs for the fuel cells go down in the future, as long as natural gas prices increase at a greater rate than that of electricity bought from the grid, fuel cells will not be a feasible option from an economic standpoint alone. Currently, the main benefits of fuel cells as an energy source can be found in their reliability, relatively compact size, and minimal pollution. At some point, alternative fuel sources may make fuel cells a good solution in an economic sense as well.

APPENDIX D:
Integration Group Decision Analysis

Andrew Huisjen
Thomas Totoe
Andy VanderMoren
Chris VanRoekel

Goal

The goal of the integration group was to effectively coordinate and facilitate research concerning the feasibility of getting Calvin off the grid. It was the responsibility of the integration group to verify that the appropriate research was being conducted and that the necessary data was available to the technology groups. Once all necessary research had been conducted, the integration group analyzed the findings and determined which technology, if any, should be recommended for implementation at Calvin College.

Method of Approach

As the Integration Group, it was our job to make sure that the necessary information was available to our technology groups. We began the semester by obtaining rather basic information such as the current electrical loads along with gas and electricity prices for the past ten years. This enabled the technology groups to appropriately size their systems to the needs of Calvin. We made sure that we were available to the technology groups in order to help them find any Calvin related data they needed.

It was also our job to make sure that the technology groups were working hard to research their respective technologies. To do this, the integration group held meetings every Friday afternoon to discuss current progress on the project, along with any concerns they might have that our group could help them with. These meetings helped keep the integration group informed as to the progress of each of the teams and the direction their research was taking.

The integration group set semester long goals for each of the groups at the beginning of the semester. The first of these goals was to choose a technology that each of the groups would research. After some discussion, it was decided that our technology groups would research fuel cells, photovoltaic cells, and cogeneration systems. Three weeks after the technology choices were made, the integration group required that a preliminary proposal be submitted to the integration group. This proposal would assist the integration group in deciding which technologies to pursue further and which technologies are not feasible.

After receiving these proposals, it was apparent that cogeneration systems were the only systems that had a legitimate chance of saving Calvin money. At this time, the integration group decided to redistribute work among the three technology teams. The integration group felt that in order to convince Henry De Vries, our client, to pursue cogeneration further, we would need to have a complete presentation with as few unknowns as possible. The other two technology groups were able to perform the required research to fill the gaps in the research the current cogeneration team had already performed.

Analysis

Having received the preliminary proposals from the technology groups, the integration proceeded to develop a decision matrix that would enable us to decide on which technology we felt was feasible and satisfied Calvin's requirements. Figure D.1 displays the distributions of the various factors used in the decision matrix on a pie chart. The integration team felt that, based on our research and understanding regarding the needs and requirements of Calvin College, these value assignments for the decision matrix were satisfactory. For example, costs concerns which is the major driving factor for this particular project, contributes a total of about thirty six percent of the total factors considered.

