Oneonta Railyards Community Heat Pump Strategy

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Oneonta Railyards
Community Heat Pump Strategy

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Sue Doughtery
Senior Project Manager

and

Otsego Now & County of Otsego Industrial Development Agency

Jody Zakrevsky
CEO Otsego Now

Prepared by:

Ramboll

Syracuse, NY

Robert M Neimeier
Client & Market Officer

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Notice

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Abstract

Oneonta Railyards is a new construction, light industrial development located on a 38-acre parcel in the southwestern portion of the City of Oneonta, NY, seeking to explore a district-style heat pump system to serve five buildings. Technology screening and assessment evaluated potential thermal resources including geothermal, air, wastewater, surface water, and industrial waste heat. Based on the projected site heating and cooling load and the available thermal resources, three scenarios were developed and compared to Business as Usual that included a fourth generation (4G) centralized configuration, a fifth generation (5G) ambient temperature loop configuration, and a decentralized approach.

Techno-economic analysis of the scenarios was completed to compare energy consumption, net present value (NPV) of total system cost over the project's lifetime, and the carbon reduction impact of the proposed scenarios. The report identifies the most cost-efficient mix of technologies and thermal resources to provide the buildings with electrification-based low-carbon heating and cooling.

Keywords

thermal energy network, district energy, ambient temperature loop, geothermal, electrification, decarbonization

Acknowledgments

Jody Zakrevsky, CEO of Otsego Now

Table of Contents

Notice ii
Abstract iii
Keywords iii
Acknowledgments iii
List of Figures v
List of Tables vi
Acronyms and Abbreviations vii

Summary S-1
1 Characterization of the Proposed Community 1
1.1 Description 1
1.2 Site Constraints and Opportunities 1
1.3 Proposed Building Information 2
1.4 Utility Prices 4
1.4.1 Electricity 4
1.4.2 Natural Gas 8
1.5 Business-as-Usual Load Profile 8
2 Technology Assessment 11
2.1 Thermal Sources 11
2.1.1 Geothermal 11
2.1.2 Air (On-site) 12
2.1.3 Wastewater (Oneonta Wastewater Treatment Plant) 13
2.1.4 Surface Water 14
2.1.5 Lutz Feed Company, Inc. 15
3 Scenarios Considered 16
3.1 Scenario: Business as Usual 17
3.2 Scenario 1: Centralized 18
3.3 Scenario 2: Ambient Loop 18
3.4 Scenario 3: Decentralized 19
4 Analytical Methods 20
4.1 Energy Consumption Analysis 20
4.1.1 Model Assumptions 20
4.1.1.1 Building Loads 20
4.1.1.2 Equipment Efficiencies—Decentralized Air-Source Heat Pumps 20
4.1.1.3 Equipment Efficiencies—Decentralized Water-Source Heat Pumps 21
4.1.1.4 Equipment Efficiencies—Process Cooling Unit 21
4.1.1.5 Equipment Efficiencies—Centralized Air-Source Heat Pumps 21
4.1.1.6 Equipment Efficiencies—Ground-Source Heat Pumps 21
4.1.1.7 Equipment Efficiencies—Boilers 22
4.1.2 Social Cost of Carbon 22
EnergyPRO model 24

4.1.2.1 EnergyPRO Model Layout 24
4.1.2.2 EnergyPRO Simulation Output Checks 27
4.1.3 Spreadsheet Calculation 29
4.2 Hydraulic Model 29
4.3 Geothermal Assessment 31
4.4 Cash-Flow Model 32
5 Results 35
5.1 Technical Results 35
5.1.1 Capital Expenditures 37
5.2 Economic Results 38
5.3 Environmental Results 40
6 Business Model 43
6.1 Identification of Tenants 43
6.2 Energy as a Service 43
6.3 Engineering, Procurement, and Construction 44
6.4 Selected Implementation Model 44
7 Lessons Learned 45
7.1 Key Findings 45
7.2 Next Steps 45
Appendix A. Site Information A-1
Appendix B. Building Model Inputs and Assumptions B-1
Appendix C. Hydraulic Modeling C-1
Appendix D. Hydrogeologic Evaluation D-1
Appendix E. Techno-Economic Analysis E-1
Appendix F. Scenario Cost Estimates F-1
Endnotes EN-1

List of Figures

Figure 1. Building Locations 3
Figure 2. Independent System Operator Map 5
Figure 3. Monthly Average Day-Ahead Electric Market Price for Zone E 6
Figure 4. New York Gas and Electric Electricity Average Delivery Charge 7

Figure 5. Calculated Final Electric Utility Rates 7
Figure 6. Real-Time Energy Prices, Natural Gas Prices, and Congestion in 2021 8
Figure 7. Project Hourly Load Profile (without Process Cooling) 10
Figure 8. Project Hourly Load Profile (with Process Cooling) 10
Figure 9. Oneonta Map 13
Figure 10. Potential Heat Generated from Wastewater Heat Pump at the Wastewater Treatment Plant 14
Figure 11. Site Heating Load Curve 17
Figure 12. EnergyPRO Model for Scenario 1 Space Heating and Comfort Cooling 24
Figure 13. EnergyPRO Model for Scenario 1 Process Cooling 24
Figure 14. EnergyPRO Model for Scenario 2 Space Heating and Comfort Cooling 26
Figure 15. EnergyPRO Model for Scenario 2 Process Cooling 26
Figure 16. Heating Season Hourly Production Schedule of Various Production Units (Upper Diagram) and State-of-Charge of the Thermal Energy Storage (Lower Diagram) 28
Figure 17. Cooling Season Hourly Production Schedule of Various Production Units (Upper Diagrams) and State-of-Charge of the Thermal Energy Storage (Lower Diagram) 28
Figure 18. Proposed Low-Temperature Hot Water Network for Scenario 1 30
Figure 19. Ground Heat Exchangers Charge and Discharge Loads 31
Figure 20. Annual Heating Production 35
Figure 21. Annual Cooling Production 36
Figure 22. Annual Fuel and Electricity Consumption 36
Figure 23. Capital Expenditures for the Scenarios 38
Figure 24. Economic Overview of the Different Scenarios: Net Present Value of the Total System Cost over the Project Lifetime 39
Figure 25. Net Present Value of Project Fuel Costs for Each Scenario 40
Figure 26. Carbon Dioxide Equivalent Emissions and Project Net Present Value for the Different Scenarios 41

List of Tables

Table 1. Building Types and Allocations 2
Table 2. Energy Use Intensity for Different Building Types 9
Table 3. Thermal Source Technologies 11
Table 4. Final Scenarios for the Techno-Economic Assessment 16
Table 5. Social Cost of Carbon with 2% Discount Rate 22
Table 6. Borefield Sizing and Performance Data 32
Table 7. Assumed Equipment Technical Lifetime 33
Table 8. Emission Factors 34
Table 9. Shadow Price of Carbon Compared to Scenario BaU 42

Acronyms and Abbreviations

°F	degrees Fahrenheit
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASHP	air-source heat pump
BaU	business as usual
BTES	borehole thermal energy storage
BHX	borehole heat exchanger
CapEx	capital expenditure
CBECS	Commercial Buildings Energy Consumption Survey
CHPS	Community Heat Pump Study
CO2	carbon dioxide
CO2e	carbon dioxide equivalent
COIDA	County of Otsego Industrial Development Agency
COP	coefficient of performance
Climate Act	Climate Leadership and Community Protection Act
CPI	Consumer Price Index
DHW	domestic hot water
DEC	New York State Department of Environmental Conservation
DOE	New York State Department of Energy
EaaS	Energy as a Service
EER	energy efficiency ratio
EPA	Environmental Protection Agency
EPC	Engineering, Procurement, and Construction
ETS	energy transfer station
EUI	energy use intensity
ft	foot/feet
GCM	geothermal conceptual model
GHG	greenhouse gas
GHX	geothermal heat exchanger
GSHP	ground-source heat pump
HDPE	high-density polyethene
HRC	heat recovery chiller
HVAC	heating, ventilation, and air conditioning
IoT	internet of things
ISO	Independent System Operator
kBTU	thousand British thermal units
kVAh	kilovolt Ampere hour
kW	kilowatt

kWh	kilowatt hour
LTW	low temperature water
MMBtu	million British thermal units
MMBtu/h	million British thermal units per hour
MT/kW	metric tons per kilowatt
MT/therm	metric tons per therms
MUSD	million United State Dollars
MW	megawatt
MWh	megawatt hour
NPV	net present value
NYSEG	New York Gas and Electric
NYSIO	New York Independent System Operator
NYUP	Upstate New York
OpEx	operating expenses
O&M	operation and maintenance
RFP	request for proposal
SDR	standard dimension ratio
sf	square foot/feet
TTES	tank thermal energy storage
UE	Underground Energy, LLC
USD/ton	United State Dollars per one ton of CO_2 emission
USGS	U.S. Geological Survey
WSHP	water-source heat pump
WWTP	wastewater treatment plant

Summary

S.1 Background and Purpose

Oneonta Railyards is a new construction, light industrial development located on a 38-acre parcel in the southwestern portion of the City of Oneonta, NY (Otsego County), seeking to explore a district-style heat pump system to serve five buildings. Oneonta Railyards encompass an extensive area characterized by a network of railroad tracks, industrial buildings, and open spaces. This study assessed the feasibility of using heat pumps as an energy-efficient and sustainable heating and cooling solution for future industrial and non-industrial buildings on the property.

Oneonta is the termination node for the DeRuyter natural gas pipeline, which is more than 60 years old and which New York Gas and Electric (NYSEG) has identified for replacement. The limited access to natural gas and electricity severely limits new or expanding industrial development in Oneonta. Otsego Now, the umbrella organization that includes the County of Oswego Industrial Development Agency (COIDA), has publicly described losing several potential enterprises totaling 475 jobs due to the lack of reliable energy for operations.

With influence from the passage of New York's Climate Leadership and Community Protection Act (Climate Act), this report assesses commercial development potential at Oneonta Railyards that embraces a low carbon approach to economic development in the City of Oneonta. Using heat pump technology can reduce dependence on fossil fuels, contribute to energy independence, and enhance overall system resilience.

S.2 Baseload, Peaking, and Backup Strategy

A clear strategy should be established with dedicated heating and cooling technologies that support baseload, peaking, and backup (emergency) operations. The rationale for serving the annual load with both baseload and peaking technologies is that the peak load occurs in limited hours annually, and it is less cost-efficient to size the relatively expensive baseload technology to meet the peak load when it can effectively meet the majority of the annual load when it is sized much smaller than the peak. As a rule of thumb, if the baseload heating capacity is 50% to 60% of the peak heating load, then it will cover approximately 90% of the annual heating energy. Distinguishing between baseload and peak load will be more cost-efficient and could allow financial resources to be allocated to other projects that economically and environmentally would make better sense.

S.3 Scenario Planning

Through a technology screening process and discussions with the Otsego Now, scenarios listed in Table S-1 were established for techno-economic modeling and analysis.

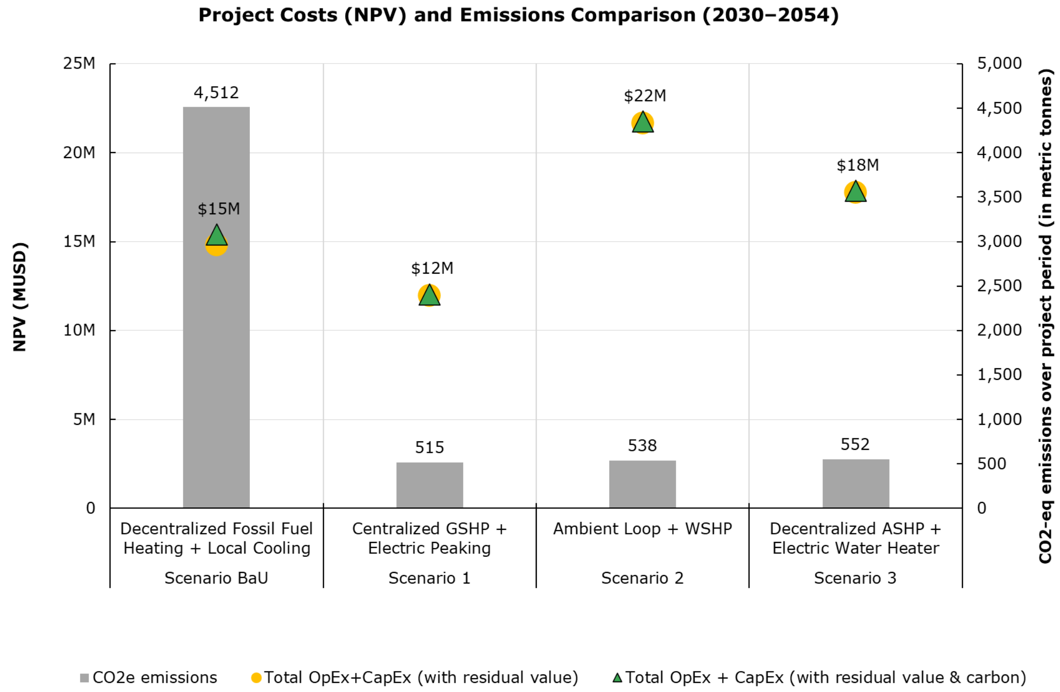
Table S-1. Final Scenario Descriptions

Scenario	Description
Scenario BaU	Scenario business-as-usual (BaU) uses fossil fuel boilers for space heating, air-cooled chillers for comfort cooling, and water-cooled chillers for the process cooling. Separate fossil fuel boilers provide domestic hot water (DHW). All systems are decentralized.
Scenario 1	A centralized two-pipe dual temperature network with a centralized energy center using ground-source heat pump (GSHP), electric boiler, and electric water heater to provide comfort heating, cooling, and DHW. Baseload is supplied by GSHP. The GSHP uses borehole thermal energy storage (BTES) as the heating source and sink. The site is heating dominant and peak load is served by a central electric boiler. This scenario includes tank thermal energy storage where it serves as heating thermal storage in the winter and transitions to cooling thermal storage in the summer. DHW is produced locally using electric resistance water heaters. The process cooling load would be covered by a separate water-cooled chiller, and the rejected heat would be used in the winter as a heating source to balance the heat extracted from the borefield. Emergency backup for heating uses a centralized fossil fuel boiler.
Scenario 2	Ambient loop: A hybrid of centralized and decentralized equipment. In the decentralized component, space heating and cooling are produced at the building level via water-to-water heat pumps. In the centralized component, an ambient loop network circulates neutral (ambient) temperature water to the buildings along with equipment to extract or reject heat, as needed, from the ambient loop using thermal sources/sinks connected to the loop. The system supplies both baseload and peak load. A geothermal borefield serves as the source/sink for the ambient loop. An air-source heat pump (ASHP) is also connected to the ambient loop and serves as the heating source/sink when the building load exceeds the borefield capacity. The process cooling loads are provided by water-cooled chillers that connect to the ambient loop. DHW for this scenario is produced via specialized water-to-water heat pumps also connected to the ambient loop. Each building is equipped with thermal energy storage that switches between heating and cooling mode seasonally. Emergency backup for heating uses building-level fossil fuel boilers.
Scenario 3	Individual building heat pump configurations: Heat pumps covering 100% of the space heating and cooling loads. DHW is produced by local electric DHW heaters. Process cooling load is provided by local water-cooled chillers.

S.4 Techno-Economic Analysis

Techno-economic analysis was completed to establish a basis for comparing scenarios and identifying the most cost-efficient mix of technologies for future energy supply. Figure S-1 shows the net present value (NPV) of costs for each scenario on the left axis and the total emissions on the right axis. From the figure, scenario 1 has the lowest NPV of the alternatives, both with and without the social cost of carbon included. All alternative scenarios significantly reduce carbon dioxide (CO_2e) emissions compared to scenario BaU.

Figure S-1. Carbon Dioxide Equivalent Emissions and Project Net Present Value for the Different Scenarios



Scenario 1 has a lower NPV than the other scenarios, mainly because of the low capital expenditure (CapEx). Although Scenario 1 has the second highest original CapEx at the beginning of the project lifetime, the equipment lifetime of the centralized equipment and network are, in general, longer than the decentralized equipment in the other scenarios. This results in a lower replacement cost and higher residual value. Scenarios BaU and 3 have similar NPVs due to the building-level equipment needed to meet the heating and cooling loads. However, scenario 2 still has the highest CapEx in NPV because of the use of both centralized and decentralized equipment. From an economic perspective alone, scenario 1 is the most favorable.

S.5 Key Takeaways

The following summarizes important topics and associated aspects of the study.

1. **Achieve electrification**
   Ensure the Oneonta Railyards can reach 100% electrification under any of the three scenarios considered. Recommend Scenario 1 (centralized distribution with GSHP) based on the lowest life-cycle cost, factoring in both CapEx and operation and maintenance (O&M) costs.
2. **Facilitate centralized systems**
   Leverage a diverse range of building types with varied heating and cooling loads to implement a centralized system, using local thermal resources (sources/sinks) to address aggregate loads cost-effectively.
3. **Assess impact of tenants and building types**
   Evaluate how actual tenants and building types influence the optimum mix of technologies—water-source heat pumps (WSHP), ASHP, boilers, and ground heat exchangers (GHX)—needed to address peak and base loads on the site.
4. **Coordinat**e **with** the **City of Oneonta efforts**
   Align the heating and cooling systems at Oneonta Railyards with the City of Oneonta's Community Heat Pump Study (CHPS). Consider connection to the city's district energy system if implemented and if the Oneonta Railyards site is near a main piping network. Include the cost contribution from building-level chillers/heat-recovery chillers in the analysis, along with the levelized cost of energy ($/million British thermal units, or MMBtu) purchased from the district system.

S.6 Recommended Next Steps

The following recommended next steps are provided to help the campus prioritize projects that can influence future systems designs and demonstrate progress toward transitioning to low-carbon operations and achieving campus carbon reduction goals.

1. Solicit potential tenants for the site
2. Select the ownership model for the buildings
3. Select the implementation model for the centralized heat pump system
4. Develop a request for proposals (RFP) to select a development team
5. Conduct exploratory hydrogeologic studies to assess capacity of on-site geo-exchange

1 Characterization of the Proposed Community

1.1 Description

Oneonta Railyards is situated in Oneonta, NY, which is in Otsego County in Upstate New York. Oneonta Railyards encompasses an extensive area characterized by a network of railroad tracks, industrial buildings, and open spaces. This study assesses the feasibility of using heat pumps as an energy-efficient and sustainable heating and cooling solution for future industrial and nonindustrial buildings on the property.

1.2 Site Constraints and Opportunities

Oneonta is the termination node for the DeRuyter natural gas pipeline, which is more than 60 years old and which NYSEG has identified for replacement. The limited access to natural gas and electricity severely limits new or expanding industrial development in Oneonta. Otsego Now, the umbrella organization that includes the County of Oswego Industrial Development Agency (COIDA), has publicly described losing several potential enterprises totaling 475 jobs due to the lack of reliable energy for operations. With the passage of the Climate Act, investment in new gas infrastructure in Oneonta might not be the most cost-effective use of ratepayer funds.

This report investigates an alternative approach to commercial development at Oneonta Railyards that embraces a low-carbon approach to economic development in Oneonta. Using heat pump technology can reduce dependence on fossil fuels, contribute to energy independence, and enhance overall system resilience. The use of heat pump systems can potentially offer the following opportunities:

- **Energy efficiency:** Heat pumps are known for their energy efficiency, and they can significantly reduce energy consumption compared to conventional heating and cooling systems. This can lead to cost savings and a reduced environmental footprint.
- **Carbon emission reduction:** Switching to heat pumps can help reduce carbon emissions, making them an environmentally responsible choice.
- **Local economic benefits:** Investing in heat pump technology can create local job opportunities and stimulate the economy through installation and maintenance of equipment.

