ENGR 333-A Natural Gas CO2 Emissions Reduction Project: Final Report

Professor Heun

December 7, 2022

Abstract:

Calvin University has committed to being carbon neutral by 2057. This entails removing all the natural gas consumption for heating, converting to electrical heating options, and then making carbon free electricity. This project looked into four different options: air source heat pumps, ground source heat pumps, renewable natural gas, and the efficiency of current equipment. Each option was examined throughout the course of the semester to determine feasibility of each solution, and which ones would be best to implement. As a class, section A decided ground source heat pumps along with thermostatic valves and the implementation of double pane windows would be the most beneficial option for Calvin to become carbon neutral. With the solution of converting all buildings on and off campus to a designated heating loop, the capital investment would equal $28 million with the breakeven year in 2061. This solution highlights what it would take to move Calvin University towards carbon neutrality.

Introduction:

In 2017 President Michael K. Le Roy signed Second Nature's President Climate Commitment. This commitment outlines that Calvin's governing body will ensure Calvin University is a carbon neutral educational institution by 2057. In June of 2022, Calvin University's presidential seat was passed from Dr. Michael K. Le Roy to Dr. Wiebe Boer. In his short time as the president of Calvin University, Dr. Boer has put many projects into motion to help Calvin achieve its goal of becoming carbon neutral by 2057. This past fall Dr. Boer tasked the ENGR 333 classes with answering the following question: What would it take to eliminate Calvin's natural gas-related net CO_2 emissions?

Methods:

The Ground Source heat pump researched ways in which to implement new ground source heat pumps on campus. This included both implementing new systems to off-campus houses, facilities, and DeWit Manor, as well as renovating current loops such as the main campus loop. This was found to be a very cost effective and efficient method in the long run as shown in more detail in *Appendix B*.

The efficiency team researched ways that Calvin could improve its heating efficiency in any of its buildings. The residence halls were identified as one of the top inefficiencies on campus. To improve the residence halls, installing thermostatic valves and double pane windows was proposed. Additional information and details on the improvements can be found in *Appendix C*.

The markets team analyzed future energy markets for each year through 2050. The three price energy categories evaluated were commercial electricity, residential electricity, and natural gas. These predicted prices were used as the basis for all cost calculations in the hero graphs. Details about the models and assumptions made for these predictions are included in *Appendix D*.

Air-source heat pumps (ASHP) paired with carbon free electricity provide efficient heating and cooling to buildings. A modular air-to-water heat pump was examined by the team with assistance from Trane Technologies as the best method for replacing the current heating systems. As can be seen in *Appendix E*, the modular units were fitted for residence halls, apartments, and homes based on calculated heat loads. These calculations suggested that ASHP was not the most cost-effective or efficient solution for heating Calvin's buildings.

Renewable natural gas (RNG) is an alternative to natural gas that supplies Calvin University's heating systems. Some everyday methane releasing sources include, but are not limited to livestock waste, wastewater, landfill waste, and forestry waste. It can be seen in *Appendix F*, that RNG does not specialize as a standalone solution for this project although there is a proposed solution outline in the Appendix.

Results and Analysis:

Information was gathered from all the sub teams of Efficiency, Ground Source Heat Pumps (GSHP), Air Source Heat Pumps (ASHP), Markets, and Renewable Natural Gas (RNG). This data included initial capital investment, embodied carbon, and implementation year. Additionally, specific data was collected from each of the sub teams. For Efficiency, the heating load reduction for efficiency projects was collected. For GSHP and ASHP, the amount of heating load that could be provided for each loop or off campus location was collected. For Markets, the future price of Natural Gas, RNG, and electricity was calculated in 2021$. All of these values were needed to formulate the Hero Graph. The term "Hero Graph" was introduced to the class by Professor Heun. A Hero Graph is a visual representation encapsulating what is suggested, how it will be done, and why the reader should care. By having all of this information in one graphic, it is easy to explain what went on through the course of the project and what the final result will be. Once all the values were entered into the Hero Graph Excel sheet, work could then begin on optimizing the solution and solving the problem of Carbon emissions due to heating.

Calculations were made to optimize the solution based on performance of the systems throughout the year, initial costs, yearly operation and maintenance costs, and feasibility on campus. It was found that although RNG was a sustainable method for replacing Natural Gas, it was not viable as the cost of infrastructure was so high and thus was not presented as a final solution. ASHP, although they do not require the ground to be torn up and are initially significantly cheaper, it was decided that this was not a viable method as they are very energy demanding in the winter to run. This is due to the fact that defrost cycles need to be run to ensure the unit will run in below freezing weather, of which Grand Rapids experiences a lot of. Additionally, ASHP need to be replaced every 10-14 years and thus adds a high cost in long term operation. This left the solution in the hands of GSHP and Efficiency teams, with the Markets team guiding future financial data. First, the efficiency team did research on several different methods as will be shown below in Appendix C. With these improvements, the heating load of campus could be greatly reduced. The implementation of GSHP as described in Appendix B, was the heart of the solution. Although they are initially a high cost and cause a lot of construction to install the heating loops and bore holes, in the long run they are very effective and thus displayed as our solution. Not only are they more energy efficient because of their large COP, they also are still very effective in the winter as they use deep bore holes to utilize the ground as a Thermal Battery.

Conclusion:

After extensive research and optimization, the students in Engineering 333 Section A proposed a solution utilizing ground-source heat pumps and efficiency improvements based on the comparison of effectiveness of sources and the financials related to each source. This team of students believes that this is a successful and financially feasible solution for eliminating Calvin's natural gas-related net CO_2 emissions by 2040 and enables the continued following of the Statement on Sustainability.

Appendices:

Contents:

Appendix A: Hero Graphs

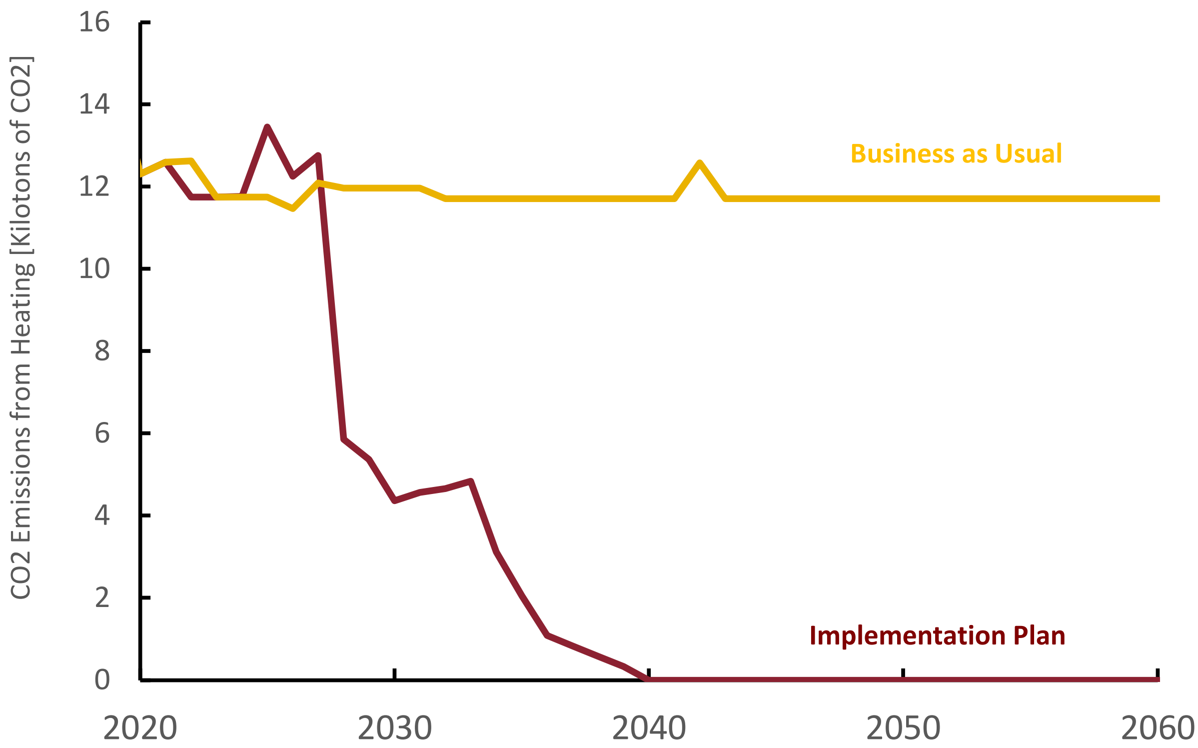


Figure A1. Calvin's annual carbon emissions for implementation plan and business as usual.

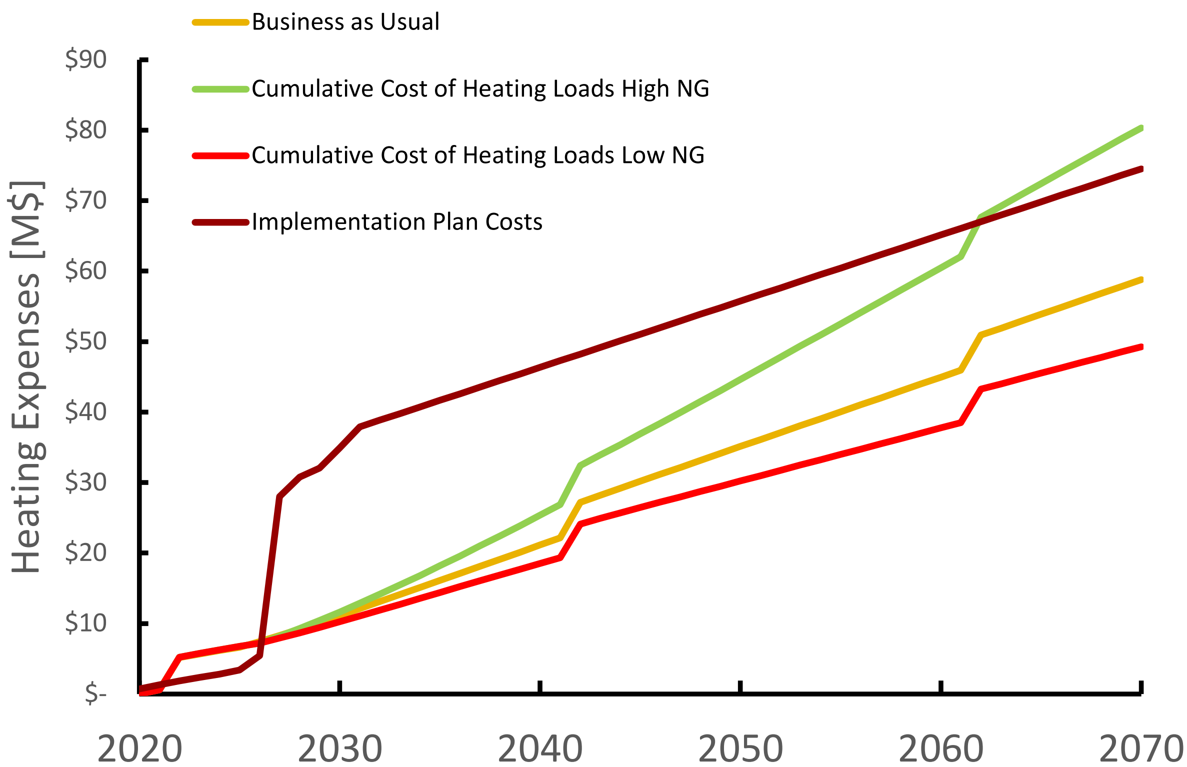


Figure A2. Calvin's cumulative heating expense for implementation plan over time showing payback period.

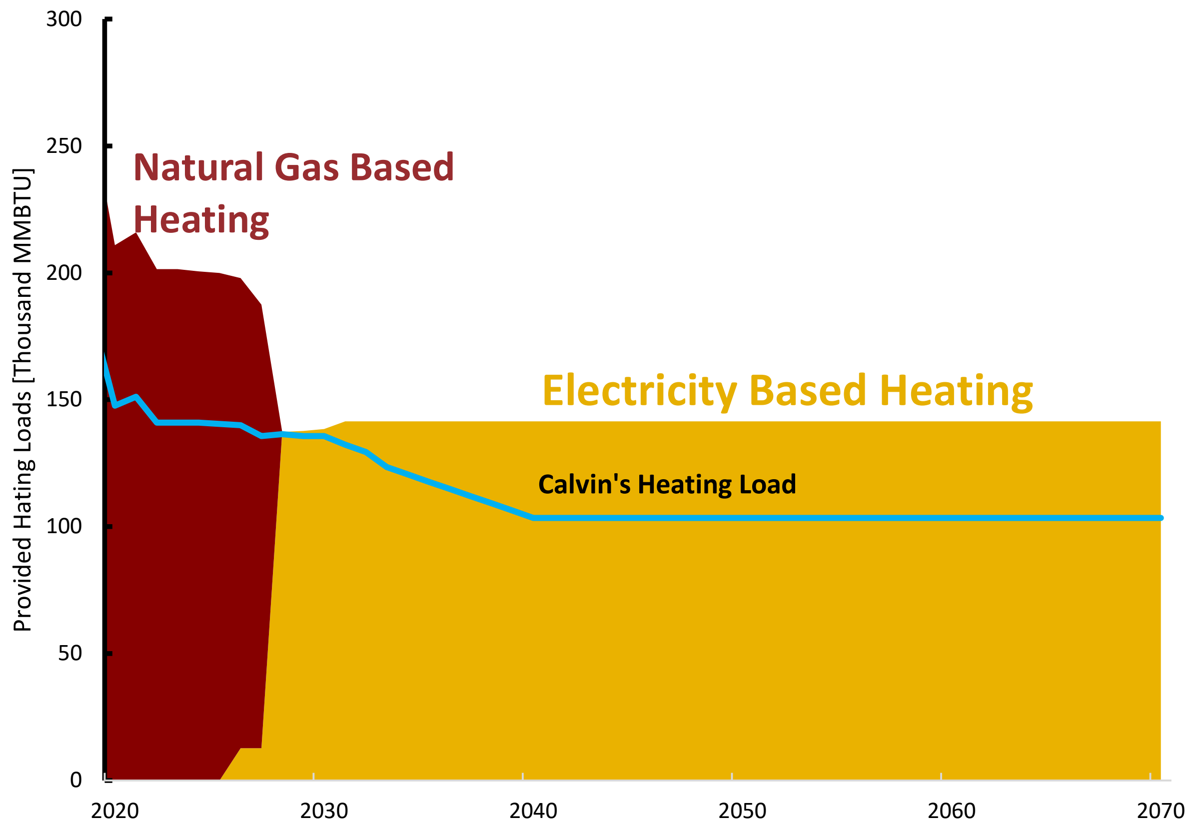


Figure A3. Sources provided to Calvin University's overall heating load.