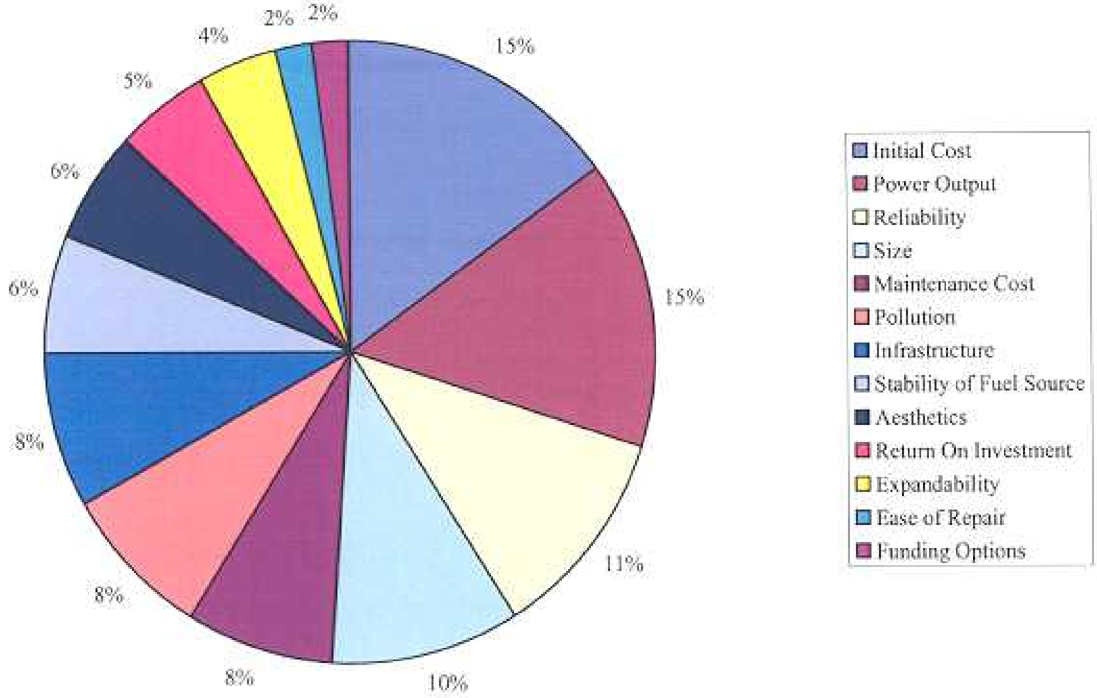


Figure D.1: Distribution of Factors Considered for the Decision Matrix

Table D.1 summarizes why solar photovoltaic and fuel cells were not chosen and also why co-generation was selected as an economically viable technology to satisfy Calvin's energy demand.

The preliminary report by the solar PV group focused on a large system. By comparing the cost data of the three technologies, the integration group decided that implementing the system proposed by the solar PV group would not be a viable option based on the cost and the space requirements. The Integration group consequently directed the efforts of the solar-PV group to be focused on a smaller system, namely the integration of the solar PV's to power street lights around the campus. The purpose of this was to reduce the electricity cost incurred by the college. The integration team deliberated the proposals of the technology groups by running them by the decision matrix. The complete work of all the technology groups can be seen in appendices 2, 3 and 4.

One section of the analysis of the integration group focused on deciding on a technology or a combination of technologies that possess the potential to get Calvin off the grid. The initial costs of proposed fuel cells are extremely high. The initial costs of the solar photo-voltaic system is the second highest followed by the proposed co-generation system and therefore the value points awarded reflect on the decision matrix. The power output of each technology primarily focuses on the efficiencies of the proposed systems. Fuel cells were awarded the most value

Table D.1: Decision Matrix for Researched Technologies

Factors	Value Assignment	Co-gen	Fuel Cells	Solar PV
Initial Cost	15	15	2	7
Power Output	15	12	15	8
Reliability	11	10	10	10
Size	10	9	9	6
Maintenance Cost	8	6	3	7
Pollution	8	5	7	8
Infrastructure	8	7	7	7
Stability of Fuel Source	6	4	4	6
Aesthetics	6	4	4	4
Return On Investment	5	5	1	2
Expandability	4	4	4	4
Ease of Repair	2	1	1	1
Funding Options	2	2	0	1
Total	100	84	67	71

points because they are the most efficient systems followed by co-generation. Based on the information presented to the integration group, the maintenance costs of fuel cells was more than twice the maintenance cost of both co-generation and solar PV systems. This information allowed the integration group to assign the value points for the three systems as can be seen in the table for maintenance costs. From a Christian perspective, stewardship of the environment is important hence pollution played a major factor in our analysis and hence the points awarded to the various proposed technologies for pollution. The integration team asked all three technology groups to use a twelve percent rate of return in their analysis so that they could all be evaluated on comparable level of sorts. The technology groups performed financial analysis on their systems and based on the results regarding the savings and the payback period (if any at all), the integration group assigned points for the rate of return. The financial analysis of the various proposed technologies can be seen in Appendices A, B and C. Aesthetics was also an important factor that the integration group considered. Solar PV was given an equal value as co-generation and fuel cell technologies because a smaller scale project is what was considered and hence aesthetics would not be a major concern.

Another major analysis that was conducted and which ties in with a factor in the decision matrix is the concern relating to the stability of fuel source. This factor is crucial because as the prices of natural gas increase, the cost savings of fuel cells and co-generations systems diminish. The fuel cell and co-generation appendices discuss in detail the particular prices of natural gas at which it will be economically beneficial to the college to invest in the particular technology over a thirty year period.

The integration group researched into gas prices to ascertain the possibility of predicting the future natural gas prices. From our research, the integration group came up with the conclusion that the base level of natural gas prices are determined by world crude oil price levels which fluctuate unpredictably. Figure 2 illustrates the predicted fluctuations in natural gas prices.