While investigating the feasibility of heat pump technologies, the following constraints were also identified and taken into consideration in the analysis.

- **Cost:** Heat pump installations can be expensive, and the upfront costs may be a significant constraint. Considering the financial feasibility of the project, including the initial investment and ongoing operational costs, is essential.

- **Energy source availability:** The success of a heat pump system depends on the availability of suitable energy sources. The study included an investigation on the potential heating sources/sinks.
- **Infrastructure and space:** The physical constraints of Oneonta Railyards, including available space and existing infrastructure, can impact the feasibility of a heat pump system.
- **Technical feasibility:** Heat pumps require suitable conditions for efficient operation. Different heat pump system types and the local climate can both impact the system capacity and efficiency. For example, centralized heat pumps generally have higher efficiency than decentralized ones, and low outdoor air temperature can also lower the system heating efficiency and capacity.

This study evaluated important constraints and opportunities by developing and analyzing different implementation scenarios. We assessed both centralized and decentralized heat pump configurations to determine the more efficient solution for Oneonta Railyards. The analysis encompassed three key aspects: technical considerations, economic implications, and environmental impact.

1.3 Proposed Building Information

The Oneonta Railyards project is planning to redevelop the site with new industrial construction. The project team developed the space programming for the site, bounded by Chestnut Street and the railroad track, to represent light industrial occupancy. Table 1 shows the resulting mix of buildings considered for this study, including office/administration buildings, warehouses, and light manufacturing facilities. The expected total gross floor area is approximately 177,000 square feet (sf).

Table 1 lists each building, including type and size, and Figure 1 shows the proposed location of each building.

Table 1. Building Types and Allocations

Building Type/Description	Building Reference	Area (sf)	Space Allocation
Office/Admin	A	50,000	28%
Nonrefrigerated Warehouse with Fine Storage	B	42,000	24%
Nonrefrigerated Warehouse with Heating Only Storage	C	30,000	17%
Refrigerated Warehouse	D	30,000	17%
Light Manufacturing Facility	E	25,000	14%
Total	**—**	**177,000**	**100%**

Figure 1. Building Locations

A BaU profile was established for each building. Since no existing buildings are present, the BaU serves as the baseline scenario for the project. The New York State Department of Energy (DOE) developed prototype building energy simulation models to represent buildings on the site. The energy simulation models were used to generate hourly energy profiles for each building type. The profiles reference either DOE prototype building models or EnergyPlus sample models to represent typical new constructions built after 2020 in New York. The following list indicates the basis for each building profile.

- **Office/admin, nonrefrigerated warehouse with fine storage and nonrefrigerated warehouse with bulk storage**
  Profiles were established based on DOE commercial prototype building models that comply with American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90.1-2019.
- **Refrigerated warehouse**
  The DOE prototype building model database excludes refrigerated warehouses. Ramboll used an EnergyPlus sample model file that was developed based on 2008 California Energy Commission Title 24 Building Energy Efficiency Standards.

- **Light manufacturing facility**
  Neither DOE nor EnergyPlus has a reference model for the light manufacturing building type. Therefore, Ramboll created a model based on the DOE nonrefrigerated warehouse, incorporating updated inputs from COMNET specific to the light manufacturing building type. The updates included plug load densities and operating schedules; process loads; occupancy densities, heat gain, and schedules; lighting power densities and schedules; space heating and cooling setpoints and schedules; ventilation rates; and domestic hot water (DHW) temperature setpoints and schedules. Additionally, the heating-only bulk storage area in the original model was updated to include zone cooling to better match the building type.

The heating and cooling sources were consistent across all building types.

- **Space heating**
  Fossil fuel boilers with an efficiency of 81% based on ASHRAE Standard 90.1-2019.
- **DHW**
  Fossil fuel water heaters with an efficiency of 81%.
- **Space comfort cooling**
  Air-cooled chillers, with a coefficient of performance (COP) of 3.4, based on ASHRAE Standard 90.1-2019.
- **Process cooling unit**
  Water-cooled chillers. The efficiencies of the units under general working condition were estimated based on Ramboll's professional experience with process cooling units in previous projects. Chillers for cooling docks were modeled with a COP of 3.3, and chillers for freezers have a COP of 2.

1.4 Utility Prices

NYSEG provides both the electricity and natural gas in Oneonta.

1.4.1 Electricity

Based on NYSEG electric rates summary,[1] the electricity rate considered in this study includes supply charges and delivery charges. We obtained the supply charges from New York Independent System Operator (NYISO). Based on NYISO pricing zone map[2] shown in Figure 2, NYSEG used the day-ahead market price of Zone E: Mohawk Valley as the hourly supply charge for the proposed buildings.

Figure 2. Independent System Operator Map

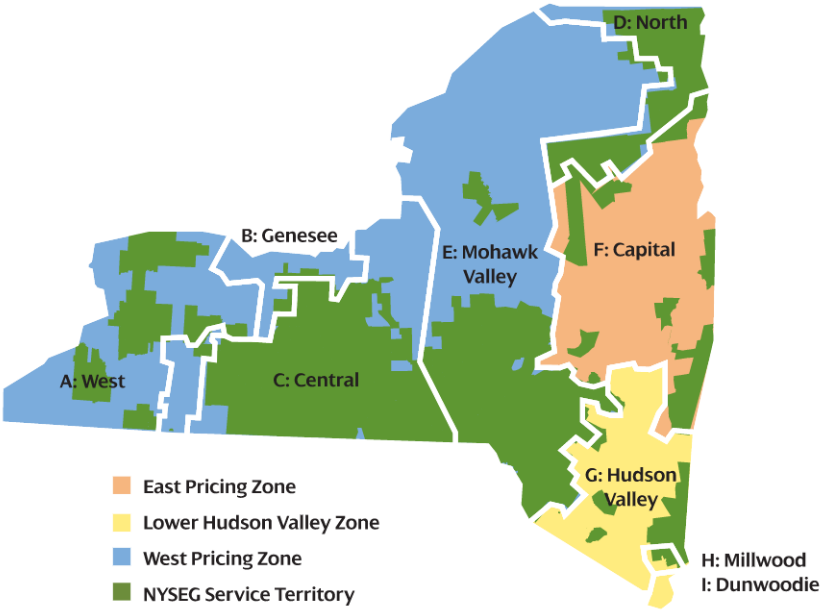
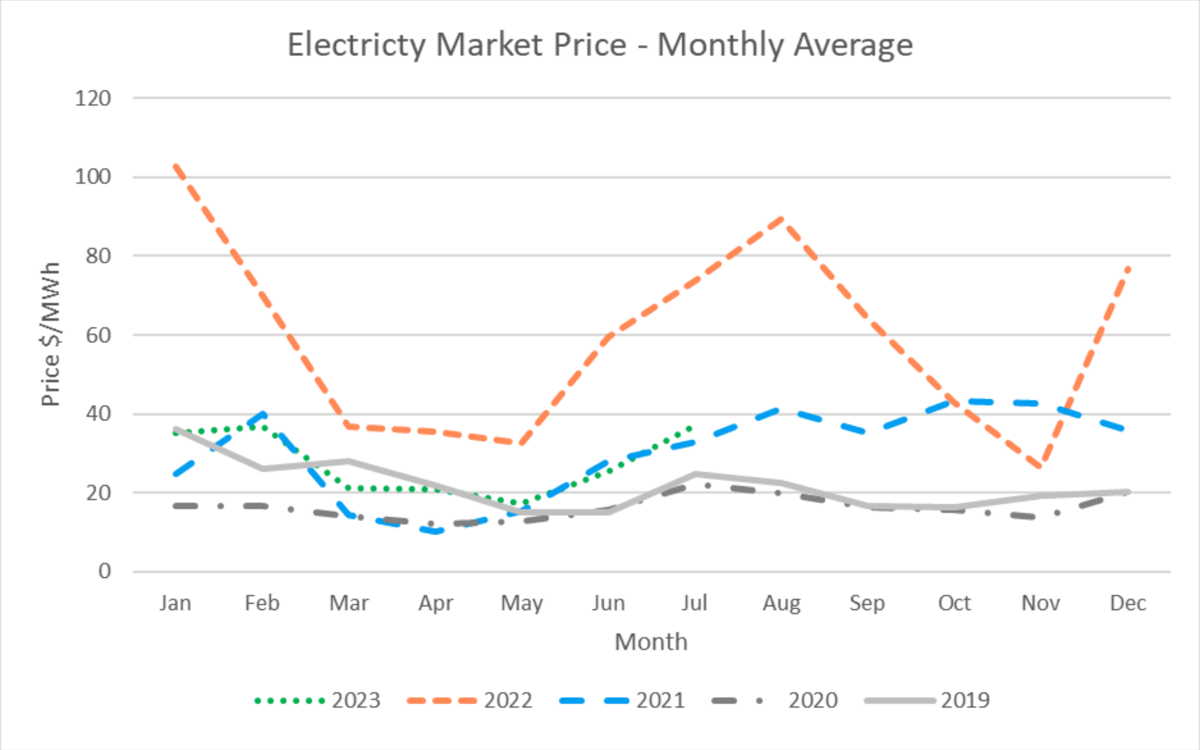


Figure 3 shows the monthly average market price from 2019 to July 2023 (the latest available data). Prices in 2022 were abnormally higher than the trend. In this case, we used the prices from 2021 and escalated them to 2022 dollars as the final supply charge for the proposed building. The inflation rate was calculated based on the U.S. Bureau of Labor Statistics' historical Consumer Price Index (CPI).[3]

Figure 3. Monthly Average Day-Ahead Electric Market Price for Zone E



The electricity delivery charges consist of flat customer charge, flat bill issuance charge, demand charge per peak kilowatt (kW), delivery charge per kilowatt hour (kWh), and reactive charge per building reactive kilovolt Ampere hour (kVAh). NYSEG applies different rate classes depending on the building type and the peak demand magnitude. Office, nonrefrigerated warehouses, and light manufacturing building types are covered under Service Classification No. 2—General Service with Demand Billings, with demand between 5 kW and 500 kW. Refrigerated warehouses with high process cooling demand are covered under Classification No. 7-1—Large General Service at Secondary Voltages. The final delivery charge was calculated for each building based on their kWh usage and kW demand per the applicable rate structure. The resulting delivery cost was then expressed per energy unit, kWh or megawatt hours (MWh), for the site (all buildings). Figure 4 shows the final average delivery charge.

Figure 4. New York Gas and Electric Electricity Average Delivery Charge

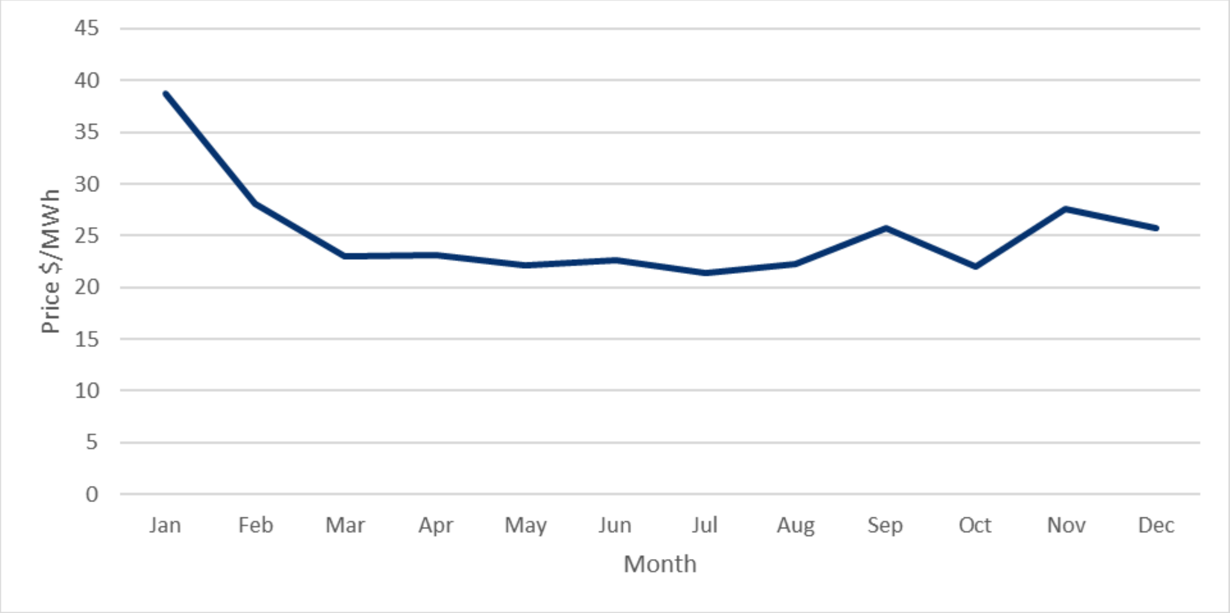
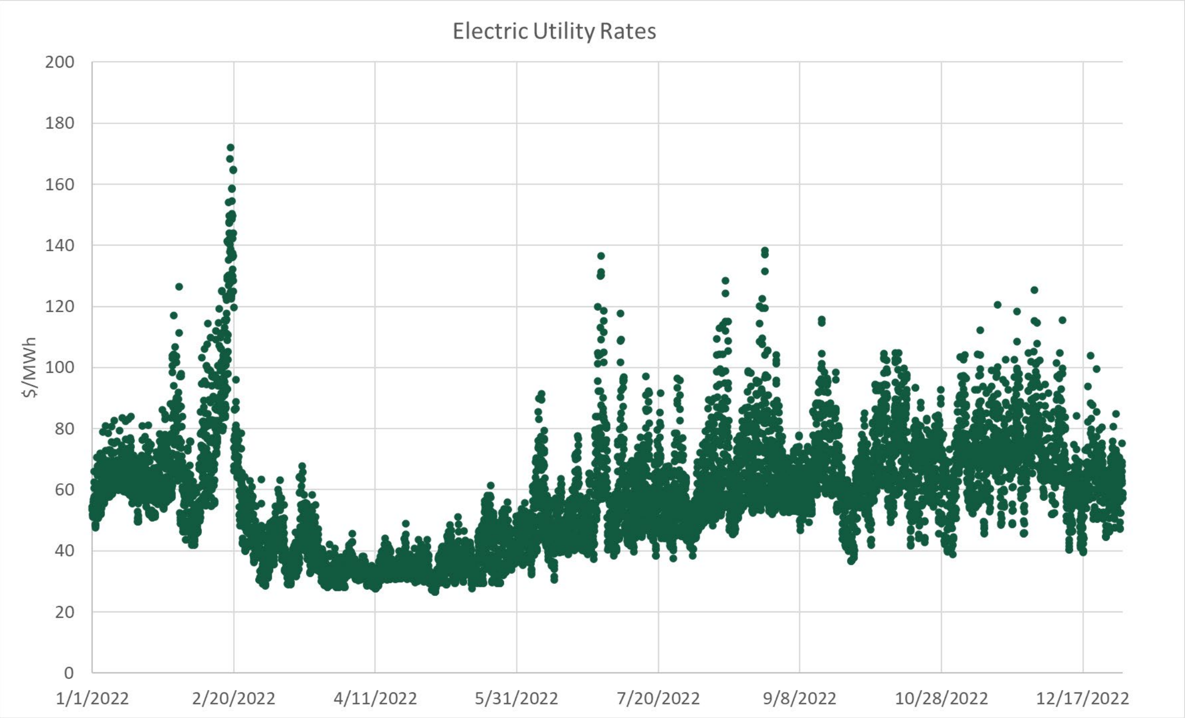


Figure 5 presents the final hourly electric rates, which were calculated as the sum of the supply charges and delivery charges. The blended average rate is $57.79/MWh. These hourly rates were used in the cost analysis for both the BaU and proposed scenarios.

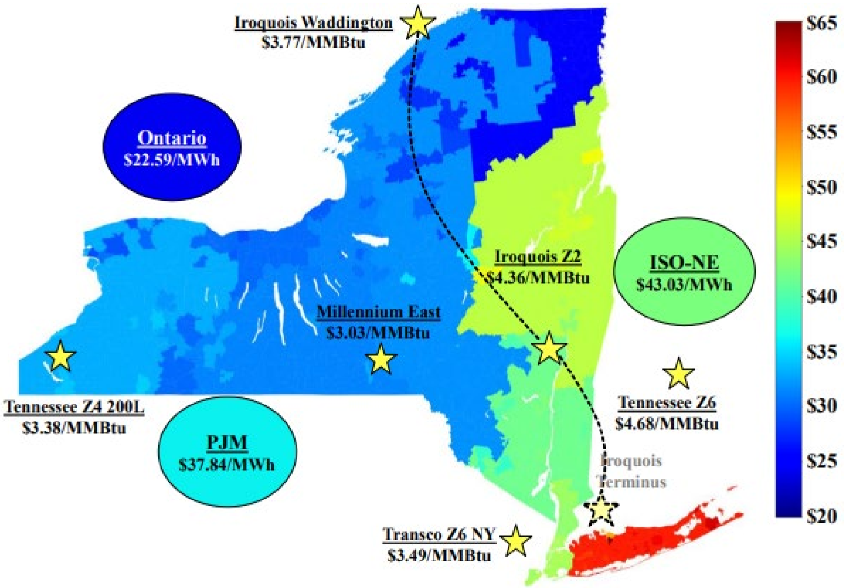
Figure 5. Calculated Final Electric Utility Rates



1.4.2 Natural Gas

Figure 6 from the report “2021 State of The Market Report for The New York ISO Markets,”[4] shows the average natural gas price in 2021. Based on the price map, the Millennium East is the closest area to Oneonta. The gas price of $3.03/MMBtu was used to estimate the fossil fuel price for the proposed buildings. The price was escalated to 2022 values with an 8% inflation rate, resulting in a final price of $3.27/MMBtu.

Figure 6. Real-Time Energy Prices, Natural Gas Prices, and Congestion in 2021



1.5 Business-as-Usual Load Profile

The hourly load profiles were generated for each building type with EnergyPlus whole building energy simulation software. These load profiles were used to estimate the energy use and the costs of scenario BaU, as well as the other proposed scenarios discussed in section 3. The model summaries are included in appendix B. The overall average site energy use intensity (EUI) of all buildings is 42.9 thousand British thermal units (kBTU)/sf. Table 2 presents the EUI values for each building type.

The building EUIs were validated against the Commercial Buildings Energy Consumption Survey (CBECS) database. All EUIs aligned closely with CBECS data, except for the refrigerated warehouse. This is attributed to the large process cooling area, especially the cooling dock, in the DOE refrigerated warehouse model, which has significantly higher EUI than the rest of the building (office area). Instead of directly using the EnergyPlus EUI (292 kBTU/sf), an EUI of 84.1 kBTU/sf was obtained from the

EnergyStar Portfolio Manager, which is based on the CBECS database. The load profile for the refrigerated warehouse building type was then generated based on DOE prototype model with cooling docks (EUI of 292 kBTU/sf) and without cooling docks (EUI of 67 kBTU/sf), scaled with a combined average of 84.1 kBTU/sf and a total area of 30,000 sf.

Table 2. Energy Use Intensity for Different Building Types

Building Type	EUI (kBTU/sf)
Office	30.4
Nonrefrigerated Warehouse with Fine Storage	28.6
Nonrefrigerated Warehouse with Bulk Storage	13.6
Refrigerated Warehouse	84.1
Light Manufacturing	77.6
Average/Total	**42.9**

The refrigerated warehouse process cooling loads (freezers, cooler, and cooling docks) are covered by special process cooling units that can either share the cooling source with space comfort cooling or use their own cooling sources. To better assess the project loads for technology screening, two sets of load profiles were plotted for the analysis: one without the process cooling loads and one with the process cooling loads.