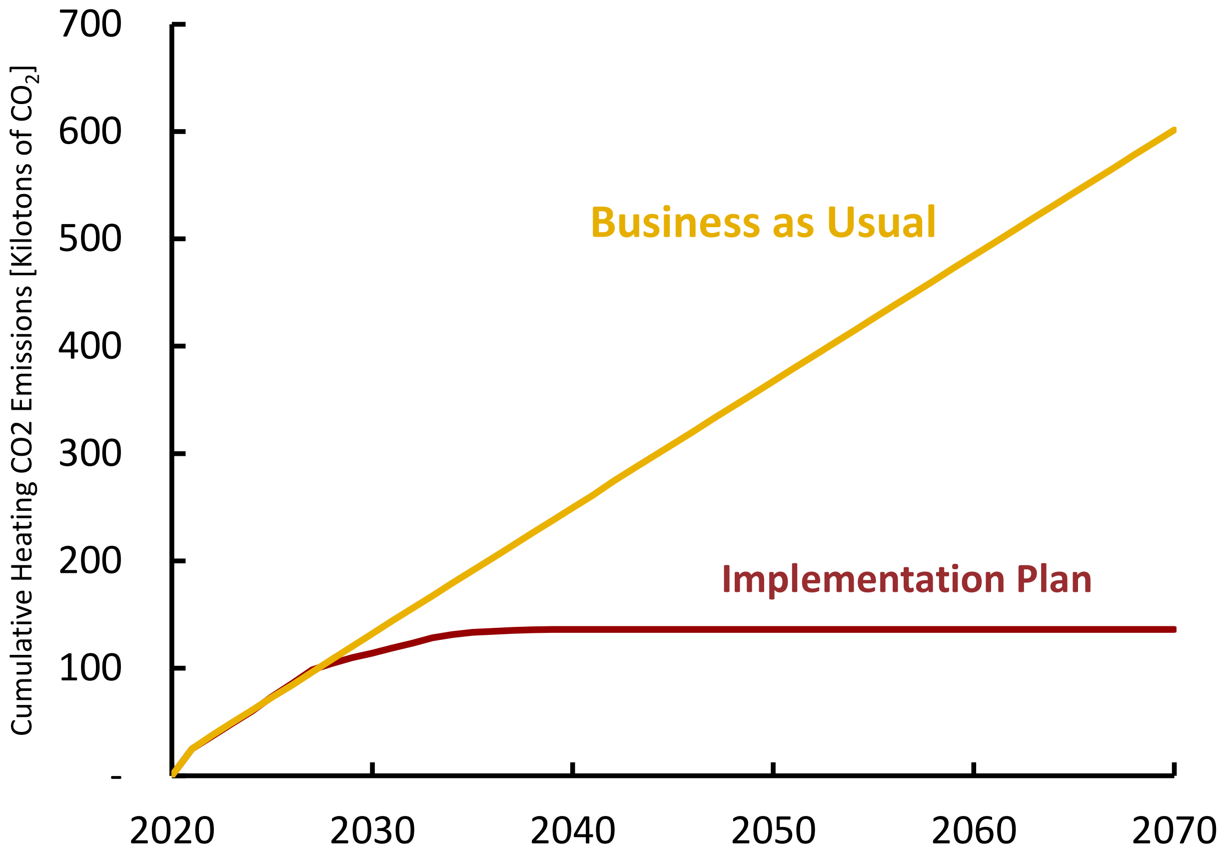


Figure A4. Cumulative carbon emissions from current heating plan and implementation plan.

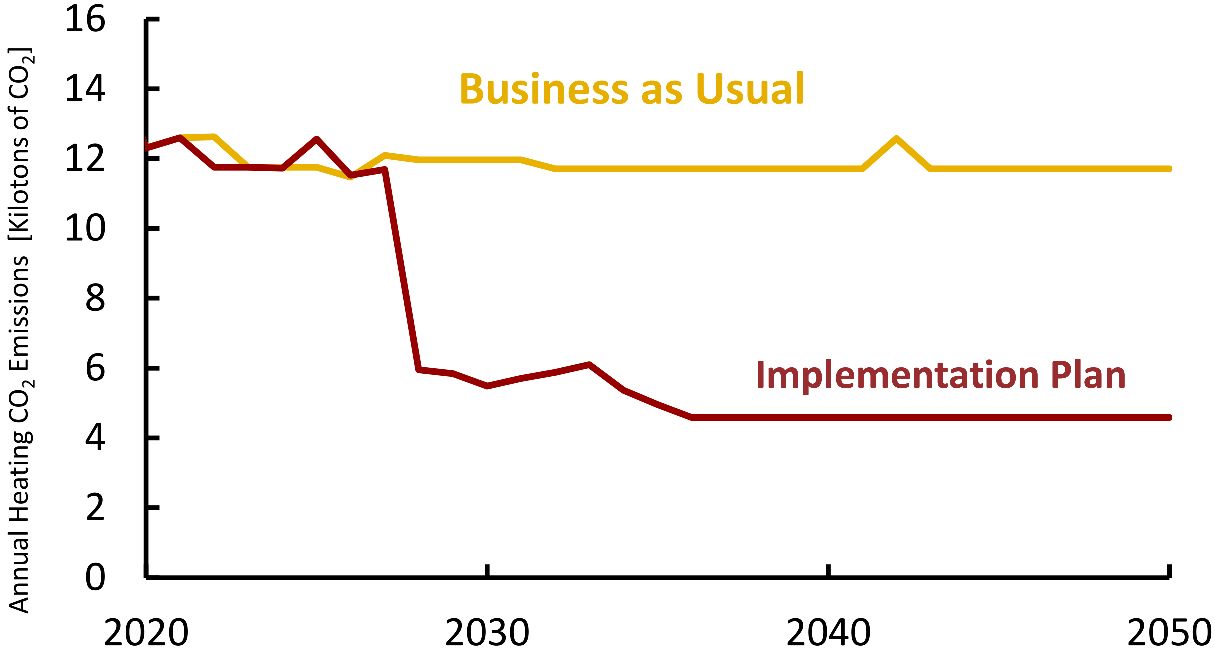


Figure A5. Annual carbon emissions associated with heating with current carbon content of electricity.

Appendix B: Ground Source Heat Pumps

Ground Source Heat Pump Team

Dat Cao, Izuchi Ebeku, Sam Hoover, Sawyer Masselink, and Ian VanderKooi
ENGR 333-A
Professor Heun
12/7/2022

Abstract:
In order to accomplish the goal of determining what it would take to eliminate carbon emissions from natural gas at Calvin University, ground source heat pumps were explored as a potential solution. The team created heat load calculations for Calvin, using them to determine required capacity for equipment. Additionally, other universities that had implemented similar systems were studied to help develop a cost model for initial estimates. By coordinating with other teams, it was determined that ground source heat pumps would be used to cover the entirety of the heating requirements at Calvin. With this information, as well as equipment specifications and cost models, the proposed solution and implementation plan was evaluated on the basis of cost and actual carbon emission reduction. The ground source heat pump implementation plan would cost about $28 million up-front, and would cost about $1 million to run annually, and it would bring carbon emissions to zero by 2040.

Introduction:

One of the largest challenges that Calvin University is facing related to sustainability is CO_2 emissions from energy consumption. Calvin University has a goal to reduce carbon emissions and has committed to becoming carbon neutral by 2057. After comparing all the alternative solutions to meet this goal, the team found that GSHP systems were able to provide one of the most feasible solutions for this large-scale project. GSHP systems provide a highly efficient solution at the tradeoff of a high initial capital investment.

Methods:

Existing System:

The existing heating system for Calvin university comprises of two heating loops and outstanding buildings. These buildings include the KE apartments, the facilities buildings, and off-campus buildings. All the heating at Calvin is currently provided through the burning of natural gas.

Building Load Calculations:

The amount of heat required for each heating load and all the other buildings were calculated using documented building sizes and typical annual weather data for Grand Rapids obtained from ASHRAE. The heating loads for each building were also calculated by accounting for heat losses through windows and walls. Heat generated by the presence of human bodies and electronic components were negligible to the total heat required for each building.

Case Studies:

As part of the research into GSHP systems, the team performed multiple case studies on other universities and colleges that were in the process of installing or have already installed GSHP systems. The cases included 13 institutions with some of the most notable being the University of Notre Dame and Ball State University. Each case provided valuable information including system costs, annual savings, and heating capacity that could be used to estimate the size and scope of the GSHP system required for Calvin University. From the data collected, the team created cost models, as shown in Figure B1.1 of the Appendix, to estimate GSHP cost based on heating capacity. Using cost quotes provided Airtech Equipment for the two existing heating loops, the accuracy of the cost model was verified. The model was then used to estimate equipment and installation costs for any of the new proposed heating loops.

Equipment:

The equipment specifications for GSHP system were provided by AirTech Equipment company. Multiple options for heat-recovery chillers were provided, but the best heat pump for each heating loop was selected. The heat for loop 1 would be supplied by a Multistack heat recovery chiller with three 786-ton chillers and one 550-ton chiller. The equipment budget for this loop was \$4,100,000. However, if the temperature of the working fluid could be reduced from 160°F to 140°F, the equipment cost would be cheaper. A 4-module, 250-ton Multistack heat-recovery chiller would be installed for heating loop 2. This would have a capital cost of $420,000 and 35-week lead time. Other heat-recovery chillers would be sourced to provide enough heat for the KE buildings, facilities building, and off-campus housing. Each piece of equipment was calculated to cost less than the cost associated with heating loop 2 because they require less heat.

Proposed Solution:

The GSHP team's proposed solution involves the installation of ground source heat pump loops to cover the heating loads of every Calvin building both on and off campus. This solution includes the creation of two new heating loops and requires the conversion of the existing steam loop to a hot water loop. The result of this implementation will be four larger GSHP loops and smaller individual GSHP systems for each off-campus house as well as the DeWit Manor. Each smaller GSHP system will utilize a horizontal piping in nearby yard space to supply the required heat, while the four larger loops will utilize vertical boreholes. These vertical boreholes would be installed underneath parking lots 1-10 and 17 with a depth of 400 ft^2 each.

Table B1. Capital cost, heating load, and borehole information for each proposed GSHP loop/system.

System	Capital Cost [$]	Heating Load [tons]	Number of Boreholes	Borehole Area [ft^2]
Heating Loop 1	$21,956,250	3,050	1,335	534,000
Heating Loop 2	$2,353,750	250	110	44,000
KE Apartments	$1,920,000	78	35	14,000
Facilities Buildings	$1,840,000	64	28	11,200
Off-Campus Housing	$228,600	3	N/A	N/A
Total:	**$28,298,600**	**3,445**	**1,508**	**603,200**

The installation timetable of this solution would occur over the course of 2025-2030 with borehole fields being installed a year before their respective GSHP loop is installed. The off-campus housing and DeWit Manor would have their systems and boreholes installed simultaneously as they are a much smaller scale. In Appendix B2, visuals for the locations of equipment and boreholes can be found. In Appendix B3, off campus housing calculations are shown, along with other calculations.

Conclusion:

Ground source heat pumps have been proven to be a viable option for Calvin to utilize on their path to carbon neutrality after thorough analysis. Despite their large up-front costs, they have many benefits. They are efficient, effective, low maintenance, and, most importantly, electrically based. Air source heat pumps also show promise, though they have a shorter lifespan, are less efficient, and are extremely difficult to use in a climate such as Michigan's. With an analysis that consisted of extensive heat load calculations, university research, equipment inquiry, and implementation planning, ground source heat pumps have emerged as a key solution for Calvin to explore as soon as possible. As social pressures for carbon neutrality rise, the last thing Calvin should be doing is scrambling to become carbon neutral in the final years up until their pledged date of 2057.

Appendix B1: Case Study Information

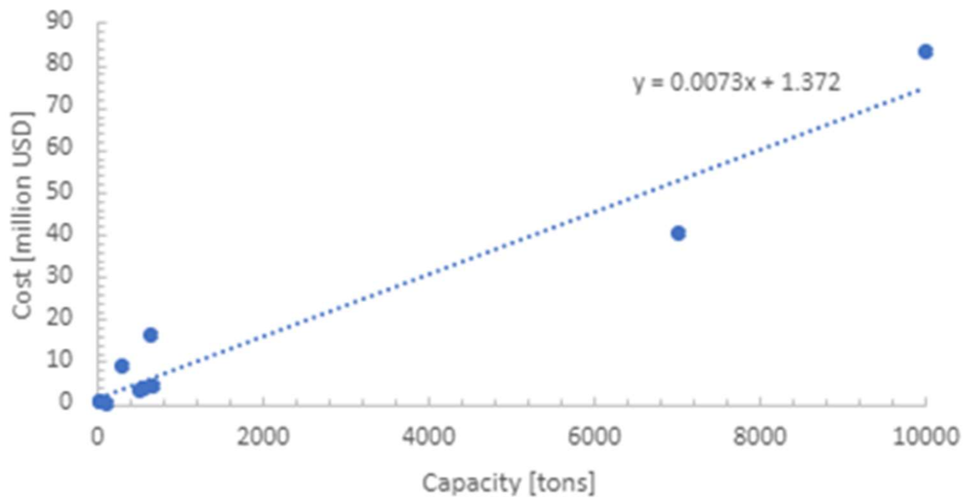


Figure B1.1. Cost model for geothermal system cost versus heating capacity based on case studies.

