Calvin Carbon Neutrality Date Project: Final Report

Engineering 333 A

Professor Heun

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Executive Summary

On 6 December 2017, then-president Michael Le Roy signed the President's Climate Commitment, which committed Calvin University to carbon neutrality by 2057. Within a global scope, humanity has already emitted approximately 83% of its carbon allowance before causing global warming of 1.5°C. The Paris Climate Accords stated this temperature increase as the point at which humanity's damage to the planet becomes irreversible. Given this, the year 2057 seemed like a dangerously late date for Calvin to achieve carbon neutrality. These concerns led President Boer to task the students of Engineering 333 with the following question: what earlier year should Calvin University choose for its carbon neutrality date? Groups of three to four students analyzed each of the four parts of the project: funding for projects and improvements, energy efficiency improvements, elimination of fossil fuel electricity consumption, and elimination of fossil fuel heating. Over the course of the semester, these four groups collaboratively analyzed data to determine how quickly Calvin could feasibly reach carbon neutrality. This analysis led the class to propose 2030 as Calvin's new carbon neutrality date. This date is aggressive, but the students of 2023's Engineering 333 class believe it is feasible if the proper steps are taken. This report details the class's suggestions for Calvin to reach carbon neutrality by the year 2030.

Introduction

Global warming is expected to reach 1.5°C in the year 2030 which makes Calvin University's current carbon neutrality date of 2057 seem dangerous and too late. These concerns prompted President Boer to task the students of Engineering 333 with the following question: what earlier year should Calvin University choose for its carbon neutrality date? The class's initial approach to answer this question was to divide it into four smaller topics: funding for sustainability initiatives, energy efficiency improvements, elimination of fossil fuel electricity consumption, and elimination of fossil fuel heating. These groups worked to determine which projects would help Calvin reach carbon neutrality and how these projects could be funded. Additionally, the class formed an executive team to manage and organize the project. This team consisted of one member from each of the four groups. The executive team ensured that deadlines were met and compiled work from each group. This team used data from each group to decide which projects should be implemented and when Calvin could afford them. Later in the semester, an administration team was formed to suggest leadership positions Calvin will need to establish in order to reach carbon neutrality.

An important step in the project was determining the primary sources of Calvin's emissions. Once this was done, researched solutions were compared to reduce each source of emissions. As shown in Figure 1, the main sources of emissions are natural gas heating, electricity consumption, and travel. Other sources of emissions include food waste, solid waste, and transmission and distribution losses. Once sources of emissions were determined, solutions to eliminate each source were researched, analyzed, and compared; the best options were chosen based on cost, effect on emissions, and feasibility.

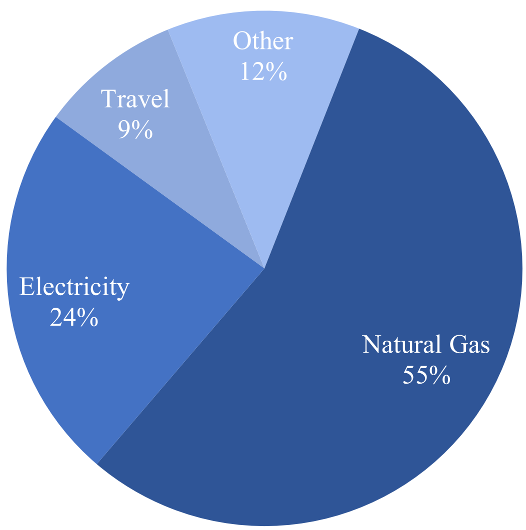

Figure 1. *Calvin's Main Sources of CO2 Emissions*

Methods

First, each group researched and analyzed opportunities for emissions reduction in their respective topics. Data for each proposed project was compiled such as upfront cost, annual cost, electricity savings, natural gas savings, carbon savings, etc. Next, the financial team developed an Excel workbook to combine and analyze data from each of the four groups. The first step in creating this model was to establish a baseline projection for electricity usage, natural gas usage, carbon emissions, and funding. This baseline projection represents the business-as-usual case: no changes are made, and Calvin continues to operate as they do currently. Once the baseline case was established, projects to help Calvin reach carbon neutrality were measured against this case. The projects that were most financially feasible and had the greatest impact on CO_2 reductions were chosen. This allowed the class to determine the necessary steps for Calvin to reach carbon neutrality. The model was designed so that project start dates could be adjusted and the projected natural gas usage, electric usage, and emissions for each year would update automatically. Adjusting implementation dates allowed the team to understand which projects should be pursued and when it would be best to implement them. The model was iteratively adjusted to find the earliest feasible carbon neutrality date for Calvin.

The class also investigated the use of carbon offsets to help Calvin reach carbon neutrality. The class determined that using only carbon offsets, Calvin could become carbon neutral immediately. The class decided against suggesting this option because it would cost about $727,000 annually and has no return on investment; for this reason, simply purchasing carbon offsets is not a good long-term solution.

Results

Using the model described above, the class decided which projects to pursue and when they should be implemented. Figure 2 shows Calvin's total carbon emissions over each year according to the class's proposed projects; each drop in emissions is caused by the implementation of the labeled carbon-reducing initiative. As seen in this graph, Calvin's carbon emissions reach zero in 2030 with rooftop solar and carbon offsets pushing Calvin's net emissions below zero. As the grid and airlines decarbonize, the amount of offsets Calvin needs to purchase will decrease. Carbon flow is plotted with cash inflow and expenses in Figure 3. The recommendations outlined here allow Calvin University to reach carbon neutrality by 2030 with minimal debt.

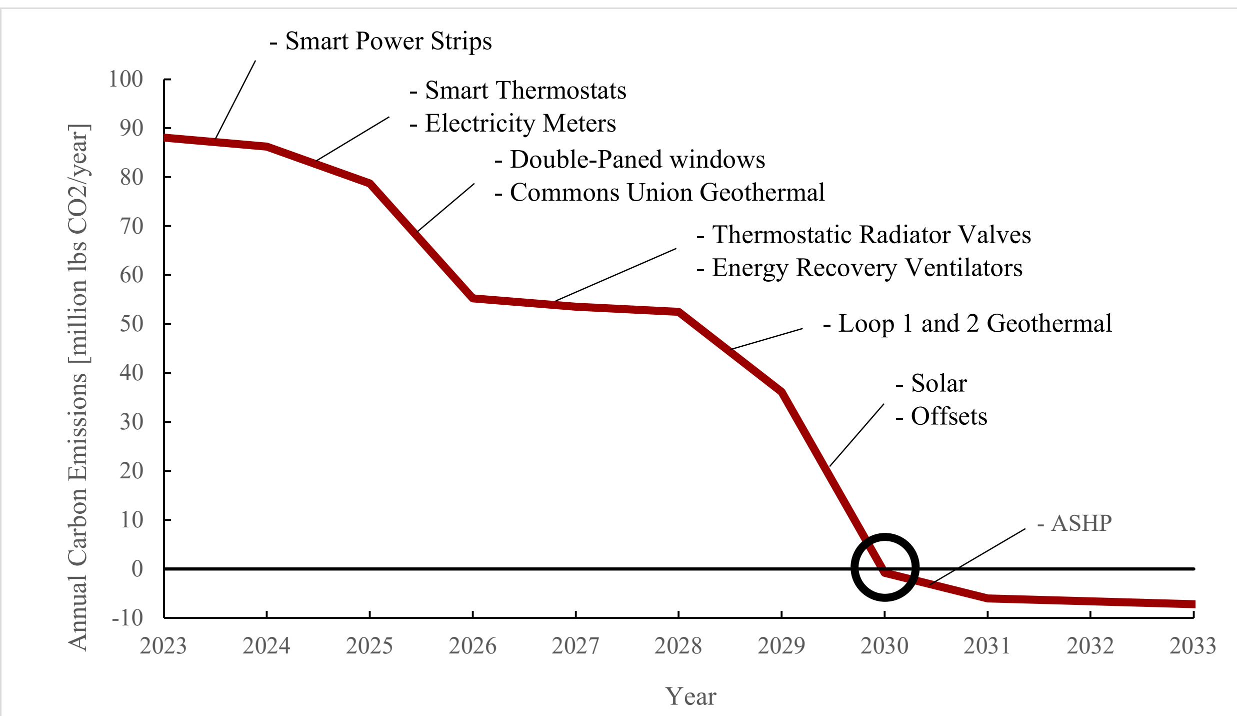

Figure 2. *Project Implementation and Carbon Impact*

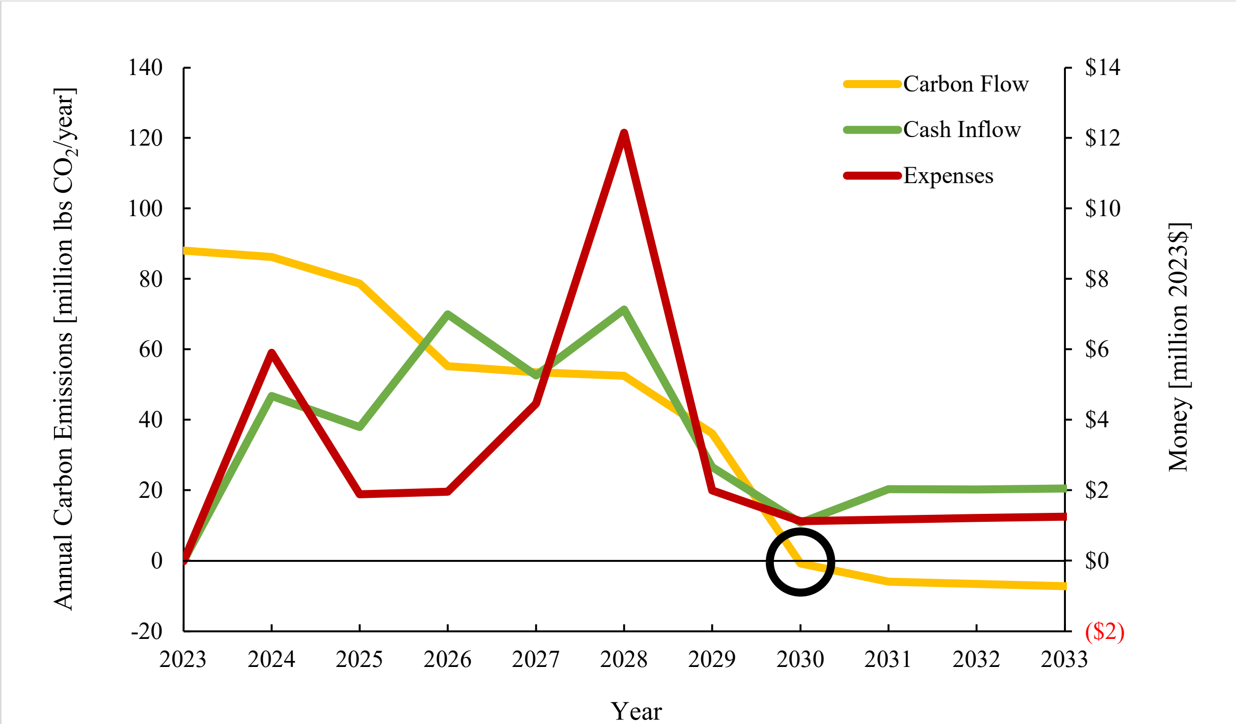

Figure 3. *Carbon flow, Cash Inflow, and Expenses by Year.*

Conclusion

Based on the analysis described in this report, the Engineering 333 class suggested a new carbon neutrality date of 2030. It was also determined that Calvin could become carbon neutral immediately with the purchase of carbon offsets, but this would not be a good long-term solution. The solution outlined in this report gets Calvin as close to carbon neutrality as possible with projects like solar and geothermal before Calvin needs to purchase carbon offsets to account for emissions that are difficult to eliminate.

Appendix A: Financial

Introduction

The financial team was tasked with identifying methods of funding Calvin University's carbon neutrality efforts by gathering sources of funding and creating a financial model. Funding research included options from government grants and programs such as the IRA, private foundation grant opportunities, and estimations of donor funding. Alongside funding research, the financial team was heavily involved in developing and maintaining a robust and comprehensive financial model. This model served as an integration point for all relevant class data, ultimately identifying a final feasible date for Calvin to become Carbon neutral. This model also allowed for future predictions of financial savings based on carbon neutrality, such as natural gas and electricity savings.

Methods & Results

The financial team's work was divided primarily between funding research and the implementation of a cash-carbon model. Funding research included public funding and the IRA, private funding through various foundations, and donor funding predictions. The cash-carbon model was developed early in the semester, and new functionality & complexity was added as more information became available. A diagram of the financial team approach is included in Appendix A1.

Public Funding:

Public funding was the second largest identified source of funding for achieving carbon neutrality. The total estimated amount of funding received by Calvin yearly from public funding opportunities is $930,000. Additional funding totaling over $3 million is available at the time of key project implementation. The primary funding source was the IRA, and funding from the identified sources relies on several important criteria. KE apartments are to be considered residential housing and must be energy star certified to qualify for some programs. Other criteria relate to specific energy efficiency requirements in the buildings where improvements are involved. A total list of public funding opportunities is included in Appendix A5. Additional IRA calculations are included in Appendix A2.

Private Funding

Private funding was another important source of funding identified for Calvin's carbon neutrality projects. Private funding was gathered from several different foundations offering grants to fund environmentally focused projects. The amount of private funding estimated for Calvin annually is just under $220,000 dollars. Significant probability adjustments were made to the published award amounts to account for Calvin's actual likelihood of winning each award. All private funding sources are listed in Appendix A6, along with the anticipated award amounts.

Donor Funding:

A significant source of Calvin's funding comes from its extensive network of alumni and private donors. Calvin asks donors to donate towards specific projects over the course of five-year fundraising drives. These cycles occur on average every seven years. To ensure a conservative funding estimate, the funding team modeled that seven-year cycle as a ten-year cycle. An estimate of $10,000,000 per fundraising drive was obtained from Greg Elzinga, split evenly over the five-year drive. This funding mode was modeled to stop once the goal of carbon neutrality was achieved. Full details on donor funding can be found in Appendix A4.

Cost Savings:

In addition, to the previously described funding sources, Calvin's savings from reduced electricity and natural gas usage were also considered as funding sources towards the carbon neutrality efforts. These savings were calculated and estimated out to 2050, and Figure A1.3. includes these cost savings.

Total Funding:

A breakdown of all funding sources until carbon neutrality is achieved is pictured below in Figure A1. The top three sources of funding are donor funding, the IRA, and public funding. The IRA category excludes all IRA funding listed in the public funding table, and only includes the 30% IRA rebate offered on all major qualifying projects, such as solar and geothermal implementations. A detailed total funding table is included in Appendix A3.

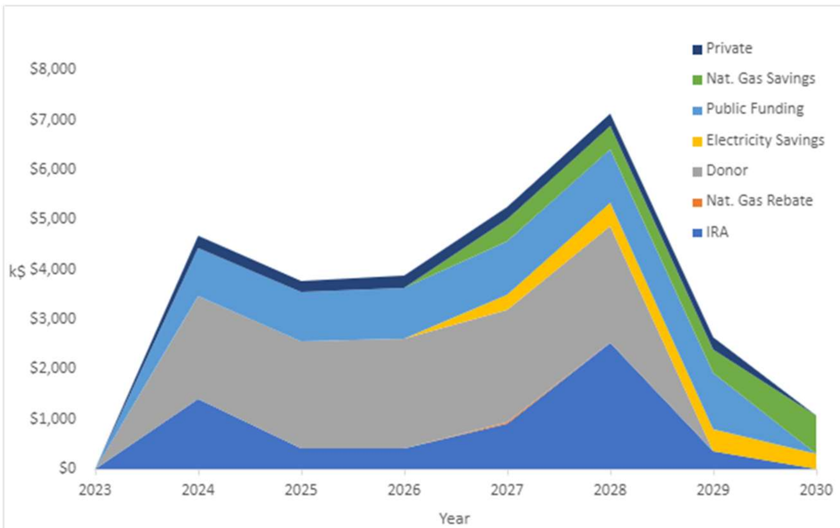

Figure A1. *Breakdown of Funding Sources Until Carbon Neutrality*

Cash-Carbon Model:

The goal of the cash-carbon model was to aggregate all the data gathered by each team into one intuitive tool which can be used to model Calvin's cash-balance and carbon-output on an annual basis over a variety of scenarios. Each project researched over the course of the semester can be placed in the cash-carbon model with a specified implementation year, and the model will simulate that project's effect on Calvins carbon-output and cash-balance. The goal of the carbon-neutrality project was to find an optimal combination of projects and implementation date which would allow Calvin to achieve an annual carbon-output of 0 lbs/year without Calvin's cash-balance dipping below zero. Examples of the output graphs from the cash-carbon model can be found in Appendix A7.