Figure 7 presents the load profile of site space heating, DHW production, and space comfort cooling (expressed as negative values). Without process cooling, the site is heating dominant with an annual heating load (including space heating and DHW production) of 2,545 MMBtu and a peak heating demand of 2.6 one million British thermal units per hour (MMBtu/h). The annual comfort cooling load is 658 MMBtu, with a cooling peak demand of 1.3 MMBtu/h.

Figure 7. Project Hourly Load Profile (without Process Cooling)

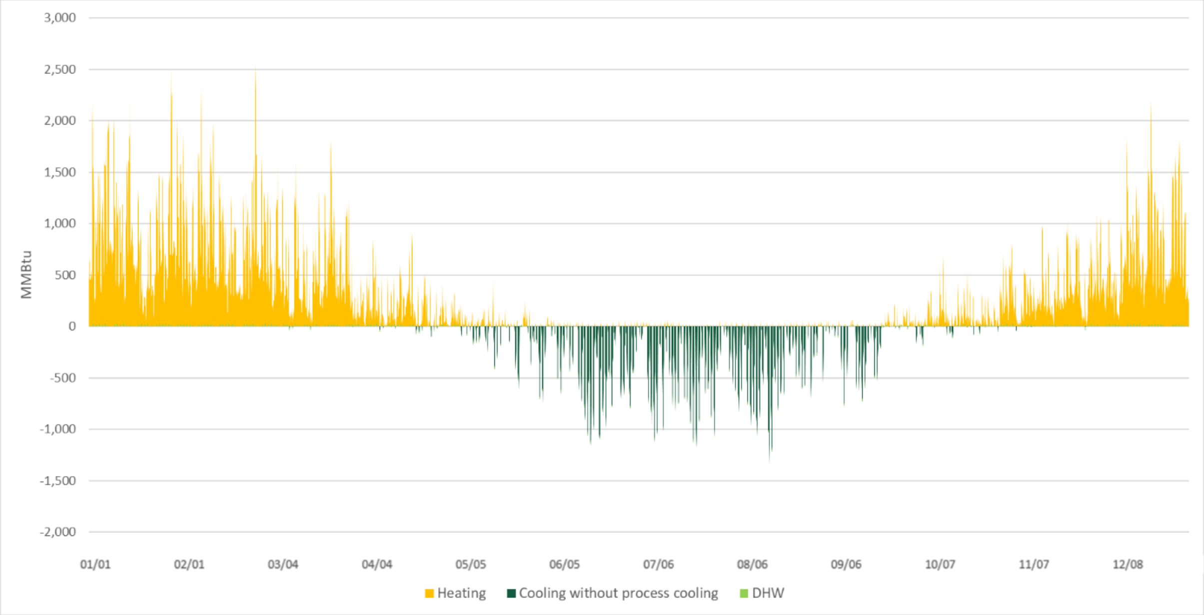
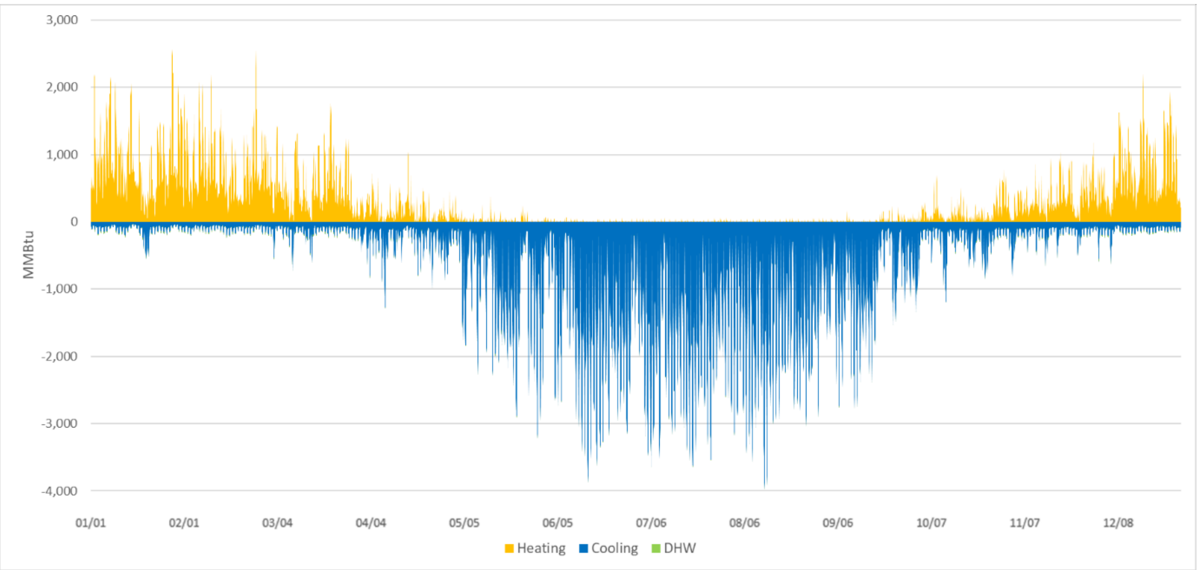


Figure 8 presents the project loads with process cooling. The process cooling load has a peak cooling demand of 2.78 MMBtu/h and an annual cooling load of 5,523 MMBtu. The high loads in summer, which fluctuate with the ambient temperature, are generated by the cooling docks, which are maintained at 32 degrees Fahrenheit (°F). The freezers and coolers with lower low temperatures (-9°F) generate consistent cooling load throughout the year. The rejected heat from the process cooling unit(s) can be used as a potential heat source for the other project buildings, as well as other buildings nearby.

Figure 8. Project Hourly Load Profile (with Process Cooling)



2 Technology Assessment

The objective of the technology screening process is to identify suitable technologies and storage options for future heating and cooling production that align with the carbon reduction goals of the Climate Act. The evaluated technologies considered centralized and decentralized (distributed) solutions.

2.1 Thermal Sources

Table 3 presents the thermal source technologies considered and the results of the screening process. The ranking ranges from 1 to 5, with 5 indicating the highest potential and 1 representing the lowest. The rankings are also color-coded: green signifies high potential (4–5), yellow represents medium potential (2–3), and blue indicates low potential (1). The following sections discuss the screening process for these technologies.

Table 3. Thermal Source Technologies

Thermal Sources	Quality	Availability	Viability at Oneonta Railyards	In/Out
Open-loop geothermal (on-site)	3	3	3	Out
Closed-loop geothermal boreholes (on-site)	3	4	3	In
Air (on-site)	2	5	4	In
Wastewater (Oneonta WWTP)	4	3	4	In
Surface water (Susquehanna River)	1	1	1	Out
Potential waste heat from Lutz Feed	Unknown	Unknown	1	Out

2.1.1 Geothermal

Geothermal technology harnesses the ground as a heat source and sink to provide energy for heating and cooling via heat pumps. This technology is a sustainable and environmentally friendly alternative to conventional fossil-fuel based heating technologies when the geothermal heat pumps use electricity from carbon-free generation assets. Heat pump technologies are also more efficient than conventional heating and cooling systems, contributing to reduced greenhouse gas emissions and energy costs while promoting a cleaner future. Geothermal systems consist of two main types: closed-loop systems and open-loop systems.

Closed-loop systems circulate a heat transfer fluid through underground pipes, transferring heat to or from the ground for cooling or heating purposes. One common configuration is drilling vertical boreholes into the ground as the heat exchangers. The system is a type of borehole thermal energy storage (BTES), which is used as heat source, heat sink, and seasonal thermal storage. BTES extracts heat from the ground in winter and rejects heat to the ground during summer. To effectively use BTES, a project needs to maintain an approximate balance between the annual heat extracted from the BTES and the annual heat rejected to the BTES. The extent to which the balance must be maintained depends on how the BTES interacts thermally with the surrounding earth. If the required balance is not achieved, the borefield temperature will drift over the long term and affect system capacity and efficiency. If the loads on a geothermal system are imbalanced enough to cause a borefield temperature drift, then steps can be taken to shift some of the excess load to another system (e.g., ASHP to directly serve loads) or to provide heat addition or extraction (depending on the imbalance) to the borefield through other means (e.g., an air cooler or ASHP connected to the ground loop).

Open-loop systems use groundwater directly for heat exchange without the need for an array of boreholes. Open-loop geothermal systems can be efficient in specific situations, but they are not as universally applicable as closed-loop systems. They are often limited by groundwater availability, quality, and regulatory considerations.

This analysis considers a closed-loop geothermal system rather than an open-loop one; the most compelling factor being uncertainty in the availability of adequate groundwater for the system. Given the uncertainty and potential limitations surrounding groundwater accessibility at the project site, a closed-loop system offers a viable alternative that does not rely on water sources of specific quantity and quality. Based on the load profile in section 1.5, the process cooling units reject a sizable amount of heat that can be used to recharge the boreholes during the cooling season to balance the heat extracted in the heating season. Additionally, the prevalence and reliability of closed-loop systems make them a more common choice in geothermal applications. Given the condition of the site and the proposed buildings, BTES would be a suitable geothermal technology for Oneonta Railyards.

2.1.2 Air (On-site)

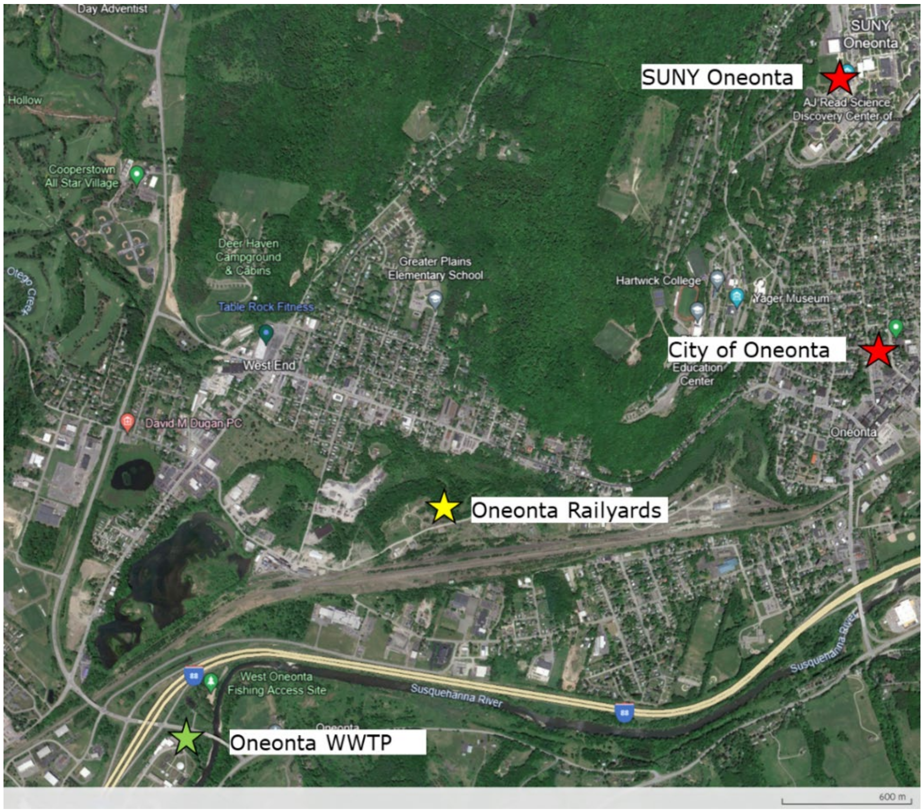
ASHPs are one of the most common on-site applications for heating and cooling. They are easy to install, provide relatively high efficiencies, and reduce carbon emissions compared to conventional systems. Air-to-air heat pumps are generally used for small loads or on building levels, whereas air-to-water heat pumps are generally used for larger loads or on district levels.

2.1.3 Wastewater (Oneonta Wastewater Treatment Plant)

Wastewater can be an effective heat source for heat pump technology if its temperatures are at least a few degrees above freezing. The higher the wastewater temperature, the more heat that can be extracted. The source of wastewater can be either the effluent or influent of a wastewater treatment plant (WWTP). Heat extracted from effluent typically suits larger heating loads due to high capital expenditures (CapEx) associated with long lengths of direct-buried pipe from the WWTP to the heat load. Influent is typically used to serve smaller loads at or near the heat source. Both types of systems require special wastewater heat pumps and/or heat exchangers that can process wastewater.

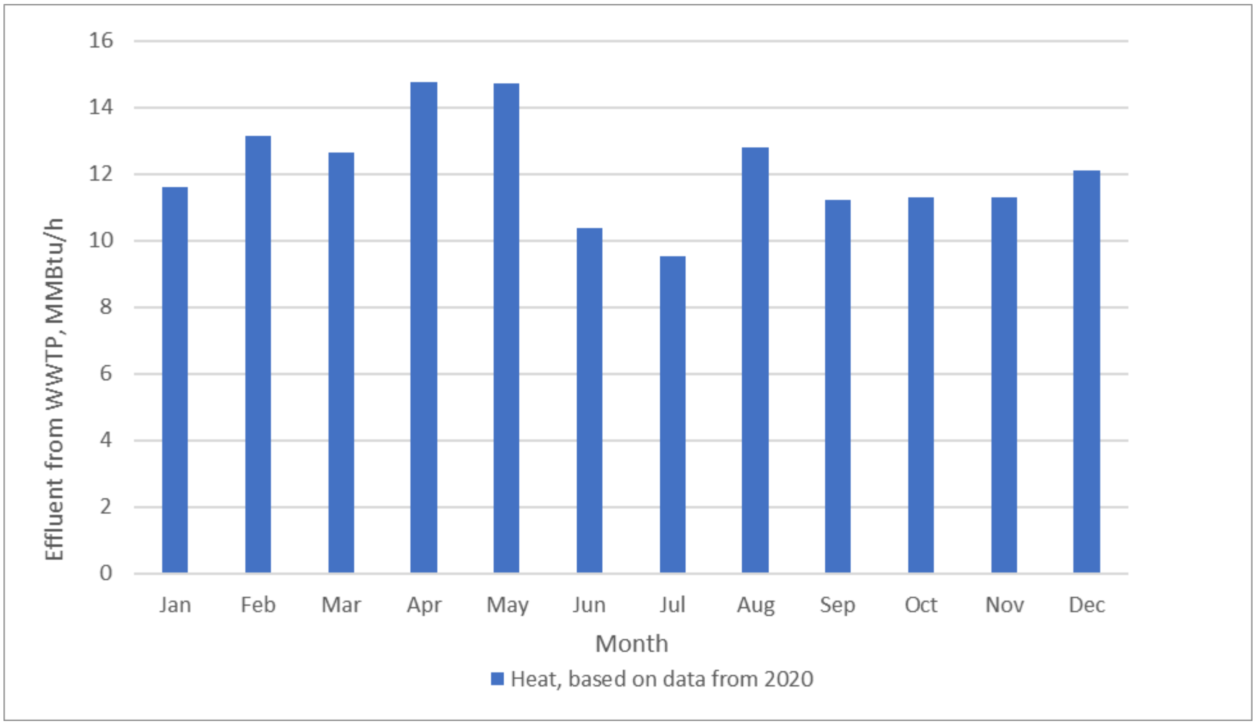
The closest wastewater treatment facility, Oneonta WWTP, is approximately 3 miles away from the Oneonta Railyards, 4 miles away from the city of Oneonta, and 6 miles away from the State University of New York at Oneonta (SUNY Oneonta), each of which is the subject of a community heat pump feasibility study. Figure 9 shows the locations of the WWTP and the three Oneonta sites. Potentially, a single energy center could be developed at the WWTP with wastewater heat pumps providing hot water to all three sites.

Figure 9. Oneonta Map



The facility produces an average effluent stream of 2,000,000 gallons per day, providing a sizeable heat source for the base heating load of the three Oneonta sites. Figure 10 shows the potential heat generated by the wastewater heat pump with effluent as the heat source. The average heat potential is 12 MMBtu/h, which is much higher than Oneonta Railyards demand. Using a wastewater heat pump system to serve just Oneonta Railyards is not economically viable because of the high capital cost of a distribution system relative to the heating load. If a larger district hot water network was developed using the WWTP as a heat source, the Oneonta Railyards should consider participating as a customer. Since wastewater as a source is not economically feasible for Oneonta Railyards alone, wastewater was excluded from further discussion in this study.

Figure 10. Potential Heat Generated from Wastewater Heat Pump at the Wastewater Treatment Plant



2.1.4 Surface Water

The Susquehanna River is located approximately one mile from Oneonta Railyards. Surface water generally has more stable and moderate temperatures, which leads to lower operating costs, higher system efficiency, and longer system lifespan as a heat source for GSHP systems. The feasibility of using the Susquehanna River as a heat source is examined based on 2022 and 2023 U.S. Geological Survey (USGS) water data.[5] The data reveals significant temperature fluctuations, with winter

(December to March) temperatures consistently below 40°F and summer (July to September) temperatures exceeding 70°F. These variations would impact GSHP system efficiency and, therefore, is not ideal to use as a heat source. The water temperature during winter is close to freezing, which is also not ideal to use as a heat source. The use of surface water was excluded from further discussions.

2.1.5 Lutz Feed Company, Inc.

Lutz Feed Company, Inc., is a feed producer located one mile away from Oneonta Railyards. The manufacturing process can generate waste heat that could be a potential heat source for heat pump systems. Ramboll made several attempts to reach out to the business owner for relevant information, but the owner did not respond and failed to provide the requested data. However, in order to use the heat from Lutz Feed as the heat source, constructing an insulated supply and return piping system would be necessary. The estimated cost for this system is approximately $1,500/ft, resulting in a total projected cost of approximately $24 million. The expenditure is deemed economically impractical for this project due to its small scale, especially when compared to other heat source options. Therefore, using Lutz Feed waste heat is not recommended at this time. The feasibility should be reassessed, however, if the project's scale increases.

3 Scenarios Considered

The number of scenarios was established through the discussion of thermal sources during the project meetings. Given the thermal sources selected for Oneonta Railyards and the proposed building conditions, Ramboll developed two centralized scenarios and one decentralized scenario. Table 4 outlines the final scenarios that the project team discussed and reviewed.