Table B1.1. Initial calculations of heating loads for each section of the implementation plan. The costs here were modeled based on the case study correlation, not actual equipment costs.

tons/hr	98% of days
Heating Loop 1	
3045.255168	
$ 23.60	Million
Heating Loop 2	
247.2404929	
$ 3.18	Million
Dorm Isolation	
32.27845175	
$ 1.61	Million
KE Loop	
75.59797507	
$ 1.92	Million
Seminary	
163.1397882	
$ 2.56	Million
Facilities	
64.0073388	
$ 1.84	Million

Appendix B2: Implementation Plan Visuals

Figure B2.1. Parking lot placements for boreholes, circled in orange.

Table B2.1. The first three years of the implementation plan, as well as heating load coverage, electricity usage, and carbon embodiment.

	2025	2026		2027
List Total production from source in what year in MMBTU		10110.4	2617.4	
Note of Implementation (ie. Installing GSHP on BV)	Install boreholes for facilities and heating loop 2	Install GSHP for Heating Loop 2	GSHP for Facilities	Install boreholes for Commons Heating Loop 1
Kw-hr usage per year		761713	197207	
Carbon Embodiement [tons CO2e]	872.737	671.53	6.62	7231

Table B2.2. The latter four years of the implementation plan, as well as heating load coverage, electricity usage, and carbon embodiment.

	2028	2029	2030	2031
List Total production from source in what year in MMBTU	124596.5	386.3	688.1	3091.4
Note of Implementation (ie. Installing GSHP on BV)	GSHP for Heating Loop 1	Flat iron, Koinonia, Travis	Garden, Cooper, Bunker, Tongue House	GHSP for KE.
Kw-hr usage per year	9386773	29106	51841	232698
Carbon Embodiement [tons CO2e]	449.897	18.75	25	297.47

Appendix B3: Calculations

Table B3.1. Cost calculations for off-campus housing.

House	Capital Investment [$]	Electricity Usage [kWhr]	Operating & Maintenance [$/year]
DeWit Manor	$75,600	46,959	8,453
Flat Iron	$31,800	11,713	2,108
Koinonia	$28,500	7,680	1,382
Travis	$31,800	12,767	2,298
Total	$167,700	79119	$14,241

House	Capital Investment [$]	Electricity Usage [kWhr]	Operating & Maintenance [$/year]
Garden	$35,700	19,946	3,590
Cooper	$31,800	12,313	2,216
Bunker	$34,500	14,332	2,580
Tongue	$34,500	13,798	2,484
Total	$136,500	60389	$10,870

Table B3.2. Yearly heating load calculations for the entire campus based on a typical meteorological year.

Values found by adjusting OADB in both Heat loss and Airflow Tabs (final value form AF)			
Temperature [F]	Hours/year	Load [Btu/hr]	Load [Btu]
97.5	0	0	0
92.5	0	0	0
87.5	3	0	0
82.5	34	0	0
77.5	301	0	0
72.5	557	0	0
67.5	751	0	0
62.5	720	3,597,733	2,590,368,117
57.5	495	6,868,400	3,399,858,153
52.5	721	10,139,067	7,310,267,396
47.5	621	13,409,734	8,327,444,775
42.5	699	16,680,401	11,659,600,126
37.5	347	19,951,068	6,923,020,445
32.5	728	23,221,734	16,905,422,629
27.5	1383	26,492,401	36,638,990,852
22.5	708	29,763,068	21,072,252,150
17.5	324	33,033,735	10,702,930,082
12.5	140	36,304,402	5,082,616,229
7.5	144	39,575,068	5,698,809,857
2.5	42	42,845,735	1,799,520,881
-2.5	18	46,116,402	830,095,237
-7.5	9	49,387,069	444,483,620
-12.5	11	52,657,736	579,235,093
-17.5	4	55,928,403	223,713,610
-22.5	0	-	-
		TOTAL	**140,188,629,253**

Table B3.3. Cost estimates for installation of different sections of the implementation plan, as well as operation costs due to electricity.

Cost Estimates		
PEC+Install Loop 1	$21,956,250.00	$
O&M (per year)	$938,677.30	$/Year
PEC+Install Loop 2	$2,353,750.00	$
O&M (per year)	$76,171.30	$/Year
PEC+Install House Group 1	$92,100.00	$
O&M (per year)	$2,910.60	$/Year
PEC+Install House Group 2	$136,500.00	$
O&M (per year)	$5,184.10	$/Year
PEC+Install KE Loop	$1,920,000.00	$
O&M (per year)	$23,269.80	$/Year
PEC+Install Facilities Loop	$1,840,000.00	$
O&M (per year)	$19,720.70	$/Year

Appendix B4: Equipment Information for 250 Ton Loop

MULTISTACK

ER

Job Name	Calvin University Geothermal Loop 2	Job Number	
Location	Grand Rapids, MI	Quote Number	QFPOINTE11162022-1
Engineer		Representative	Frank Pointe
Contractor		Rep Office	Grand Rapids

Mechanical Modules: (1) MSH135ANHCMQAA--BHCHCOBAJ-AA-H , (2) MSH135ANHCMQAA--BHCHCOBAJ-CA-H
(1) MSH105ANHCMQAA--BHCHCOBAJ-AA-H &
Accessory Modules:

SUMMARY PERFORMANCE DATA

							EVAPORATOR			CONDENSER			
Load	Capacity (tons)	Input kW	THR (MBtu/h	kW/Ton	EER (Btu/ Wh)	COP (kW/k W)	Flow Rate (GPM)	Leaving Temp. °F	ΔP (ft H2O)	Cond Flow (GPM)	Entering Temp. °F	Leaving Temp. °F	ΔP (ft H2O)
100%	211.1	353.2	3.739	1.673	7.173	2.100	690.5	42.00	6.000	376.6	120.0	140.0	6.000
75%	158.4	266.5	2.810	1.683	7.129	2.090	690.5	42.00	6.000	376.6	125.0	139.9	6.000
50%	105.6	177.1	1.871	1.677	7.154	2.100	690.5	42.00	6.000	376.6	130.0	139.9	6.000
25%	52.78	93.96	0.9541	1.780	6.741	1.980	690.5	42.00	6.000	376.6	135.0	140.1	6.000

The 25 % points have incorporated a cycling penalty per AHRI 550/590.

Cooling COP	Heating COP	Heating and Cooling COP
2.100	3.100	5.200

No Tower Relief		kW/Ton	EER (Btu/Wh)	COP (kW/kW)
	PLV	N/A	N/A	N/A

EVAPORATOR DESIGN DATA	(Based on 30% PG)
Entering Temperature °F	50.00
Leaving Temperature °F	42.00
Design Flow (GPM)	690.5
Pressure Drop (Full Load)	2.597 PSI / 6.000 ft H2O
Chiller Minimum Flow (GPM)	172.6
Min. GPM For Sizing System Bypass	258.9
Heat Exchanger Style	Brazed Plate
Fouling Factor (h-ft2-°F/Btu)	.000100
Header Size (in.)	10
Header Connection Type	Grooved Coupling

CONDENSER DESIGN DATA	(Based on Water)
Entering Temperature °F	120.0
Leaving Temperature °F	140.0
Design Flow (GPM)	376.6
Pressure Drop (Full Load)	2.597 PSI / 6.000 ft H2O
Chiller Minimum Flow (GPM)	94.20
Min. GPM For Sizing System Bypass	141.2
Heat Exchanger Style	Brazed Plate
Fouling Factor (h-ft2-°F/Btu)	.000100
Header Size (in.)	10
Header Connection Type	Grooved Coupling

PHYSICAL DATA	Section 1	Section 2
Length (in.)	200	
Width (in.)	100	
Height (in.)	80	
Estimated Dry Weight (lbs.)	21760	
Estimated Operating Weight (lbs.)	24970	
Refrigerant Type	R-134A	
Refrig. Charge (lbs/circuit)	42, 40	

Dimensions are estimated and do not include frames, J-boxes, Multiflush, etc

ELECTRICAL DATA (Direct Connect-Per Module)	MCA	MOP		
(3) MSH135A	247	350		
(1) MSH105A	196	250		
MCA				
MOP				
Voltage	460/60/3			

CHILLER DATA	
Compressor Description	Scroll
Compressor RLA (per comp.)	58, 46

*Parallel feeds not required (Assumes no larger than 500 MCM/kcmil wire)

MOUNTING/LIFTING FRAME	
Materials	Option Not Selected
I-Beam Size	Option Not Selected
Bolt together frame - # of pieces	Option Not Selected
End Type	Option Not Selected

Software Version# : 1.0.4435.67000

Performance Run Date: 11/16/2022 10:14:39 AM

Outside the scope of AHRI Standard 550/590 (I-P).

MEMBER AHRI

Figure B4.1. Equipment information for the 250-ton loop.

MULTISTACK

Variable Flow Design Requirements

Chilled Water System (Evaporator)

Ensure a chiller DP transmitter (DP1) is incorporated into the piping design and set to: **2.60 PSI**

DP1 to be installed directly after the chiller with no pressure adding devices between the chiller and DP1. *(mechanical only ΔP)*

Ensure a system DP transmitter(s) (DP2) is incorporated into the piping design

Ensure a system bypass valve(s) (V1) is incorporated into the piping design

Design of system bypass (V1) must be a characterized ball or globe type valve and be pressure dependent

System bypass valve (V1) stroke time needs to be selected for less than 60 seconds

Chiller minimum flow is: **172.6 GPM**

System bypass valve must be design for a minimum of: **258.9 GPM**

Note: this is a minimum requirement for the chiller ONLY! Other system components such as pumps or air handling units may have higher minimum flow requirements and bypass sizing may be adjusted accordingly.

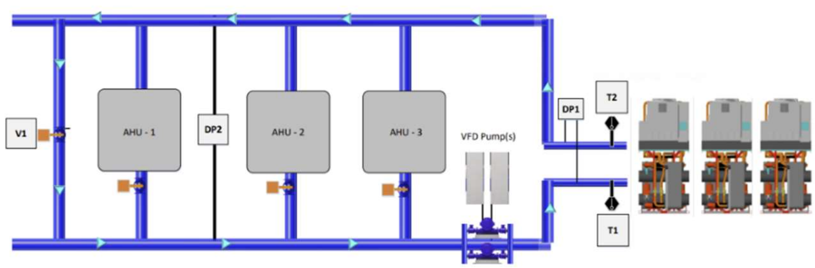
Bypass loop volume (Includes piping between V1 & chiller): **1040 Gallons**

Note: the bypass loop should be designed for a minimim of a 2 minute loop at all conditions. To obtain ensure the above volume is met.

Refer to Multistack Variable Flow Engineering Bulletin for more details

The pump or the bypass valve must control to maintain chiller DP setpoint, the opposite device (Pump or Bypass Valve) must maintain system DP setpoint.

When a pump module is supplied by Multistack it will be factory configured to control to DP across the chiller unless otherwise specified and noted on the chiller selection.



LEGEND

WIRED & CONTROLLED BY CONTROLS CONTRACTOR
V1 – SYSTEM BYPASS VALVE
DP1 – CHILLER DIFFERENTIAL PRESSURE
DP2 – SYSTEM DIFFERENTIAL PRESSURE
VFD Pump(s)

WIRED TO CHILLER MASTER CONTROLLER
T1 – CHW RETURN TEMP SENSOR
T2 – CHW SUPPLY TEMP SENSOR

SCHEMATIC ONLY – REFER TO JOB SPECIFIC DRAWING FOR CONSTRUCTION

Figure B4.2. Chilled water equipment information for the 250-ton loop.

MULTISTACK

Variable Flow Design Requirements

Hot Water System (Condenser)

Ensure a chiller DP transmitter (DP1) is incorporated into the piping design and set to: 2.597 **PSI**

DP1 to be installed directly after the chiller with no pressure adding devices between the chiller and DP1.

Ensure a system DP transmitter(s) (DP2) is incorporated into the piping design

Ensure a system bypass valve(s) (V1) is incorporated into the piping design

Design of system bypass (V1) must be a characterized ball or globe type valve and be pressure dependent

System bypass valve (V1) stroke time needs to be selected for less than 60 seconds

Chiller minimum flow is: 94.20 **GPM**

System bypass valve must be design for a minimum of: 141.2 **GPM**

Note: this is a minimum requirement for the chiller ONLY! Other system components such as pumps or air handling units may have higher minimum flow requirements and bypass sizing may be adjusted accordingly.

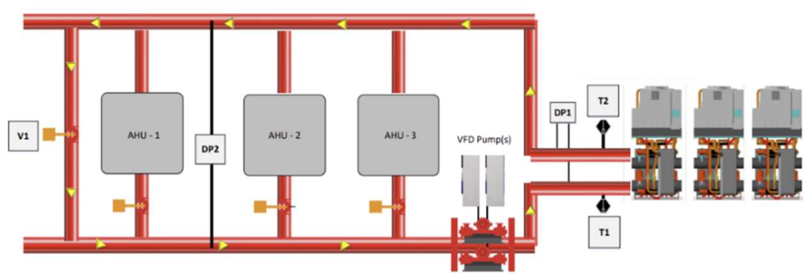
Bypass loop volume: (Includes piping between V1 & chiller) 498.6 **Gallons**

Note: the bypass loop should be designed for a minimim of a 2 minute loop at all conditions. To obtain, ensure the above volume is met.