Conclusion

The financial team provided estimates and methods for modelling funding from private, public, government, and donor sources. In addition, the financial team developed and implemented a cash-carbon model which integrated information from every other team to provide a model of Calvin's annual carbon-output and cash-balance.

Appendix A1: Figures & Tables

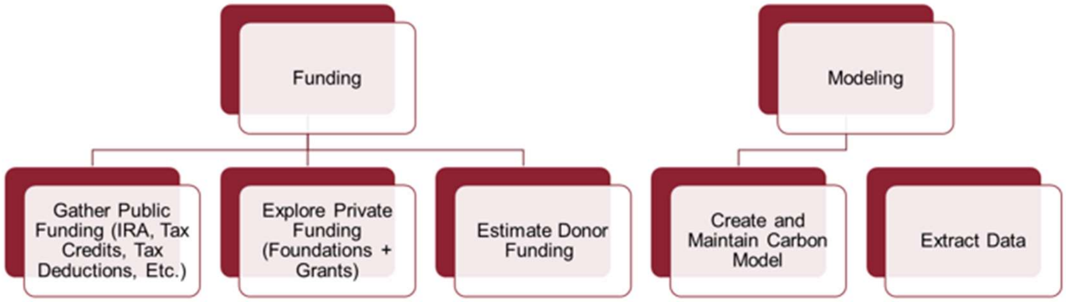

Figure A1.1. *The Overall Method of Approach from the Financial Team is Summarized in this Chart.*

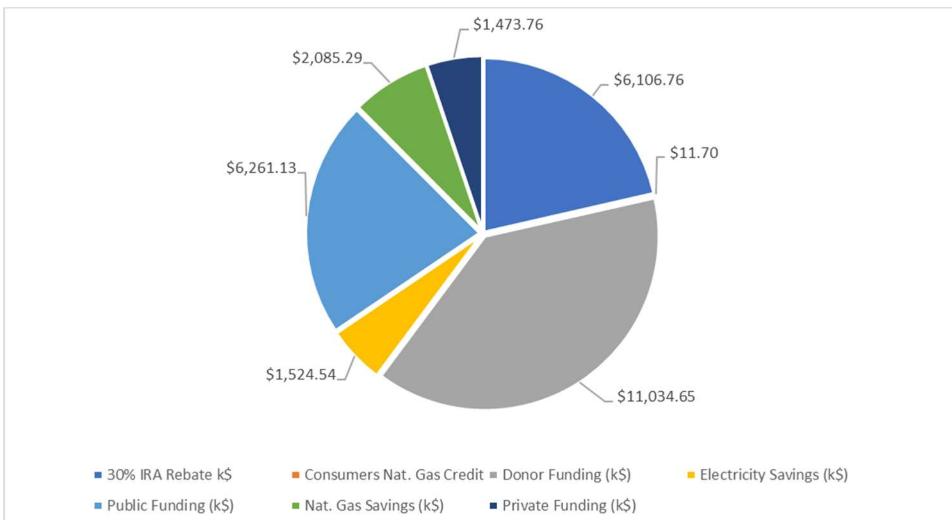

Figure A1.2. *Total Breakdown of Funding Sources Until Carbon Neutrality.*

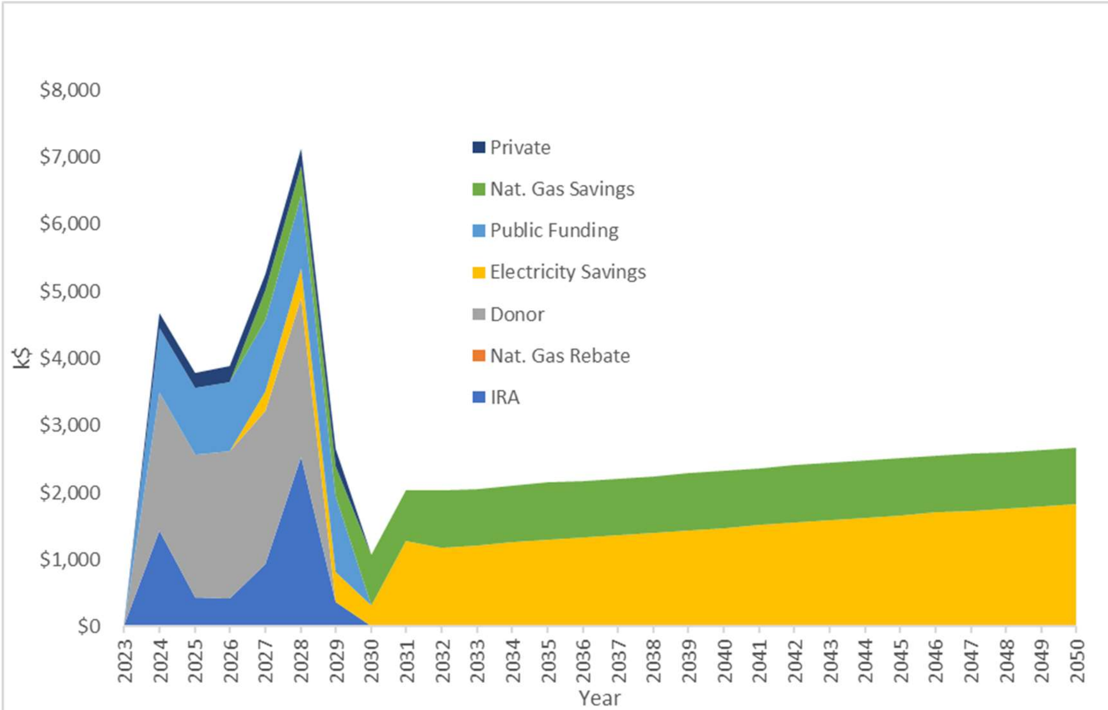

Figure A1.3. *Funding Timeline from Present Time to 2050 Illustrating Funding Sources Before and After Carbon Neutrality is Reached.*

Appendix A2: IRA Calculations

Table A2.1. *IRA Calculations to Determine Amount Saved Based on Square footage of Buildings with Sustainability Projects Implemented.*

BUILDING SQUARE FOOTAGES (DEDUCTION CALCULATIONS)			
BUILDING	**SQUARE FOOTAGE**	**DEDUCTION AMOUNT ($/SQ-FT)**	**FUNDING AMOUNT (k$)**
Academic Buildings	1,416,030	$ 1.50	$ 2,124.05
Dorms	481,995	$ 1.50	$ 722.99
KE Appartments	170,315	$ 1.50	$ 255.47
Total			$ 3,102.51

Table A2.2. *IRA Calculations to determine Amount Saved Based on Number of Apartments on Campus Meeting or Planning to Meet IRA Efficiency Requirements.*

ON CAMPUS HOUSING (Knollcrest East Appartments)		
# OF UNITS	**$/UNIT**	**Funding Amount**
120	$ 5,000.00	$ 600,000.00

Appendix A3: Total Funding Breakdown

Table A3.1. *Yearly Breakdown of Funding Amounts from Identified Funding Sources*

Year	Money Inflow (k$)	30% IRA Rebate k$	Consumers Nat. Gas Credit	Donor Funding (k$)
2023	$0.00	$0.00	$ -	$0.00
2024	$4,678.93	$1,426.11	$ -	$2,066.00
2025	$3,792.60	$429.96	$ -	$2,134.18
2026	$3,891.14	$417.53	$ 0.25	$2,204.61
2027	$5,261.67	$932.81	$ 2.39	$2,277.36
2028	$7,135.44	$2,536.36	$ 2.51	$2,352.51
2029	$2,658.84	$364.00	$ 2.51	$0.00
2030	$1,079.21	$0.00	$ 4.03	$0.00
2031	$2,027.54	$0.00	$ 4.03	$0.00
2032	$2,025.85	$0.00	$ 4.57	$0.00
2033	$2,052.92	$0.00	$ 4.57	$0.00
2034	$2,102.04	$0.00	$ 4.57	$0.00
2035	$2,147.63	$0.00	$ 4.57	$0.00
2036	$2,174.98	$0.00	$ 4.57	$0.00
2037	$2,211.46	$0.00	$ 4.57	$0.00
2038	$2,238.81	$0.00	$ 4.57	$0.00
2039	$2,284.40	$0.00	$ 4.57	$0.00
2040	$2,320.87	$0.00	$ 4.57	$0.00
2041	$2,366.47	$0.00	$ 4.57	$0.00
2042	$2,402.94	$0.00	$ 4.57	$0.00
2043	$2,439.41	$0.00	$ 4.57	$0.00
2044	$2,475.88	$0.00	$ 4.57	$0.00
2045	$2,512.36	$0.00	$ 4.57	$0.00
2046	$2,548.83	$0.00	$ 4.57	$0.00
2047	$2,576.19	$0.00	$ 4.57	$0.00
2048	$2,603.54	$0.00	$ 4.57	$0.00
2049	$2,640.01	$0.00	$ 4.57	$0.00
2050	$2,667.37	$0.00	$ 4.57	$0.00
	$75,317.34	$6,106.76	$102.61	$11,034.65

Table A3.2. *Yearly Breakdown of Funding Amounts from Identified Funding Sources (cont.)*

Electricity Savings (k$)	Public Funding (k$)	Nat. Gas Savings (k$)	Private Funding (k$)
$ -	$0.00	$ -	$0.00
$ -	$960.69	$ -	$226.13
$ 2.48	$992.39	$ -	$233.59
$ 2.32	$1,025.14	$ -	$241.30
$ 297.58	$1,058.97	$ 443.29	$249.26
$ 449.35	$1,093.92	$ 443.29	$257.49
$ 453.04	$1,130.02	$ 443.29	$265.99
$ 319.78	$0.00	$ 755.41	$0.00
$ 1,268.10	$0.00	$ 755.41	$0.00
$ 1,173.02	$0.00	$ 848.26	$0.00
$ 1,200.09	$0.00	$ 848.26	$0.00
$ 1,249.20	$0.00	$ 848.26	$0.00
$ 1,294.79	$0.00	$ 848.26	$0.00
$ 1,322.15	$0.00	$ 848.26	$0.00
$ 1,358.62	$0.00	$ 848.26	$0.00
$ 1,385.97	$0.00	$ 848.26	$0.00
$ 1,431.56	$0.00	$ 848.26	$0.00
$ 1,468.04	$0.00	$ 848.26	$0.00
$ 1,513.63	$0.00	$ 848.26	$0.00
$ 1,550.10	$0.00	$ 848.26	$0.00
$ 1,586.58	$0.00	$ 848.26	$0.00
$ 1,623.05	$0.00	$ 848.26	$0.00
$ 1,659.52	$0.00	$ 848.26	$0.00
$ 1,695.99	$0.00	$ 848.26	$0.00
$ 1,723.35	$0.00	$ 848.26	$0.00
$ 1,750.70	$0.00	$ 848.26	$0.00
$ 1,787.18	$0.00	$ 848.26	$0.00
$ 1,814.53	$0.00	$ 848.26	$0.00
$31,380.71	$6,261.13	$18,957.71	$1,473.76

Appendix A4: Donor Funding Resources

Table A4.1. *Donor Funding Prediction Parameters*

Estimates From Greg/assumptions		
Fundraise Cycle	10	Years
Fundraise Length	5	Years
In Use in Model	2000	k$/Year

Estimates from Greg Elzinga		
	5 Year Total k$	**Per Year k$**
Conservative	$ 5,000	$ 1,000
Base	$ 10,000	$ 2,000
Optimistic	$ 15,000	$ 3,000

Table A4.2. *Yearly Breakdown of Donor Funding*

Year	Years Past	Temp	Incoming 2023K$/Year
2023	0	0	$ -
2024	1	1	$ 2,000
2025	2	2	$ 2,000
2026	3	3	$ 2,000
2027	4	4	$ 2,000
2028	5	5	$ 2,000
2029	6	6	$ -
2030	7	7	$ -
2031	8	8	$ -
2032	9	9	$ -
2033	10	0	$ -
2034	11	1	$ 2,000
2035	12	2	$ 2,000
2036	13	3	$ 2,000
2037	14	4	$ 2,000
2038	15	5	$ 2,000
2039	16	6	$ -
2040	17	7	$ -
2041	18	8	$ -
2042	19	9	$ -
2043	20	0	$ -
2044	21	1	$ 2,000
2045	22	2	$ 2,000
2046	23	3	$ 2,000
2047	24	4	$ 2,000
2048	25	5	$ 2,000
2049	26	6	$ -
2050	27	7	$ -

Appendix A5: Public Funding Recommendations

Table A5.1. *Table of Public Funding Sources and Annual Amounts*

Grant/Program Name	Annual Amount Estiamted ($)
Section 45L Tax Credits for Zero Energy Ready Homes	$ 300,000.00
Energy Efficient Home Credit	$ 150,000.00
Credit for builders of new energy efficient homes	$ 480,000.00
energy efficient commercial buildings deduction	ONLY IN YEAR OF IMPROVEMENTS
TOTAL FUNDING ESTIMATE (PUBLIC):	**$ 930,000.00**

Table A5.2. *Table of Public Funding Sources, Initial Amount Offered and Calvin's Predicted Probability of Success*

Grant/Program Name	Predicted Award Frequency	Amount Offered ($)	Calvin's Probability Of Success (0-1)
Section 45L Tax Credits for Zero Energy Ready Homes	1	$ 600,000.00	50.00%
Energy Efficient Home Credit	1	$ 300,000.00	50.00%
Credit for builders of new energy efficient homes	1	$ 600,000.00	80.00%
energy efficient commercial buildings deduction	1	$ 3,102,510.00	95.00%

Appendix A6: Private Funding Recommendations

Table A6.1. *Table of Private Funding Sources and Annual Amounts*

Foundation/Program	Annual Amount Estiamted ($)
Roy A Hunt Foundation	$ 6,000.00
Joyce Foundation	$ 5,000.00
Patagonia	$ 625.00
IREM Foundation	$ 500.00
Climateworks Foundation	$ 100,000.00
MacArthur Foundation	$ 60,000.00
Mitsubishi Corp. Foundation for the Americas - MCFA	$ 3,000.00
TOTAL FUNDING ESTIMATE (PRIVATE):	**$ 218,906.25**

Table A6.2. *Table of Private Funding Sources, Initial Amount Offered, and Calvin's Predicted Probability of Success.*

Grant/Program Or Donor Name	Predicted Award Frequency	Amount Offered ($)	Calvin's Probability Of Success (0-1)
Roy A Hunt Foundation	1	$ 50,000.00	12%
Joyce Foundation	1	$ 100,000.00	5%
Patagonia	1	$ 12,500.00	5%
IREM Foundation	1	$ 5,000.00	10%
Climateworks Foundation	1	$ 1,000,000.00	10%
MacArthur Foundation	3	$ 1,000,000.00	2%
Mitsubishi Corp. Foundation for the Americas - MCFA	1	$ 300,000.00	1%