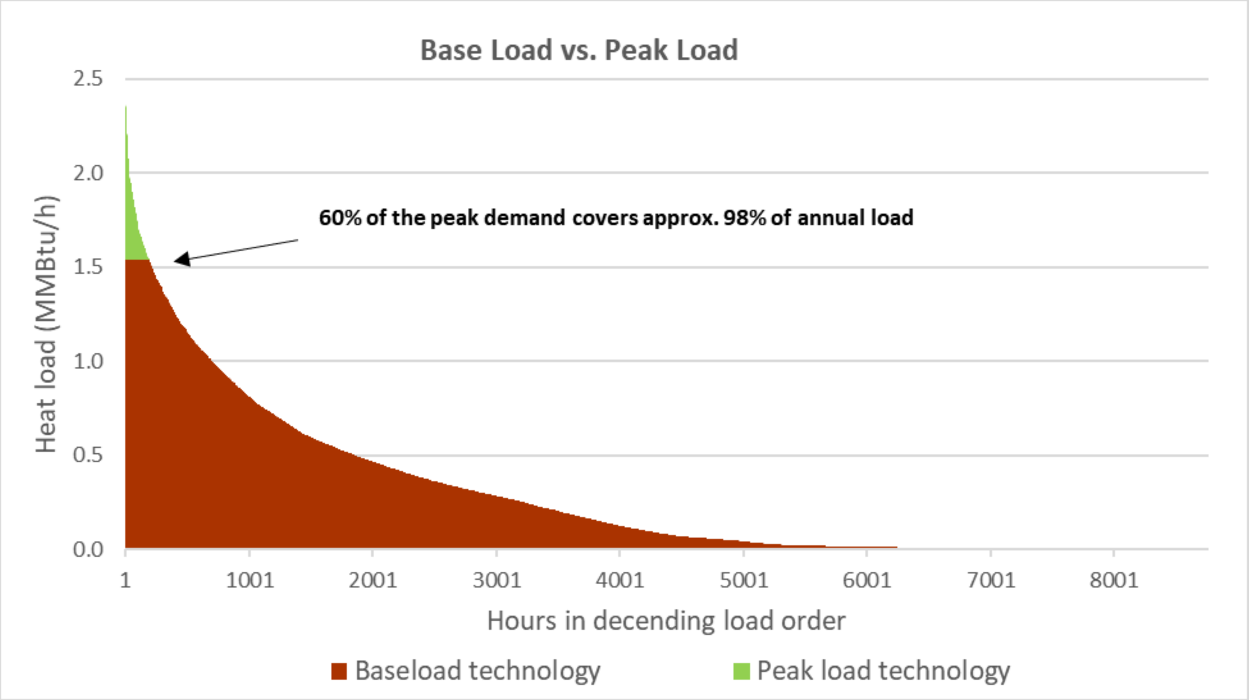
Table 4. Final Scenarios for the Techno-Economic Assessment

System Component / Technology	Scenario BaU	Scenario 1	Scenario 2	Scenario 3
Network configuration	Decentralized	Centralized	Ambient loop (with BTES)	Decentralized ASHP
Baseload technology	Fossil fuel boiler + Air-cooled chiller	GSHP (with BTES)	Individual WSHP	Individual HP
Peaking technology – heating	Fossil fuel boiler	Electric boiler	Individual WSHP	Individual HP
Peaking technology – cooling	Air-cooled chiller	GSHP	Individual WSHP	Individual HP
Summer, DHW	Fossil fuel DHW heater	Electric DHW heater	Individual DHW WSHP	Electric DHW heater
Winter, DHW	Fossil fuel DHW heater	Electric DHW heater	Individual DHW WSHP	Electric DHW heater
Backup heat (emergency)	Local fossil fuel boiler	Centralized fossil fuel boiler	Local fossil fuel boiler	Local fossil fuel boiler
Process cooling unit	Water-cooled chiller	Water-cooled chiller (connected to thermal borefield)	Water-cooled chiller (connected to the ambient loop)	Water-cooled chiller
Thermal energy network	None	4G (2-pipe, dual-temperature)	Ambient loop (2-pipe)	None
Thermal energy storage	N	Y	Y	Y

All scenarios are equipped with fossil fuel emergency backup boilers sized to meet the peak heating loads. In the centralized scenario (scenario 1), the backup boilers are located at the new energy centers; in the ambient loop and decentralized scenarios (scenarios 2 and 3), the backup boilers located at the individual buildings.

The site is heating dominant and the equipment is sized to meet the peak heating demand. In the centralized scenario (scenario 1), the heating load is managed using a combination of baseload technology (centralized GSHP) and a peaking technology (electric boiler). As shown in Figure 11, the base load technology (heat pumps) will cover approximately 60% of the peak heating load (in MMBtu/h), thereby covering approximately 98% of the annual demand for heating (in MMBtu per year). If the baseload technology was sized to cover peak heating demand, it would require nearly twice the capacity (and associated CapEx) to cover only an additional 2% of the annual heat load.

Figure 11. Site Heating Load Curve



3.1 Scenario: Business as Usual

Scenario BaU uses fossil fuel boilers for space heating demand, air-cooled chillers for comfort cooling, and water-cooled chillers for the process cooling demand. Separate fossil fuel boilers provide DHW. All units are decentralized, serving each building independently, and no thermal energy storage is used in this scenario.

3.2 Scenario 1: Centralized

Scenario 1 is based on centralized networks using two-pipe dual temperature thermal distribution. This scenario uses centralized GSHP as the baseload technology, which covers space heating, and comfort cooling. The GSHP uses BTES as the heating source and sink. In the heating season, the GSHP extracts energy from the geothermal borefield to provide space heating. When the heating demand exceeds the borefield capacity, electric boilers will cover the excess heating demand. In the cooling season, the heat pumps reject heat into the borefield to balance the heat extracted in the heating season. This scenario uses tank thermal energy storage, which serves as heating thermal storage in the winter and transitions to cooling thermal storage in the summer. DHW is produced locally using electric resistance water heaters.

The process cooling load would be covered by a separate water-cooled chiller, and the rejected heat would be used in the winter as a heating source to balance the heat extracted from the borefield. In the summer, some of the heat rejected from the process cooling chillers could be used to recharge the boreholes to balance the heat extracted for space heating.

3.3 Scenario 2: Ambient Loop

Scenario 2 features an ambient loop system that is a hybrid of centralized and decentralized equipment. In the decentralized component, space heating and cooling are produced at the building level via water-to-water heat pumps. In the centralized component, an ambient loop network circulates neutral (ambient) temperature water to the buildings along with equipment to extract or reject heat, as needed, from the ambient loop using thermal sources/sinks connected to the loop. The ambient loop consists of a two-pipe distribution system that uses uninsulated plastic pipe instead of preinsulated steel pipe to carry the heat transfer fluid. Uninsulated plastic pipe is used because the circulated fluid is close to or at ambient temperature. Heat transfer from the loop piping to its surroundings can be beneficial in moderating the loop temperature.

A geothermal borefield serves as the source/sink for the ambient loop in this analysis. The ambient loop extracts heat from the borefield in heating season and rejects heat to the borefield in cooling season, so that the loop can be maintained at a stable temperature to serve the water-to-water heat pumps at the building level. An ASHP is also connected to the ambient loop and serves as the heating source/sink when the building load exceeds the borefield capacity.

The process cooling loads are provided by water-cooled chillers, which connect to the ambient loop. Since the ambient loop has a supply and return temperature set of approximately 54°F/44°F, which is higher than general ambient temperature in heating season and lower in cooling season, the units connected to the ambient loop would run at higher efficiencies. DHW for this scenario is produced via specialized water-to-water heat pumps also connected to the ambient loop.

Each building is equipped with thermal energy storage that switches between heating and cooling mode seasonally.

3.4 Scenario 3: Decentralized

Scenario 3 is decentralized with ASHPs installed at the building level for space heating and cooling. The heat pumps are sized to address 100% of the space heating and cooling peak loads. The process cooling loads are served by water-cooled chillers at the building level.

DHW for this scenario is produced locally using electric resistance water heaters. As in scenario 2, building-level fossil fuel boilers are used for backup heating. Each building is equipped with thermal energy storage that switches between heating and cooling mode seasonally.

4 Analytical Methods

The scenarios are assessed with techno-economic analysis. The objective of the analysis is to identify the most cost-efficient mix of technologies for future supply of heating and cooling. The analysis consists of two sections: energy consumption analysis and cash-flow analysis.

4.1 Energy Consumption Analysis

The total fuel consumption and costs of each scenario, including scenario BaU, was estimated using one of two approaches: EnergyPRO modeling or spreadsheet calculations.

The operations of centralized systems were modeled with EnergyPRO to assess how the different energy production and conversion units, as well as the energy storage equipment, would be operated together considering technical, economic, and environmental aspects. Scenarios 1 and 2 were modeled through EnergyPRO. Decentralized scenarios, which are scenarios BaU and 3, were modeled using Microsoft Excel with hourly building demands and system efficiencies.

The pump energy use of the distribution systems, as well as the distribution piping sizes, were determined through hydraulic modeling using TERMIS software.

4.1.1 Model Assumptions

4.1.1.1 Building Loads

As stated in section 1.5, EnergyPlus models generated project hourly load profiles for space heating, comfort cooling, and process cooling. Those profiles are used in both EnergyPRO modeling and Microsoft Excel calculations.

4.1.1.2 Equipment Efficiencies—Decentralized Air-Source Heat Pumps

The decentralized ASHP heating efficiencies (COP) are estimated based on the performance data for a typical 60-ton ASHP unit. The efficiencies are based on 70% part load ratio. Appendix B contains the table of heating COP. The hourly COP profile was generated for the calculation based on the efficiency table and the hourly ambient temperature profile. The heating COP used in the calculation has an average value of 2.4. The cooling efficiencies (the energy efficiency ratio (EER)) are estimated based on ASHRAE standard 90.1. The cooling EER used in the calculation has an average of 11.6.

4.1.1.3 Equipment Efficiencies—Decentralized Water-Source Heat Pumps

Scenario 3 includes water-to-water heat pumps that use ambient loop water to generate DHW, space heating, and space cooling.

The water-source heat pump (WSHP) heating efficiency for space heating and DHW heating were estimated as the average heating COP of a series of typical WSHP. Appendix B includes the efficiencies of the typical WSHP. The space heating efficiency was calculated to be a COP of 3.1. The efficiencies for DHW heat pumps were calculated for winter (COP of 3.7) and summer (COP of 4.1) separately.

The space cooling efficiency was estimated based on Carrier model 30WG.[6] A COP of 6.5 is used in the analysis based on a water-source temperature of 54°F.

4.1.1.4 Equipment Efficiencies—Process Cooling Unit

The cooling efficiencies of the process cooling units are estimated based on engineer's experience with previous projects. When using air as the heat sink in most of the scenarios, the cooling docks with evaporator inlet temperature at 32°F are estimated to have a cooling COP of 3.3; the freezers with evaporator inlet temperature at -9.4°F are estimated to have a cooling COP of 2.

When using ambient loop as the heat sink in scenario 2, the efficiencies are estimated based on the same evaporator inlet temperatures described previously but with heat sink temperature of 44°F in winter and 54°F in summer. In this case, the cooling docks and freezer COP calculated to be 6.5 and 3.5, respectively.

4.1.1.5 Equipment Efficiencies—Centralized Air-Source Heat Pumps

The centralized ASHP efficiencies are estimated based on the performance data of a Carrier 60-ton air-to-water heat pump unit AWB60SP. The heating COP ranges from 5.0 to 7.0 based on the ambient temperature, with an average COP of 6.6. The cooling COP ranges from 3.4 to 6.5, with an average COP of 5.1.

4.1.1.6 Equipment Efficiencies—Ground-Source Heat Pumps

The GSHP in scenario 1 has a heat sink/source with relatively stable temperature throughout the year. As a result, the heating and cooling efficiencies do not vary much based on the ambient temperature. The COPs used in the model are 3.1 for heating and 4.5 for cooling.

4.1.1.7 Equipment Efficiencies—Boilers

The efficiencies of the electric and natural gas boiler efficiencies are based on engineering experiences from previous projects. The electric boiler efficiency is assumed as 98%, and natural gas boiler assumed as 80%. The efficiencies are consistent throughout the year.

4.1.2 Social Cost of Carbon

The social cost of carbon was estimated based on the New York State Department of Environmental Conservation (DEC) document, "Annual Social Cost Estimates."[7] The document "Annual Social Cost Estimates" presents values only up to 2050. Values for years 2051 through 2054 are extrapolated based on the values of previous years with linear regressions. Table 5 presents the values used to calculate the social cost of carbon over the life of the project. The DEC guidance document expresses the values in 2020 dollars. Ramboll calculated the social cost of carbon expressed in 2022 dollars based on the U.S. Bureau of Labor Statistics' historical CPI.[8]

Table 5. Social Cost of Carbon with 2% Discount Rate

Emissions Year	Carbon ($ per metric ton of CO_2) 2020	2022
2020	$125	$142
2021	$127	$144
2022	$129	$146
2023	$130	$148
2024	$132	$149
2025	$134	$151
2026	$135	$153
2027	$137	$155
2028	$139	$157
2029	$141	$159
2030	$142	$161
2031	$144	$163
2032	$146	$165
2033	$147	$167
2034	$149	$169
2035	$151	$171

Table 5 continued

Emissions Year	Carbon ($ per metric ton of CO_2)	
	2020	2022
2036	$153	$173
2037	$154	$175
2038	$156	$177
2039	$158	$179
2040	$160	$180
2041	$162	$183
2042	$164	$185
2043	$166	$187
2044	$168	$190
2045	$170	$192
2046	$171	$194
2047	$173	$196
2048	$175	$198
2049	$176	$200
2050	$178	$201
2051	$180	$203
2052	$181	$205
2053	$183	$207
2054	$185	$209

EnergyPRO model

4.1.2.1 EnergyPRO Model Layout

The layout of EnergyPRO model for scenario 1 is shown in Figure 12 and Figure 13.

Figure 12. EnergyPRO Model for Scenario 1 Space Heating and Comfort Cooling

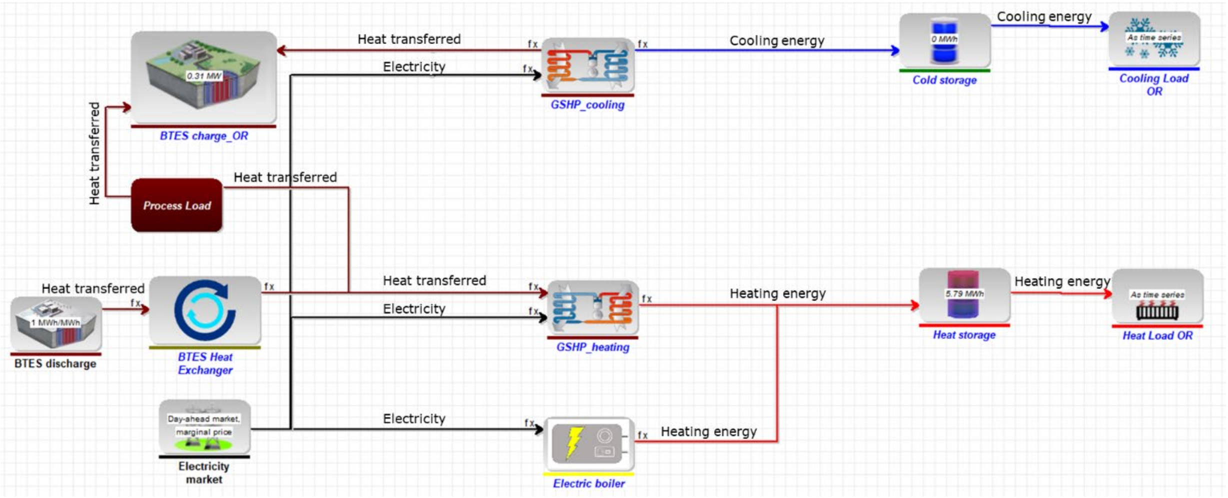
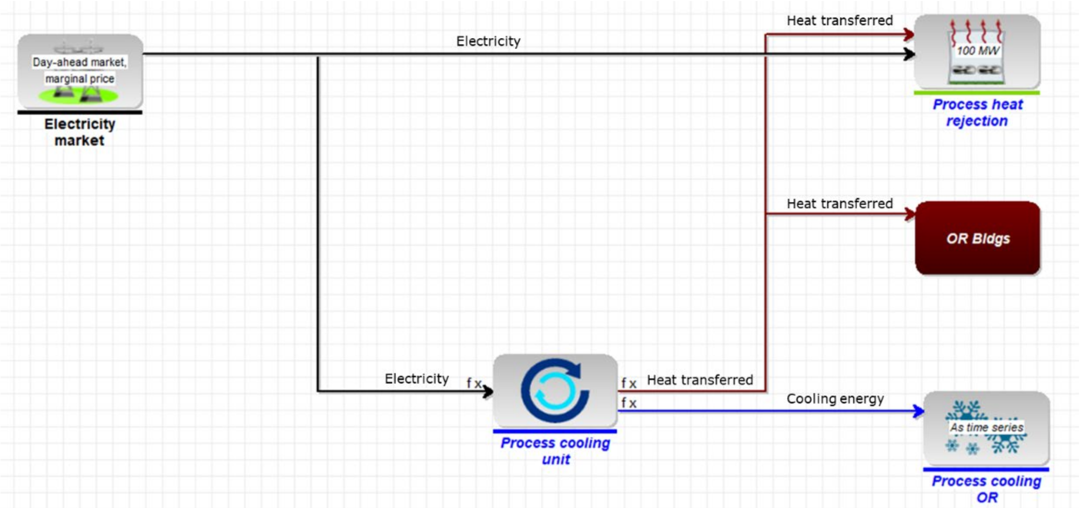


Figure 13. EnergyPRO Model for Scenario 1 Process Cooling



In EnergyPRO, each connector color represents a different type of energy flow:

- Blue: Cooling energy
- Red: Heating energy
- Black: Electricity
- Maroon: Heat transferred between units and heat source/sink

OR stands for Oneonta Railyards. On the right side of the layout, the heat load OR, cooling load OR, and process cooling OR blocks represent the energy demands that must be covered. The heating and cooling units are represented by the energy-production-and-conversion blocks in the middle of the layout, and the thermal and utility sources/sinks are on the left side.

In scenario 1, the rejected heat from process cooling unit is used as a heat source for space heating. This process is presented with the process load block in Figure 12 and the OR bldgs block in Figure 13. The process load block, which is connected to GSHP heating and BTES charge OR, represents the rejected heat that the GSHP uses directly in winter and sends to the BTES to recharge the boreholes in summer. The OR bldgs block represents the same portion of rejected heat used for space heating, instead of going into the heat rejected unit.

Thermal energy storage (heat storage and cold storage) works as a buffer between energy supply and energy demand. One physical tank will act as heat storage in the heating season and cold storage in the cooling season; in the EnergyPRO model, they are modeled as two separate units. The presence of thermal storage allows the system to take advantage of the lower electricity prices on the market when the electric heat pumps can run at full capacity covering the demand and charging the storage using excess capacity. During times when the electricity price increases, the stored energy can be discharged to cover the demand while reducing the output from the energy-production units.

Figure 14 and Figure 15 illustrate the layout of the scenario 2 model.

Figure 14. EnergyPRO Model for Scenario 2 Space Heating and Comfort Cooling

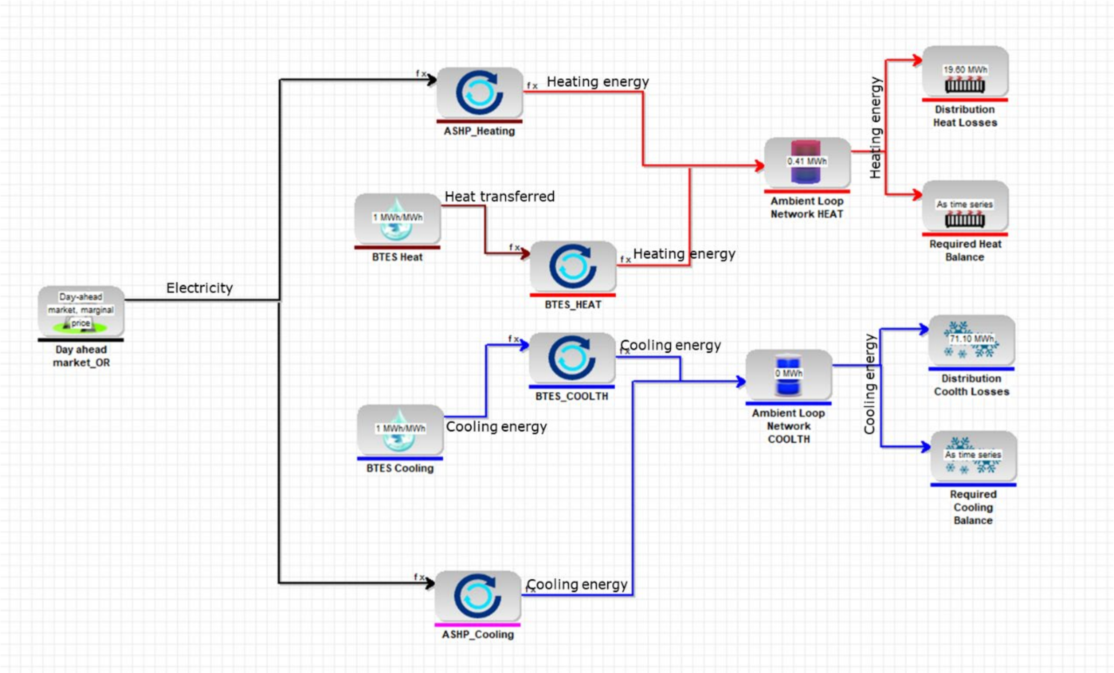
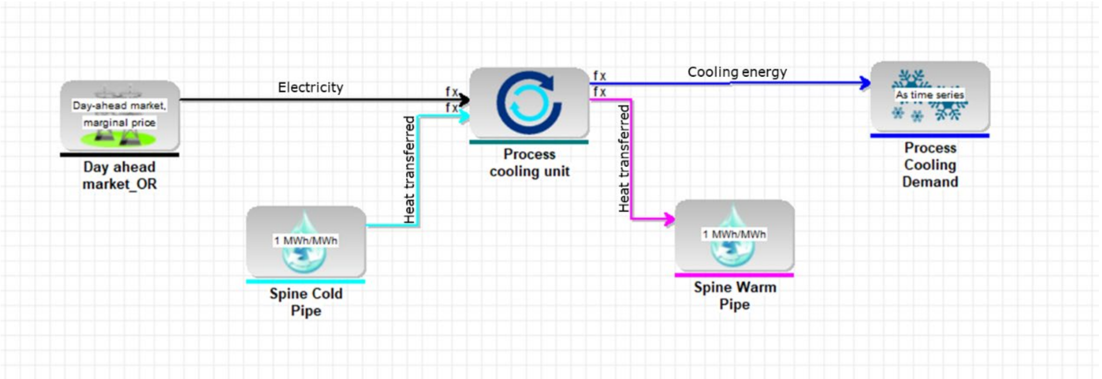


Figure 15. EnergyPRO Model for Scenario 2 Process Cooling



Similar to the scenario 1 model, Figure 14 and Figure 15 show the scenario 2 space heating, comfort cooling, and process cooling demand on the right side of the layout; the ambient loop piping modules and the process cooling unit are in the middle, and the energy and utility sources are on the left side.