Refer to Multistack Variable Flow Engineering Bulletin for more details

The pump or the bypass valve must control to maintain chiller DP setpoint, the opposite device (Pump or Bypass Valve) must maintain system DP setpoint.

When a pump module is supplied by Multistack it will be factory configured to control to DP across the chiller unless otherwise specified and noted on the chiller selection.



LEGEND

WIRED & CONTROLLED BY CONTROLS CONTRACTOR

V1 – SYSTEM BYPASS VALVE

DP1 – CHILLER DIFFERENTIAL PRESSURE

DP2 – SYSTEM DIFFERENTIAL PRESSURE

VFD Pump(s)

WIRED TO CHILLER MASTER CONTROLLER

T1 – HW RETURN TEMP SENSOR

T2 – HW SUPPLY TEMP SENSOR

SCHEMATIC ONLY – REFER TO JOB SPECIFIC DRAWING FOR CONSTRUCTION

Figure B4.3. Hot water equipment information for the 250-ton loop.

Product Overview:

Model Description	Compressor Description
(3) MSH135A,(1) MSH105A	Water Cooled Modular Scroll

Services & Special Features:

- Chiller Waterside Maximum Working Pressure is 150 PSIG
- Heat exchanger maximum working pressure (refrigerant 650 PSI)
- Lead compressor sequencing (24hrs)
- Automatic internal rescheduling if fault occurs
- Multiple, independent refrigeration systems
- Automatic logging of any fault condition
- Electronic chilled water control
- Quick interconnect modular design
- Filters in evaporator and condenser supply headers
- Stainless steel evaporator and condenser inlet header
- Electrical design intended for Design
- R-134A Refrigerant
- 5kA SCCR
- Electrical Connection Type - Direct Connect
- 5 Year Warranty: Compressor
- 1 Year Warranty: All Parts
- 1 Year Warranty: Parts (less Compressor)
- 1 Year Warranty: Refrigerant
- 4x4 Rails And Waffle Pads
- Dedicated Heat Recovery Controls
- Interoperability Web Portal for Mechanicals (BACnet MS/TP)
- Power Phase Monitor (for Direct Connect per module)
- Acoustical Panels - indoor rated
- Orifice Plates-Evap (to obtain min pressure drop of 6 feet) (MSH135A-2 ft)(MSH105A -2 ft)
- ¾" Insulation (Evaporator)
- NEMA 2 Var. Flow Cond (Man. Valve, Mot. Valve)-(C-Steel Valves)
- NEMA 2 Var. Flow Evap (Mot. Valve ,Man. Valve)-(C-Steel Valves)
- ¾" Insulation (Condenser)
- Evap Flow Switch-Thermal Dispersion Type (24 Volt Factory Powered & Installed On Each Module)
- Cond Flow Switch-Thermal Dispersion Type (24 Volt Factory Powered & Installed On Each Module)
- Orifice Plates-Cond (to obtain min pressure drop of 6 feet) (MSH135A-4.65 ft)(MSH105A-5.17 ft)

Excluded By Multistack:

- Multiflush™ (Debris Removal System) - Cond
- Interconnecting piping between sections if two sections exist.
- Multistack recommends a 2-3 minute minimum loop time. Contact Multistack if you have questions regarding system loop time design

Figure B4.4. Service information.

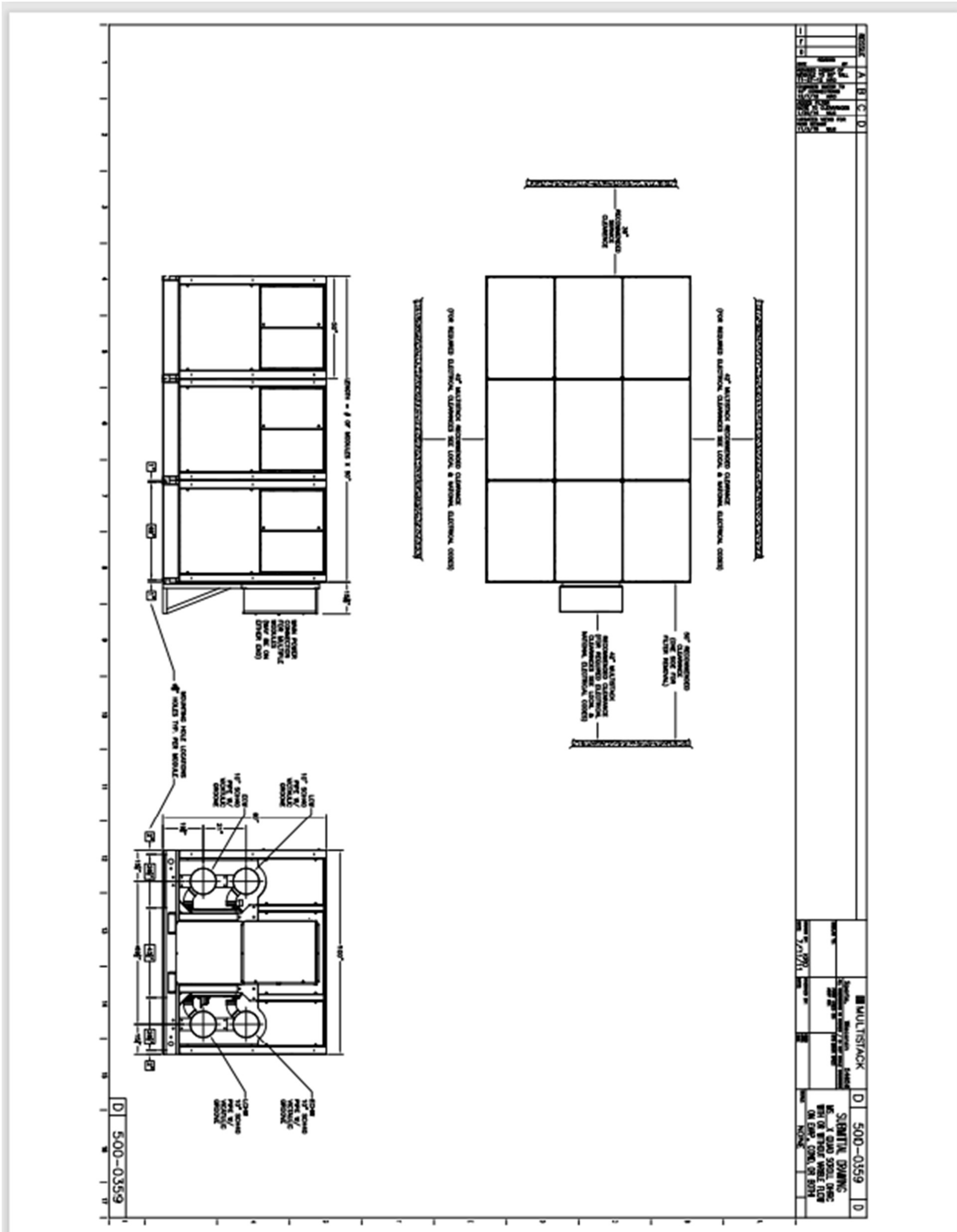


Figure B4.5. Equipment schematics for the 250-ton loop.

Appendix B5: Equipment Information for 3050 Ton Loop

MULTISTACK

Job Name	Calvin University Geothermal Loop 1 140 LWT	Job Number	
Location	Grand Rapids, MI	Quote Number	QFPOINTE11162022-2
Engineer		Representative	Frank Pointe
Contractor		Rep Office	Grand Rapids

Chiller Model Number	Frame Type	Rated Capacity
MSH1100MNHFBABAHKABAHGAA+AH-G	Frame 1 10 TTH375	800.0

SUMMARY PERFORMANCE DATA

Load	Capacity (tons)	Capacity (MBH)	Input kW	kW/Ton	Flow Rate (GPM)	Entering Temp. °F	ΔP (PSI)	Cond Flow (GPM)	Entering Temp. °F	Leaving Temp. °F	ΔP (PSI)
100%	800.0	12920	974.3	1.218	3393	50.00	11.18	875.6	110.0	140.0	3.010
90%	720.0	11640	878.5	1.220	3054	50.00	8.730	875.6	113.0	140.0	3.010
80%	640.0	10350	784.0	1.225	2715	50.00	6.600	875.6	115.9	140.0	3.010
75%	600.0	9713	736.8	1.228	2545	50.00	5.660	875.6	117.4	140.0	3.010
70%	560.0	9075	690.6	1.233	2375	50.00	4.790	875.6	118.9	140.0	3.010
60%	480.0	7822	604.8	1.260	2036	50.00	3.460	875.6	121.8	140.0	3.010
50%	400.0	6533	508.3	1.271	1697	50.00	2.400	875.6	124.8	140.0	3.010
40%	320.0	5243	411.6	1.286	1357	50.00	1.540	875.6	127.8	140.0	3.010
30%	240.0	3932	308.9	1.287	1357	48.24	1.540	875.6	130.8	140.0	3.010
25%	200.0	3226	242.5	1.212	1357	47.54	1.540	875.6	132.5	140.0	3.010
20%	160.0	2562	188.8	1.180	1357	46.83	1.540	875.6	134.0	140.0	3.010
	80.00	1281	94.70	1.184	1357	45.41	1.540	875.6	137.0	140.0	3.010

Cooling COP	Heating COP	Heating and Cooling COP
2.890	3.890	6.780

No Tower Relief | NPLV.IP | 1.245

EVAPORATOR DESIGN DATA	(Based on 30% PG)
Entering Temperature °F	50.00
Leaving Temperature °F	44.00
Design Flow (GPM)	3393
Pressure Drop (Full Load)	11.18 PSI / 25.83 ft H2O
Chiller Minimum Flow (GPM)	1357
Minimum ΔP(ft)	1.540 PSI / 3.557 ft H2O
Number Of Passes	2
Tube Type	3/4" diameter 0.025" Copper Enhanced
Fouling Factor (h-ft2-°F/Btu)	0.000100
Connection Size (in.)	12"
Connection Type	OGS Grooved Coupling
Head Style	Dish
Head Mounting	Inlet: Right Outlet: Right

CONDENSER DESIGN DATA	(Based on Water)
Entering Temperature °F	110.0
Leaving Temperature °F	140.0
Design Flow (GPM)	875.6
Pressure Drop (Full Load)	3.010 PSI / 6.953 ft H2O
Chiller Minimum Flow (GPM)	555.0
Minimum ΔP(ft)	1.200 PSI / 2.772 ft H2O
Number Of Passes	2
Tube Type	3/4" diameter 0.025" Copper Enhanced
Fouling Factor (h-ft2-°F/Btu)	0.000100
Connection Size (in.)	8"
Connection Type	OGS Grooved Coupling
Head Style	Dish
Head Mounting	Inlet: Right Outlet: Right

PHYSICAL DATA	
* Length (Shell Only)	See Multistack for Details
Width (in.)	See Multistack for Details
Height (in.)	See Multistack for Details
Estimated Shipping Weight (lbs.)	See Multistack for Details
Estimated Operating Weight (lbs.)	See Multistack for Details
Refrigerant Type	R-134A
Estimated Refrig. Chg. (lbs/circuit)	2855
Shell Configuration	Side by Side

*** See Head drawing for additional length for the heads**

ELECTRICAL DATA	
Voltage	460-60-3
Power Input (KW)	974.3
Compressor RLA (per comp.)	133.6
MCA (each power supply)	702 , 702
MOP (each power supply)	1000 , 1000

Triple feeds required.

Software Version #: 1

Outside the scope of AHRI Standard 550/590 (I-P).

MEMBER AHRI

Performance Run Date: 11/16/2022 12:09:40 PM

Figure B5.1. Equipment information for the 3050-ton loop.

Other Services & Special Features:

- GIII Flexsys Controller
- BAS Communication Module: BACNET MSTP
- Vibration Isolation (Neoprene waffle pads)
- Evaporator Standard Heat Exchanger (150 PSI)
- Condenser Standard Heat Exchanger (150 PSI)
- Main Power Door Interlock Disconnect Switch
- 2 Pass Evaporator
- 2 Pass Condenser
- Refrigerant (134-A)
- ¾" Insulation (Evaporator)
- ¾" Insulation (Condenser)
- Extended Range Design (CL300)
- Evaporator OGS Groove Coupling
- Condenser OGS Groove Coupling
- 10kA SCCR
- Chiller to ship charged unless otherwise specified
- Factory Run Test Included
- Freight Included
- Factory Start Up Included
- Warranty: Compressor (5 Year)
- Warranty: All Parts (1 Year)
- Warranty: Parts (less Compressor) (1 Year)
- Warranty: Refrigerant (1 year)

Control Options

Excluded By Multistack:

- Any Travel and Diagnosis for Warranties
- Refrigerant Monitoring Equipment as governed by ASHRAE 15 standard
- Rigging
- Sound Test
- Vibration Isolation
- Seismic Provisions including: Seismic Testing & Certification
- Couplings for Water Connections

Figure B5.2. Service information.

Appendix C: Efficiency Improvements

Efficiency Improvements Team

Matthew Carlson, Jacob Heeres, Anthony Nykamp, and Jacob VanWyngarden,
ENGR 333-A
Professor Heun
12/7/2022

Abstract
Various efficiency improvement options were explored to help reduce the overall heat load of Calvin University. One such improvement identified was the addition of thermostatic radiator valves, which reduced the campus heating load by 1%. Another efficiency improvement was a dorm window replacement project. By replacing the single pane windows in the dorms with double pane windows, which reduced 54%, with a price estimate of roughly $900,000.