Appendix A7: Cash-Carbon Model Example Graphs

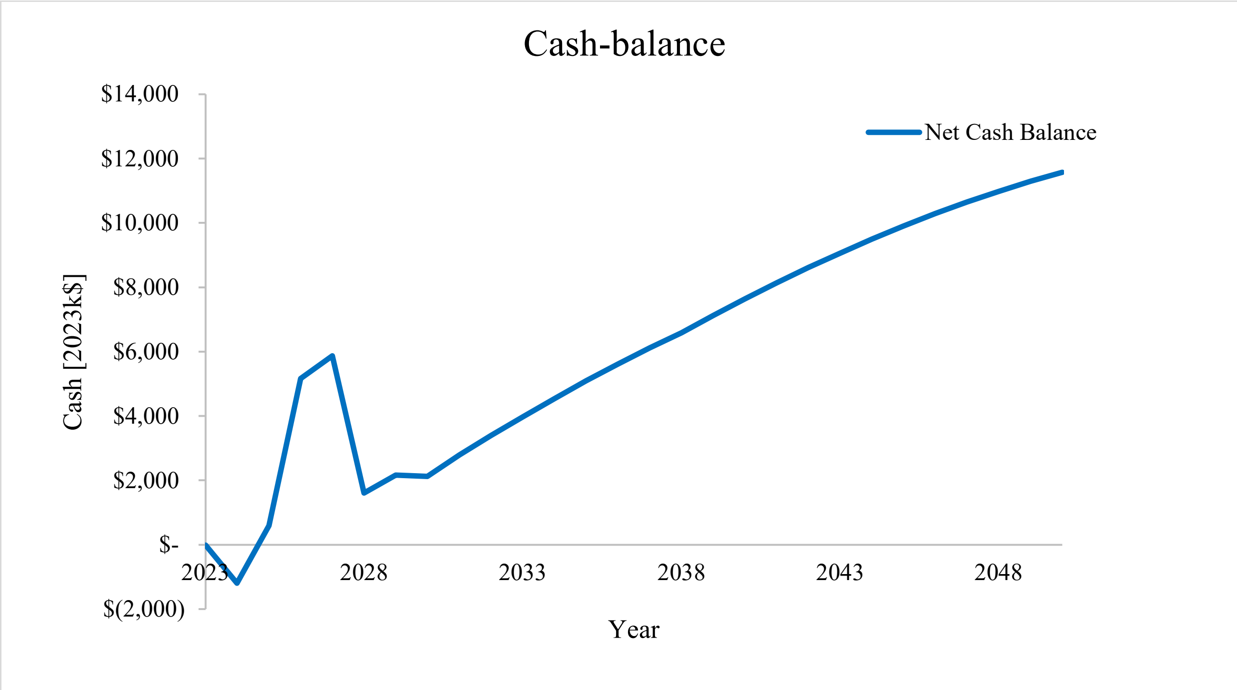

Figure A7.1. *Example Cash-Balance Graph from Cash-Carbon Model*

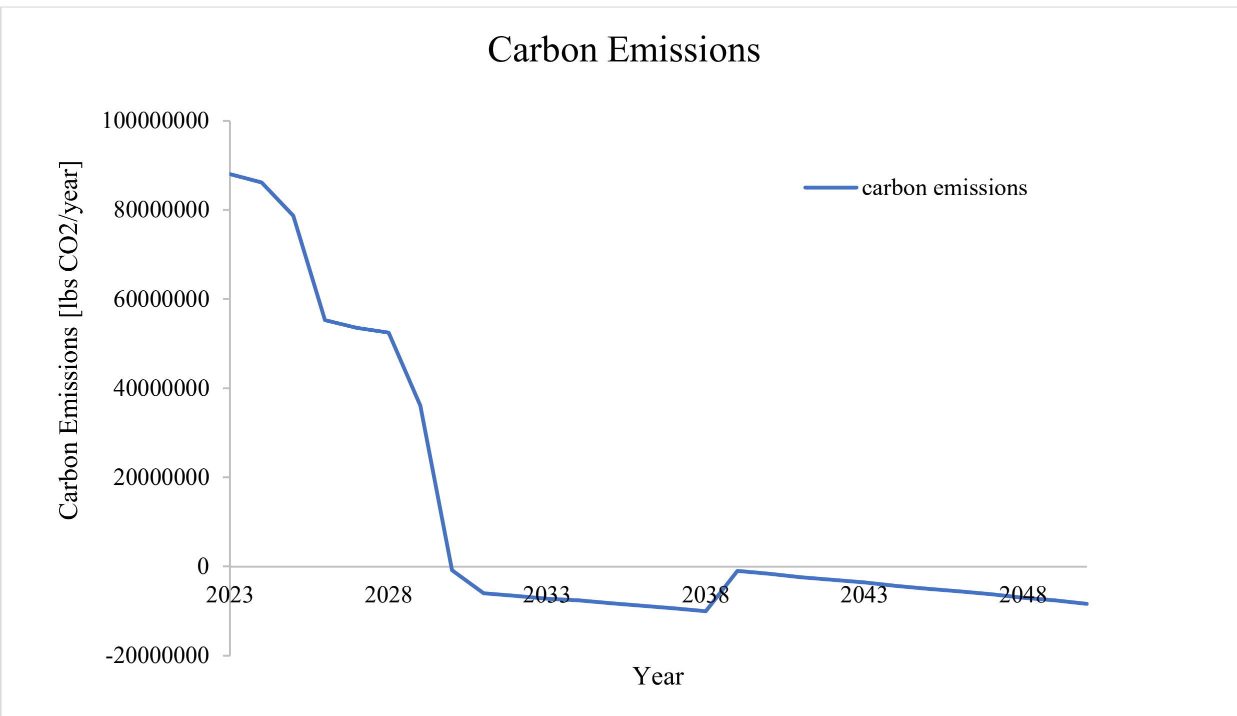

Figure A7.2. *Example Carbon-Output Graph from Cash-Carbon Model*

Appendix B: Efficiency

Introduction

The efficiency team was tasked with generating a business-as-usual energy usage model for Calvin including natural gas and electricity data. Another task was to research and implement heating and electricity efficiency upgrades to reduce CO_2 emissions of Calvin. The team used past energy usage data to predict usage out to 2050 to provide a baseline for carbon reduction. They also used past ENGR333 reports and researched different methods to reduce electricity and natural gas usage that could be implemented at Calvin University. The options that were implemented into the final model were based on the cost, decrease in energy usage, and payback period. The team consisted of Owen Kalsbeek, Panashe Makuvaro, and Luke Penning.

Methods

The business-as-usual energy model was the initial task for the efficiency team. To construct the baseline usage model, past electricity and natural gas data was required. The efficiency team looked at multiple years of AASHE STARS reports that Calvin submitted, which included yearly electricity and natural gas data, as well as other CO_2 data useful to other scopes of this project. The data collected from the STARS report was not current, so in collaboration with Section B, updated data was obtained from Keystone. From this, the efficiency teams acquired data from 2019-2022.

Based on the total square footage of Calvin, an equation was fit to predict the energy usage. The equation was then used to extrapolate the data to future years using future square footage predictions. An energy reduction factor of 1.5% per year was also included in the electricity usage prediction to account for CERF projects that are currently ongoing and are being planned.

The other main task of the efficiency team was to find possible projects for heating and electricity efficiency upgrades. Research began with projects from past ENGR 333 students, then moved into additional brainstormed ideas at the beginning of the semester. Each project was then researched to determine energy savings, initial costs, and annual costs (operations and maintenance). The cost and energy savings were used to determine how feasible the projects were for carbon neutrality within the scope of the model.

There were six total heating projects studied by the efficiency team:

- Solar Windows in the dorms
    - Solar windows are double-paned windows with solar panels built into them. Visible light is able to pass through whereas infrared and UV light is converted into electricity. This allows the windows to keep the room cooler, as well as generate its own electricity.
- Smart Thermostats in academic buildings
    - Smart thermostats are thermostats that use infrared sensors to detect occupancy and activity level and adjust the temperature accordingly therefore reducing heating load when there is nobody in the room.
- Double-Paned Windows in the dorms
    - Double-paned windows would be able to reduce the heating load by providing an insulation gap to keep the inside of the building warmer in the winter months. Since the dorms do not have air conditioning, the double-paned windows would keep the cooler air in the buildings in the summer months.

- Thermostatic Radiator Valves in the dorms
    - Thermostatic radiator valves would be used to adjust the flow of water to the radiator automatically. This is more efficient than having to react to changes in room temperature and adjusting the water flow manually. The dorms at Calvin are also known to get too hot in the winter, where students would have to open their windows, wasting the energy from the boilers.
- Energy Recovery Ventilators in all academic buildings
    - Energy recovery ventilators are heat exchangers that take the exhaust air from inside and pre-heat or pre-cool the outside air to reduce the amount of work that the air handling units or boilers would have to provide.
- Pool Cover for the Aquatic Center
    - A pool cover would reduce the heat lost by evaporation in the pool, therefore reducing the cost of heating the pool over time.

Three projects were researched and considered for electricity efficiency upgrades:

- Washers and Dryers in the dorms
    - The washers and dryers in the dorms are not current models, so upgrading the washers and dryers to newer, more efficient models would reduce the amount of energy used. Dryers that rely on natural gas would also be replaced with electric dryers to move Calvin towards carbon neutrality.
- Smart Power Strips in all academic buildings
    - Smart power strips are essentially normal power strips with technology built into them that allows them to detect phantom loads. When an electronic device is in stand-by mode, which may still draw current, the smart power strip recognizes that and would cut power to the device and shut it down.

The data for the thermostatic radiator valves, energy recovery ventilators, and pool cover were taken from last year's report and the costs were converted to 2023$. The solar window estimates were taken from a journal by T. Miyazaki, where they found an efficiency improvement of around 40% in an office building. However, because these windows would only be implemented in the dorms, that 40% was multiplied by roughly 22% to account for the percentage of the campus being dorms. A similar process was done with the double-paned windows, the washers, and the dryers. Data for the double-paned windows was found from Home Advisor, and then adjusted to only cover the square footage of the dorms. Costs were estimated by Armored Roofing and Construction. Data for the washers and dryers was found by going into the dorms and finding the current appliances, then researching online using ajmadison.com to find the updated versions of the existing Calvin appliances. A simple calculation using the washer or dryers' energy factor (ft^3/kWh/cycle) from the website, dividing it by the load capacity (ft^3) and multiplying it by an average of 295 cycles per year, gave an estimated electricity usage in kWh/yr that could be compared between new and old models. This gave an estimated efficiency increase and again was adjusted based on square footage covered. Cost data was also taken from this website.

Data for the smart thermostats was taken from the Energy Star website, as well as a study done on different unspecified universities. It was estimated that the campus would require 1240 smart thermostats based on square footage. This was then used to calculate prices. Finally, the data for smart power strips was found from an article on reducing plug loads in office buildings. On average, there are 2000 computers per one million square feet of a college campus. Calvin has about 1.5 million square feet of academic buildings and it was estimated that a power strip would be needed for every 1.5 computers, thus Calvin would require 2000 power strips. The estimates for the efficiency increase by the power strips were also multiplied by about 50%, as the academic buildings make up a bit over 50% of the campus in square footage.

Results

The business-as-usual model for energy usage is found in Appendix B1. Because the energy consumption is based partially on square footage, as the square footage increases, the heating load slightly decreases due to the increased efficiency of new buildings. It was estimated that the baseline electricity usage would be 20.66 GWh and the baseline natural gas usage would be 40.06 GWh if nothing changed. Current CERF projects were added to the model with a percent decrease in electricity consumption per year.

The nine proposed efficiency projects were considered based on four criteria: initial investment, annual investment, annual energy savings, and payback period. The results for each of the different proposed efficiency projects can be found below in the table in Appendix B2. Of the nine proposed projects, five of them were deemed to be feasible and implemented into the final cash-carbon model based mostly on the payback period. Table B1 shows the five projects that were implemented along with the dates of implementation and initial investment. The solar windows were not chosen because they were very expensive and had a long payback period compared to the double-paned windows. New washers and dryers were not chosen because they had very little annual energy savings and had a long or no payback period. Finally, the pool cover was also excluded based on a relatively high payback period given the low efficiency increase.

Table B1*. Projects chosen for cash-carbon model.*

Project	Date of Implementation	Initial Investment (k$)
Smart Thermostats	2025	620
Double-Paned Windows	2026	1,500
Thermostatic Radiator Valves	2026	171
Energy Recovery Ventilators	2025	1,008
Smart Power Strips	2024	50

Conclusion

Overall, the baseline energy usage model was used to predict the energy usage out to 2050. This was used as a basis for the cash-carbon model. Over the course of the project, the efficiency team looked into nine separate heating and electricity efficiency upgrade projects. The projects were assessed based on cost, percent decrease in energy usage, and the payback period. In total, five efficiency projects were implemented into the final cash-carbon model that were found to be economically and energetically efficient. Although not vital components in decreasing CO_2 emissions, they were essential to save money throughout the project yielding more money to spend on projects that would decrease CO_2 emissions. Through this work, the final date of 2030 was able to be calculated.

Appendix B1: Business as Usual Graph

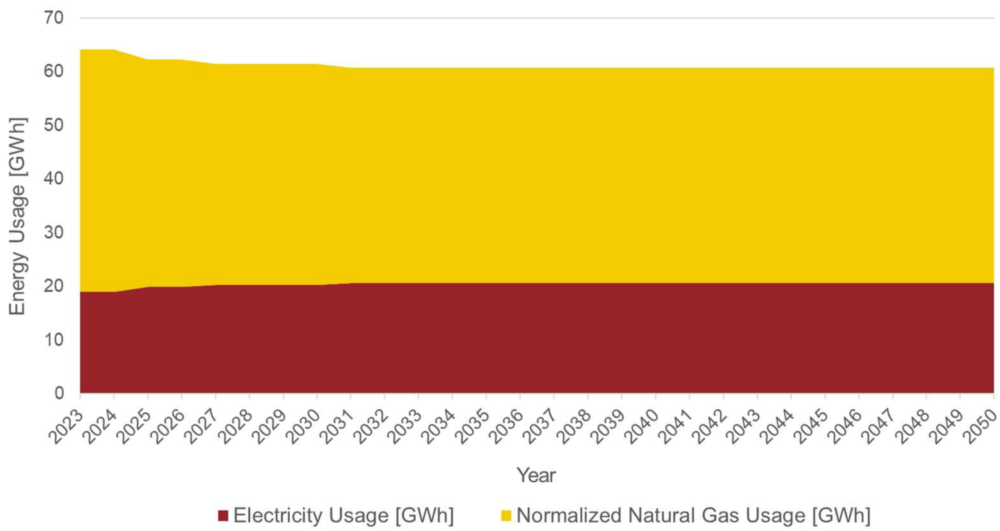

Figure B1.1. *Graph of Business-As-Usual Combined Energy Usage (Electricity and Natural Gas).*

	Additional Square Footage	Calendar Year	Square Footage	Electricity Usage [kWh]	Electricity Usage [GWh]	kWh/sqft electricity
CURRENT		2022	2,181,407	19,809,021	19.81	9.08
		2023	2,181,407	19,293,998	19.00	8.84
		2024	2,181,407	19,293,998	19.00	8.84
SPORTS COMPLEXES BUILT	100,000	2025	2,281,407	20,178,473	19.88	8.84
		2026	2,281,407	20,178,473	19.88	8.84
COMMONS UNION BUILT	50,000	2027	2,331,407	20,620,710	20.31	8.84
		2028	2,331,407	20,620,710	20.31	8.84
		2029	2,331,407	20,620,710	20.31	8.84
		2030	2,331,407	20,620,710	20.31	8.84
POD APARTMENTS BUILT	40,000	2031	2,371,407	20,974,500	20.66	8.84
		2032	2,371,407	20,974,500	20.66	8.84
		2033	2,371,407	20,974,500	20.66	8.84
		2034	2,371,407	20,974,500	20.66	8.84
		2035	2,371,407	20,974,500	20.66	8.84
		2036	2,371,407	20,974,500	20.66	8.84
		2037	2,371,407	20,974,500	20.66	8.84
		2038	2,371,407	20,974,500	20.66	8.84
		2039	2,371,407	20,974,500	20.66	8.84
		2040	2,371,407	20,974,500	20.66	8.84
		2041	2,371,407	20,974,500	20.66	8.84
		2042	2,371,407	20,974,500	20.66	8.84
		2043	2,371,407	20,974,500	20.66	8.84
		2044	2,371,407	20,974,500	20.66	8.84
		2045	2,371,407	20,974,500	20.66	8.84
		2046	2,371,407	20,974,500	20.66	8.84
		2047	2,371,407	20,974,500	20.66	8.84
		2048	2,371,407	20,974,500	20.66	8.84
		2049	2,371,407	20,974,500	20.66	8.84
		2050	2,371,407	20,974,500	20.66	8.84