The process cooling unit in scenario 2 is connected to the ambient loop. As shown in Figure 15, the process cooling unit extracts heat from the spine cold pipe and rejects heat to spine warm pipe. The two-pipe modules represent the piping system of the ambient loop.

4.1.2.2 EnergyPRO Simulation Output Checks

The goal of EnergyPRO is to optimize the annual operation of the production units to meet energy demands (such as heating and cooling) at the lowest yearly operating cost. Simply stated, EnergyPRO assigns to each production unit a marginal cost of production in each hour of the year, considering relevant external conditions such as ambient temperature (for the ASHP) and electricity price (for electric-driven machines). The units with the lowest marginal cost of production would be called into operation first. If more production capacity is required to cover demand, units with progressively higher marginal production costs would be dispatched to meet remaining loads. The optimization process in EnergyPRO also involves the optimal utilization of the energy storages while considering technical constraints, such as unavailability and minimum operational duration.

One of the outputs of an EnergyPRO simulation is the hour-by-hour production schedule of the different energy-production-and-conversion units. For example, Figure 16 shows the production schedule and thermal energy storage state for three days in the heating season for scenario 1, while Figure 17, displays the same information for three days in the cooling season.

As seen in Figure 16, the heat from the GSHP has higher priority over the electric boiler. The figure also shows how EnergyPRO optimizes the operation of the available technologies based on the availability of storage capacity and electricity prices. When electricity prices are lower during early hours of the day, the GSHP generates more heat than the building requires and charges the thermal storage. Later, when electricity prices are higher, the GSHP stops working, and the system uses the stored heat from thermal storage to meet the building heating load.

This is also shown in Figure 17, where the operation of the GSHP (middle chart) is shown together with the state of charge of the thermal storage (bottom chart) and the electricity price (top chart). In periods with lower electricity prices, the heat pump operates at full capacity to cover the simultaneous cooling demand and recharge the thermal energy storage. Conversely, in hours with higher electricity prices, the heat pump stops operating and the cooling demand is covered by discharging the storage. Using thermal storage, the GSHP covers all the demand during the period shown in Figure 16, thereby eliminating the need for the electric boiler during this time.

Figure 16. Heating Season Hourly Production Schedule of Various Production Units (Upper Diagram) and State-of-Charge of the Thermal Energy Storage (Lower Diagram)

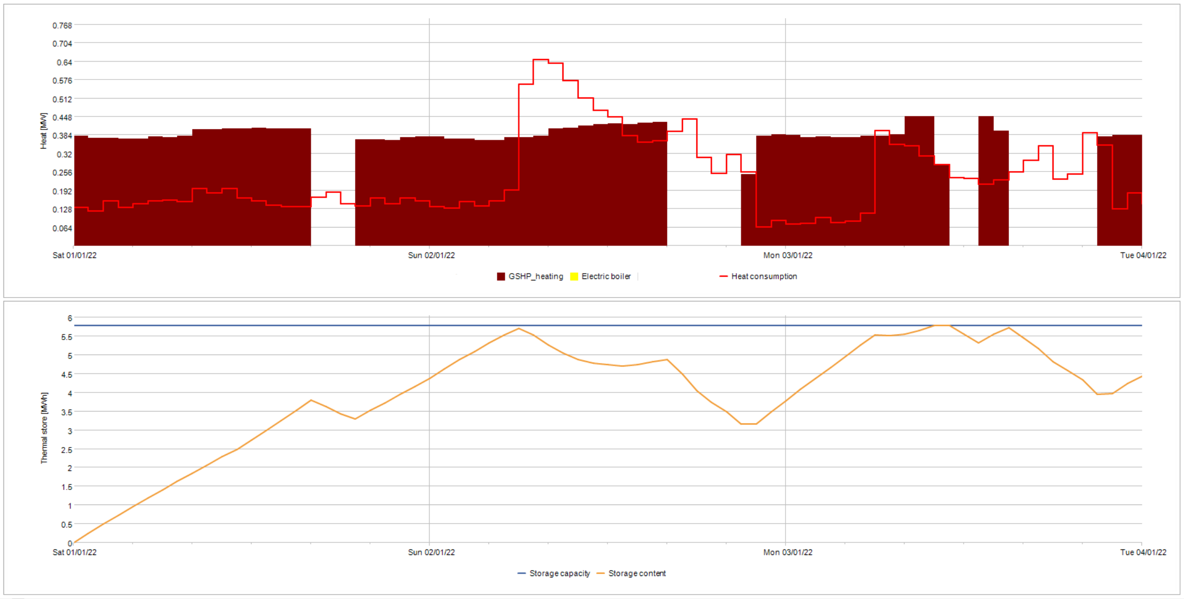
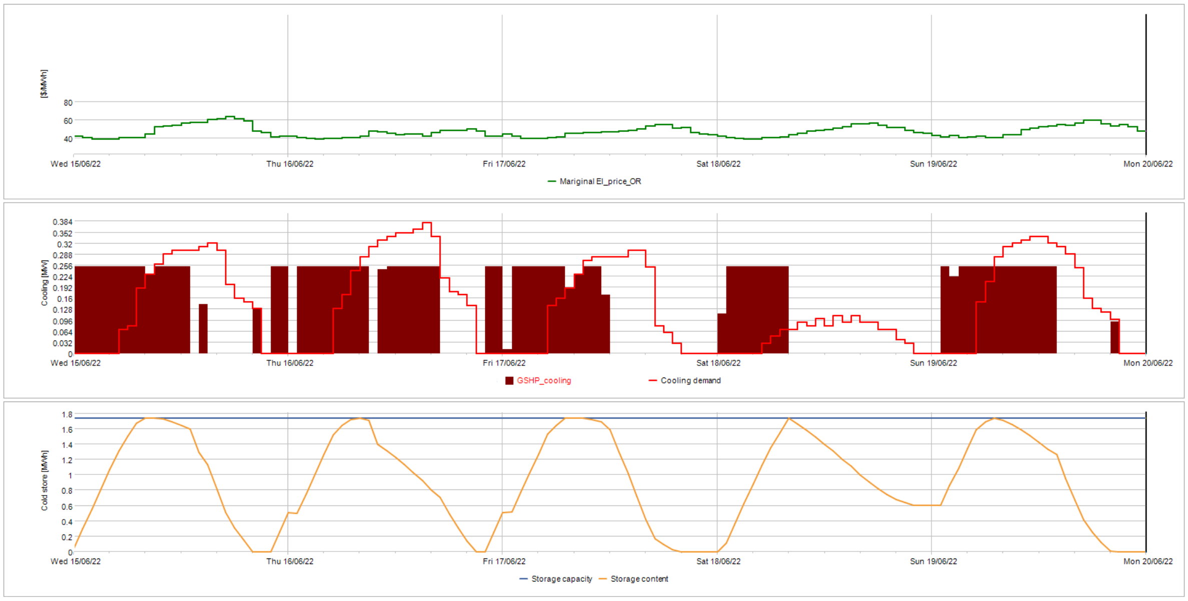


Figure 17. Cooling Season Hourly Production Schedule of Various Production Units (Upper Diagrams) and State-of-Charge of the Thermal Energy Storage (Lower Diagram)



4.1.3 Spreadsheet Calculation

Scenarios BaU and 3 both use decentralized heating, DHW heating and cooling systems that are sized to meet full building loads. Each building is equipped with building level thermal storage tanks f or space heating, DHW, and comfort cooling. No energy exchange or sharing occurs between buildings. This straightforward analysis, compared to other scenarios, used Microsoft Excel 8,760-hour calculation models to determine annual energy use and costs. The building's energy use was calculated using the annual hourly load profiles, estimated hourly equipment efficiencies, and previously described utility rates.

4.2 Hydraulic Model

Hydraulic modeling plays a crucial role in designing and analyzing piping distribution systems, encompassing water supply networks, sewer systems, and energy distribution systems. These systems require efficient and reliable hydraulic performance, and hydraulic modeling enables engineers to predict and optimize fluid flow within them. Hydraulic modeling assists in determining appropriate pipe sizes, identifying potential pressure losses, predicting temperature differentials, evaluating system capacity to meet demands, and identifying operational issues. With its ability to simulate various scenarios, hydraulic modeling provides engineers valuable insights for informed decision-making and supports optimal performance of piping distribution systems.

Hydraulic modeling is a tool for evaluating the current situation and the impact of changes to the distribution network. For instance, the model predicts the results from modifications such as pipe size alterations, network sectioning through valve opening or closing, or expanding the distribution network by connecting additional consumers. In this project, all the piping is new, and the hydraulic model is used to evaluate different production strategies involving multiple heat sources operating at varying temperatures. The model also aids in determining maximum throughput, optimal pipe sizing, and pump requirements.

New distribution networks were modeled for scenarios 1 and 2. Simulations were done using TERMIS software. The model for scenario 1, centralized hot water network, is shown in Figure 18 as an example. The analysis, based on future peak heating demand, provided piping sizes, system pressure drops, and operating pressures for the distribution systems. A future energy center, which contains the central equipment, is located in between building C and building D in the model. Ramboll picked this location since it is in the middle of the site, close to building D, with high process cooling load, and parking P3, where the boreholes are located. The model assumes direct-buried piping throughout the distribution.

Figure 18. Proposed Low-Temperature Hot Water Network for Scenario 1

Appendix C summarizes the model assumptions and outputs for the three distribution systems. The results from the analysis were used to size the main distribution pumps and determine piping sizes and quantities, which were then incorporated into the scenario cost estimates.

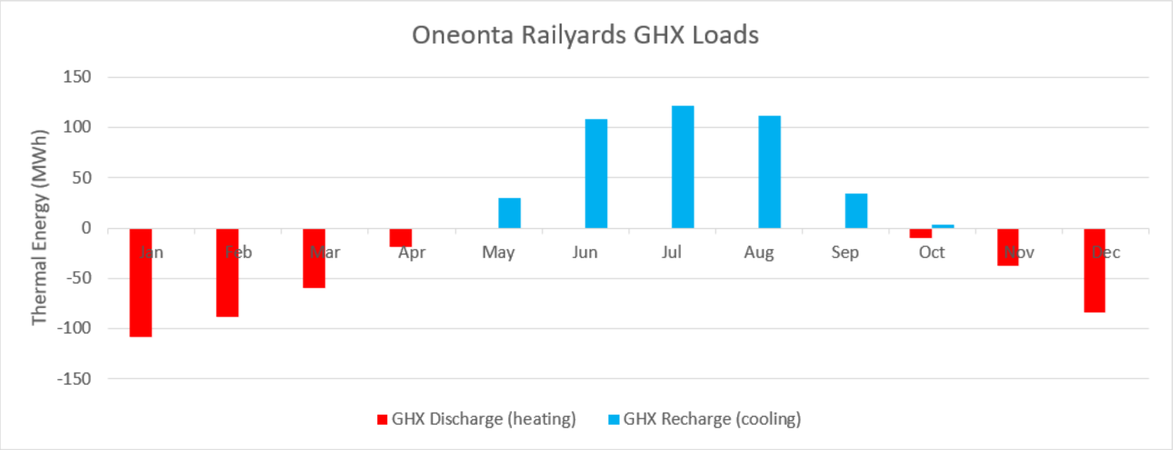
4.3 Geothermal Assessment

Underground Energy, LLC (UE), conducted a dedicated geothermal assessment for the Oneonta Community Heat Pump Study (CHPS). Appendix D contains the final assessment report.

UE developed a geothermal conceptual model (GCM) that characterized the ground conditions and subsurface heat transfer mechanisms. Based on the model and monthly load data, UE developed the conceptual design of GHXs in a borefield arrangement for Oneonta Railyards.

Ramboll modeled the monthly loads for the geothermal heat exchanger monthly loads in EnergyPRO. Figure 19 illustrates the monthly loads for the centralized scenarios (scenarios 1 and 2), which are identical.

Figure 19. Ground Heat Exchangers Charge and Discharge Loads



According to the final assessment report, the common borehole heat exchanger (BHX) design for Oneonta Railyards is as follows:

- 6-inch diameter bores arranged in a hexagonal pattern
- 1.25-inch standard dimension ratio (SDR) 11 high-density polyethene (HDPE) U-bend BHX

25% ethanol antifreeze solution

Table 6 presents a summary of the borefield conceptual design sizing and performance data.

Table 6. Borefield Sizing and Performance Data

Design Characters	Value
Number of Bores	75
Borefield Geometry	5 × 15
Bore Depth (ft)	500
Total Bore Length (ft)	37,500
Bore Spacing (ft)	20
Ground Thermal Conductivity (Btu/h·ft·°F)	1.3
Grout/Backfill Thermal Conductivity (Btu/h·ft·°F)	1.2
Average Ground Temperature (°F)	50.6
Maximum Supply Temperature (°F)	60.6
Minimum Supply Temperature (°F)	33.0
Max. Recharge Specific Thermal Capacity (Btu/h·ft)	95
Max. Discharge Specific Thermal Capacity (Btu/h·ft)	-100
Maximum Borefield Thermal Capacity (tons)	938
Maximum Borefield Thermal Capacity (MW)	3.3

4.4 Cash-Flow Model

The cash-flow model in the spreadsheet was used to perform the NPV analysis for each scenario. NPV analysis evaluates the profitability and viability of an investment or project over an extended period, typically spanning several years. For this analysis, we used a 25-year time horizon and a discount rate of 3.0%. The model assists in making informed investment decisions by comparing the NPVs of different scenarios.

The total NPV cost includes the following components:

- **CapEx**
  Calculated using unit sizes and normalized dollar-per-unit-size values, with estimates derived from the building demand profiles; the normalized per-unit-size costs are generated using the cost estimates from previous projects and RS Means database. The project lifetime was set at 25 years. When the equipment reaches its end-of-life within this period, a replacement cost equal to the original CapEx is assigned to the next year in the NPV calculation. Table 8 lists the equipment lifetimes assumed for the CapEx NPV calculation.

Table 7. Assumed Equipment Technical Lifetime

Item	Technical Lifetime (Years)
Building-level installations	
Air-cooled chiller	15
ASHP	15
Building-level TTES	25
Electric boilers	15
Electric DHW heater	15
ETS	25
Fossil fuel boilers	20
Fossil fuel DHW heater	15
Local DHW heat pump	15
Water-cooled chiller	20
Distribution system	
Ambient network	50
Electrical infrastructure upgrades	50
LTW network	50
Energy center	
Air-cooled chiller	20
Geothermal borefield	40
Building for energy center	50
Electric boilers	20
Fossil fuel boilers	25
Heat pump (GSHP, WSHP, HRC)	25
Heat pump (ASHP)	20
TTES	30

- **Fuel cost**
  For centralized scenarios, costs are directly modeled in EnergyPRO as stated in section 4.1.3 with hourly utility price. For decentralized systems, costs are calculated based on annual energy usage from spreadsheet calculations, as stated in section 4.1.4, and the annual average utility rates.

- **O&M cost**
  This category consists of both a fixed O&M cost and a variable O&M cost:
  - **Fixed O&M cost:** includes all costs that are independent of how the system is operated, such as service agreements, spare parts, and any necessary reinvestments to keep the technology operating within the NPV timeframe.
  - **Variable O&M cost:** includes cost for auxiliary materials (e.g., water, lubricants, fuel additives), treatment and disposal of residuals, spare parts, and output related repair and maintenance.

  In general, centralized heating and cooling systems have only fixed O&M cost, and decentralized systems have only variable O&M cost. Planned and unplanned maintenance costs may fall under fixed costs (e.g., scheduled yearly maintenance works) or variable costs (e.g. work that depends on actual operating time).

- **Carbon dioxide (CO2) emission cost**
  These costs are calculated based on the usage of each fuel type and their CO_2 emission factors, which are shown in Table 9.

Table 8. Emission Factors

CO_2e Emissions	2022	2030	2040
Electricity*	0.0001059 MT/kWh	0.0000588 MT/kWh	0 MT/kWh
Natural Gas**	0.00531 MT/therm	0.00531 MT/therm	0.00531 MT/therm

Notes:

* Electric emission for 2022 is based on eGrid 2020 values for Upstate New York (NYUP) subregion. According to the Climate Act, assuming a zero-emission electric grid in 2040, emissions are projected to be zero in 2024.

** EPA emissions factors for GHG inventories https://www.epa.gov/system/files/documents/2022-04/ghg_emission_factors_hub.pdf

5 Results

The results from the modeling effort are analyzed from three perspectives: technical results, economic results, and environmental impacts.

5.1 Technical Results

Figure 20 and Figure 21 show the annual heating and cooling production from the main technologies in the different scenarios. The heating and cooling end-use demands are the same in all scenarios; scenario 1 has additional network and thermal storage loss that create additional load on the production units. The ambient loop scenario and decentralized scenarios are assumed to have negligible distribution losses.

Figure 22 shows the energy consumption (fuel and electricity) required to meet the heating and cooling demands. The energy consumption differs between scenarios due to conversion efficiencies of the production units. Scenario BaU has the highest fuel consumption because the heating system has the lowest efficiency. Scenarios 1 and 2, which both use a centralized distribution system and borefield, have slightly higher fuel consumption than scenario 3, due in part to the pumping electricity used in distribution system. Scenario 2, which includes the ambient loop, has the lowest process cooling unit use because the system efficiency is higher with ambient loop as the heat source/sink. However, this also results in higher centralized ASHP energy use, where the ASHP is used to balance the rejected heat from process cooling that is discharged into the ambient loop. See appendix E for the detailed modeling results for the scenarios considered.