Introduction:

Several different options to increase the efficiency of Calvin's heating system were examined. The focus of the efforts was to reduce the CO2 emissions from natural gas heating, this was accomplished by reducing the energy required by the heating system. The cost of implementing these changes was also examined. The recommended solution includes thermostatic radiator valves and double paned windows, which result in a more energy efficient campus.

Research and Methods:

In order to improve the efficiency of Calvin University's heating, research was done into different options which Calvin carried out to minimize its heating load. Main areas of concern were identified to be the older buildings, with an emphasis on the residence halls. Furthermore, a large source of lost heat was found to be the dorm room windows, as a lack of reliable room climate controls drove students to open the window during the winter due to an overheated room. Research was done into other universities' solutions to similar problems. Brown University, located in Providence, Rhode Island, also has old residence hall buildings, with heating systems dating back to the 1960s, much like Calvin University. Brown University's Dorm Energy Efficiency Program (DEEP) also identified overheating and open windows as a source of inefficiency and combatted this issue with added temperature controls to individual dorm rooms. This improvement saw a fifty percent reduction in thermal energy, and an annual savings of $0.75 per square foot (GreenerU).

The option and feasibility of replacing Calvin's natural gas boilers with electric boilers was also researched. As the boilers at Calvin age, their efficiency decreases significantly, down to about 75% after just ten years. Electric boilers, on the other hand, are almost 100% efficient, and do not require natural gas.

New heat load calculations were done for the residence halls, taking into account the ability to keep the rooms at a controlled temperature without opening the windows using the thermostatic radiator valves as well as weather data. Additionally, new required heat loads were calculated in the scenarios of replacing the single pane dorm windows with double or triple pane windows efficiency improvements.

Results and Analysis:

Several different implementations were deemed to be most effective after our research and calculations were concluded. It was found that thermostatic valves would provide substantial energy savings, especially considering their implementation cost. The proposed solution involves installing these valves in conjunction with double pane windows to further reduce heat loss. The potential energy and cost savings are shown in Table 1 below.

Table C1. This table displays the reduction in heating load and the expected cost of implementation for three different options examined.

Dorm Annual Energy Savings after Implementation			
	Heat Load Reduction [MMBTU/yr]	Heat Load Reduction [%]	Cost Estimate [2022$]
Thermostatic Valves Only	900	11%	$163,600
Valves and Double Pane Windows	4300	54%	$899,800

Valves and Triple Pane Windows	5500	67%	$1,554,200

Implementing the thermostatic valves along with double pane windows was determined to be the best balance of cost and energy savings. The reduction in heating load over time as changes are implemented is displayed in Figure 1 below.

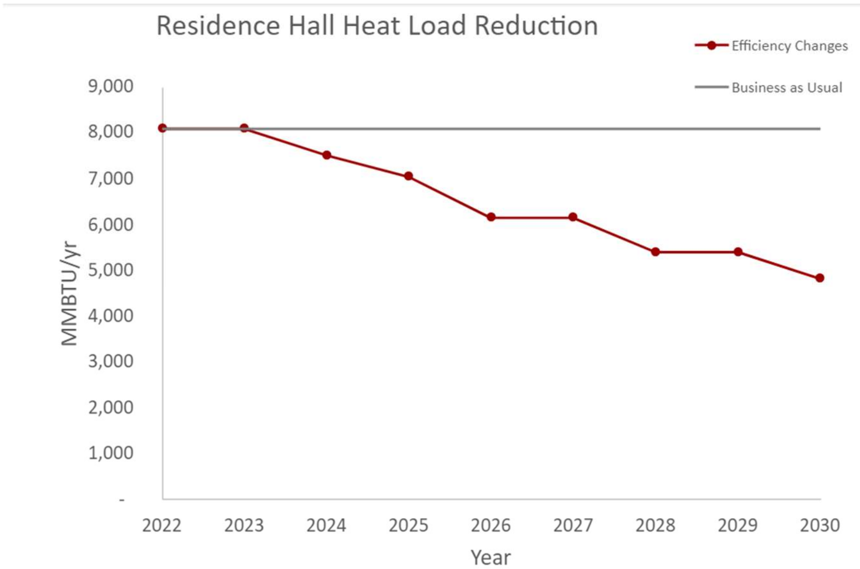


Figure C1. This figure displays the reduction in heating load as changes are implemented over time compared to the heating load if no efficiency improvements are implemented.

Conclusion:

In order to increase the efficiency of the Calvin University campus, the efficiency team investigated multiple sources of inefficiencies and options for how to remedy those inefficiencies. The two main sources of inefficiency that the team found were inefficient boilers and heat loss through windows. The team considered electric boilers to replace the inefficient natural gas boilers, but ultimately did not suggest implementing natural gas boilers because ground source heat pumps would have a significantly lower electricity requirement, and despite the high initial investment, ground source heat pumps would break even with the electric boilers after only 8 years. The efficiency team also considered heat loss through windows which resulted from open windows due to overheating of rooms. To solve this issue, it is recommended that thermostatic valves be installed to combat the opening of windows resulting in an 11% heat load reduction. The efficiency team is also recommending that the single pane windows in the residence halls be replaced with double pane windows. This change will result in a 54% heating load reduction.

Appendix C1: Electric Boilers

Electric boilers are much more efficient than natural gas boilers, as natural gas boilers lose efficiency as they age. Replacing the old natural gas boilers with electric boilers would give significant efficiency improvements, shown below in Figure C1.1.

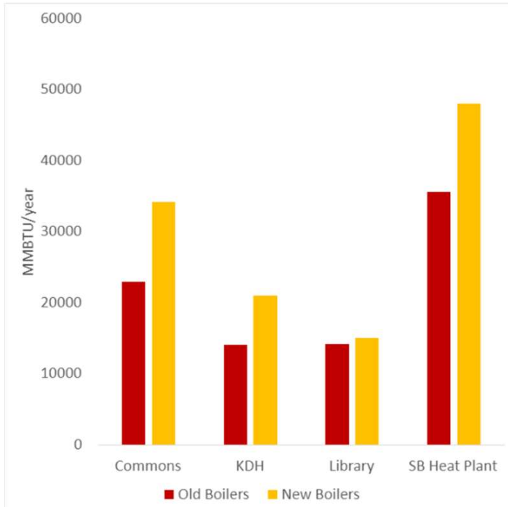


Figure C1.1. The heat output of old natural gas boilers compared to new electric boilers assuming the same energy input.

These efficiency improvements are summarized below in Table A1, which shows the energy efficiency improvement and the energy savings per year.

Table C1.1. The effects of switching to electric boilers on the campus heating load.

Efficiency Improvement	18.1%
CCF's of Methane Saved/yr:	302,679
MMBTU Saved/yr	31,387.8

Despite these drastic energy improvements, the ground source heat pump solution was chosen instead of implementing electric boilers due to the long-term cost savings. Electric boilers are incredibly energy intensive to run, as shown below in Figure A2. Despite the much lower initial capital investment, the amount of electricity that would be required to heat campus overtakes the cumulative cost of the ground source system in just 7 years.

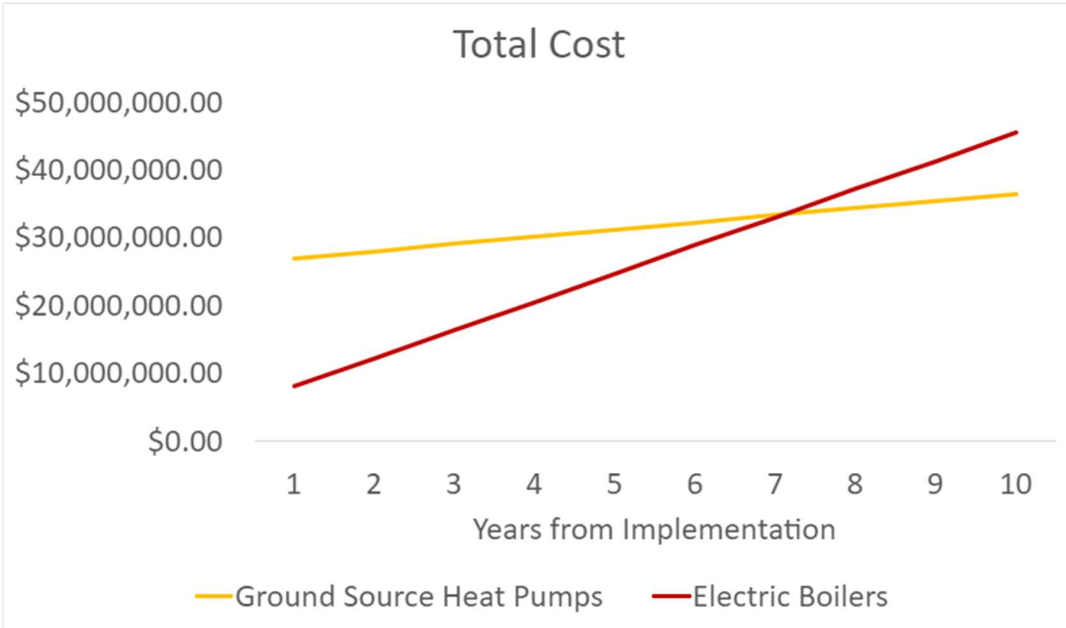


Figure C1.2. This graph displays the cost over time for installing and operating ground source heat pumps and electric boilers.

References:

Ecosystem. (2022, June 21). *Brown University's Thermal Efficiency Project*. Ecosystem. Retrieved December 6, 2022, from https://ecosystem-energy.com/news/brown-universitys-thermal-efficiency-project/

Facilities management. Thermal Efficiency Project | FACILITIES MANAGEMENT | Brown University. (n.d.). Retrieved December 6, 2022, from https://www.brown.edu/facilities/projects/capital-projects/completed/thermal-efficiency-project

Glass Performance Chart. All Weather Windows. (2019, January 2). Retrieved December 6, 2022, from https://www.allweatherwindows.com/the-pros/architect/glass-performance-chart/

Appendix D: Energy Markets

Energy Markets Team

Nate Anderson, Anna Giboney, Gia Mien Le, and Jonathan Washburn
ENGR 333-A
Professor Heun
12/7/2022

Abstract:
The goal of the markets team was to understand the economy of the energy markets for natural gas, RNG, and electricity to understand its impact when implementing a carbon-neutral heating system at Calvin. Current and future costs data was obtained through the EIA, whose experts had done extensive research and analysis on five different energy markets scenarios, the worst being low oil and gas supply, and the best being high oil and gas supply. By calculating the ratio between Calvin's energy cost and energy cost from the EIA, the markets team was able to make a projection of what Calvin had to pay for future energy consumption. This was divided into three categories: commercial sector electricity prices, residential sector electricity price, and Michigan natural gas price. With this data, Calvin would be able to make optimized decisions regarding carbon-free heating solutions.

Introduction:

What will things cost in the future? If someone knew the answer to that, they would be famous. This is where the markets team comes into play for the CO2 emissions project. The team's goal is to help answer the question of "How future changes in energy markets (for natural gas, RNG, and electricity) will affect timing and strategy for implementing a zero-carbon heat system at Calvin". The markets team analyzed the cost predictions of natural gas and electricity at Calvin, in the state of Michigan, and across the nation.

Calvin is not just responsible for heating the campus, but they also have off campus housing. Due to having to heat off campus housing, it caused the markets team to investigate residential electricity costs as well as commercial electricity costs (what Category Calvin's campus falls into). Natural gas costs are researched to be able to plan out what Calvin would be paying to heat the campus in the future without any changes to reduce CO2 emissions.

Research: EIA Validation and Assumptions

EIA is the energy information administration. Every year, they release an Annual Energy Outlook that models future energy prices nationally. These models included specific prices for various forms of energy for each year through 2050.

These price models were based on quite a few assumptions. EIA has industry experts make assumptions about future energy markets in order to make their models. For example, these assumptions included increased energy consumption, increasing renewable energy consumption, and renewable energy growth outpacing increased electricity demand. The list of assumptions made by EIA for their 2022 Annual Energy Outlook is in Appendix D2. Relying on assumptions and models made by industry experts was preferable to trying to create models from scratch.

The Annual Energy Outlook produces several of what they call, "side cases," such as assuming high renewables cost or assuming a low oil supply. But, EIA's best projections for the future prices of energy are their reference case. It combines all of their best assumptions made by industry experts to model the future price of energy. So, the EIA reference case was used as a basis for the energy price calculations.

EIA Data Analysis:

As aforementioned, the EIA provided five predictions based on a variety of market conditions for both electricity and natural gas prices. From the five scenarios presented in Figure D1.1 and Figure D1.2 in Appendix D1, the markets team selected the best case with high oil and gas supply, the worst case with low oil and gas supply, and the recommended reference state for Calvin's price calculations to showcase the range of payback periods.

Energy cost predictions for Calvin were divided into three different subcategories: commercial sector electricity price, residential sector electricity price, and Michigan natural gas price. These divisions were made due to different ratings Calvin had to pay for certain facilities. The projections were ratios based on data obtained from the EIA and energy prices at Calvin in 2021. More detailed explanations and calculations can be found in Appendix D3.

Results: Final Graphs

Once the EIA provided data was multiplied by the price ratios to predict Calvin's future cost, Figures D1.3-D1.5 in Appendix D1 were developed. Similar to the EIA Figures D1.1 and D1.2, the range of predictions depicts the variety of possible future market conditions. The three scenarios highlighted in these graphs are the best, worst, and recommended cases.

As established in the price ratio calculations, Calvin has a contract that expires in 2025 for a set natural gas cost. Thus, the cost jumps in 2025 back to the normal market price and the predictions go forward from there in Figure D1.5.