Figure B1.2. *Business as usual Excel table.*

Heating Usage ccf	Heating Usage kWh	HDD	kWh/HDD	Normalized Natural Gas Usage [kWh]	Normalized Natural Gas Usage [GWh]	kWh/sqft heating	Total Usage [GWh]
1,486,750	43,561,383	6,343	6,868	42,699,495	42.70	19.57	62.51
1,539,294	45,100,917	6,218	7,254	45,100,917	45.10	20.68	64.39
1,539,294	45,100,917	6,218	7,254	45,100,917	45.10	20.68	64.39
1,447,446	42,409,799	6,218	6,821	42,409,799	42.41	18.59	62.59
1,447,446	42,409,799	6,218	6,821	42,409,799	42.41	18.59	62.59
1,402,572	41,094,995	6,218	6,610	41,094,995	41.09	17.63	61.72
1,402,572	41,094,995	6,218	6,610	41,094,995	41.09	17.63	61.72
1,402,572	41,094,995	6,218	6,610	41,094,995	41.09	17.63	61.72
1,402,572	41,094,995	6,218	6,610	41,094,995	41.09	17.63	61.72
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03
1,367,222	40,059,253	6,218	6,443	40,059,253	40.06	16.89	61.03

Figure B1.3. *Business as usual Excel table cont.*

Appendix B2: Projects and Results

Table B2.1. *Table of Projects Researched, with Respective Costs, Energy Savings, and Payback Periods*

Project	Initial Investment (k$)	Annual Investment (k$)	Annual Energy Savings (%)	Payback Period (yr)
Solar Windows	8,000	100	8.9	26
Smart Thermostats	620	40	10.5	3
Double-Paned Windows	1,500	40	3.5	15
Thermostatic Radiator Valves	170	10	3.4	3
Energy Recovery Ventilators	1,008	60	13.0	4
Pool Cover	7.3	2.6	0.1	10
Replace Washers	70	1	0.05	15
Replace Dryers	81	1	0.004	Never
Smart Power Strips	50	5	1.3	1

Appendix B3: Sources

Calvin University | Scorecard | Institutions | STARS Reports. 28 Feb. 2019, reports.aashe.org/institutions/calvin-college-mi/report/2019-02-28.

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Appendix C: Electricity

Introduction

The electricity team's task for this project was to research ways to eliminate fossil fuel electricity consumption at Calvin. With this goal in mind, the team had three main goals to focus on:

1) *Determine current emissions from purchased grid electricity.*
2) *Decide if it is reasonable for Calvin to wait for the grid to decarbonize or if Calvin needs to invest in clean electricity options.*
3) *Determine cost of solar and wind energy implementation.*

The team then divided to pursue each of these goals and find accurate results. It was decided that the most feasible alternative electricity sources would be solar and wind. After researching and finding data relevant to Calvin's campus for grid decarbonization as well as solar and wind electricity production, models were assembled that described carbon reduction and, for solar and wind, costs. These separate models were then brought into the full class model to describe all electricity focused aspects of the solution.

Past Project Research

Initial research consisted of looking back through past ENGR 333 projects and categorizing information based on relevance to each team. Past projects not applicable to our project were filtered out. The full table of past project information can be found in Appendix C1.

Quantifying Emissions and Grid Decarbonization

To quantify emissions from purchased grid electricity, emission factors were used. Research results indicated that Consumers Energy utilized Environmental Protection Agency (EPA) emission factors for Greenhouse Gas Inventories to estimate their electricity grid emissions. Since the electricity purchased by Calvin comes from Consumers Energy, EPA emission factors were also used to estimate Calvin's CO_2 emissions based on electricity purchased. Past EPA emission factor reports can be found at the epa.gov website. A summarized table of useful data used can be seen in Appendix C2.

Methods

To predict how the electricity grid will decarbonize over time, three models were created. The first model consisted of data that aligns with the MI Clean Energy Framework and Inflation Reduction Act (IRA) incentives. Data was extrapolated from a model created using the MI Clean Energy Framework from 5 Lakes Energy. This model along with predicted emission factors can be found in Appendix C3 (Figure C3.1 and Table C3.1). This first model is considered the fast grid decarbonization model, as it contains the most aggressive goals and clean energy implementations to reduce grid emissions the most in the shortest amount of time.

The second model created is moderate speed grid decarbonization. Methodology of grid decarbonization for this model aligns with the Consumers Energy 2021 Clean Energy Plan. Goals of this plan include:

- Retire all coal plants by 2025 (sharp decrease)

- 35% renewable electricity production by 2025

- 47% renewable electricity production by 2030

- 49% renewable electricity production by 2035

- 63% renewable electricity production by 2040

- net-zero by 2040 with carbon offsets

Since our final recommended carbon neutrality date was prior to 2030, it was assumed the grid would continue to decarbonize according to these set clean energy goals, without becoming net-zero through offsets. Predicted emissions factors can be found in Appendix C3 (Figure C3.2 and Table C3.2)

The third model was the slow decarbonization model, and utilized the goals laid out in the MI Healthy Climate plan laid out by Governor Whitmer in 2020 and MI energy provider IRP's. Percent reduction in emissions was interpolated using Figure C3.3 in Appendix C3, and emission factors were estimated. See Table C3.3 in Appendix C3 for the full slow decarbonization model predicted emission factors.

Results

All predicted emission factors for each grid decarbonization model were graphed, and results can be seen below.

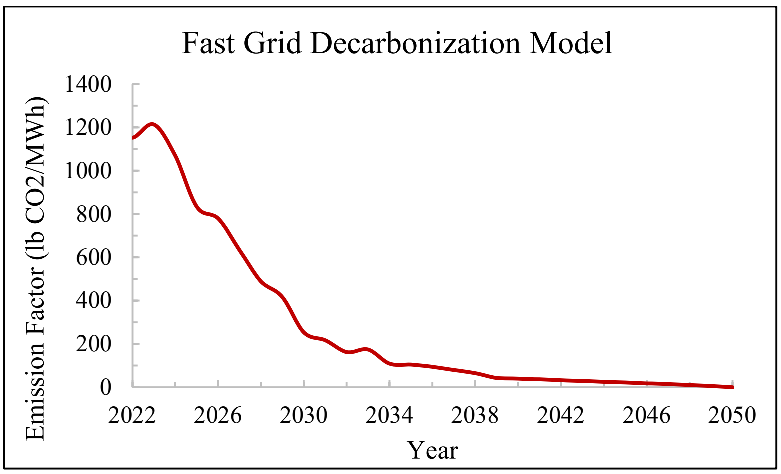

Figure C1. *Fast Grid Decarbonization Aligning with MI Clean Energy Framework and IRA Incentives.*

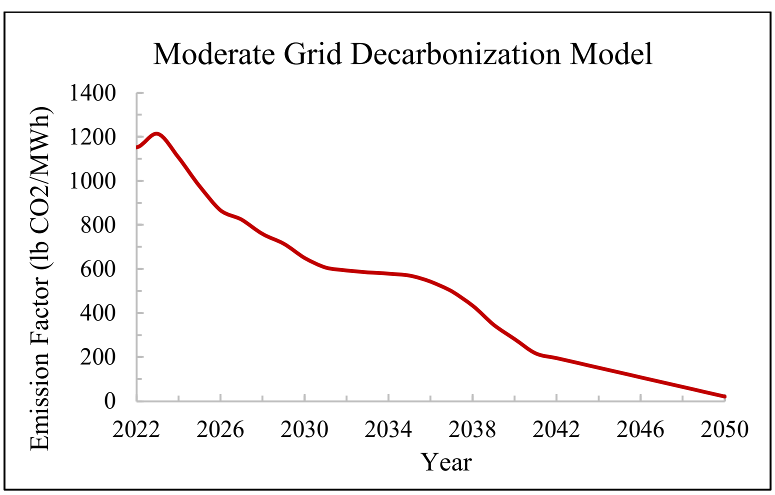

Figure C2. *Moderate Grid Decarbonization Aligning with Consumers Energy 2021 Clean Energy Plan.*

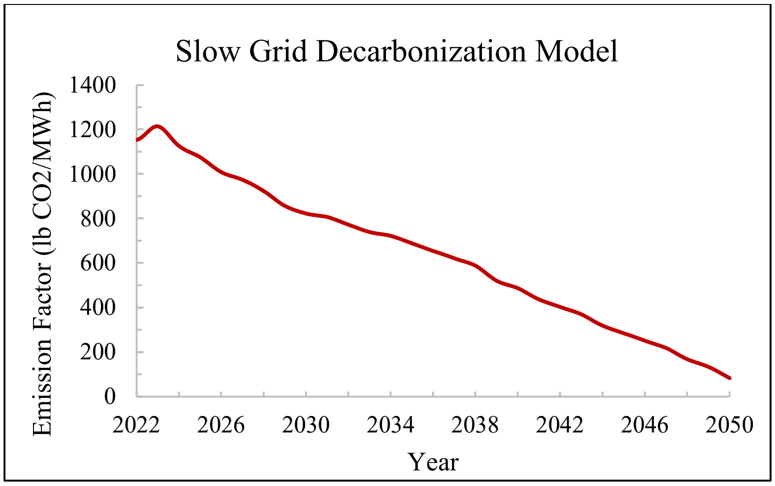

Figure C3. *Slow Grid Decarbonization Aligning with MI Healthy Climate Plan and Energy Provider IRP's.*

The visual representation is useful to show how the electricity grid will decarbonize in each scenario. To calculate Calvin's emissions from purchased electricity, simply multiply the amount of electricity purchased (MWh) by the emission factor to get lbs CO_2. As clean energy electricity solutions are implemented at Calvin, the amount of electricity required to be purchased will be reduced, resulting in a reduction in emissions. The next sections will discuss these options.

Solar

Methods

Calculations for solar pricing were completed using a per wattage basis. According to two solar energy companies, EnergySage and Energy Link, the upfront costs for solar installation and setup in Michigan in 2023 is \$3.50 per watt for rooftop and \$3.72 per watt for parking lot canopies. From here, using a 350-watt solar panel size of 1.8 square meters, costs per panel and per unit area could be calculated. Yearly operations and maintenance costs for the solar system were calculated using data acquired from the following National Renewable Energy Laboratory figure assuming Calvin's campus to be a commercial roof-mount system:

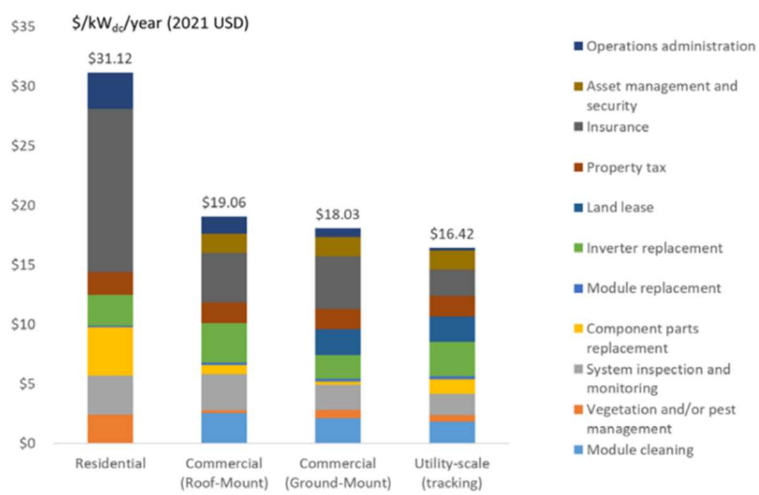

Figure C4. *NREL Calculated O&M Costs for Photovoltaic Systems.*

After calculating costs, an estimate of available space for solar panels was required. Fortunately, this was a calculation that a previous ENGR 333 class had already completed. For rooftop availability on campus the following data in Table C1 from the 2018 ENGR 333-A class project was utilized. In their calculations, the 2018 class considered which rooftops would be suitable for solar and which wouldn't, and the results include only the suitable locations. Due to the higher cost of parking lot canopies compared to rooftop as well as the extra construction required, it was determined that rooftop would be the most feasible for Calvin and area calculations were not performed for a solar canopy system.

Table C1. *Calvin University Campus Roof Area Calculated by 2018 Calvin ENGR 333-A class.*

Building	**Area (m^2)**	**Area (acres)**	**Roof Type**
Student Union	4,200	1.04	Unknown
Prince Center	3,500	0.86	Flat
Hekman Library	3,400	0.84	Flat
Hiemenga Hall	2,400	0.59	Flat
Physical Plant	2,000	0.49	Flat
DeVos CC	1,300	0.32	Flat
CFAC (Center area)	1,200	0.30	Flat
DeVries Hall	1,200	0.30	Flat
North Hall	800	0.20	Flat
Mail Services	700	0.17	Flat
Total	**20,700**	**5.12**	

With data for both cost and area, energy output could then be calculated for solar panels. Using an NREL solar irradiation map of the United States, it was determined that a 350-watt panel could produce 2.45 kWh of electricity in a day. This value could then be adjusted to get a value per square meter, which could then be scaled up for each building on Calvin's campus. This electricity output was then used to calculate yearly capacity as well as emissions savings using 2023 emission factors.

Results

The previously described research and calculations resulted in a solar model for Calvin's campus able to quantify costs, electricity production capacity, and any savings resulting from utilizing an on-campus renewable energy source. The data calculated from this model for each available rooftop on campus can be found in Table C2.

Table C2. Calvin University Rooftop Solar Data.

Campus Building	Area (m^2)	Panels	Initial Cost (k$)	Yearly Maintenance (k$)	Yearly Capacity (MWh)	Emission Savings (tons CO_2)	Emission Savings (% 2023 CO_2)	Electricity Savings (% 2023 Electricity)
Mail Services	700	386	473	2.83	345	210	0.48%	1.82%
North Hall	800	441	540	3.24	394	239	0.54%	2.08%
DeVries Hall	1,200	662	811	4.86	592	359	0.82%	3.12%
CFAC	1,200	662	811	4.86	592	359	0.82%	3.12%
DeVos Center	1,300	717	878	5.26	641	389	0.88%	3.38%
Plant	2,000	1,104	1,352	8.10	987	599	1.36%	5.20%
Hiemenga Hall	2,400	1,325	1,623	9.73	1,185	719	1.63%	6.24%
Library	3,400	1,877	2,299	13.78	1,679	1,019	2.31%	8.84%
Prince Center	3,500	1,932	2,367	14.18	1,728	1,049	2.38%	9.10%
Student Union	4,200	2,319	2,841	17.02	2,074	1,259	2.86%	10.92%

Additionally, the percentages for emissions savings and electricity supplied from solar compared to total demand for each available rooftop on campus can be found in Figure C5.