Figure 20. Annual Heating Production

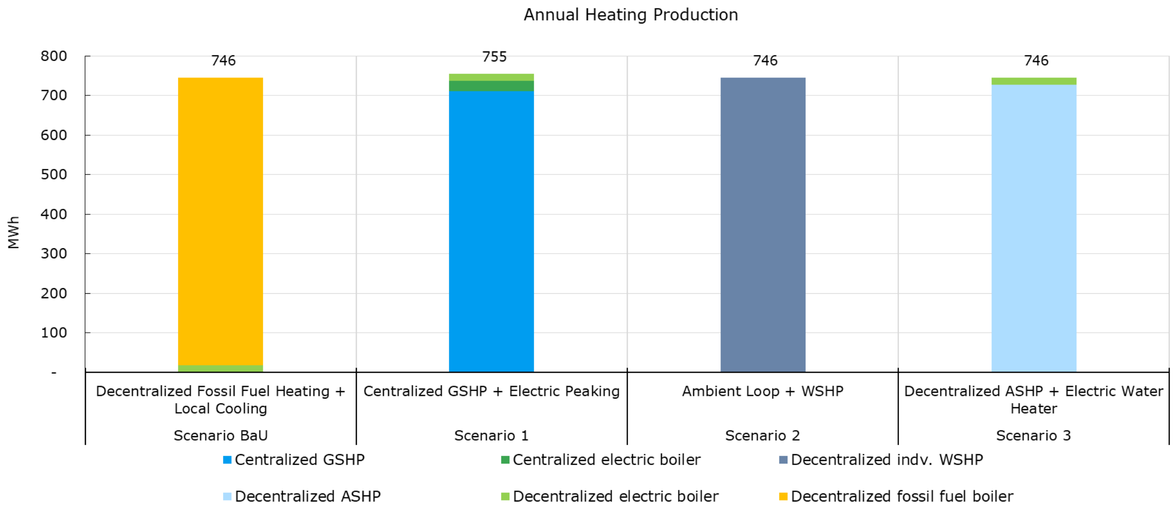


Figure 21. Annual Cooling Production

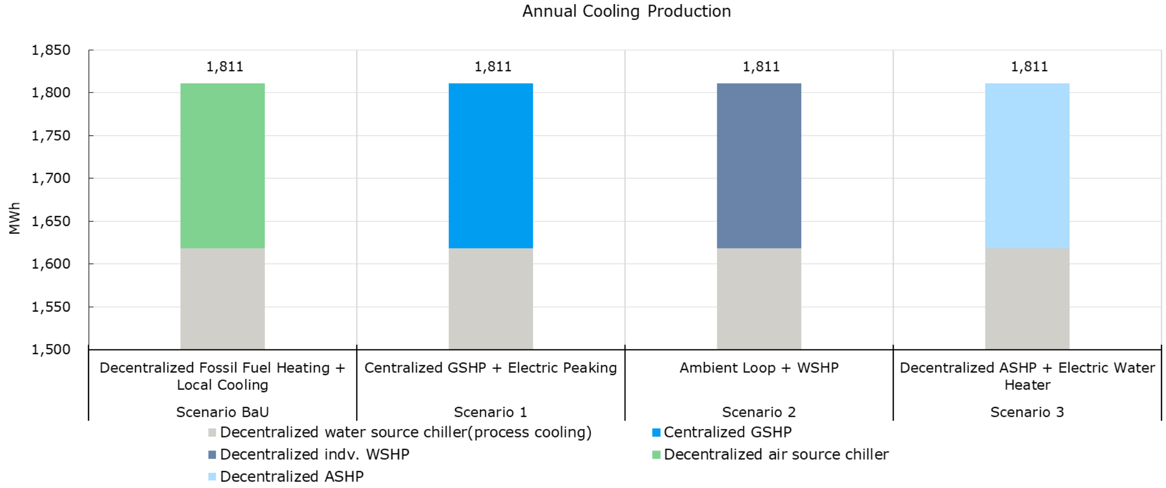
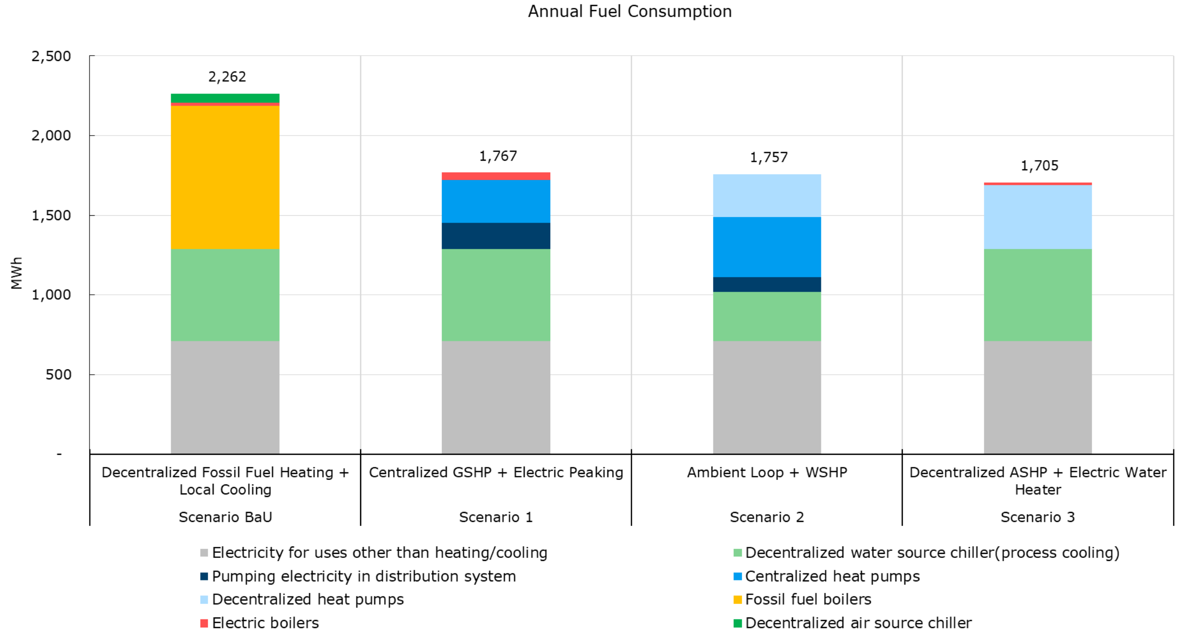


Figure 22. Annual Fuel and Electricity Consumption



5.1.1 Capital Expenditures

Cost estimating was performed based on RS Means and engineering experience from previous projects for same equipment types. See appendix F for the full-cost estimate with associated breakdown.

The cost estimates include raw labor and material in addition to these markups:

- General conditions, 15%
- Overhead & profit, 10%
- Design contingency,[9] 20%
- Bid contingency, 5%
- Phasing, 10%

Figure 23 denotes the CapEx for scenario BaU and the scenario variants divided, respectively, into CapEx for building level installations, distribution system, centralized system, and other expenses. As expected, the CapEx for scenario BaU is the lowest; scenario 2 is the most CapEx intensive at approximately $22 million.

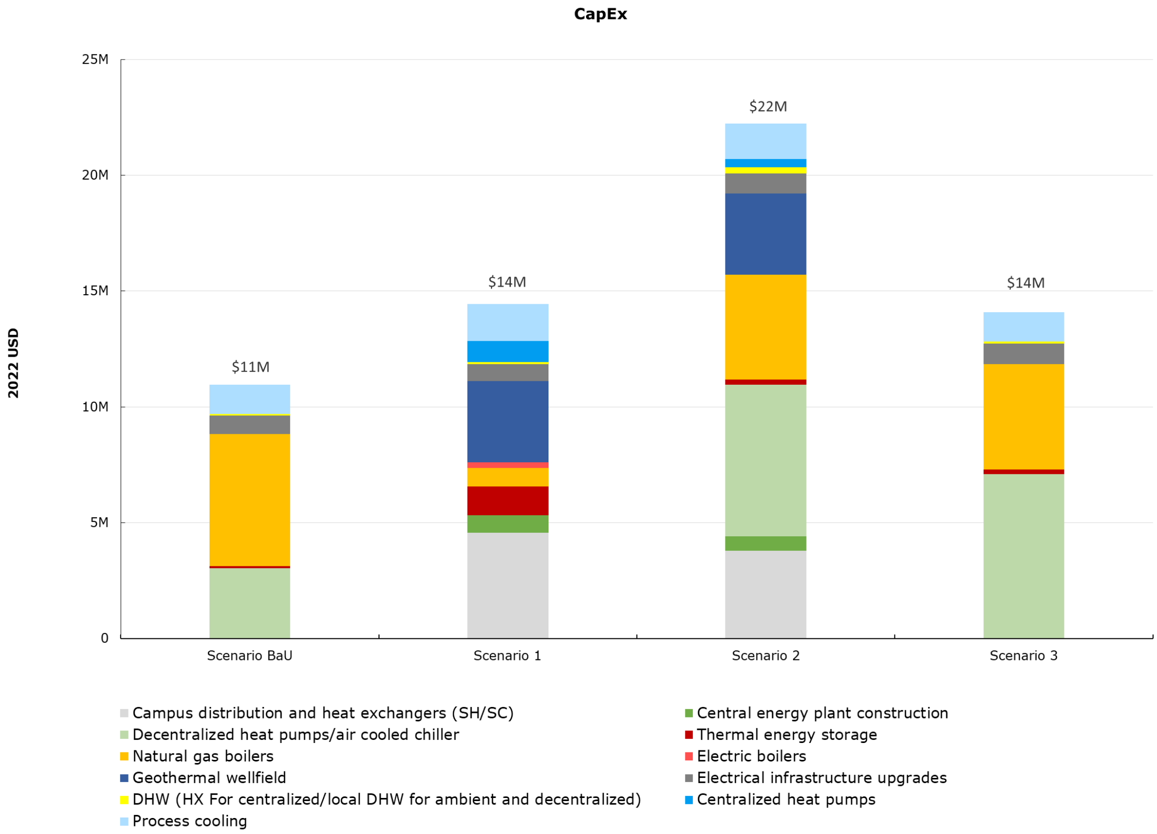
Although scenario BaU has the lowest CapEx, it is only marginally lower than the CapEx of the electrification scenarios. Comparing scenario BaU (decentralized natural gas equipment for space heating) with scenario 3 (decentralized electric equipment) provides the estimated capital cost impact to cover 100% of the annual heating load through electrification assets for new construction. Scenario 3 costs an additional $3.1 million, which is 28% of the total CapEx of scenario BaU. The additional cost is mainly from the expense of the decentralized heat pumps. Since all scenarios, including scenario BaU, are new constructions, the expenditure differences for electrical infrastructure upgrades are minimal.

Scenario 1 has a total CapEx of $14 million, which is $3.5 million more than scenario BaU and only $0.3 million more than scenario 3. The major additional costs of scenario 1, compared to the decentralized scenarios, is the centralized network expenses, including geothermal borefield, distribution system, and central energy plant construction. These costs total $8.8 million, about 60% of scenario 1 total cost. The scenario 1 cost would be higher with a four-pipe distribution system instead of the two-pipe distribution. By using a two-pipe system in scenario 1, the CapEx of the centralized heat pumps compared to the decentralized equipment is kept to a minimum. Scenario 1 total CapEx is only 32% higher than scenario BaU and 2% higher than scenario 3.

The ambient loop scenario (scenario 2) has both centralized and decentralized equipment, which results in the highest CapEx—100% more than scenario BaU and more than 50% higher than scenarios 1 and 3.

In scenarios 2 and 3, individual thermal energy storage tanks would be in the building mechanical rooms, limiting the size that can be installed based on available space. However, the thermal energy storage tanks in the centralized scenario (scenario 1) would be located outdoors, allowing for larger storage capacities.

Figure 23. Capital Expenditures for the Scenarios



5.2 Economic Results

Figure 24 provides an overview of the economic performance of the different scenarios in terms of project NPV of costs over the project lifetime. Assets having an expected technical lifetime beyond the project end period are assigned a residual value (for the end of the project lifetime) assuming linear depreciation of the asset's value (original CapEx) over its expected technical lifetime. The NPV method, together with the residual value of assets, provides an equitable comparison across the scenarios despite the specific technical lifetime of the different assets.

Figure 25 presents the NPV of all scenarios' fuel costs. Scenario BaU has the lowest fuel cost due to the low cost of fossil fuel. However, because of the small size of the project, the fuel costs are relatively low compared to the CapEx. The buildings are modeled as new construction meeting ASHRAE standards with efficient heating, ventilation, and air conditioning (HVAC) systems. The warehouses, which cover 58% of the total project area, have relatively low lighting and miscellaneous usage compared to the office and light manufacturing buildings. All these factors result in a low operating expenses (OpEx) compared to the CapEx.

Scenario 1 has a lower NPV than the other scenarios, mainly because of the low CapEx. Although Scenario 1 has the second highest original CapEx at the beginning of project lifetime, the equipment lifetime of the centralized equipment and network are in general longer than the decentralized equipment in other scenarios, which results in a lower replacement cost and higher residual value. Scenarios BaU and 3 have similar NPVs due to the building-level equipment needed to meet the heating and cooling loads. However, Scenario 2 still has the highest CapEx in NPV because the use of both centralized and decentralized equipment. From an economic perspective alone, scenario 1 is the most favorable.

Figure 24. Economic Overview of the Different Scenarios: Net Present Value of the Total System Cost over the Project Lifetime

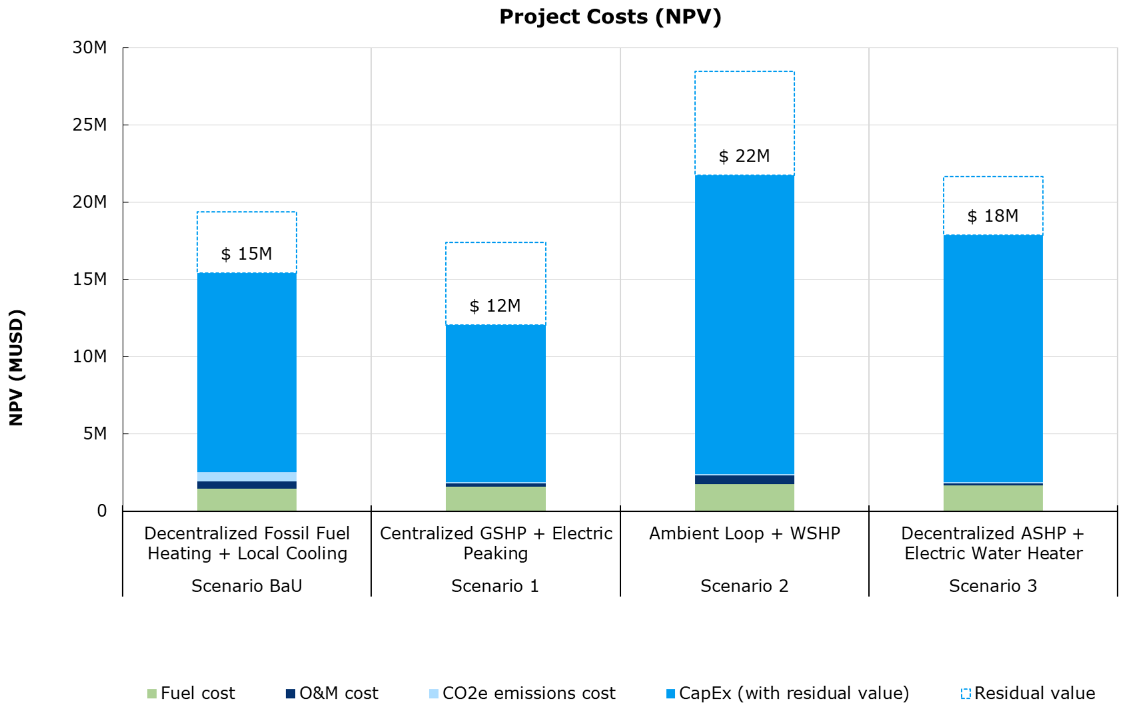
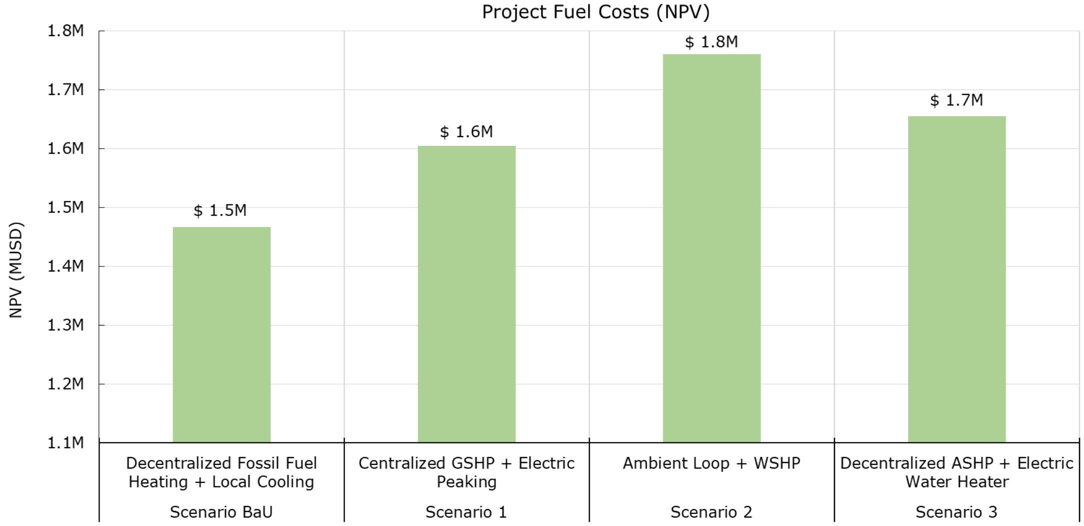


Figure 25. Net Present Value of Project Fuel Costs for Each Scenario



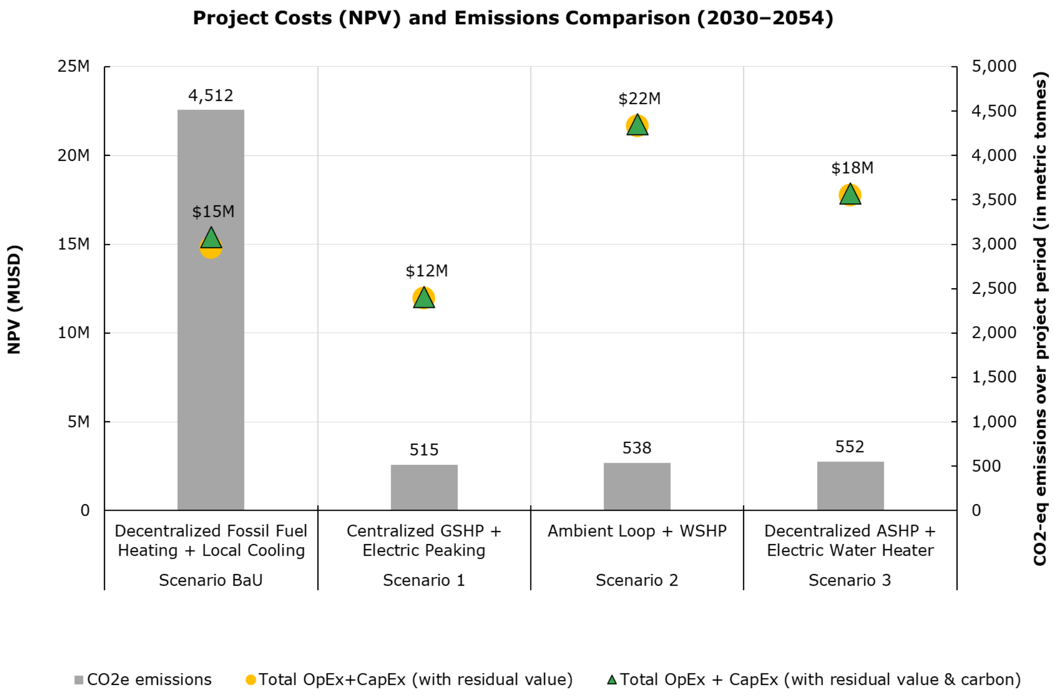
5.3 Environmental Results

Figure 26 shows the CO_2 emissions for the different scenarios together with the total NPV: CapEx, OpEx, and residual value. The total NPV is shown with social costs of carbon (green triangle with data labeled above) and without social costs of carbon (yellow circle) for each scenario. We calculated the social cost of carbon for the project's lifetime using the values listed in Table 5, starting in 2030 with a 25-year project life. From this representation, the social cost of carbon does not have a significant impact on the total NPV of scenario BaU because of the high CapEx. Scenario 1 has the lowest NPV of the alternatives both with and without the social cost of carbon included.