Conclusion:

The goal for the markets team is to assist in determining how the future changes in energy markets for natural gas, RNG, and electricity will affect timing and strategy for implementing a zero-carbon heat system. By researching, collecting data, and analyzing trends on the different markets, predictions for the future markets that Calvin would face were able to be calculated. Having the future costs for the different markets allows the class to be able to run different implementation timelines and strategies. For example, if residential electricity is projected to be much cheaper than natural gas in the future compared to right now, installing ground-source heat pumps in a decade would be a great option. Knowing these projections and being able to run multiple different scenarios will lead to the best course of action that Calvin should take.

Appendix D1: **Figures and Tables**

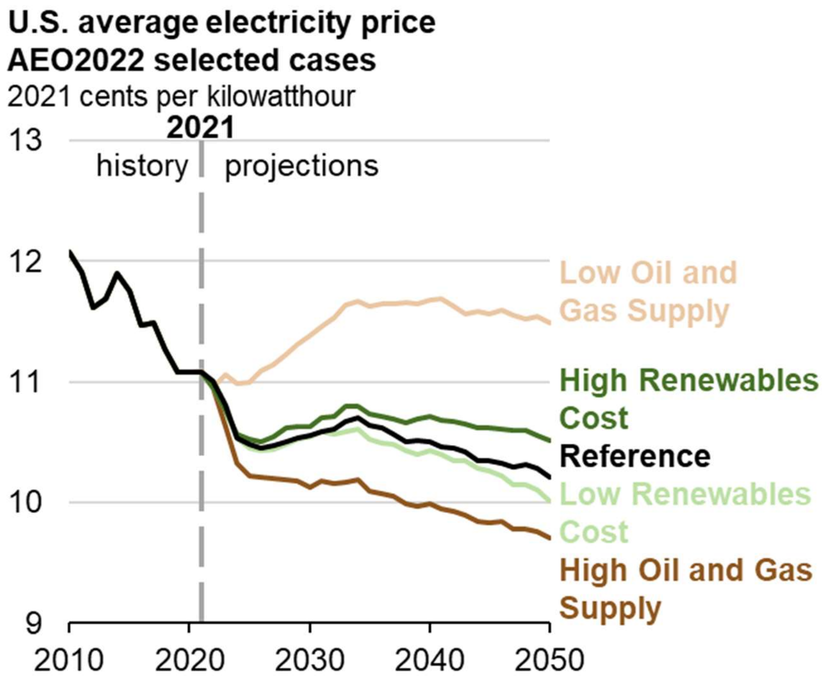


Figure D1.1. EIA National Average Electricity Price Predictions.

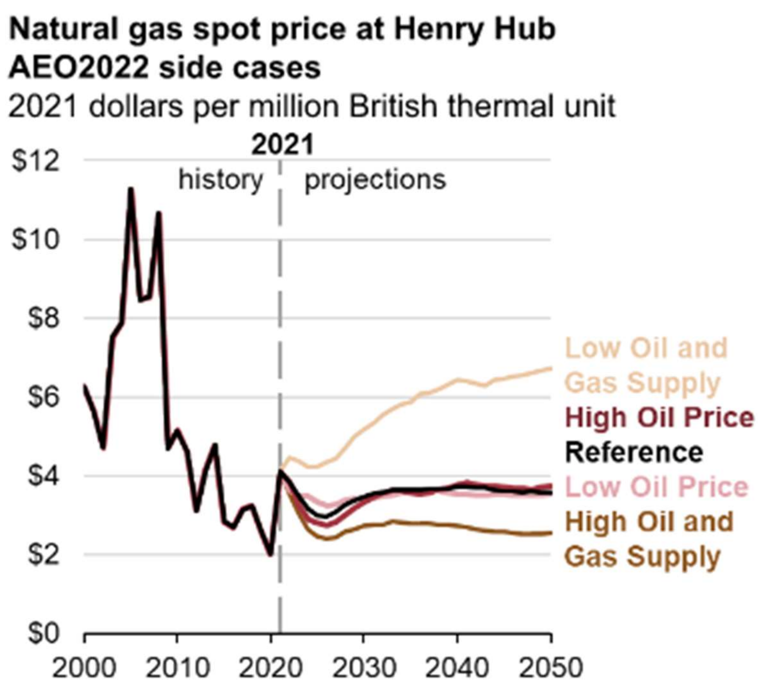


Figure D1.2. EIA National Average Natural Gas Price Predictions.

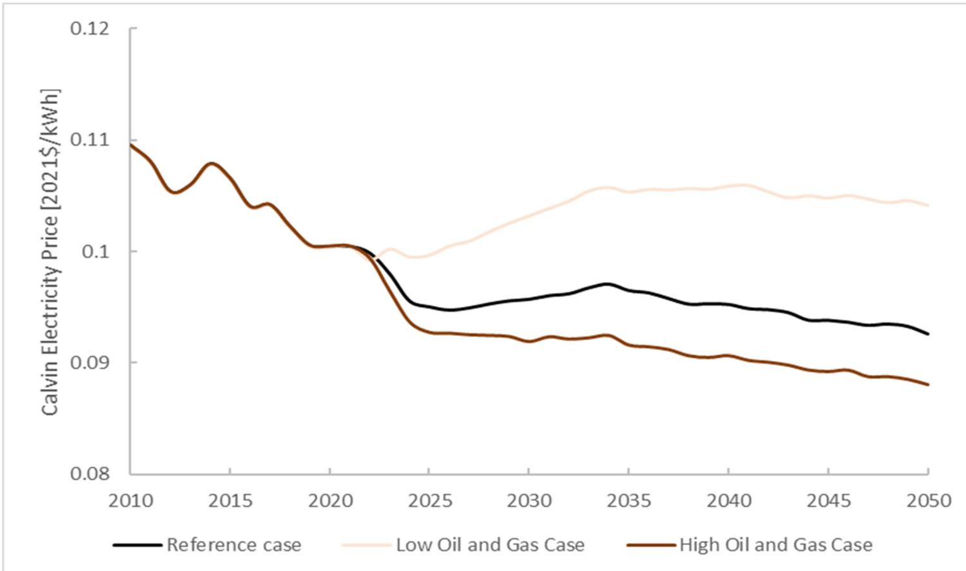


Figure D1.3. Calvin's Commercial Electricity Price Predictions.

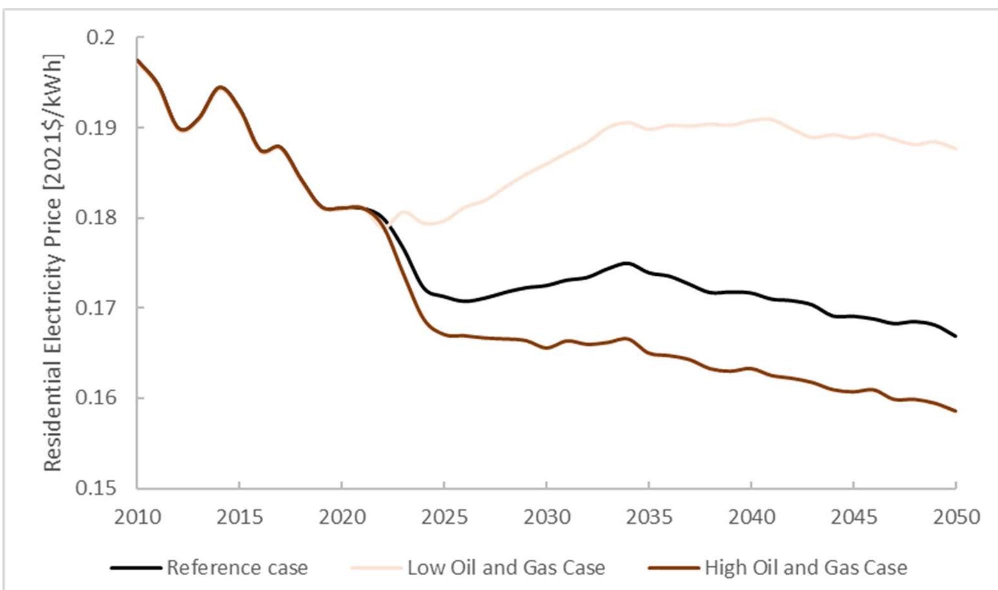


Figure D1.4. Calvin's Residential Electricity Price Predictions.

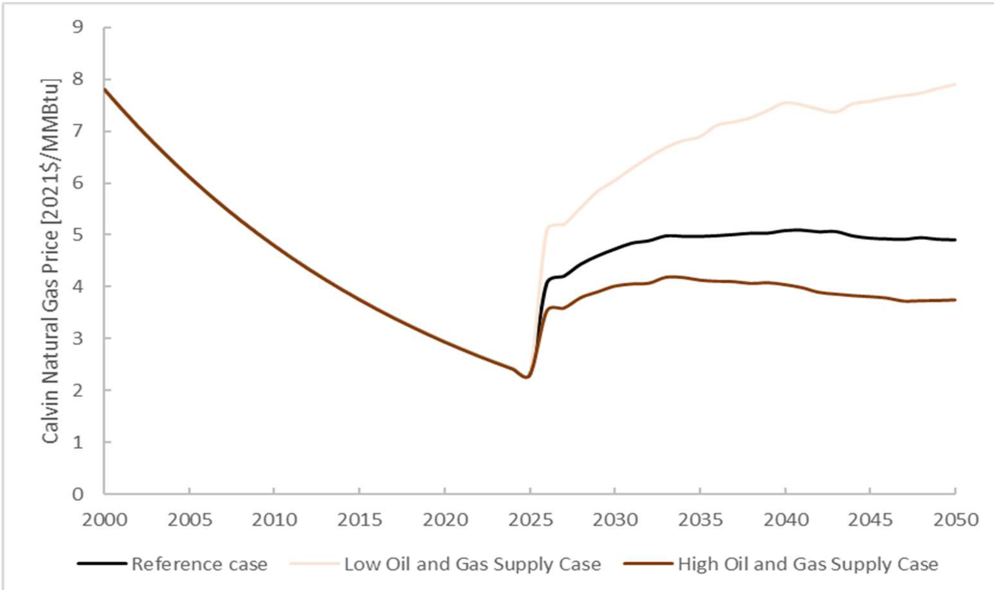


Figure D1.5. Calvin's Natural Gas Price Predictions.

Appendix D2: EIA 2022 Annual Energy Outlook Assumptions

Petroleum and natural gas remain the most-consumed sources of energy in the United States through 2050, but renewable energy is the fastest growing.

- Motor gasoline remains the most prevalent transportation fuel despite electric vehicles gaining market share
- Energy-related carbon dioxide (CO2) emissions dip through 2035 before climbing later in the projection years
- Energy consumption increases through 2050 as population and economic growth outweighs efficiency gains
- Electricity continues to be the fastest-growing energy source in buildings, with renewables and natural gas providing most of the incremental electricity supply

Wind and solar incentives, along with falling technology costs, support robust competition with natural gas for electricity generation, while the shares of coal and nuclear power decrease in the U.S. electricity mix.

- Electricity demand grows slowly across the projection period, which increases competition among fuels
- Renewable electricity generation increases more rapidly than overall electricity demand through 2050
- Battery storage complements growth in renewables generation and reduces natural gas-fired and oil-fired generation during peak hours
- As coal and nuclear generating capacity retire, new capacity additions come largely from wind and solar technologies

U.S. crude oil production reaches record highs, while natural gas production is increasingly driven by natural gas exports.

- U.S. production of natural gas and petroleum and other liquids rises amid growing demand for exports and industrial uses
- Driven by rising prices, U.S. crude oil production in the Reference case returns to pre-pandemic levels in 2023 and stabilizes over the long term
- Refinery closures lower domestic crude oil distillation operating capacity, but refinery utilization rates remain flat over the long term
- Consumption of renewable diesel increases as a share of the domestic fuel mix

Appendix D3: **Price Ratio Calculations**

1. Commercial sector electricity price ratio

This was a prediction of how much Calvin had to pay for electricity usage on campus. Since Calvin is an institution, they are charged at a commercial rate. To make a prediction of Calvin's payment in the future, the ratio is obtained by dividing Calvin's electricity consumption per 2021$ by the EIA electricity consumption per 2021$ at the reference state (see **Figure 1**, black solid line) in 2021, and multiplied by the EIA's electricity cost at the reference state at that year iteratively to future years. Equation and ratio value can be seen below.

$$\left(\frac{Calvin's\ Cost\ [\frac{2021\$}{year}]}{Calvin's\ Consumption\ [\frac{kWh}{year}]}\right)\left(\frac{1}{Reference\ State}\ [\frac{kWh}{2021\$}]\right) = 0.9074141$$

2. Residential sector electricity price ratio

The residential electricity price was necessary because this was the predicted rate Calvin would pay to run a ground-source heat pump if it was implemented. Unlike the commercial sector projection, the ratio was calculated based on the national average electricity cost per consumption in 2021 and electricity cost per consumption at the reference state provided by the EIA. Future cost rates were found by multiplying the ratio to the electricity price at the referenced state. The output was in 2021$. Equation and ratio value can be seen below.

$$\left(\frac{Average\ Residential\ Cost\ [\frac{2021\$}{kWh}]}{Reference\ State\ \ [\frac{2021\$}{kWh}]}\right) = 1.6351104$$

3. Natural gas price ratio

Similar to the process of calculating future cost prediction for electricity, the ratio was first found by dividing the 2021 relevant natural gas cost per consumption by the 2021 reference state natural gas cost per consumption provided by the EIA, and multiplied by natural gas cost iteratively for each year. The difference here was the relevant natural gas cost per consumption was the average Michigan natural gas rate. The costs were in 2021$. Below are the equation and ratio value.

$$\left(\frac{Average\ Michigan\ Cost\ \left[\frac{2021\$}{MMBtu}\right]}{Reference\ State\ \left[\frac{2021\$}{MMBtu}\right]}\right) = 1.366049126$$

References

"Annual Energy Outlook 2022 - U.S. Energy Information Administration (EIA)." Annual Energy Outlook Key Takeaways from the Reference Case and Side Cases - U.S. Energy Information Administration (EIA), 3 Mar. 2022

Appendix E: Air Source Heat Pumps

Air Source Heat Pump Team

Jess Camp, Ryan MacIntyre, Aubree Peters, Alin Stoica, Drew Stoneburner

ENGR 333-A

Professor Heun

12/7/2022

Abstract:

Air-source heat pumps (ASHP) paired with carbon free electricity are capable of providing efficient heating and cooling to buildings. This technology was considered as a potential solution for the heating and cooling of Calvin's campus. Research and calculations suggested that ASHP's do not present the optimum solution for eliminating Calvin's net CO_2 emissions related to heating.