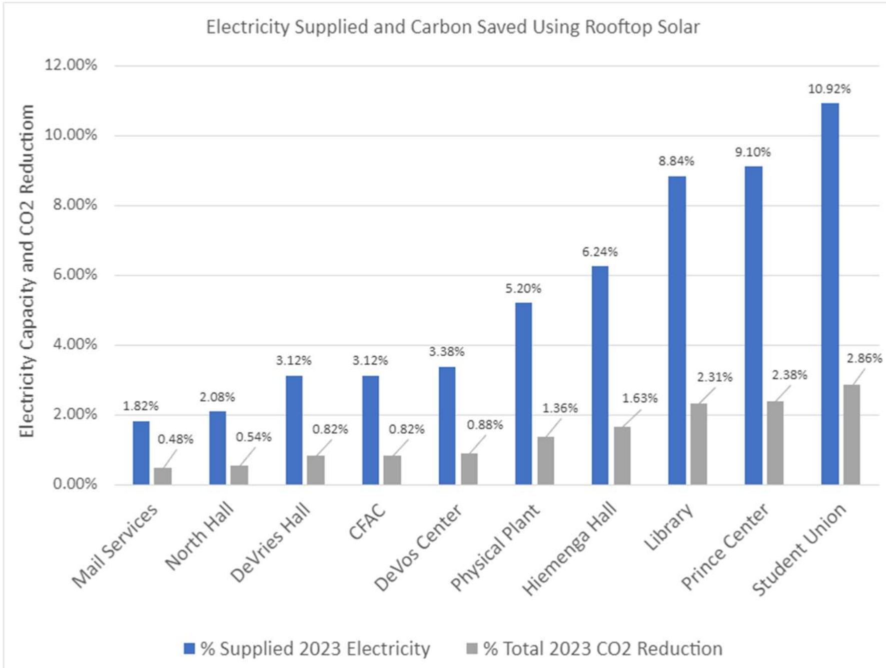

Figure C5. *Electricity Supplied and Carbon Saved Using Rooftop Solar.*

The final solution determined by the class to achieve carbon neutrality by 2030 utilizes 15,000 m^2 of roof space. This translates to 72.4% utilization of available roof space and results in a yearly electricity capacity of 7.4 GWh costing $10,145,000 upfront with yearly maintenance costing $60,790. This solar system would reduce Calvin's overall CO_2 emissions by 10.2% and would be able to produce 39% of the campus' required electricity.

Wind

Methods

The first issue that was considered when looking into wind as an energy source for Calvin was the feasibility of having a system on-campus. A variety of logistical challenges arose when considering an on-campus solution. One of these is a height limit of 200 ft due to the proximity of Gerald R. Ford International Airport to Calvin's Campus. Additionally, noise must be limited to 55 dB at the campus property line and a large amount of land area would be required with recommended spacing between turbines being equivalent to 4 to 10 rotor diameters apart. With all these complications, as well as the results of the 2018 ENGR 333-B project indicating that an on-campus wind system would never bring a return on investment, it was decided that Calvin's campus is not a feasible location to integrate wind power.

After ruling out on-campus options, off-campus options such as collaborating with companies or contributing towards wind farms were considered. When researching costing, the following figure was found in a U.S. Department of Energy wind market report highlighting the lower project costs for capacities greater than 20 MW. However, for Calvin's energy needs, a project in the 5 to 6 MW range is optimal, leading to significantly higher cost per capacity.

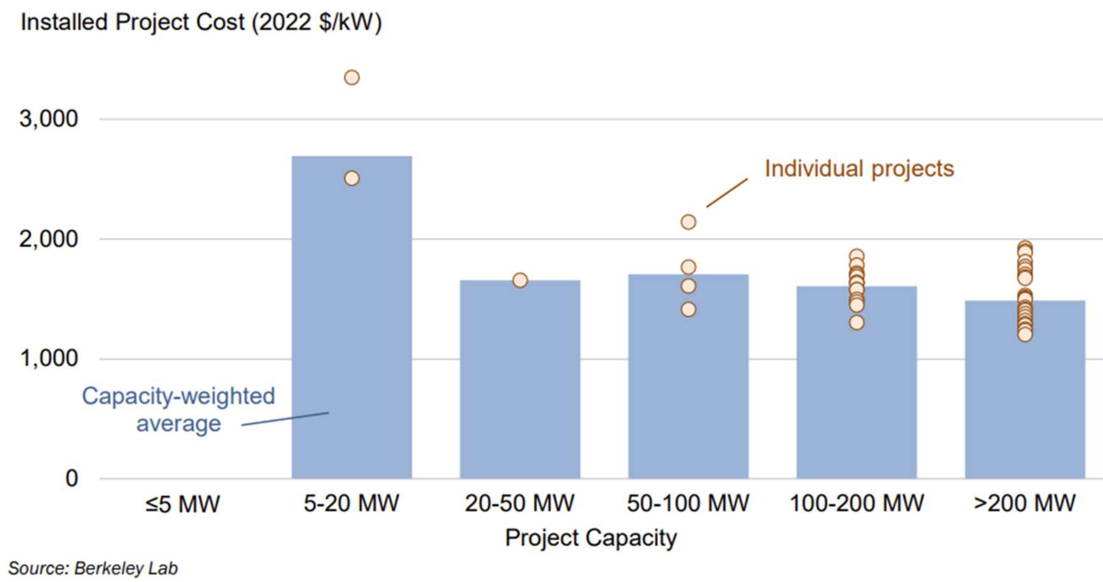

Figure C6. *Installed Wind Power Project Costs by Project Size: 2021 and 2022 projects.*

Results

As a result of the research done, a model was constructed that calculates energy capacity and cost for wind farms over multiple years scaling with nameplate capacity. For the full class model, a nameplate capacity of 5 MW was chosen. Data from the model is represented in Table C3 below for the years 2023 to 2030.

Table C3. *5 MW Nameplate Wind Farm Data*

Year	Capacity (MW)	Annual Capacity (MWh/yr)	Annual Carbon (lb CO2/ MWh)	Capacity Cost (2023 M$/MW)	Cumulative Cost (2023 M$)	Energy Cost (2023 $/MWh)	Energy Cost (2018 Usage) (2023 M$/total MWh)
2023	5	7008	8508413	10.8	10.80	57.08	1.288
2024	4.97	6963	7699154	0.200	11.00	57.08	1.288
2025	4.94	6919	6749910	0.200	11.20	57.08	1.288
2026	4.90	6874	5961467	0.200	11.40	57.08	1.288
2027	4.87	6830	5627151	0.200	11.60	57.08	1.288
2028	4.84	6787	5149737	0.200	11.80	57.08	1.288
2029	4.81	6743	4824395	0.200	12.00	57.08	1.288
2030	4.78	6700	4357751	0.200	12.20	57.08	1.288

Ultimately, for the final project solution, off-campus wind was not included as a project. Though the calculations suggest that wind power can provide roughly the same savings at a similar cost that solar does, the off-campus factor significantly hurts the feasibility of wind. With an off-campus solution, Calvin would need to sell the electricity that it produces to the power grid and then buy that electricity back. Unfortunately, the selling price for this electricity is much lower than the price at which Calvin would need to buy it back, which makes wind an economically unfeasible option.

Renewable Energy Credits

To allow Calvin's emissions from electricity consumption reach net-zero, Renewable Energy Credits from Consumers Energy were researched. Renewable Energy Credits are an additional expense on purchased grid electricity that sources electricity from clean energy sources rather than fossil fuels. After contacting Shannon Steinebach (Associate Product Manager of Clean Energy Products at Consumers) it was determined that these credits would cost $0.014 per kWh of Calvin's purchased electricity to offset 100% of emissions. Assuming all of Calvin's current baseline usage (20 GWh) is offset using REC, the annual cost would be around $800,000. This is a very cost-effective way to reduce emissions compared to implementing clean energy projects, however, does not lead to increased funding (See Appendix A). This option was sent to the financial group to incorporate into the cash-carbon model.

Conclusion

The goal of the electricity team for this project was to determine feasible ways to eliminate fossil fuel electricity consumption at Calvin. This was explored by first quantifying Calvin's electricity emissions, followed by estimating grid decarbonization and implementation of clean energy projects such as solar and wind. In the class cash-carbon model, the slow grid decarbonization model was utilized to serve as a conservative estimate of total electricity emissions. The implementation of many clean energy projects serves to decrease Calvin's purchased electricity and therefore emissions, while others such as the addition of geothermal heating (See Appendix D) increased electricity usage. Other efficiency projects will also decrease electricity requirements (See Appendix B). From group analysis, rooftop solar is recommended to be implemented as funding is available. Renewable Energy Credits were recommended to offset remaining emissions from purchased grid electricity. These recommendations were conveyed to the financial group and incorporated into the cash-carbon model. Wind was deemed not feasible due to cost and size constraints.

Appendix C1

Table C1.1. *Summary of past ENGR333 Projects. Projects were read and categorized based on relevance to each team. Past projects not applicable in any way to our project were filtered out.*

Finances	Efficiency	Electricity	Heating	Probably Irrelevant?

	Project & Relevant Information
Electricity	2004 Off-Grid Project (Cogeneration) • *Solar was infeasible in 2004 due to space.* • *Fuel Cells were cost prohibitive. High maintenance costs.* • *A 5 MW cogeneration plant was cost-prohibitive.* • *Conclusion: Should implement a 1.2 MW cogeneration plant to offset some of Calvin's grid usage.*
Electricity	2004 Off-Grid Project (Wind) • *Calvin uses a small enough amount of energy that NG prices make on-site cogeneration more expensive than buying from the grid.* • *Recommend implementing a 250-kW wind turbine* • *Solar was cost-prohibitive.* • *Conclusion: Should implement an energy savings program.*
Electricity	2006 Wind Power Project • *Nothing for campus-wide decarbonization* • *Recommendation: 1.8 kW wind turbine near Gainy Athletic Fields*
Electricity	2007 Carbon Neutrality Project • *Total Sequestration: 51 MTCE/yr* • *Total Emissions: 66.4*10^3 MTCE/yr* • *Conclusion: Not currently feasible without looking off campus* • *Install 4 wind turbines on Calvin-owned property over a 20-year period. Will reduce 10% of Calvin's carbon emissions, but later profits will allow the purchase of carbon credits.*
Efficiency, Finances	2008 CEEF Project • *Focused on efficiency improvements that will provide savings to contribute to an energy efficiency fund. (Efficiency)*
Efficiency, Heating	2010 BHT Dorm Project • *Focused on efficiency improvements and heating/cooling solutions for BHT, but the analysis seems relevant to other dorms as well.*
Heating	2012 West Wing Geothermal Project • *Conclusion: many benefits to geothermal systems, but HVAC still wins economically due to existing infrastructure.* • *Geothermal has no route to payback given current (2012) NG prices. (Heating)*
Efficiency, Heating, Finances	2015 Operations Efficiency Project • *Lighting: replacing fluorescent lights with LEDs.* • *Window-reflective coating: Reduces heat loss through windows.* • *Heat Recovery Ventilator: Transfer heat from stale exhaust air to fresh air. Reuses heating.* • *Temperature change: small changes in temperature have huge savings.* • *Did not look at carbon emissions, just cost savings.*

	2017 Dorm Energy Model • *Model of energy consumption with breakdown of usage.* • *Provides some recommendations regarding reductions in dorm energy usage.*
	2017 Fieldhouse Energy Model • *Model of energy consumption with breakdown of usage.* • *Provides some recommendations regarding reductions in fieldhouse energy usage.*
	2017 Energy Savings Project • *Very similar to the 2015 Operations Efficiency Project but focuses on NG.* • *Did not look at carbon emissions, just cost savings.*
	2017 On-site Cogeneration Project • *Recommendation: GE Jenbacher cogeneration system.* • *Can operate continuously to provide a baseline electricity output to Calvin's campus.* • *Projected to save $504,000 on electricity and heating if fully funded and $420,000 if paying off a four-year loan.* • *Projected to reduce carbon emissions of central campus by 25% and heating costs by 30%.*
	2018 Renewable Energy Generation Project (A) • *Primary recommendation: Solar panels. 2.1 GW-hr/yr of solar costing $3.34 million. Also geothermal for heating for DeWit Manor, Perkins House, 2 PN houses, and 2 other houses costing $157 thousand.* • *These would exclusively occupy roof space.* • *Solar would save $225 thousand/yr, and geothermal would save $15 thousand/yr.*
	2018 Renewable Energy Generation Project (B) • *Same recommendation as section A.* • *Implementing a 2.1 GW-hr/yr solar farm costing $3.7 million would save approximately 3.9 million lbs of carbon per year, offsetting its upfront emissions within 1.3 years.* • *Solar would save $184 thousand/yr.*
	2019 Energy Rebound Project • *Focused on energy rebound. Not directly relevant to Calvin's carbon neutrality, but it could add nuance (or a correction factor) to calculations if provided enough time to implement their methodology.*

Appendix C2

Table C2.1. *EPA CO_2 Emission factors from public data sheets. Note: intermediate data from years where no data was found was assumed to be linear between data points.*

Year	CO_2 Factor (lb/MWh)
2007	1651.11
2014	1629.38
2015	1569.23
2018	1272.01
2020	1312.62
2021	1189.32
2022	1153.11
2023	1214.13

Appendix C3

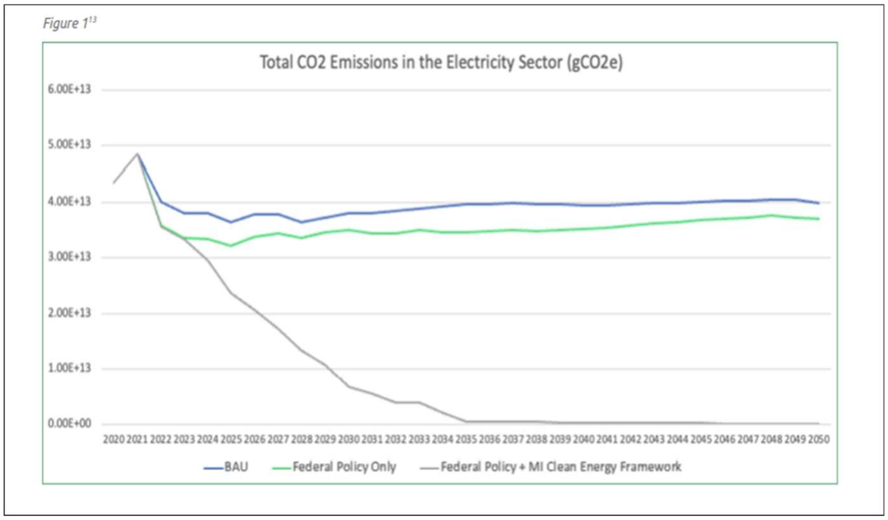

Figure C3.1. *MI Clean Energy Framework Model from 5 Lakes Energy*

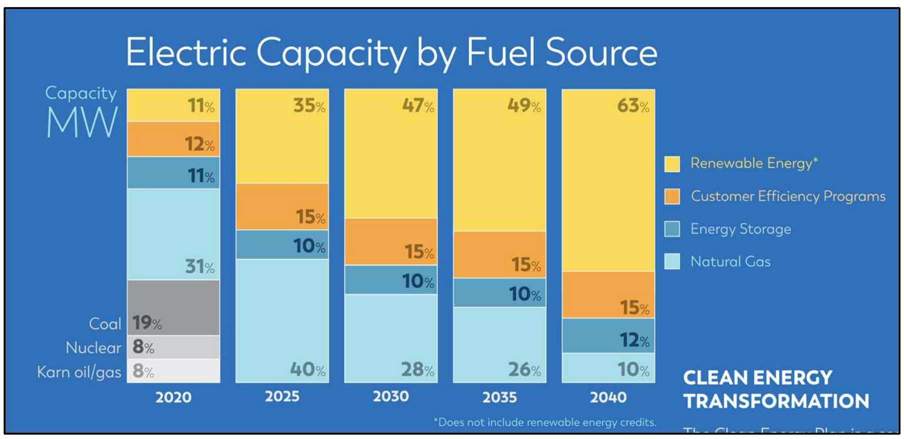

Figure C3.2. *Consumers Energy Clean Energy Plan Goals*

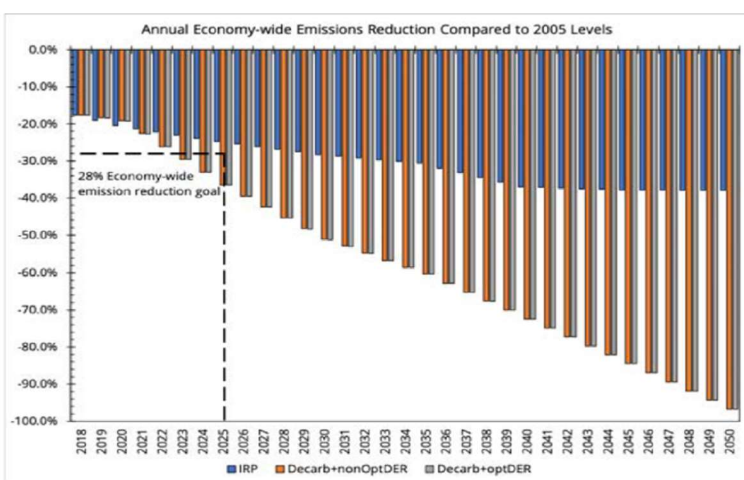

Figure C3.3. *MI Healthy Climate Plan Emission Reduction Goals*

Table C3.1. *Fast Grid Decarb predicted emission factors using precent reduction of total electricity grid CO_2 emissions from MI Clean Energy Framework model. Green highlight denotes predicted values.*