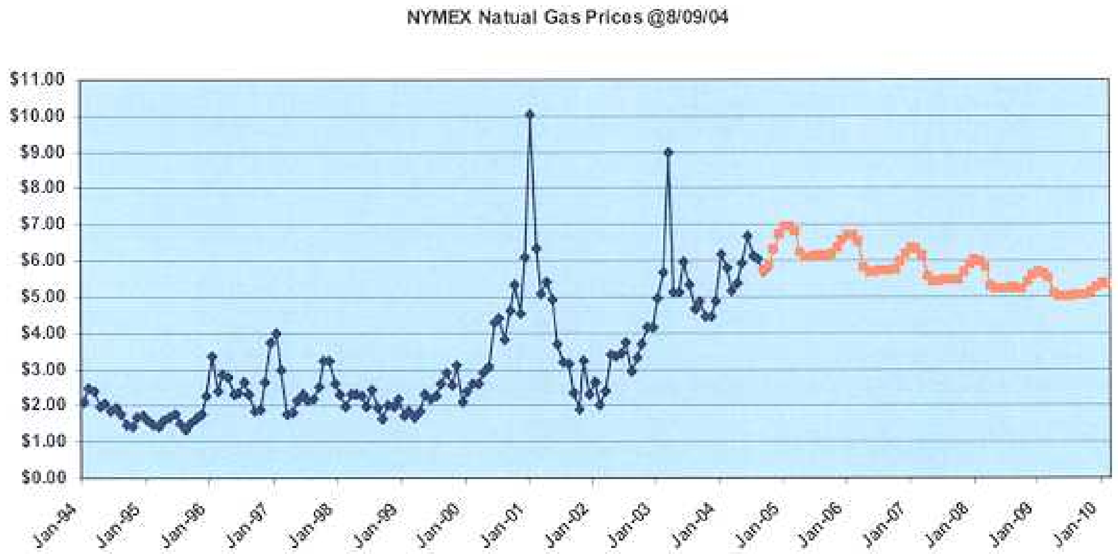


Figure D.2: Predicted natural gas prices

Based on these fluctuations in natural gas prices, the integration team assigned the value points to the three technologies for stability of fuel price.

The integration group having compiled all the results for the decision matrix chose the co-generation system.

The integration team also researched into electricity pricing in order to determine future electricity prices. This is because the integration group recognized that if Calvin College would save a lot if it generated its own electricity. From our research, the integration group learned that electricity prices have been frozen over that pasts five years and that any increases in electricity pricing has occurred because of rising fuel costs. The integration group also learned that electricity pricing would increase in 2005 because of increased emissions standards and increased cost of business operations. Based on these findings, the integration group came to the conclusion that electricity prices are increasing, but at a constant unpredictable rate and therefore the technology groups were directed to use a flat rate for their calculations bearing in mind that an increased cost of electricity makes co-generation more profitable.

A challenge that the integration team was faced with now was the determination of an appropriate location of this cogeneration system. Figure D.3 displays the two possible locations that the integration

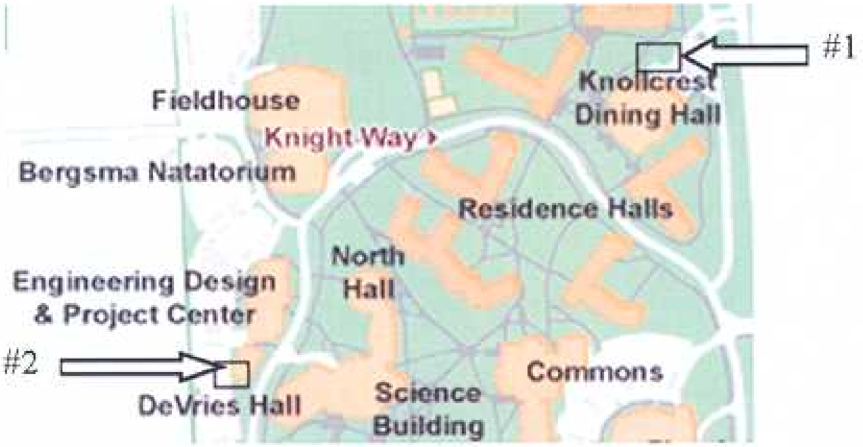


Figure D.3: Possible locations for proposed co-generation system team proposed for the system. Location #1 is the site of the construction of the new Knollcrest Dining Hall building. What the integration team proposes is a new power plant to be included with this construction process where this co-generation system can be located. Location #2 refers the Prince power plant. From our research, the integration team learned that this power plant houses some obsolete boilers and other equipment which can be removed for the proposed co-generation system to be placed. Another idea can be to further build a small power plant right beside this plant which would cover only about five parking spots adjacent to the plant. The advantage of using location #2 is that it would save the college money because it would not require tunnels.