Introduction:

The air-source heat pump team was formed to investigate how air-source heat pumps (ASHPs) could be utilized to determine what it would take to eliminate Calvin's natural gas related net CO_2 emissions. ASHPs take heat from the outside of a building and transfer it to the inside of the building similar to a refrigerator, and they have the ability to both heat and cool a building. They would be used to replace the current heating systems that Calvin uses, and they run on electricity, so any heat provided by air-source heat pumps would be heat that used to come from natural gas consumption and would now be carbon neutral if it is paired with carbon free electricity.

Methods:

The team created a schedule for the semester with intermediate deadlines to complete the project. Initial research was performed by each team member to understand air source heat pumps, how they function, where they are most efficient, and how they are useful in eliminating CO_2 emissions when paired with carbon free electricity. The building heat loads were calculated next by an appointed team so that the correct size air-source heat pump could be utilized. The client, GMB, put the team in touch with an associate from Trane Technologies that worked with the team to find an appropriately sized air-source heat pump to serve the buildings. Once the most advantageous air-source heat pump was decided upon, calculations were performed to obtain the number of units required to serve each building based on the building loads. The cost of the unit and the cost of installation were calculated next, using an estimating technique provided by Trane. Adjustments were made based on new building efficiencies provided by the efficiencies team. Lastly, a cost comparison between air-source heat pumps for campus buildings and ground-source heat pumps was performed to decide upon an ultimate solution.

Research:

To begin the project, the team began individual research on air source heat pumps and where these units could be effective on a college campus. A study conducted by the Michigan Public Service Committee (MPSC) investigated heat pumps, both air source and geothermal, for space and water heating. This explained how heat pumps could be implemented in new and pre-existing buildings in Michigan. It also delved further into their effectiveness in cold climates during the winter and their lifecycles. Within the data they provided, it led the team to further studies completed by the American Council for Energy Efficiency Economy (ACEEE), Efficiency Maine, Northeast Energy Efficiency Partners (NEEP) and others that allowed the team to understand the difficulties and processes of installing air source heat pumps. This study can be found in the References section below.

Moving forward, after the heating loads for school campus were calculated, the team then met with Trane, an ASHP supplier local to the Grand Rapids area. Through multiple emails and meetings with Scott Moorlag, it was determined that modular AXM system would be the best fit for the heating loop that connects to the dorms. It was also determined that ASHP technology is not sufficient for heating water to 140°F with an outside temperature under 0°F, so a backup electric boiler system would also need to be purchased and connected into the system to be able to properly heat during cold winter days. As for the houses, the residential units that Trane carried could not provide high enough loads for the class's calculations, so individual room units from Mitsubishi would need to be installed in nearly every room. All ASHPs that were researched have a lifetime of 10-14 years which would require them to be replaced multiple times before 2057 which greatly increases the overall cost for installing ASHPs on campus. The information from these datasheets for these systems are in Appendix Table A4.

The final aspect of the project that the team investigated was embodied carbon for both air source and ground source heat pumps. While not much data was accumulated for the specific systems that the teams researched, information was found using the Inventory of Carbon and Energy (ICE) database and the weight of materials used in each system.

Analysis and Results:
After meeting with Trane, Scott Moorlag performed feasibility studies using the software Trane had to size their equipment based on the calculated heating loads. After performing simulations for the faculty buildings on campus, air-source heat pumps were determined to not be a feasible solution due to costs as well as the high demand of heating loads. However, the residence halls, Knollcrest East apartments, and the off-campus houses were suitable for air-source pumps and analyses was performed and the results can be found in Appendix Tables E1 through E3. Total cost estimations are summarized in Table 1 below.

Table 1. Total cost of ASHP implementation (in 2021 US Dollars).

Building Type Implementation	Total ($)
Residence Halls	3,937,500
KE Apartments	3,225,000
Houses	643,500
Grand Total:	7,806,000

Due to a higher overall cost compared to the ground-source solution and the inefficiency of air-source heat pumps during colder days below 0°F, ASHPs would not be suitable for the existing environmental conditions. Details such as commercial and residential grade unit features are shown in the appendix and summarized in table E4.

Conclusion:
After analyzing the possible uses of air-source heat pumps in the solution of this project, the class decided that all heating on campus should be carried out using ground-source heat pumps instead of air-source heat pumps. This decision was a result of air-source heat pumps being impractical, inefficient, and expensive. Air-source heat pumps require a higher capital investment than ground-source heat pumps, are more energy intensive, require backup boilers for any cold days, and need to be replaced every 10-14 years. Because of all these reasons, air-source heat pumps were not included in the recommended implementation plan.

Appendix E1: Trane Data

According to Trane, the most suitable buildings for the air-source heat pumps were the residence halls, Knollcrest East Apartments, and the houses that Calvin University owns. Academic buildings were not considered due to the high heat load demand. Tables E1 through E3 provide the specifications for the solution found for the buildings where the pumps would be most suitable. An important note, to maintain consistency between the Renewable Natural Gas, Ground Source Heat Pumps, and Air Source Heat Pumps, each team utilized the same set of heat loads provided by the ground source team.

The residence halls (Table E1) and Knollcrest East Apartments (Table E2) would be equipped with modular units of at least 2 per buildings of commercial grade. The houses owned by Calvin University specifications are provided in table E3. The solution for the houses included residential units.

Table E1.1. Residence Halls specifications for ASHP units (2xAXM030).

Residence Halls	Heat Load (BTU/hr)	Num ber of units	Electricity Demand (kWh/yr)	Cost of Units (Thousand $)	Installation Costs (Thousand $)	Installation year
Beets/Veenstra	387,341	2	1,004,246	150	375	2026
Boer/Bennink	463,685	3	1,506,367	225	562.5	2025
Bolt/Heyens/Timmer	622,240	3	1,506,367	225	562.5	2030
Kalsbeed/Huizenga/van Reken	717,242	4	2,008,493	300	750	2028
Noordewier/VanderWerp	458,826	3	1,506,367	225	562.5	2032
Rooks/VanDellen	432,675	3	1,506,367	225	562.5	-
Schultze/Eldersveld	432,459	3	1,506,367	225	562.5	-

Table E1.2. KE Apartments specifications for ASHP units (2xAXM030).

KE Apartments	Heat Load (BTU/hr)	Number of units	Electricity Demand (kWh/yr)	Cost of Units (Thousand $)	Installation Costs (Thousands $)	Installation year (-)
New Construction	265,571	2	0	150	375	2028
Alpha-Beta-Delta-Gamma-Kappa	168,053	2	1,004,246	150	450	2032
Phi-Chi Apartments	181,778	2	1,004,246	150	375	2025
Rho-Tau Apartments	117,949	2	1,004,246	150	375	2023
Theta-Epsilon Apartments	265,571	2	1,004,246	150	375	2026
Zeta-Lambda Apartments	173,825	2	1,004,246	150	375	2027

Table E1.3. Houses specifications for ASHP units (Indoor unit: MSZ-FS18NA, Outdoor unit: MUZ-FS18NA).

House	Heat Load (BTU/hr)	Number of units	Electricity Demand (kWh/yr)	Cost of Units (Thousand $)	Installation Costs (Thousand $)	Installation year (-)
DeWit Manor House	213,095	12	169,243	36	90	2023
Flat Iron Lake House	53,150	3	42,311	9	22.5	2023
J.M. Perkins Leadership House	34,850	2	28,207	6	15	2023
1230 Lake Drive, Koinonia House (P.N.)	57,934	3	42,311	9	22.5	2023
232 Travis Street, Travis House (P.N.)	42,773	3	42,311	9	22.5	2023
3151 Hampshire Boulevard, Garden House	90,511	5	70,518	15	37.5	2023
3230 Burton Street, Cooper House	55,876	3	42,311	9	22.5	2023
3830 Lake Drive, Bunker House	65,036	4	56,414	12	30	2023
3926 Lake Drive, Tongue House	62,614	4	56,414	12	30	2023

The total costs for the air-source solution are provided in the main body of the report, in the Analysis and Results section. In the cost analysis, the commercial-grade modular units selected for the residence halls and Knollcrest East apartments have a longer lifespan, and thus costs unit replacement was neglected, thus the costs totaling for $3,937,500 and 3,225,000 respectively.

However, for the Calvin University owned houses solution, Trane recommends replacing the entire units at least every 14 years, in which case, the total cost to implement the solution for 34 years would be $643,500. Specifications of the air-source heat pumps selected from Trane's catalog are summarized in table E4.

Table E1.4. Units selected for the air-source solution using Trane and Mitsubishi Electric as vendors.

Unit	Grade	Application	Heating capacity (BTU/hr)	Efficiency (COP)	Power Input (kWh)
2xAXM030	Commercial	KE Apartments and Residence Halls	419,000 (at 0°F minimum)	2.03	54.62
MSZ-FS18NA (indoor) and MUZ-FS18NA (exterior)	Residential	Houses	19,000 (at -5°F minimum)	3.46	1.61

The commercial-grade modular units come into a package of at least two 30-ton modules. One module is 95 in long, 48 in wide, 88 in tall, with a clearance of minimum 96 in between each module. The modules are placed outside, near the building, thus removing at least 127 ft^2 of green space.

On the other hand, the residential-grade units provided for the houses are small and mountable on the interior and exterior walls. One unit is formed of a package of one exterior and one interior module. Both modules are placed such that to minimize the length of air ducts through the walls. The exterior module provides the pumping and heating while the interior module directs the warmed air into the room.

The solution for the houses would not account for using air-source heat pumps as hot water suppliers, instead electric boilers would be considered, adding redundancy to the solution, since the residential units cannot provide hot-water circulation in the building. However, the commercial-grade modular unit can provide hot water. But according to Trane, these units only provide hot water of temperature of up to 140°F on cold days. Therefore, additional boilers need to be utilized which both complicates, and adds extra yearly maintenance to the solution.

Table E1.5. Performance Data for Trane Model AXM Thermafit (1 Module).

TRANE

Heat Pump Performance Data

This manual uses a typical 60-ton air-cooled heat pump consisting of two modules with brazed plate load heat exchangers for example purposes. The model number and a heat pump's precise electrical and refrigerant data can be found on the heat pump model nameplate. See "Model Number and Coding," p. 6.

Table 9. Typical AXM air-to-water heat pump selection of two 30 ton modules

Heat Pump System (two 30-ton heat pump modules) Model # AXM030			
Unit			
Number of modules	2	Refrigerant	R410A
Compressors per Module			
Type	Scroll	Refrigerant Circuits	2
Number	2	Total refrigerant charge	42
Fans per module			
Type	EC axial fan	Number	2
Evaporator per module			
Type	Brazed Plate	Number	1
Weight per Module			
Net weight per module	3,000 lbs.		
Cooling conditions			
Fluid	water	Outlet fluid temperature	44 °F (7 °C)
Fouling factor	0.00010 h ft2- °F/Btu	Design ambient temperature	95 °F (37.3 °C)
Inlet fluid temperature	54 °F (12 °C)	Elevation	0 ft
Cooling performance per bank			
Cooling capacity	59.21 Tons	Flow rate	137.8 GPM
Minimum unloading	14.8 Tons	Pressure drop	10.2 ft H_2O
Compressors Input Power	67.97 kW	EER (A1)	9.62 Btu/Wh
Fans Input Power	6.000 kW	Efficiency - 100% Load	1.2493 kW/Ton
Total Input Power (A1)	73.97 kW	NPLV.IP	0.9125 kW/Ton
Heating conditions			
Inlet fluid temperature	109 °F	Design ambient temperature	19.99 °F
Outlet fluid temperature	120 °F	External Relative Humidity	0 %
Heating performance per bank			
Heating capacity	541.10 MBtu/h	Pressure Drop	18.3 ft H_2O
Compressors Input Power	68.00 kW	COP (A1)	2.14
Fans Input Power	5.990 kW	Total Air Flow	46,000 SCFM
Total Input Power (A1)	74.00 kW	Available Pressure	0 Psig
Flow Rate	98.01 GPM		
Electrical performance per Module			
Power Supply	460/3/60 V-ph-Hz	Chiller FLA	59.8 A

ASHP References:

Trane. (2022). Modular Air-to-Water Heat Pumps. In *Application Guide Supplement*. Retrieved October 4, 2022

Mitsubishi Electric. (2021). M-series and P-series Catalog. In *Mitsubishi Electric Heating & Air Conditioning*. : Trane. Retrieved November 15, 2022

Got Ductless. (2022). *Mitsubishi MSZ-FS18NA and MUZ-FS18NA*. Retrieved November 26, 2022, from Mitsubishi%20MSZ-FS18NA%20&%20MUZ-FS18NA%20(FS18)%20Hyper-Heating%20H2i®%20System%20–%20Got%20Ductless.html

Michigan Public Service Commission. (2021). *New Technologies and Business Models: Heat Pumps for Space and Water Heating*. Retrieved September 8, 2022. https://www.michigan.gov/-/media/Project/Websites/mpsc/workgroups/emerging-tech/MPG_New_Tech_Heat_Pumps_Full_Slides.pdf?rev=5e8020c2583d4993a065d19cd0f20f72

Appendix F: Renewable Natural Gas

Renewable Natural Gas Team

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12/7/2022

Abstract:

Renewable Natural Gas is a beneficial way for businesses and individuals to decrease their Carbon Dioxide Emissions. By using resources such as livestock waste, wastewater flow, energy crops, and landfill, they can feed a biodigester which decreases the natural Carbon Emissions from these resources and sequesters it for a beneficial heating source. Although Renewable Natural Gas is a viable way to decrease Carbon Emissions, the initial capital cost for infrastructure is very high and the biodigesters need to be consistently and constantly fed. Renewable Natural Gas production is not a viable option at Calvin, but outsourcing can be a good way to fill in any gaps found in needed energy production.