Year	GRID CO2 emissions (tera lbs)	% Reduction	Emission Factor (lb/MWh)
2024	2.95	0.119	1069.1
2025	2.3	0.220	833.6
2026	2.15	0.065	779.2
2027	1.75	0.186	634.2
2028	1.35	0.229	489.3
2029	1.15	0.148	416.8
2030	0.7	0.391	253.7
2031	0.6	0.143	217.5
2032	0.45	0.250	163.1
2033	0.48	-0.067	174.0
2034	0.3	0.375	108.7
2035	0.288	0.040	104.4
2036	0.26	0.097	94.2
2037	0.22	0.154	79.7
2038	0.18	0.182	65.2
2039	0.12	0.333	43.5
2040	0.11	0.083	39.9
2041	0.1	0.091	36.2
2042	0.09	0.100	32.6
2043	0.08	0.111	29.0
2044	0.07	0.125	25.4
2045	0.06	0.143	21.7
2046	0.05	0.167	18.1
2047	0.04	0.200	14.5
2048	0.03	0.250	10.9
2049	0.015	0.500	5.4
2050	0	0	0.0

Table C3.2. *Moderate Grid Decarb predicted emission factors using precent reduction based on Consumers Energy implementation of clean energy projects. Green highlight denotes predicted values.*

Year	% Emitting	% Reduction	Emission Factor (lb/MWh)
2024	45	0.118	1105.7
2025	40	0.111	975.6
2026	38	0.050	867.2
2027	35	0.079	823.9
2028	33	0.057	758.8
2029	30	0.091	715.5
2030	28	0.067	650.4
2031	27.4	0.021	607.1
2032	27	0.015	594.0
2033	26.7	0.011	585.4
2034	26.3	0.015	578.9
2035	25	0.049	570.2
2036	23	0.080	542.0
2037	20	0.130	498.6
2038	16	0.200	433.6
2039	13	0.188	346.9
2040	10	0.231	281.8
2041	9	0.100	216.8
2042	8	0.111	195.1
2043	7	0.125	173.4
2044	6	0.143	151.8
2045	5	0.167	130.1
2046	4	0.200	108.4
2047	3	0.250	86.7
2048	2	0.333	65.0
2049	1	0.500	43.4
2050	0.5	0.500	21.7

Table C3.3. *Slow Grid Decarb predicted emission factors using extrapolated precent reduction of total electricity grid CO_2 emissions from MI Healthy Climate Plan. Green highlight denotes predicted values.*

Year	% reduction (from 2005)	Emission Factor (lb/MWh)
2024	33	1125.6
2025	36	1075.2
2026	40	1008.0
2027	42	974.4
2028	45	924.0
2029	49	856.8
2030	51	823.2
2031	52	806.4
2032	54	772.8
2033	56	739.2
2034	57	722.4
2035	59	688.8
2036	61	655.2
2037	63	621.6
2038	65	588.0
2039	69	520.8
2040	71	487.2
2041	74	436.8
2042	76	403.2
2043	78	369.6
2044	81	319.2
2045	83	285.6
2046	85	252.0
2047	87	218.4
2048	90	168.0
2049	92	134.4
2050	95	84.0

Appendix D: Heating

Introduction

The objective of the heating team was to determine how to eliminate fossil fuel heating by developing an affordable, low-carbon heating solution for Calvin's Campus. The team researched viable options and proved feasibility through calculations and information received from GMB and facilities. As the project developed, the heating team explored Ground Source Heat Pumps (GSHP), Air Source Heat Pumps (ASHP), Renewable Natural Gas (RNG), and Carbon Offsets. The heating team consisted of Caleb Gaffner, David Visser, Jared Skaggs, and Stephen Langerak.

Methods

The first task of the heating team was to research different heating options to reduce Calvin's carbon emissions from heating. Those options included GSHP, ASHP, and RNG. In addition to this, the heating team also researched carbon offsets; carbon offsets are purchasable rights to emission reductions elsewhere to compensate for Calvin's emissions. The team used information from GMB to estimate GSHP costs. The report from GMB also outlined costs for simply replacing the natural gas boilers and chillers that Calvin currently uses. This case was used as the baseline and all other projects were measured against this case. This allowed the team to determine what it would take for Calvin to become carbon neutral.

GSHP:

A GSHP is a system that utilizes stable temperatures below Earth's surface to heat and cool buildings. See Figure D1.1 for a diagram of a GSHP system. From the beginning of the project, the GSHP (also called geothermal) seemed like one of the most viable options for replacing Calvin's natural gas heating system. This was because the Engineering 333 report from 2022 concluded that geothermal was a viable option to eliminate Calvin's heating related emissions. Research into other universities around the nation was done to confirm this. All the universities that were researched invested in geothermal plants to help them reach carbon neutrality. Because these universities had similar goals to Calvin and were able to use GSHPs to achieve them, it seemed likely that Calvin could use this solution as well.

Calvin currently has two main heating loops on campus. Loop 1 covers all the academic buildings and athletic facilities as well as three dorms (BHT, RVD, and SE). Because there are so many buildings on Loop 1, it is responsible for more than 80% of the total heating load on campus. Loop 2 covers Knollcrest, as well as the rest of the dorms (KHVR, BB, NVW, and BV). The desire was that both loops could be powered by GSHP instead of the current natural gas boilers.

ASHP:

ASHPs have the ability to both heat and cool a building by exchanging heat with outside air. This makes them a viable solution for individual buildings/rooms that are not connected to Loops 1 or 2. ASHPs are used here instead of GSHP; this is because implementing GSHPs here would require additional infrastructure like creating a new heating loop and adding ductwork to buildings. The downsides of ASHPs are that they are expensive, require more maintenance and repair than GSHP, and are less efficient than GSHP. Because of this, they are only used in instances where installing GSHP is not feasible.

RNG:

The production of RNG uses resources such as livestock waste, wastewater, crops, and landfill to generate natural gas. Even though RNG contains carbon, it is considered carbon neutral because it comes from renewable sources. If Calvin could acquire or produce enough RNG, current boilers could be used to heat campus. This alternative was researched because it was a part of the 2022 Engineering 333 project report and this year's class wanted to confirm last year's conclusions. That previous class concluded that generating RNG on campus was not a viable alternative to natural gas due to the sheer quantity of livestock, wastewater, or land that would be required to meet Calvin's needs. This year's team wanted to confirm 2022's conclusion and see if it was possible to purchase RNG from an external company.

Carbon Offsets

Carbon offsets are purchasable rights to emission reductions elsewhere in order to compensate for the purchaser's emissions. The class is proposing a new carbon neutrality date of 2030 but Consumers Energy estimates the grid will not be carbon free until 2040; because of this, Calvin will need to purchase carbon offsets to account for emissions associated with purchased electricity before the grid decarbonizes in 2040. Of course, Calvin could just wait for the grid to decarbonize in 2040, but the class wanted to reach carbon neutrality faster than that. Offsets can also be used to cover carbon emissions associated with Calvin-sanctioned travel. Offsets are an important part of the class's solution because they can be used to cover emissions that are difficult to eliminate.

Results

GSHP:

Calvin was already planning to implement a GSHP plant on campus; this system will replace the current boilers and chillers in the Commons plant and construction will begin in 2024. The boreholes for this system will be placed in Commons Lawn and the CFAC parking lot. The carbon savings for this project will be approximately 23 million lbs/yr. This comes at an initial cost of $5.7 million with an annual cost of $15,000 per year; this annual cost includes operations and maintenance (O&M) as well as depreciation based on the estimated lifespan of the plant. These costs are relative to the baseline cost of the boilers and chillers that will be replaced. This Commons geothermal plant was calculated to have a payback period of 21 years.

In addition to this, another GSHP system should be started in 2026. This system will power the rest of Loops 1 and 2 and will use boreholes in Parking Lot 8. This geothermal plant will have a carbon savings of about 16 million lbs/yr. This comes at an initial cost of roughly $3.7 million with an annual cost of around $7,000 per year. The initial cost includes repaving Lot 8 after drilling boreholes and the annual cost includes O&M as well as depreciation based on estimated lifespan. The costs for this system were calculated as relative to the baseline cost. The payback period for this plant is slightly shorter than the commons plant at 20 years. Figure D1 shows which buildings are on each of the loops, with Loops 1 and 2 shown in red and blue respectively. The buildings not included on either of those loops will be addressed in the ASHP section.

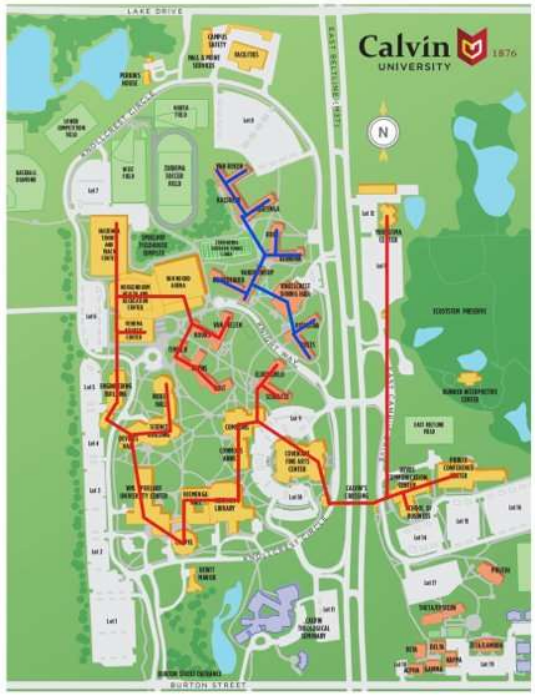

Figure D1. *Loops 1 and 2 as Red and Blue Respectively*

ASHP:

The team decided that buildings not on Loops 1 or 2 should be heated via ASHP. These buildings include the KE apartments, DeWit manor, facilities, and mail & print. The heating team believes ASHP are the best long-term solutions for replacing natural gas boilers in these buildings. See Figure D5.1 for a map of ASHP locations. The class decided to implement ASHP in 2029 based on the cash-carbon model. Implementing ASHP in these locations would have a carbon savings of 5 million lbs/yr. It would cost roughly $1.5 million initially and would have an annual cost of $9,700 per year. Similar to the GSHP calculations, this cost includes O&M as well as depreciation based on estimated lifespan and is relative to the baseline cost of the system it is replacing.

Accounting for the impacts of GSHPs for Loops 1 and 2 and the ASHPs in the rest of the buildings, the remaining natural gas emissions are nearly zero. Figure D2 shows the effect that each of these projects has on Calvin's natural gas emissions and when they occur. For example, although the Commons GSHP begins construction in 2024, the effects will not be seen until 2026. The same is true for the rest of the projects.

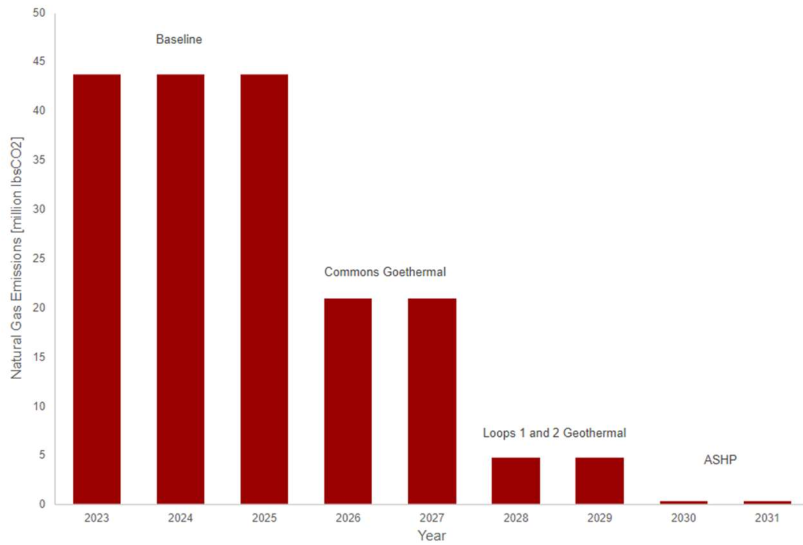

Figure D2. *Effects of Projects on Natural Gas Emissions*

RNG

After research and calculations, the team decided that RNG was not a viable option for heating Calvin's Campus. RNG is expensive and very hard to generate in large enough quantities to meet Calvin's needs. The team also investigated the possibility of purchasing RNG; Calvin could purchase RNG from DTE. However, even if Calvin was able to buy all the RNG DTE supplies, it would only cover 7% of Calvin's annual natural gas needs. For this reason, RNG was not used as part of this solution.

Carbon Offsets

Buying carbon offsets is a proactive and responsible approach for individuals and businesses to mitigate their carbon footprint and contribute to the fight against climate change. When one purchases a carbon offset, they are essentially paying a third party to prevent or reduce emissions elsewhere. One example of a project that would generate carbon offsets is replacing carbon intense energy generation with higher efficiency plants or a renewable energy source. Another common example is reforestation. Calvin could become carbon neutral immediately just by purchasing carbon offsets. However, the class decided this is not a viable option because it would cost $726,860 per year and has no return on investment. The cost of carbon offsets is also projected to rise in the future so this would not be a good long-term solution. However, offsets are a good way neutralize any remaining carbon emissions once all other carbon reducing initiative have been implemented. Calvin will need to pay approximately $245,010 in the year 2030 to go carbon neutral as a university. This cost will decrease to 163,340 in 2039 as the grid and airlines decarbonize.

Conclusion

The best plan of action found by the heating team to reach an earlier carbon neutrality date was as follows: the installation of two geothermal plants for heating Loops 1 and 2, the installation of ASHP to replace natural gas boilers in remaining buildings, and the use of carbon offsets to reach carbon neutrality. The team decided this was the most effective way for Calvin to feasibly eliminate natural gas heating from campus and achieve carbon neutrality in the year 2030.