All alternative scenarios significantly reduce CO_2e emissions compared to scenario BaU due to:

- Near elimination of natural gas use for energy production
- Beneficial electrification and progressive decarbonization of the electric grid, in alignment with the Climate Act's goal of a 100% carbon-free electric grid by 2040.

Figure 26. Carbon Dioxide Equivalent Emissions and Project Net Present Value for the Different Scenarios



The shadow price of carbon represents the price of carbon that makes the NPV of each alternative scenario equal to the NPV of scenario BAU. The shadow price is calculated as:

$$\text{Shadow price (Sc. X)} = -\frac{\text{NPV(Scenario X cost)} - \text{NPV(BaU cost)}}{\text{NPV(Sc. X CO}_2\text{e emissions)} - \text{NPV(BaU CO}_2\text{e emissions)}}$$

The NPV of costs in the equation above includes:

- CapEx
- Residual value of CapEx
- OpEx (energy costs and O&M costs)

It does not include the social cost of carbon to avoid double counting carbon costs. The lower the shadow price of carbon for a scenario, the more cost-efficient the scenario is in reducing carbon emissions.

Table 9 compares the shadow price of carbon for the scenarios. Scenario 1 has a lower NPV than scenario BaU, which results in a zero shadow price of carbon. For the other scenarios, a shadow price of carbon between $1,053 and $2,427 per metric ton would make their economic impacts comparable to those of scenario BaU.

Table 9. Shadow Price of Carbon Compared to Scenario BaU

Scenario	Scenario BaU Decentralized Fossil Fuel Heating + Local Cooling	Scenario 1 Centralized GSHP + Electric Peaking	Scenario 2 Ambient Loop + WSHP	Scenario 3 Decentralized ASHP + Electric Water Heater
Shadow Price of Carbon (USD/ton)	—	0	2,427	1,053

6 Business Model

6.1 Identification of Tenants

Oneonta Railyards site is currently vacant, and potential tenants for the proposed buildings have not yet been identified. Once tenants are identified, a commercial developer can be retained to design and construct the buildings.

The centralized heating and cooling plant recommended in scenario 1 could be implemented through one of two operating models:

1. Energy as a Service (EaaS), offered through a third party
2. Engineering, Procurement, and Construction (EPC), owned and operated by the client

The following sections describe the two models and their benefits and risk exposure.

6.2 Energy as a Service

EaaS is an innovative approach to delivering energy solutions, transforming the traditional model of energy consumption into a more dynamic and service-oriented framework. In this model, energy is not just a commodity but a customizable service that meets the specific needs of end users. The interaction with stakeholders in the EaaS ecosystem involves collaboration between service providers, consumers, and technology providers. Service providers play a crucial role in designing and implementing tailored energy solutions, while consumers actively engage in managing their energy usage and costs. Technology providers contribute by offering innovative solutions such as smart meters, internet of things (IoT) devices, heat pumps, and energy management platforms. This collaborative approach fosters a more sustainable and efficient energy ecosystem, promoting transparency, flexibility, and cost savings for all stakeholders involved.

The EaaS arrangement would appear as a utility agreement to the property owner, much like the purchase of electricity or gas through NYSEG. All risk associated with the installation, operation (performance and reliability), maintenance, and financing would lie with the EaaS provider. Any rebates or tax incentives would be incorporated into the cost of energy.

6.3 Engineering, Procurement, and Construction

Under an EPC arrangement, the property owner would build, own, and operate the heating and cooling plant and would assume all risks associated with the implementation related to performance, financing, and reliability.

The benefits to the owner would be the resilient, sustainable, and efficient heating and cooling system as described in scenario 1.

6.4 Selected Implementation Model

Ultimately, the selection of an implementation model is dependent on many factors, among them the owner’s preference, the types of tenants and buildings that occupy site, and the development team assembled. The type of ownership arrangement of the buildings themselves would play a large factor in the implementation of an on-site community heat pump system.

7 Lessons Learned

7.1 Key Findings

The key findings from the study are as follows:

1. **Achieve electrification**
   Oneonta Railyards can achieve 100% electrification under any of the three scenarios considered. Scenario 1 (centralized distribution with GSHP) is recommended based on the lowest life-cycle cost considering CapEx and O&M costs.
2. **Facilitating centralized systems**
   A diverse range of building types with varied heating and cooling loads facilitates the implementation of a centralized system and leverages local thermal resources (sources/sinks) to address the aggregate loads cost effectively.
3. **Impact of tenants and building types**
   The building types represent a hypothetical industrial site. Actual tenants and building types will impact the optimum mix of technologies (WSHP, ASHP, boilers, GHX) required to address peak and base loads on the site.
4. **Coordination with City of Oneonta efforts**
   The type of heating and cooling systems at Oneonta Railyards should be coordinated with the city of Oneonta's CHPS. If a district energy system is implemented at the city level and Oneonta Railyards site is in near a main, then connection to the city system should be considered. If the district energy system is heating only (low-temperature hot water), then the cost contribution associated with the building-level chillers/heat-recovery chillers would need to be factored in the analysis, along with the levelized cost of energy ($/MMBtu) purchased from the district system.

7.2 Next Steps

For the project to progress, the next steps include:

1. Solicit potential tenants for the site
2. Select the ownership model for the buildings
3. Select the implementation model for the centralized heat pump system
4. Develop a request for proposals (RFP) to select a development team

Conduct exploratory hydrogeologic studies to assess capacity of on-site geo-exchange

Appendix A. Site Information

ONEONTA RAILYARD MASTER PLAN

OTSEGO now
HUB FOR ECONOMIC PROGRESS

SITE INFO

- 🟥 BOUNDARY LINE
- 🟩 DEC WETLAND
- 🟩 100’ DEC WETLAND BUFFER
- 🟦 NYS DEC STREAM
- S.W.B. STORMWATER BASIN

LAND USE

TOTAL BUIDABLE LAND: 37.15 ACRES

TOTAL SITE: 78.79 ACRES

PROPOSED COMMERCIAL BUILDING SIZE

- A - 50,000 SQ. FT.
- B - 42,000 SQ. FT.
- C - 30,000 SQ. FT.
- D - 30,000 SQ. FT.
- E - 25,000 SQ. FT.

177,000 SQ. FT. TOTAL

VEHICLE PARKING

P1= 180
P2= 204
P3= 143
P4= 76

603 TOTAL VEHICLE PARKING

N
SCALE:
0 120’ 240’
Drawing Scale: 1”=120’-0”
DATE: 07.23.2020

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ELAN.3 CONSULTING

ONEONTA RAILYARD MASTER PLAN

OTSEGO now
HUB FOR ECONOMIC PROGRESS

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177,000 SQ. FT. TOTAL

VEHICLE PARKING

P1= 180
P2= 204
P3= 143
P4= 76

603 TOTAL VEHICLE PARKING

PROPOSED PARCEL SIZE

LOT 1 = 11.5 ACRES ±
LOT 2 = 5.5 ACRES ±
LOT 3 = 8.0 ACRES ±
LOT 4 = 4.6 ACRES ±
REMAINING LANDS = 49.19 ACRES ±

TOTAL = 78.79 ACRES

N
SCALE:
0 120' 240'
Drawing Scale: 1"=120'-0"
DATE: 07.23.2020

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Appendix B. Building Model Inputs and Assumptions

Oneonta Railyards
Summary of Building Model Inputs

Building Type	Layout	Envelope	HVAC Equipment	Setpoints
Office	All office area	Steel-Frame Walls 33% double pane window	Gas furnace and DX coils	Heating: 70°F Cooling: 75°F
Non-refrigerated Warehouse with Fine Storage	15% office, 85% fine storage area	Metal Building Wall; 1% punched windows in office	Gas furnace and DX coils	Office: heated to 70F, cooled to 75°F; Storage: heated to 60°F, cooled to 80°F.
Non-refrigerated Warehouse with Bulk Storage	7% office and 93% bulk storage area	Metal Building Wall; 1% punched windows in office	Gas furnace and DX coils, no cooling in the bulk storage	Office: heated to 70°F, cooled to 75°F; Bulk storage: heated to 50°F.
Refrigerated Warehouse with Dock	5% office, 26% dock, 15% cooler, and 54% freezer area.	Exterior wall with R10 insulation for office, R25 for dock, R28 for coolers, and R36 for freezers; 10% double pane window	Gas furnace and DX coils in the office, process cooling for dock, coolers and freezers	Office: heated to 68°F, cooled to 73°F; Coolers: heating season 36°F, cooling season to 40°F; Freezers: heating season -4°F, cooling season 0°F; Blast freezers: heating season -17°F, cooling season -13°F; dock: heating season 32°F, cooling season to 50°F
Refrigerated Warehouse without Dock	7% office, 20% cooler, and 73% freezer area.	Exterior wall with R10 insulation for office, R28 for coolers, and R36 for freezers; 10% double pane window	Gas furnace and DX coils in the office, process cooling for coolers and freezers	Office: heated to 68°F, cooled to 73°F; Coolers: heating 36°F, cooling season 40°F;

Building Type	Layout	Envelope	HVAC Equipment	Setpoints
				Freezers: heating season -4°F, cooling season 0°F; Blast freezers: heating season -17°F, cooling season -13°F;
Light Manufacturing	5% office and 95% light manufacture area.	Metal Building Wall; 1% punched windows in office	Gas furnace and DX coils	Office: heating season 70°F, cooling season to 75°F; Light manufacturing: heated to 60°F, cooled to 80°F.

Oneonta Railyards
Decentralized Air Source Heat Pump Heating Efficiencies

Typical 60 Ton ASHP

OAT (°F)	ASHP Max Capacity/Unit (kBtu/h)	kW/Unit	COP (kW/kW)	Max LWT (°F)	Max ΔT (°F)	Min EWT (°F)
-10	471.18	92.40	1.49	100	21.6	78.4
-5	482.51	92.39	1.53	106	21.6	84.4
0	464.90	86.51	1.57	113	21.6	91.4
5	449.07	81.08	1.62	120	21.6	98.4
10	476.74	80.16	1.74	124	21.6	102.4
15	506.16	80.45	1.84	128	21.6	106.4
20	592.89	90.68	1.92	131	21.6	109.4
25	650.42	91.84	2.08	131	21.6	109.4
30	694.37	90.82	2.24	131	21.6	109.4
35	738.32	90.01	2.40	131	21.6	109.4
40	782.27	89.34	2.57	131	21.6	109.4
45	791.07	84.56	2.74	131	21.6	109.4
50	791.07	79.24	2.93	131	21.6	109.4
55	791.07	74.77	3.10	131	21.6	109.4

Oneonta Railyards
Decentralized Water-to-Water Heat Pump Efficiencies

Typical WSHP

Unit	Space Heating COP (kW/kW)	DHW Winter COP (kW/kW)	DHW Summer COP (kW/kW)
LWB62SP	2.71	3.39	3.88
LWB82SP	2.88	3.53	4.01
LWB142SP	3.24	3.84	4.37
LWB172SP	3.2	3.81	4.36
LWB202SP	3.27	3.81	4.33
LWB252SP	3.19	3.85	3.36
Average	**3.08**	**3.71**	**4.05**

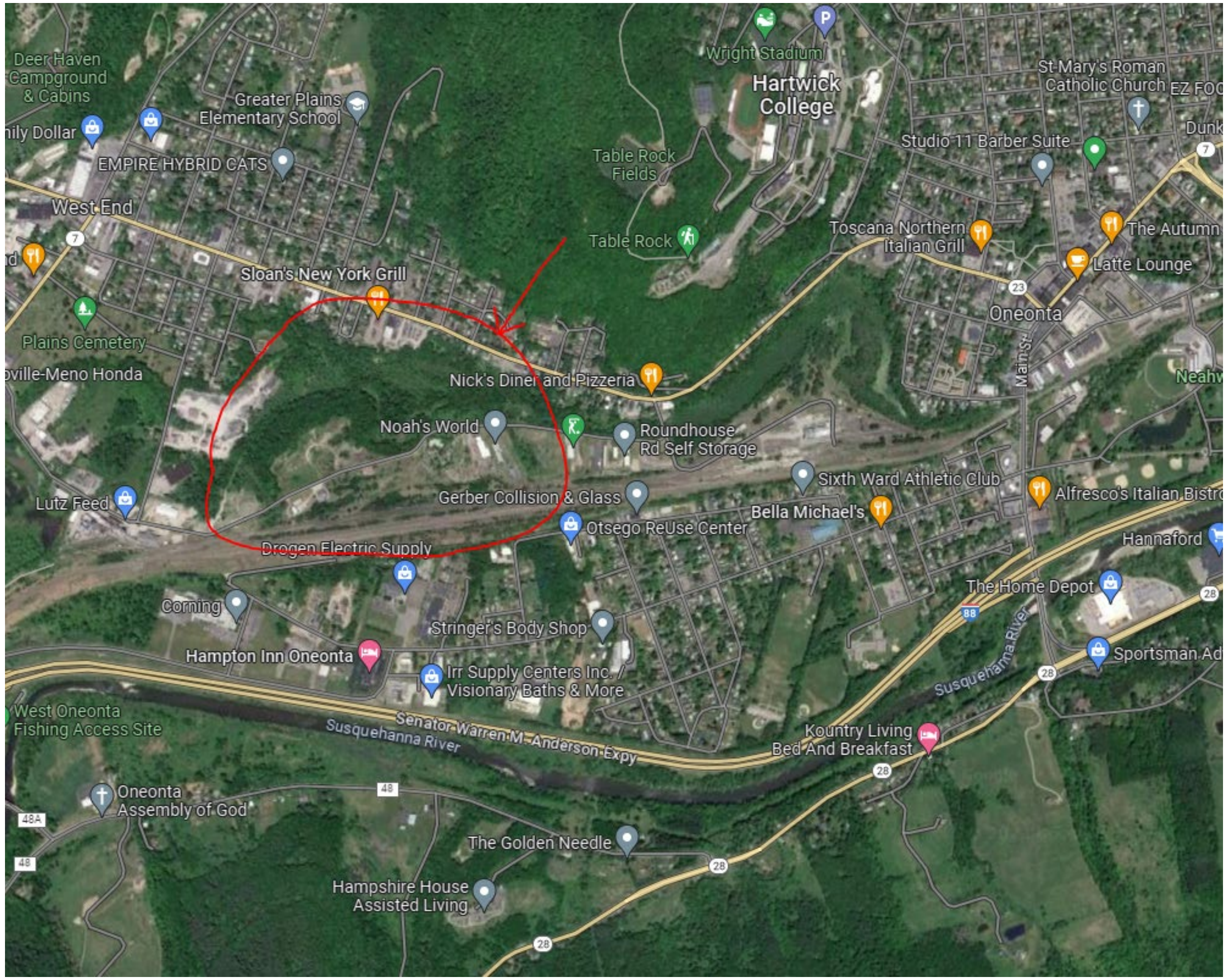
Appendix C. Hydraulic Modeling

Oneonta Railyards

Hydraulic Model

Bright ideas.
Sustainable change.

Site Location & Proposed Site Plan



Hot Water Distribution System

Scenario 1 – 4G HW System

Centralized GSHP + BTES

Hot Water Distribution Loads

Building Name	Bldg. ID	Hourly Peak [MMBtu/h]		
		Space Heating	Domestic Hot Water	Total
Office/Admin	A	0.449	0.018	0.467
Non-refrigerated Warehouse with Fine Storage	B	0.498	0.006	0.500
Non-refrigerated Warehouse with Heating Only Storage	C	0.434	0.004	0.435
Refrigerated Warehouse	D	0.490	0.000	0.490
Light Manufacturing Facility	E	1.160	0.002	1.162
SUM	-	-	-	**3.053**

Theoretical Capacity:
Hot Water

Assumptions:

- Supply Temp.: 170 °F
- Return Temp.: 140 °F
- ΔT: 30 °F

- EN253, steel (pipe dimensions)
- Roughness: 0.0039” (0.1 mm)
- Pressure gradient:

0.0066	[Psi/ft]
1.5	[ft/100 ft]
150	[Pa/m]

- Velocities:

Pipe Size ["]	Velocity [Ft/s]
< 2”	3.3
2” - 6”	4.9
8” - 10”	6.6
12” - 14”	8.2
16” <	11.5

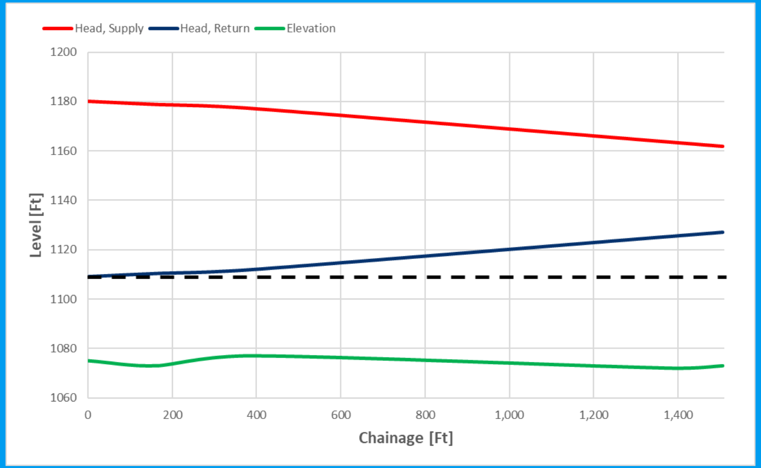
Nom. Dia [”]	ex. Dia [”]	Int. Dia [”]	Flow	Capacity ΔT 25 °F	Velocity	Press. Grad.
			[GPM]	[MBtu/hr]	[ft/s]	[ft/100 ft]
1”	1.3	1.1	5.0	69	1.8	**1.5**
1 ¼”	1.7	1.5	9.7	133	2.1	**1.5**
1 ½"	1.9	1.7	14	196	2.3	**1.5**
2"	2.4	2.1	27	366	2.7	**1.5**
2 ½”	3.0	2.8	52	718	3.2	**1.5**
3"	3.5	3.2	80	1,096	3.6	**1.5**
4"	4.5	4.2	159	2,181	4.2	**1.5**
5"	5.5	5.2	278	3,816	4.8	**1.5**
6"	6.6	6.3	459	5,904	**5.1**	1.4
8"	8.6	8.3	934	12,799	6.4	**1.5**
10"	10.7	10.4	1,683	20,580	**6.6**	1.2
12"	12.7	12.3	2,643	36,246	8.2	**1.5**

Hot Water Distribution

Assumptions:

- Supply Temp.: 170 ºF
- Return Temp.: 140 ºF
- ΔT: 30 ºF
- Ambient Temp: 46.4 ºF

- Min. ΔP: 14.5 psi
- Min. Pressure: 14.5 psi(g)
- Max. Pressure: 110 psi(g)



* The model does not account for internal losses.
An additional 14.5-21 psi should be added when specifying the main pumps.