Introduction:

Renewable natural gas (RNG) is an alternative to natural gas that supplies Calvin University's heating systems. The difference between RNG and natural gas is that RNG has a lesser impact on the environment and can be used as a direct substitute of natural gas with no equipment upgrades needed. Methane from everyday waste that decomposes is harmful to the atmosphere as it is an aid in climate change. Some everyday methane releasing sources include, but are not limited to livestock waste, wastewater, landfill waste, and forestry waste. As these wastes naturally produce methane, an anerobic biodigester can trap this methane gas and purify it to be utilized as an RNG. The team working on an RNG solution analyzed the previous sources as potential options for a standalone solution.

Methods:

The RNG team looked into four main methods of RNG production. These included Livestock Waste, Wastewater, Landfill Waste, and Forestry Waste. The team broke off and researched the four separate waste opportunities to analyze what inputs Calvin would need compared to how much could actually be inputted from campus. Each source provides different amounts of methane gas during its decomposition. These sources were further researched for their contributions in eliminating net CO_2 emissions.

Results and Analysis:

Through the course of the semester, the RNG team found the needed input from each source, the current available input that Calvin University could supply to an anerobic digestor, and using the available inputs as a source for electricity. Information on these findings can be seen in Appendix F2. It was found that the Calvin could not meet the needed input with the current supply for neither heating nor electricity. After these findings, alternative solutions such as outsourcing and overall solutions were pursued.

Outsourcing:

RNG outsourcing options were also researched. This is a viable option although the cost is quite significant. The best assumptions of pricing for RNG as a source for electricity and heating were obtained. Utilizing the usage requirements, Table F2.5 and Table F2.6 display the costs necessary per year to provide.

Final Solution:

It can be seen through this reflection, the RNG is not a viable standalone solution. Although to answer the research question that was presented, RNG proposed two solutions. The first solution being for Calvin University to become an agriculture-based school, implement a farm that could utilize the livestock manure as a source, and sufficiently heating the schooling campus. An optimization between different animals was calculated upon their purchase costs, maintenance cost, and spatial cost produced the result that poultry would optimally be more cost efficient. The maintenance costs are based upon food, bedding, and any veterinary expenses. The spatial costs include both indoor and outdoor spaces. Table F7 provides details that these costs would entail.

Table F1. Optimized livestock solution with cost details.

Optimized Livestock Solution	
# Chickens	62,712
Space Per Chicken [ft^2/chicken]	12
Space Needed [ft^2]	752,547
Space Needed [acres]	17
Space Cost [\$/ ft^2]	\$0.08
Cost for Space	\$62,461
Cost Per Chicken	\$3.00
Chicken Purchase	\$188,137
Maintenance Per Day Per Chicken	\$0.33
Maintenance Per Day	\$20,629
Maintenance Per Year	**\$7,529,592**
Chicken and Space Purchase	**\$250,598**

To purchase an anerobic digestor facility to accommodate the inputs provided from the livestock requires both space and equipment purchasing. It is to be noted that maintenance costs were not included due to lack of information. It is known however that an anerobic digestor facility would require 24-hour supervision and maintenance through a year. Table F8 displays the financial details of such a facility. Financial information was provided by Ozinga Energy. Spatial information was based upon Kent County Waste to Energy Facility sizing and output.

Table F2. Anerobic digestor facility pricing based on space and equipment costs for the livestock solution.

Digestor Facility	
Space Required [ft^2]	1,853,614
Space Required [acres]	43
Cost for Space	**\$153,850**
Digestor Facility Pricing	**\$995,294,118**

Due to the financials and changes that would be required of this solution, RNG proposed another solution. Ozinga Energy currently builds and operates RNG facilities for uses across the country. Similar to the Sun FundED deal, Calvin University could enter into a similar deal with Ozinga Energy. Ozinga Energy could build and maintain a facility with the help of Calvin University financially and then sell or provide Calvin with the RNG needed to heat campus. This would not require Calvin University to become an agriculture-based school while still providing a net-carbon heating source. Any inquires or questions regarding this solution should be directed to Jason Van Den Brink at jasonvandenbrink@ozingaenergy.com.

Conclusion:

Renewable natural gas may be the future. If prices and availability were to improve, RNG could very well be a beneficial solution. Although RNG was not found to be a viable solution compared to the other sources, an abundant amount of information was learned. The RNG team has presented a solution to answer the research question.

Appendix F1: Methods

Livestock Waste:

The anaerobic digestion of livestock waste captures the methane given off during the manure breakdown. A 'slurry' of manure is fed into the digester and is digested over a period of 30-40 days in the absence of oxygen. The by products from this digestion process leave the digester much cleaner and still usable for crop fertilization. The size of a herd needed to produce the methane demand of Calvin is unreasonable for integration of farming on campus. In addition, the transport of manure for digestion on campus is also unreasonable considering the time, cost, and carbon emissions affiliated with transportation of that scale.

Wastewater:

Wastewater is fed into an anaerobic digestor to allow for the methane to be taken out of the wastewater to create RNG. Wastewater is a constant source on campus due to people living on campus and others coming there for periods of time. With a visit to Grand Rapids Water Resource Recovery Facility, the team's knowledge was expanded on wastewater as a source for RNG. This facility recycles the water, hence requiring numerous filtration processes and large amounts of space. In turn the facility produces RNG and recycles the water back into the ecosystem. Based on the input to this facility and the output of RNG it creates wastewater as a standalone solution would not meet Calvin's need.

Landfill Waste:

Landfills are the thirds largest source of man-made methane in the United States. While this method of disposable waste produces a lot of methane, a digestor is not needed since the gas is produced under large piles of garbage where oxygen is not present. Also known as Landfill gas, the RNG produced from landfills are extracted using a network of pipes underneath the piles of waste in the landfill. Frankly Calvin would not supply enough waste, with fluctuations in the summer months to meet the required amounts as a standalone solution.

Forestry Waste:

Most crops, lawn clippings, trees and tree trimmings can be used to feed an anerobic digestor. By feeding this forestry biomass into the anerobic digestor, the process of the biomass being broken down produces a release of methane. This methane is sequestered like the other sources listed above and then can be used as a Renewable Natural Gas source. The process of collecting all of this biomass is labor intensive and also differs in possible input dependent on the time of year.

Appendix F2: Results and Analysis

Needed Input:

It was found that an average of 141,000 MMBtu per year of heat is consumed on Calvin's campus with efficiency improvements resulting with an average daily need of 386 MMBtu. These values were used as references while calculating the feasibility of each source. It should be noted that Calvin does not actually utilize 386 MMBtu per day, as there are fluctuations in need based on the weather. There could be fluctuation in this value due to an increase in enrollment and efficiency improvements. Rather this value is used for the purpose of the analysis of the sources.

Each source supplied an appropriate output value. These values were then used to find the number in animals, tons, or gallons needed to meet Calvin's need. Based on research regarding the four different sources and Calvin's current usage, the need from each source individually to supply Calvin with enough heat can be found in Table F2.1.

Table F2.1. Need based on source to supply Calvin University with enough heat per year.

Animal Type	MMBtu/Animal/Year	# Animals Needed for Calvin Need
Dairy Cow	48.55	2,904
Beef Cow	40.59	3,474
Swine	15.68	8,991
Poultry	2.25	62,761
Energy Crop	**MMBtu/ton, dry**	**Tons of Crop Needed**
Willow	17.1	8,246
Poplar	15.55	9,068
Switchgrass	15.86	8,890
Miscanthus	15.8	8,924
Biomass sorghum	14.48	9,738
Pine	12.42	11,353
Eucalyptus	12.37	11,399
Energy Cane	15.8	8,924
Forest Residue	17.19	8,202
Forest Thinnings	18.05	7,812
Primary/Secondary residue	17.19	8,202
Mixed Wood	13	10,846
Landfill	**MMBtu/day**	**Tons of Landfill Needed**
	386	1,788,432
Waste Water	**MMBtu/day**	**Million Gallons/day**
	2.4	58,750

Available Input:

With the four different sources, it becomes evident that the amount of supply to an anerobic digester necessary for Calvin to produce enough RNG is not available for use. Research and assumptions about the amount that Calvin could input into a digestor were made. The values that were obtained for forestry, landfill, wastewater, and livestock waste are shown in Table F2.2.

From Table F2.2, it becomes evident that Calvin does not have anywhere near the amount needed for the heating requirement, even with the combination of all sources. This allows one to understand that designing and maintaining an anaerobic digestor on campus would not be a feasible solution to heat the whole campus due to the lack of supplies. As a result, it becomes apparent that developing RNG on campus would not be feasible for Calvin to succeed.

Table F2.2. The supply Calvin can produce in MMBtu per day with the remaining amount still needed.

Source	Forestry	Landfill	Waste Water	Livestock
Theoretical Supply [MMBtu/day]	3.158	0.590	0.045	0
Still Needed [MMBtu/day]	382.842	385.410	385.955	386.000

Electricity Sourcing:

Seeing that RNG would not be feasible as a heating source, the other sources of alternative natural gas would require additional electricity usage. The RNG team investigated RNG as an electricity source instead. Efficiency between the input to output is generally greater for electricity than it is for heating.

Utilizing the current electrical need, the Sun FundED contribution, and conversions from the MMBtu per day production to kilowatt hours per day for each source, an average contribution from the addition of a digestor to campus can be seen in Table F2.3. The electrical need and changes with varying contributions can be seen in Table F2.4.

It can be seen in Table F2.4 that a digestor would make a greater impact for electricity rather than heating. Overall, a digestor would cover about 2% of the current electrical load. With purchasing equipment and maintenance costs, a digestor would not be financially feasible for its' contribution.

Table F2.3. Electrical output in RNG for each source available on Calvin's campus.

Source	Current [MMBtu/day]	Electricity Generation [kWhr/day]	kWhr/yr
Waste Water	0.04	13.13	4,791.56
Forestry	3.16	925.28	337,725.89
Landfill	0.59	172.75	63,054.77
			405,572.22

Table F2.4. Calvin's electrical need with the Sun FundED and digestor contributions.

Calvin Electricity Need	
Current Usage [kWhr/yr]	19,900,000
With Solar	8.00%
Need to Purchase [kWhr/y	18,308,000
With Digester [kWhr/yr]	405,572
Potential Need [kWhr/yr]	17,902,428

Outsourcing:

Table F2.5. Outsourcing RNG prices for heating compared to current pricing.

RNG Outsourcing for Heating	
RNG Cost/MMBtu	$18.00
Current Cost	$394,800
Cost after 2025	$740,250
New Annual Total	**$2,538,000**

Table F2.6. Outsourcing RNG prices for electricity taking into account the Sun FundED contribution.

RNG Outsourcing for Electricity	
RNG Cost/kWhr Premium	$0.02
Sun FundED Cost/kWhr	$0.075
Current Cost	$2,000,000
Cost for Sun FundED	$119,400
Cost for RNG	$2,352,098
New Annual Total	**$2,471,498**

These tables compare the current spending with a new annual total if pursuing an outsourcing option. In terms of heating, the amount required to outsource would substantially increase spending. While in terms of electricity, the amount does increase but not quite to the scale heating required. This is due to the improved efficiency to utilizing RNG as an electricity source.

RNG References:

About RNG. (n.d.). The Coalition for Renewable Natural Gas. https://www.rngcoalition.com/about-rng

Alternative Fuels Data Center: Renewable Natural Gas (Biomethane) Production. (2019). Energy.gov. https://afdc.energy.gov/fuels/natural_gas_renewable.html

How much do farm animals cost. (n.d.). https://farmityourself.com/how-much-do-farm-animals-cost/

Inc, A. (n.d.). U.S. Farmland Prices Per Acre by State | AcreTrader. Acretrader.com. Retrieved December 5, 2022, from https://acretrader.com/resources/farmland-values/farmland-prices

Mccune, K. (n.d.). How Much Space Do I Need To Raise Pigs? Family Farm Livestock. https://familyfarmlivestock.com/how-much-space-do-i-need-to-raise-pigs/

Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field. (2012). Proceedings of the Water Environment Federation, 2012(11), 4532–4588. https://doi.org/10.2175/193864712811708879

Sheehy, P., & Oldham, M. (2022). Michigan Renewable Natural Gas Study Stakeholder Meeting #3. https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/workgroups/RenewableNaturalGas/ICFMPSCDTMB-MI-RNG-Study-Stakeholder-Meeting-3-220628.pdf?rev=70515df131f6411885129a91e87583c5&hash=F9AC82731AC8EFC57F4FBAFB6475E7C0

So you want to farm? (2017, March 3). Farm Progress. https://www.farmprogress.com/livestock/so-you-want-farm

RNG Q&A: Facts About Renewable Natural Gas. (n.d.). The Coalition for Renewable Natural Gas. Retrieved December 5, 2022, from https://www.rngcoalition.com/rng-qa?gclid=Cj0KCQiAyMKbBhD1ARIsANs7rEE48gywLWezhR7OGmY15A8X7wiZXBZwx6Qam8mvG2sd2vjV7NP9OdEaAkCAEALw_wcB