Appendix D1: GSHP Diagram

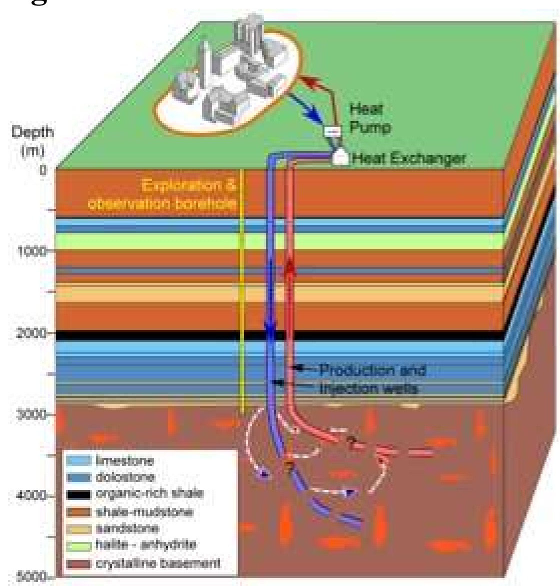

Figure D1.1. *Diagram of a GSHP*

Appendix D2: Map of Buildings on Loops 1 and 2

Figure D2.1. *Map of Loops 1 (red) and 2 (blue) on Campus*

Appendix D3: Building Heating Loads and Costs

Table D1.1. *Calculated Loads and Initial Cost Estimates of Each Building and Loop*

Option	Upfront Cost (millions of 2023$)	Power required (kWh/yr)	Load (BTU/yr)	Natural Gas Reduction (MCF/yr)	CO_2 Redution (kg-CO_2/yr)	Building Square Footage (ft^2)
Heating loop 1	25.030125	9386773.00	124597000000.00	135043.2237	19986397.11	164018500
Heating loop 2	2.683275	761713.00	10110370157.00	10958.02451	1621787.627	304705.00
KE	2.1888	232698.00	3091417195.00	3350.601892	495889.08	170315.00
DeWit Manor	0.086184	46959.00	535073531.90	579.9341452	85830.25349	7875.00
Flat Iron Lake House	0.036252	11713.00	133457122.90	144.6461801	21407.63466	2340.00
Koinonia House	0.03249	7680.00	145469451.30	157.6656232	23334.51224	3095.00
Travis House	0.036252	12767.00	107401000.60	116.4055102	17228.01551	5094.00
Garden House	0.040698	19945.67	227268601.20	246.3228213	36455.77755	4025.00
Cooper House	0.036252	12313.25	140301885.10	152.0648078	22505.59156	3545.00
Bunker House	0.03933	14331.83	163302314.40	176.9935952	26195.05209	3715.00
Tongue House	0.03933	13798.13	157221125.00	170.4025583	25219.57863	3520.00
Facilities	2.0976	197207.00	2617442962.00	2836.889617	419859.6633	35790.00
TOTAL:	32.35	10717898.87	142025725346.40	153933.18	22782109.90	2184204.00

Appendix D4: Borehole Locations

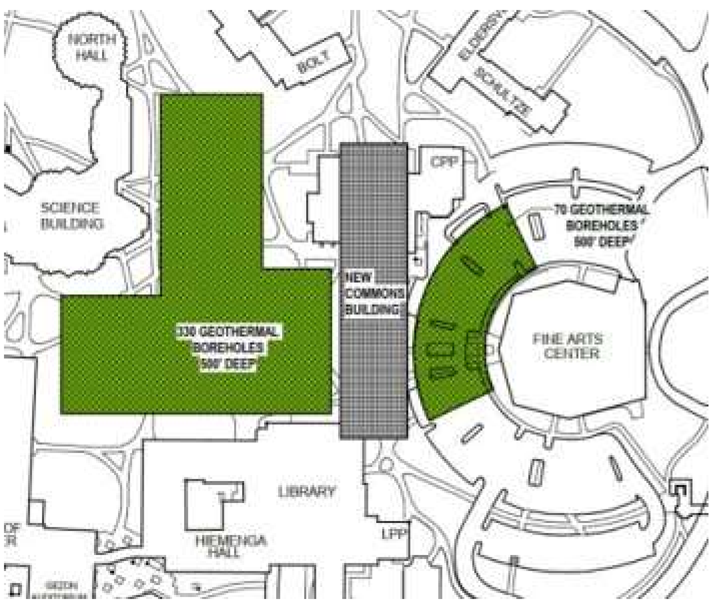

Figure D4.1. *Map of Borehole Locations for the Commons Geothermal Plant*

Figure D4.2. *Borehole Locations for the Loops 1 and 2 Geothermal Plant*

Appendix D5: Buildings to use ASHP

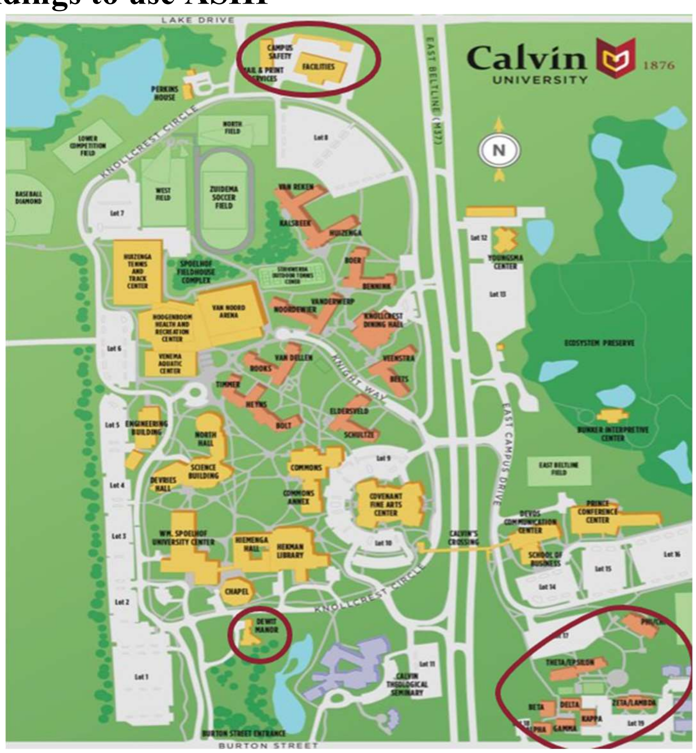

Figure D5.1. *Locations of buildings that will use ASHP (i.e. not on Loop 1 or 2)*

Appendix D6: Project Plan and Timeline

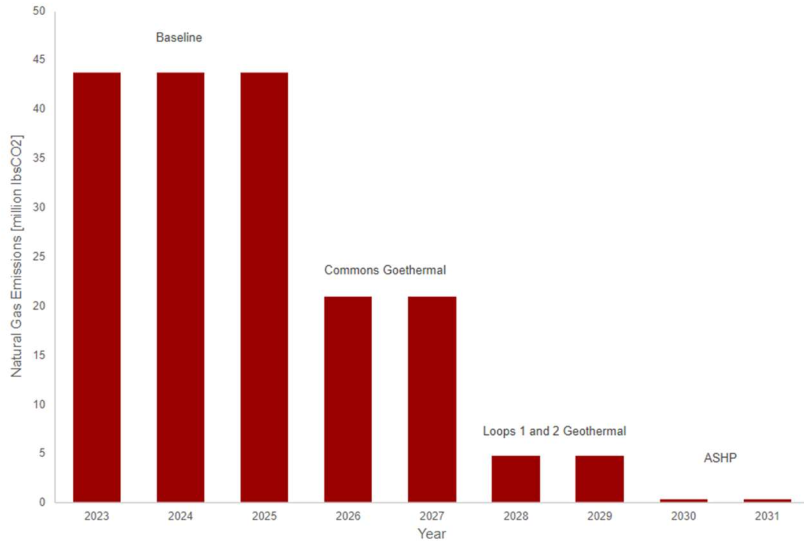

Figure D6.1. *Graph Showing the Effects of Each Project and When it Will Happen*

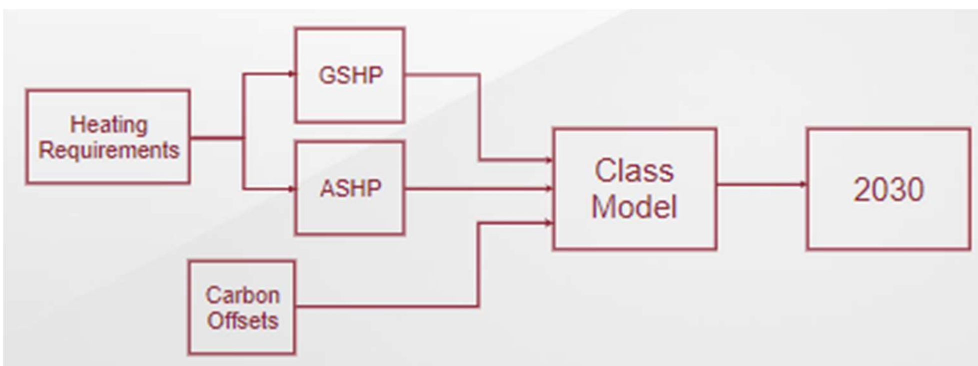

Figure D6.2. *Overall Heating Roadmap to Carbon Neutrality Date of 2030*

Appendix E: Administration

Introduction

Calvin's net carbon neutrality hinges on success in three categories: physical carbon reduction, financial feasibility, and logistical oversight. Sparked by a *Chimes* article from 2021 in which Professor Matthew Heun commented, "We've never had any sort of top-down on sustainability on our campus. I think the most important thing Calvin could do would be to hire someone with the Calvin carbon story as their job title," it became apparent throughout the semester that Calvin's current structure for sustainability is not sufficient for the execution of the proposed projects. We found that relevant information was spread across many departments. No single office had access to the information necessary to understand the full carbon story at Calvin. Limited information access leads to reduced reporting and makes it difficult to judge the effectiveness of past initiatives. A group was designated to identify the challenges with Calvin's current sustainability structure, establish a set of responsibilities that will help clarify Calvin's carbon story, and propose a new sustainability structure that remedies current shortcomings. This splinter group consisted of Kyle Borror (Electricity), Caleb Clark (Electricity), Stephen Langerak (Heating), Luke Penning (Efficiency), and Jared Skaggs (Heating).

Methods & Results

In preliminary research, Carbon neutral universities were analyzed for solutions that may help Calvin achieve carbon neutrality. *Second Nature* is a non-profit organization committed to accelerating climate action in, and through, higher education; their list of carbon neutral schools was used. There are currently zero universities in the United States that are 100% fossil-fuel free without using offsets. About half of the universities have access to a fully decarbonized grid. And only one of the remaining colleges (Colorado College) explicitly mentions the challenge of purchasing electricity from a carbon-intensive grid. Despite this, Colorado College was able to reduce their emissions by 50%, purchasing offsets for the remainder. They did this by working with their local energy provider to prioritize grid decarbonization—paying for the development of grid solar power. Many schools used biomass boilers that burn sustainably sourced woodchips. Some colleges had small-scale on-campus cogeneration plants, and many implemented some on-site solar with additional energy offsets purchased from e-Green Certified sources. Every school was committed to LEED building certification (in some capacity). A more complete summary of the results from this research is provided in Appendix E1. Most importantly, the carbon neutrality plan for every net-zero school started with a dedicated sustainability committee in the administration.

Next, we sought to better understand Calvin's current sustainability structure and the reasons for its shortcomings. This was done through discussion with the coordinator for the dormitory sustainability coordinators (SC) and by searching through the organization charts available on Workday. From this, we were able to develop a block diagram that represented the current structure, shown in Figure 1. Cabinet members are shown in blue and employees without sustainability in their job description are shown in red. The current structure relies heavily on the Energy, Environment, and Sustainability Committee (EESC) as well as faculty senate to establish sustainability initiatives.

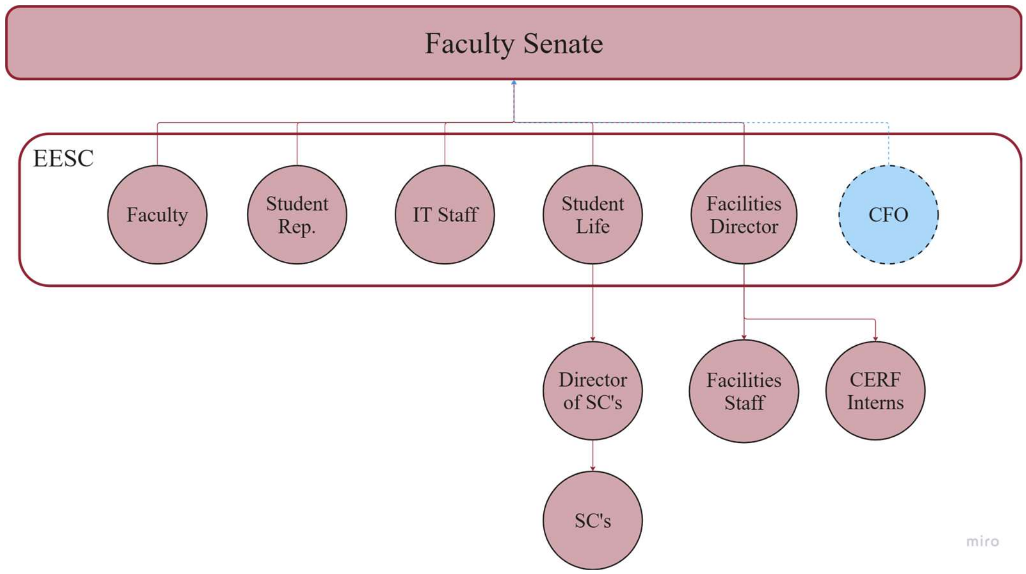

Figure E1. *Calvin's current sustainability structure. Cabinet members are shown in blue, and employees without sustainability in their job description are shown in red.*

Analysis of the current structure revealed two primary issues: 1) EESC does not have enough capacity or decision-making power and 2) Case-by-case consulting does not allow for timely feedback on relevant projects.

Regarding this first issue: EESC is entirely composed of faculty, students, and staff who are passionate about sustainability and want to contribute to our school's efforts. However, everyone on the committee has their own job responsibilities, leaving them with limited bandwidth as individuals to work on large sustainability projects. Additionally, EESC must pass their proposals through faculty senate before reaching a Presidential cabinet with no one who has sustainability as their primary responsibility. This leads to inaction on EESC recommendations. Another effect of members' limited bandwidth is a lack of communication and coordination on sustainability initiatives. This has led to occasions where two groups are working towards the same initiative, or (worse) no one working towards something that was discussed. It also means that data regarding Calvin's sustainability efforts are spread throughout campus which allows for neither accountability nor a cohesive sustainability narrative.

Regarding the second issue: EESC meets only once (or twice) a month, which leads to slow committee response times. If a cabinet mandate or proposal is passed to EESC either directly from the administration or from faculty senate, it will require >2 weeks to get a response. This could disincentivize cabinet members from passing mandates through EESC when timely decisions are necessary, *even if* they are sustainability related. This limited meeting time would also make it difficult for the committee to coordinate the proposed campus-wide sustainability initiatives (e.g., geothermal, rooftop solar, etc.).

Turning towards solutions, we discovered a sustainability roadmap for Calvin from 2016. A taskforce spent nine months working to renew Calvin's sustainability goals leading up to President Le Roy's signing of the President's Climate Commitment. Their third recommendation was to appoint a Director of Sustainability. While this was added to Calvin's sustainability strategy, it was later changed to Officer of Sustainability and has yet to be created. We also discovered that most of Calvin's sustainability strategy is assigned to an unfilled cabinet position: VP for People, Strategy, and Technology. To ensure that Calvin makes progress towards carbon neutrality, it is crucial to invest in qualified individuals with "the Calvin carbon story as their job title," as Professor Matthew Heun claimed back in 2021.

We identified three primary responsibilities for the appointee:

1. Maintain sustainability strategy,
2. Collect, organize, and report sustainability data, and
3. Spearhead proposed carbon neutrality initiatives.

We recommend the following options as changes to Calvin's current structure: Tier 1) repurpose EESC to report directly to President Boer, Tier 2) create a Director of Sustainability, supported by EESC, or Tier 3) Create an Office of Sustainability led by a Director of Sustainability to coordinate all other on-campus groups. With the goal being the organization of sustainability efforts on Calvin's campus, we believe that a cabinet-level coordinator of sustainability will streamline the efforts of EESC, unify tangential organizations like the Calvin Clean Water Institute (CWI) and Plaster Creek Stewards (PCS), and advocate for sustainability at the cabinet level to ensure that Calvin is meeting sustainability strategy goals and carbon neutrality targets. Additionally, the consolidation of campus-wide sustainability data will demonstrate a commitment to accountability and may attract donors if presented effectively. For these reasons, we strongly recommend either Tier 2 or Tier 3 if Calvin is committed to achieving carbon neutrality before 2057. An example administrative structure that solves the issues associated with our current sustainability hierarchy is provided in Figure 2. With a dedicated faculty member or office, EESC would no longer be capacity-limited nor lack decision-making power. The decision-making efficiency provided by a cabinet-level coordinator would expedite Calvin's carbon neutrality and is necessary to ensure the success of campus-wide initiatives as well as grassroots efforts.

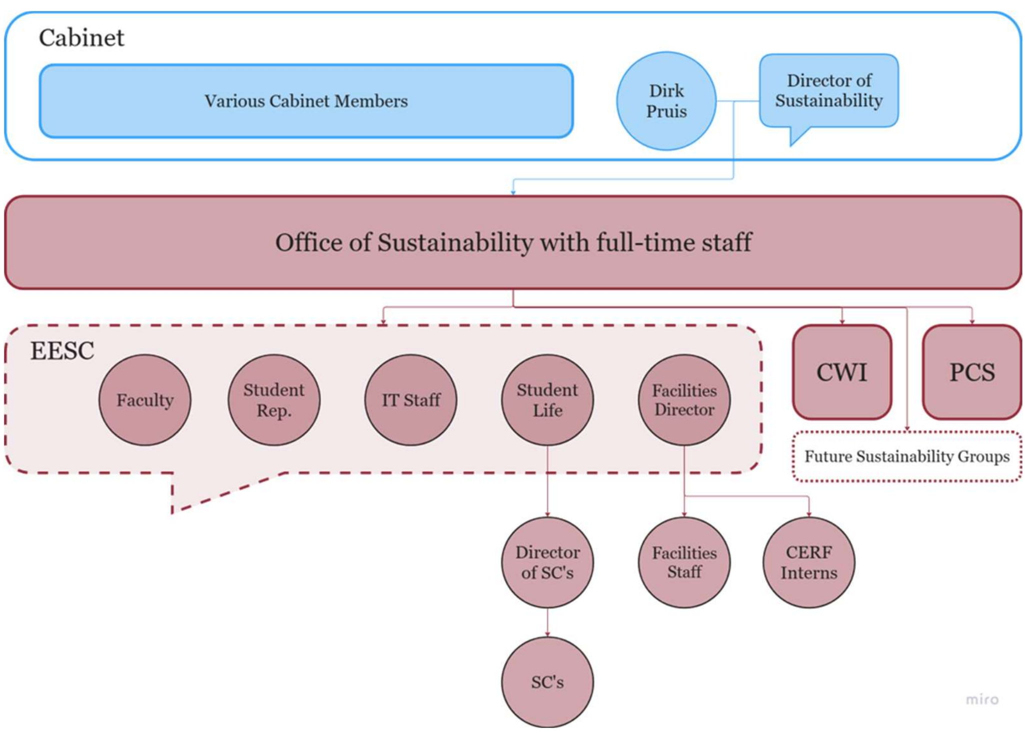

Figure E2. *Recommended sustainability structure. Cabinet members are shown in blue, and employees without sustainability in their job description are shown in red.*

Conclusion

A team was created to determine the changes to Calvin's current sustainability structure necessary to guarantee effective logistical oversight and progress towards carbon neutrality. Ultimately, limited EESC meeting frequency as well as member faculty and staff resources will significantly hinder Calvin's progress towards carbon neutrality. Calvin's sustainability strategy goals are not being accomplished because they are assigned to an unfilled cabinet position. We strongly recommend that a cabinet-level Director of Sustainability at Calvin be appointed to ensure that these issues do not extend our suggested target for carbon neutrality: 2030.

Appendix E1

Colby College | Waterville, ME

- Cogeneration turbine produces 10% of electricity + heat/hot water.
- All electricity is purchased from 100% renewable sources.
  - On-campus solar (5300 panels) produces ~16% of electricity needs.
- LEED standards for all new construction and major renovation projects.
- Converting central heating from oil to wood chip biomass with NG as a backup.
  - Biomass plant saves close to one million gallons of oil per year.
- Increasing recycling and composting efforts, contracting with a local landfill that uses CH_4 recapture.
- Energy efficiency projects. Very vague.
- Geothermal heating/cooling in two major new construction projects.
- Fuel efficient vehicles for facilities and campus security.
- References
  - https://www.colby.edu/green-colby/green-campus/
  - https://www.colby.edu/wp-content/uploads/2013/10/Climate-Action-Plan-July-2010.pdf

Middlebury College | Middlebury, VT

- Biomass gasification plant burns locally sourced wood chips. Meets "most" of the heating and cooling needs on campus and cogenerates 15-20% of electricity.
  - Cut carbon footprint by 40-50%.
- Blue Source assessed their forests and assigned them carbon credits.
- 143 kW AllEarth Renewables solar farm.
- 500 kW solar array accounts for 5% of total energy sources on core campus.
- 500 kW Wilber Solar farm means that solar accounts for 8% of total energy.
- Electricity comes primarily from carbon neutral sources: nuclear and hydroelectricity.
- References:
  - https://www.middlebury.edu/franklin-environmental-center/sustainability-action/carbon-neutrality-2016
  - https://www.middlebury.edu/sites/www.middlebury.edu/files/2022-06/Middlebury_CAP.pdf?fv=ByYmhF0o

Bowdoin College | Brunswick, ME

- Reached carbon neutrality in 2018. Have a goal to be entirely fossil-fuel free by 2042.
- Purchase some electricity from a carbon-neutral grid.
- Reduced onsite carbon emissions by 29%.
- Invests in carbon offsets and renewable energy credits (RECs) associated with wind farms.
- Efficiency improvements with a focus on LEED certification. Reduced electricity usage by 600000 kW-hrs (3.2%).
- Combined heat and power (CHP) reduced annual electricity usage by 7%.
- 1.2 MW on-campus solar project with a contract for an additional 8 MW solar farm.
- References:
  - https://www.bowdoin.edu/sustainability/carbon-neutrality/index.html
  - https://www.bowdoin.edu/climate-action-plan/index.html
  - https://buildingos.com/s/bowdoin/storyboard2853/?chapterId=16643
  - https://www.bowdoin.edu/sustainability/pdf/2009-blueprint-for-carbon-neutrality.pdf

American University | Hamilton, NY

- Reached carbon neutrality in 2018. They publicly submit annual GHG emissions reports to Second Nature for review and to maintain the certification.
- They defined "Scope 1" as on-site NG and fleet emissions, "Scope 2" as purchased electricity, and "Scope 3" as all other emissions including commuting, travel abroad, waste, etc.

- Scope 1: Solar thermal panels use the sun's energy to produce hot water. Transition from centralized steam plant to a decentralized low temperature hot water system. Remaining emissions are offset with landfill gas capture and use.
- Scope 2: Decreased electricity usage/sq. Ft by more >20% between 2005 and 2017. Turning off lights, unplugging chargers, LED bulbs, and using a building automation system that allows facilities to monitor buildings for unusual activity, LEED buildings. Further decreased with on-campus solar (amount not specified) and solar farms in North Carolina. AU also purchases e-certified renewable energy credits to match the remaining electricity used on campus.
- Scope 3: Additional offset projects- energy efficient cookstoves in Kenya (Paradigm Project), tree planting in DC, wind power offsets in India, efficient trucking, waste emissions are offset through landfill capture and use.
- References:
    - https://www.american.edu/about/sustainability/tracking-progress.cfm
    - https://www.american.edu/about/sustainability/upload/american-university-climate-action-plan.pdf

Colgate University | Hamilton, NY
- First step was forming a "sustainability council" and hiring and hiring a sustainability director whose job is to measure annual campus carbon footprint (started in 2009).
- Reduction in gross emissions by 49% since 2009.
- References:
    - https://www.colgate.edu/about/sustainability/climate-action-planning
    - https://www.colgate.edu/about/third-century-plan/third-century-sustainability-plan

University of San Francisco | San Francisco, CA
- Conserve energy and carbon (reduce demand).
- Enhance efficiency (reduce intensity).
- Decarbonize supply (renewable electricity).
- Offset (reduce emissions elsewhere).
- References
    - https://myusf.usfca.edu/sites/default/files/default/sustainability/usf-climate-action-plan_submit_dec2014.pdf

Colorado College | Colorado Springs, CO
- Colorado College's grid is carbon intensive which might make some of their initiatives more applicable to Calvin.
- Behavioral change program: 14 weeks, 14 habits, 14% energy usage reduction.
- Equivalent to LEED certification for new buildings was developed.
- Renovated library with geothermal for net-zero heating/cooling.
- Small-scale solar projects around campus.
- Working with the local energy provider to add 255 MW of solar to the grid.
- A variety of carbon offsets including landfill methane capture for remaining emissions.
- Targeted 50% reduction in CO_2 emissions.
- References:
    - https://www.coloradocollege.edu/offices/sustainability/carbonneutral2020/index.html
    - https://www.coloradocollege.edu/offices/sustainability/documents/CCCarbonNeutralityPlan.pdf

Allegheny College | Meadville, PA
- 42% reduction in GHG emissions, 19.2% improvement in energy efficiency, 30% reduction in paper consumption, 100% electricity from wind, 8.5 MWh of solar generated on campus each year, 40% water reduction.
- New construction is LEED silver certified.

- Geothermal heat pumps on dorms.
- All electricity is purchased from Green-e certified, wind-generated, renewable sources.
- Plan and energy/economic data for carbon neutrality are not publicly available.
- References:
    - https://sites.allegheny.edu/sustainability/topics/

Dickinson College | Carlisle, PA

- All lighting has been replaced by high-efficiency LEDs.
- Residence halls are connected to a central, optimized power, heating, and cooling plant.
- Renovations improve energy saving features (windows, insulation, etc.).
- EnergyStar Appliances.
- 25-30% of annual electricity is produced by a 3 MW on-site solar farm.
- Virtual power-purchasing agreement enables development of a 45 MW solar farm in Texas.
- Green-e Certified Renewable Energy Credits (to offset remaining energy needs).
- Behavioral initiatives: education, events, etc.
- References:
    - https://www.dickinson.edu/info/20052/sustainability/2566/climate_action_plan
    - https://www.dickinson.edu/download/downloads/id/2483/sust_performance_cap_2009_pdf
    - https://www.dickinson.edu/download/downloads/id/12090/2019_greenhouse_gas_inventory_report.pdf

Catawba College | Salisbury, NC

- 16 geothermal wells across campus for heating and cooling.
- 837 kW of on-campus solar.
- 76 solar thermal modules provide 3.17 mBTUs.
- LEED certified buildings.
- Various energy efficiency projects.
- Renewable energy credits from NC solar farms. Green-e Certified.
- Landfill Gas Capture and Use Project for additional offsets.
- $242 million in donations in one year to provide funding for emissions offsets.
- References:
    - https://catawba.edu/sustainability/
    - https://catawba.edu/carbonneutral/

Appendix F: Additional Figures

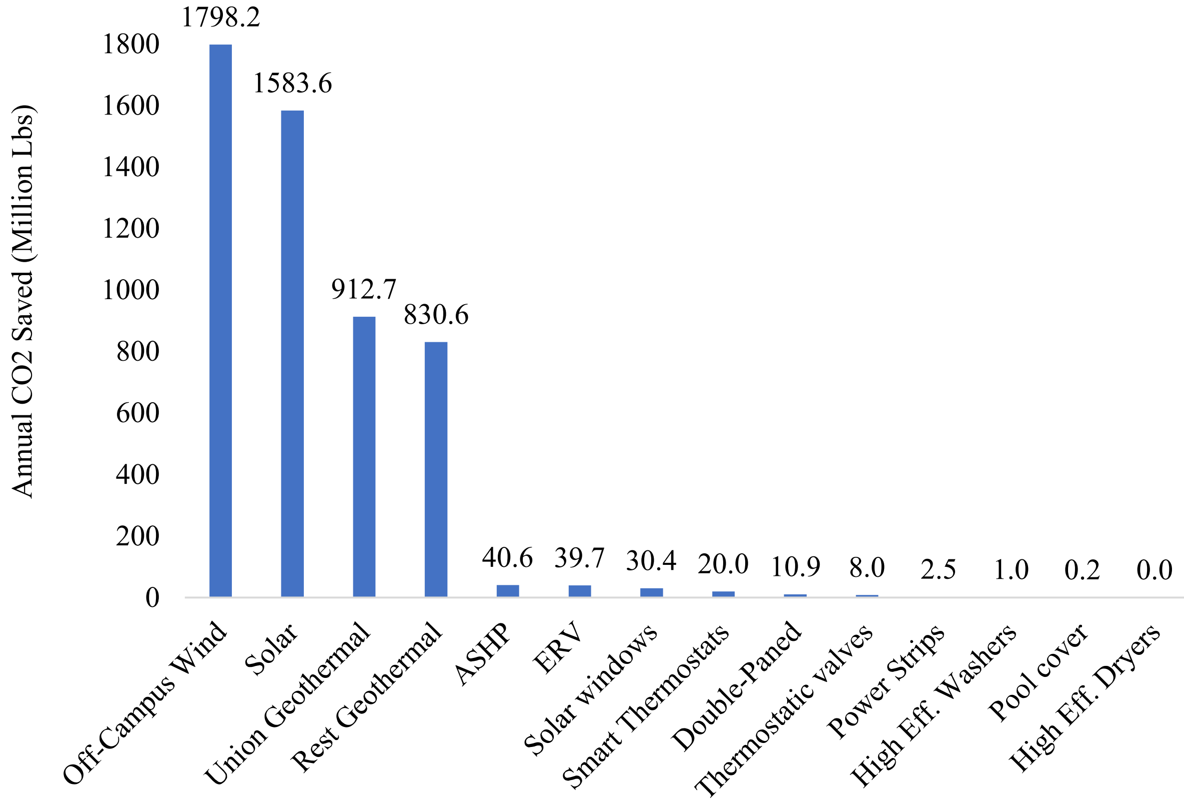

Figure F1. *Annual CO_2 Saved for Investigated CO_2 Reduction Projects.*

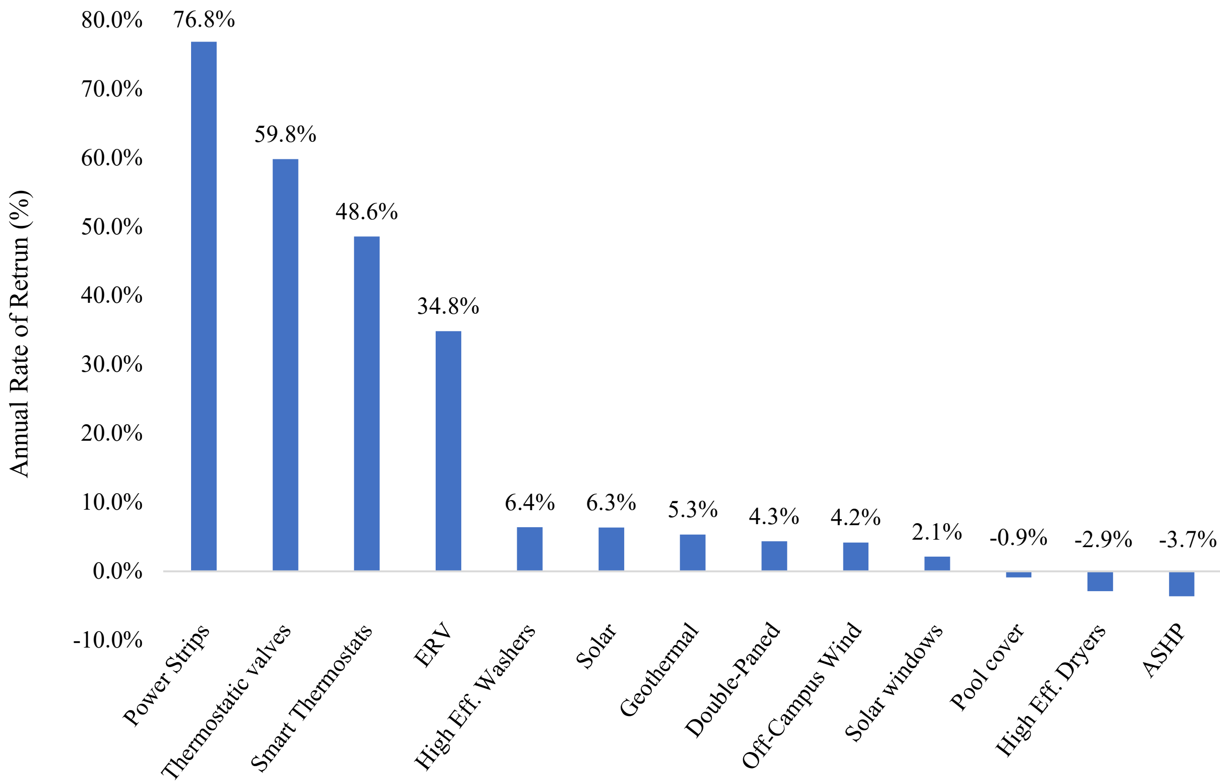

Figure F2. *Annual Rate of Return for Proposed CO_2 Reduction Projects.*

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