Production		
Load	[MMbtu/h]	3.2
Flow	[GPM]	206
Temp. Supply	[F]	170
Temp. Return	[F]	139
Pressure, Supply	[psig]	44.3
Pressure, Return	[psig]	14.5
ΔP	[psi]	29.8*

Distribution System		
Max. Pressure	[psig]	44.8
Min. Pressure	[psig]	14.9
ΔP	[psi]	14.5

Pipe Type	Trench [Ft]
c) 1"	0
d) 1 1/4"	0
e) 1 1/2"	0
f) 2"	0
g) 2 1/2"	884
h) 3"	1,505
i) 4"	749
j) 5"	163
k) 6"	0
l) 8"	0
m) 10"	0
n) 12"	0
SUM	3,300

Chilled Water Distribution

Scenario 1 – 4G CHW System
Centralized GSHP + BTES
Comfort Cooling Only

Chilled Water Distribution Loads

Building Name	Bldg. ID	Hourly Peak [MMBtu/h]
Office/Admin	A	0.765
Non-refrigerated Warehouse with Fine Storage	B	0.304
Non-refrigerated Warehouse with Heating Only Storage	C	0.031
Refrigerated Warehouse	D	0.038
Light Manufacturing Facility	E	0.200
SUM	-	**1.337**

Theoretical Capacity:
Chilled Water

Assumptions:

- Supply Temp.: 44 °F
- Return Temp.: 54 °F
- ΔT: 10 °F

- EN253, steel (pipe dimensions)
- Roughness: 0.0039” (0.1 mm)
- Pressure gradient:

0.0133	[Psi/ft]
3.1	[ft/100 ft]
300	[Pa/m]

- Velocities:

Pipe Size ["]	Velocity [Ft/s]
< 2”	4.9
2” - 6”	6.6
8” - 10”	8.2
12” - 14”	9.8
16” <	11.5

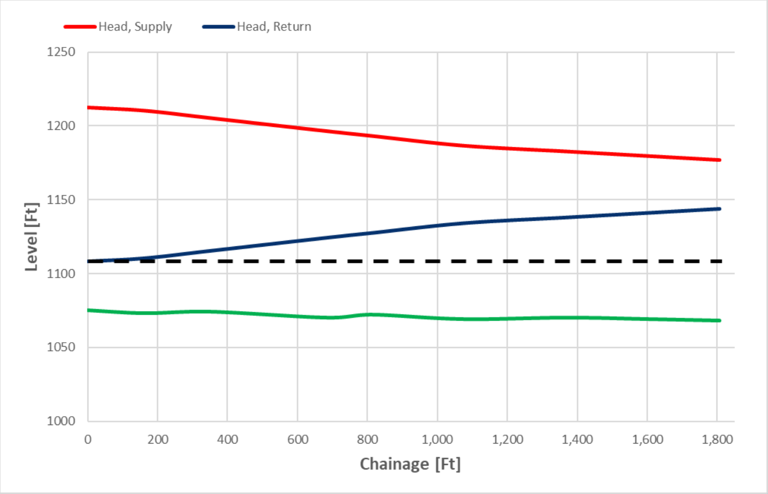
Nom. Dia ["]	ex. Dia ["]	Int. Dia ["]	Flow	Capacity ΔT 10 °F	Velocity	Press. Grad.
			[GPM]	[MBtu/hr]	[ft/s]	[ft/100 ft]
1”	1.3	1.1	7.6	38	2.4	**3.1**
1 ¼”	1.7	1.5	14.7	73	2.8	**3.1**
1 ½"	1.9	1.7	22	109	3.1	**3.1**
2"	2.4	2.1	41	204	3.6	**3.1**
2 ½”	3.0	2.8	81	403	4.3	**3.1**
3"	3.5	3.2	123	618	4.8	**3.1**
4"	4.5	4.2	247	1,235	5.7	**3.1**
5"	5.5	5.2	434	2,171	6.5	**3.1**
6"	6.6	6.3	648	3,242	**6.6**	2.5
8"	8.6	8.3	1,398	6,997	**8.3**	2.8
10"	10.7	10.4	2,183	10,922	**8.3**	2.1
12"	12.7	12.3	3,683	18,430	**9.9**	2.4

Chilled Water Distribution

Assumptions:

- Supply Temp.: 44 ºF
- Return Temp.: 54 ºF
- ΔT: 10 ºF
- Ambient Temp: 53.6 ºF

- Min. ΔP: 14.5 psi
- Min. Pressure: 14.5 psi(g)
- Max. Pressure: 110 psi(g)



* The model does not account for internal losses.
An additional 14.5-21 psi should be added when specifying the main pumps.

Production		
Load	[MMbtu/h]	1.3
Flow	[GPM]	264
Temp. Supply	[F]	44
Temp. Return	[F]	54
Pressure, Supply	[psig]	60.3
Pressure, Return	[psig]	14.5
ΔP	[psi]	45.8*

Distribution System		
Max. Pressure	[psig]	60.2
Min. Pressure	[psig]	15.8
ΔP	[psi]	14.5

Pipe Type	Trench [Ft]
c) 1"	20
d) 1 1/4"	72
e) 1 1/2"	0
f) 2"	0
g) 2 1/2"	1,400
h) 3"	0
i) 4"	1,645
j) 5"	163
k) 6"	0
l) 8"	0
m) 10"	0
n) 12"	0
SUM	3,300

Ambient Loop

Heating Simulation Results

Scenario 2 – 5G Ambient System

GSHP + BTES + ASHP

Ambient Loop Heating Loads

Building Name	Bldg. ID	Hourly Peak [MMBtu/h]		
		Space Heating	Domestic Hot Water	Total
Office/Admin	A	0.321	0.013	0.333
Non-refrigerated Warehouse with Fine Storage	B	0.356	0.004	0.360
Non-refrigerated Warehouse with Heating Only Storage	C	0.310	0.003	0.313
Refrigerated Warehouse	D	0.350	0.000	0.350
Light Manufacturing Facility	E	0.829	0.002	0.830
SUM	-	-	-	**2.187**

Clarifications

- Peak loads represent building-level WSHP demands on the ambient loop
- Loads assume WSHP COP of 3.5
- No building-level peaking technologies

Assumptions:

Heat (Ambient Temp: 46.4 °F)

- Supply Temp.: 54 °F
- Return Temp.: 44 °F
- ΔT: 10 °F

- EN253, steel (pipe dimensions)
- Roughness: 0.0039” (0.1 mm)

- Velocities:

Pipe Size ["]	Velocity [Ft/s]
< 2”	4.9
2” - 6”	6.6
8” - 10”	8.2
12” - 14”	9.8
16” <	11.5

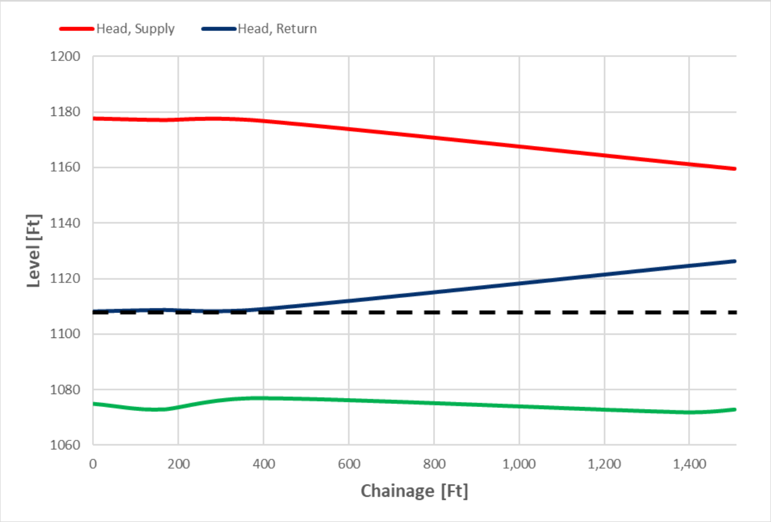
Theoretical Capacity:
Ambient Loop

Nom. Dia ["]	ex. Dia ["]	Int. Dia ["]	Pressure Gradient 1.5 [ft/100 ft]			
			Flow [GPM]	Capacity [MBtu/hr]	Velocity [ft/s]	Press. Grad. [ft/100 ft]
1”	1.3	1.1	5.3	26	1.6	**1.5**
1 ¼”	1.7	1.5	10.2	51	1.9	**1.5**
1 ½"	1.9	1.7	15	76	2.2	**1.5**
2"	2.4	2.1	29	142	2.5	**1.5**
2 ½”	3.0	2.8	56	281	3.0	**1.5**
3"	3.5	3.2	86	431	3.3	**1.5**
4"	4.5	4.2	173	863	4.0	**1.5**
5"	5.5	5.2	304	1517	4.6	**1.5**
6"	6.6	6.3	503	2509	5.2	**1.5**
8"	8.6	8.3	1,027	5126	6.1	**1.5**
10"	10.7	10.4	1,857	9266	7.1	**1.5**
12"	12.7	12.3	2,924	14590	7.9	**1.5**

Ambient Distribution, Heating

Assumptions:

➢Supply Temp.:	54 °F
➢Return Temp.:	44 °F
➢ΔT:	10 °F
➢Ambient Temp:	46.4 °F
➢Min. ΔP:	14.5 psi
➢Min. Pressure:	14.5 psi(g)
➢Max. Pressure:	110 psi(g)



* The model does not account for internal losses.
An additional 14.5-21 psi should be added when specifying the main pumps.

Production		
Load	[MMbtu/h]	2.2
Flow	[GPM]	431
Temp. Supply	[F]	54
Temp. Return	[F]	44
Pressure, Supply	[psig]	44.9
Pressure, Return	[psig]	14.5
ΔP	[psi]	30.4*

Distribution System		
Max. Pressure	[psig]	46.4
Min. Pressure	[psig]	14.0
ΔP	[psi]	14.5

Pipe Type	Trench [Ft]
c) 1"	0
d) 1 1/4"	0
e) 1 1/2"	0
f) 2"	0
g) 2 1/2"	0
h) 3"	79
i) 4"	1,847
j) 6"	984
k) 8"	390
l) 10"	0
m) 12"	0
SUM	3,300

Ambient Loop

Cooling Simulation Results

Scenario 2 – 5G Ambient System

GSHP + BTES + ASHP

Ambient Loop Cooling Loads

Building Name	**Bldg. ID**	**Hourly Peak [MMBtu/h]**
Office/Admin	A	0.647
Non-refrigerated Warehouse with Fine Storage	B	0.257
Non-refrigerated Warehouse with Heating Only Storage	C	0.026
Refrigerated Warehouse	D	2.380
Light Manufacturing Facility	E	0.169
SUM	-	**3.480**

Clarifications

- Peak loads represent building-level WSHP demands on the ambient loop
- Loads assume WSHP COP of 6.5

<u>Assumptions:</u>

Cool (Ambient Temp: 53.6 °F)

- Supply Temp.: 44 °F
- Return Temp.: 54 °F
- ΔT: 10 °F

- EN253, steel (pipe dimensions)
- Roughness: 0.0039” (0.1 mm)

- Velocities:

Pipe Size ["]	Velocity [Ft/s]
< 2”	4.9
2” - 6”	6.6
8” - 10”	8.2
12” - 14”	9.8
16” <	11.5

Theoretical Capacity:
Ambient Loop

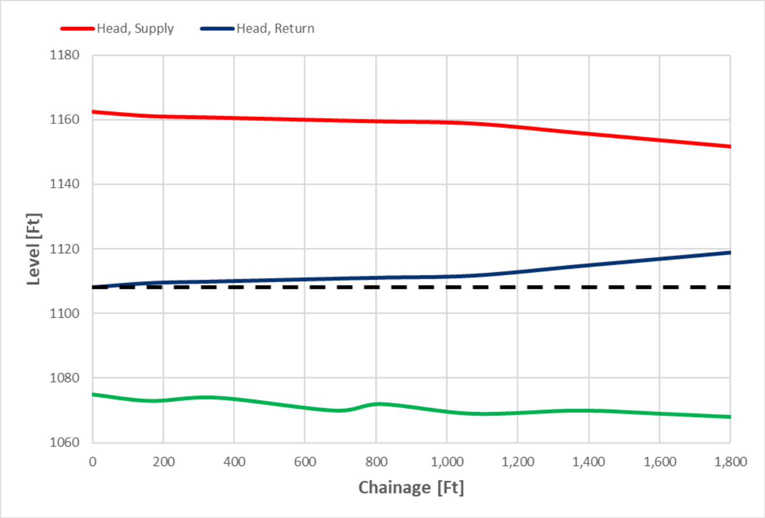
Nom. Dia ["]	ex. Dia ["]	Int. Dia ["]	Pressure Gradient 1.5 [ft/100 ft]			
			Flow [GPM]	Capacity [MBtu/hr]	Velocity [ft/s]	Press. Grad. [ft/100 ft]
1”	1.3	1.1	5.3	26	1.6	**1.5**
1 ¼”	1.7	1.5	10.2	51	1.9	**1.5**
1 ½"	1.9	1.7	15	76	2.2	**1.5**
2"	2.4	2.1	29	142	2.5	**1.5**
2 ½”	3.0	2.8	56	281	3.0	**1.5**
3"	3.5	3.2	86	431	3.3	**1.5**
4"	4.5	4.2	173	863	4.0	**1.5**
5"	5.5	5.2	304	1517	4.6	**1.5**
6"	6.6	6.3	503	2509	5.2	**1.5**
8"	8.6	8.3	1,027	5126	6.1	**1.5**
10"	10.7	10.4	1,857	9266	7.1	**1.5**
12"	12.7	12.3	2,924	14590	7.9	**1.5**

Ambient Distribution, Cooling

Assumptions:

- Supply Temp.: 44 °F
- Return Temp.: 54 °F
- ΔT: 10 °F
- Ambient Temp: 53.6 °F

- Min. ΔP: 14.5 psi
- Min. Pressure: 14.5 psi(g)
- Max. Pressure: 110 psi(g)



* The model does not account for internal losses.
An additional 14.5-21 psi should be added when specifying the main pumps.

Production		
Load	[MMbtu/h]	3.5
Flow	[GPM]	688
Temp. Supply	[F]	44
Temp. Return	[F]	54
Pressure, Supply	[psig]	38.4
Pressure, Return	[psig]	14.5
ΔP	[psi]	23.9*

Distribution System		
Max. Pressure	[psig]	39.4
Min. Pressure	[psig]	14.6
ΔP	[psi]	14.5

Pipe Type	Trench [Ft]
c) 1"	0
d) 1 1/4"	0
e) 1 1/2"	0
f) 2"	0
g) 2 1/2"	0
h) 3"	79
i) 4"	1,847
j) 6"	984
k) 8"	390
l) 10"	0
m) 12"	0
SUM	3,300

Trench of Pipe

Hot Water 4G System

Pipe Type	Trench [Ft]	Volume [Gal]
a) 1/2"	0	0
b) 3/4"	0	0
c) 1"	0	0
d) 1 1/4"	0	0
e) 1 1/2"	0	0
f) 2"	0	0
g) 2 1/2"	884	552
h) 3"	1,505	1,296
i) 4"	749	1,086
j) 5"	163	362
k) 6"	0	0
l) 8"	0	0
m) 10"	0	0
n) 12"	0	0
SUM	3,300	3,296

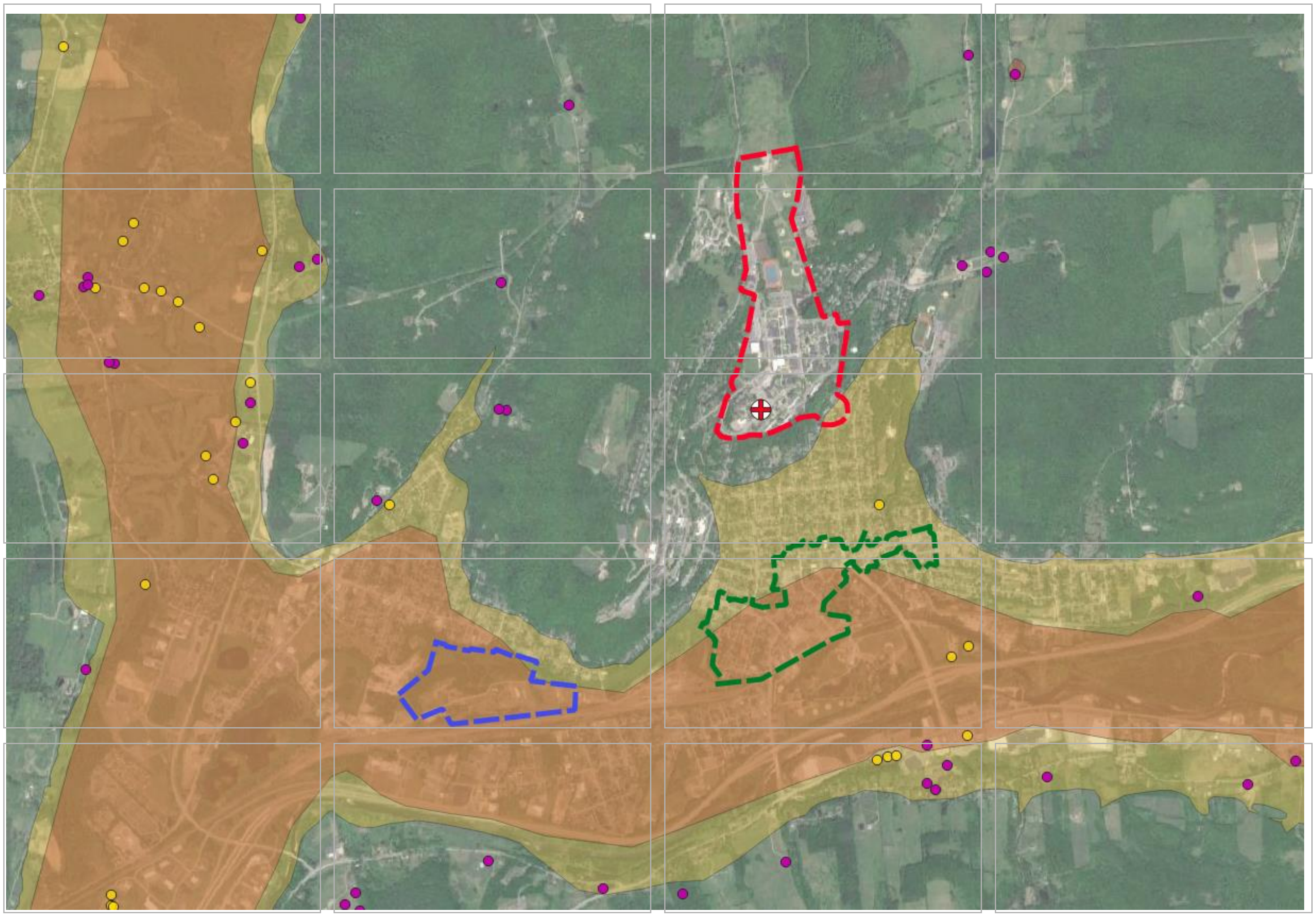
Chilled Water 4G System

Pipe Type	Trench [Ft]	Volume [Gal]
a) 1/2"	0	0
b) 3/4"	0	0
c) 1"	20	2
d) 1 1/4"	72	13
e) 1 1/2"	0	0
f) 2"	0	0
g) 2 1/2"	1,400	875
h) 3"	0	0
i) 4"	1,645	2,386
j) 5"	163	362
k) 6"	0	0
l) 8"	0	0
m) 10"	0	0
n) 12"	0	0
SUM	3,300	3,638

Ambient Loop 5G System

Pipe Type	Trench [Ft]	Volume [Gal]
a) 1/2"	0	0
b) 3/4"	0	0
c) 1"	0	0
d) 1 1/4"	0	0
e) 1 1/2"	0	0
f) 2"	0	0
g) 2 1/2"	0	0
h) 3"	79	68
i) 4"	1,847	2,680
j) 6"	984	3,199
k) 8"	390	2,180
l) 10"	0	0
m) 12"	0	0
SUM	3,300	8,126

Appendix D. Hydrogeologic Evaluation



Final Report

Geothermal Assessment

Oneonta Community Heat Pump Study Areas
Oneonta, NY

Prepared for:

RAMBOLL

November 2023

www.underground-energy.com

UE Project No. RAM.2022.01-03

Pursuing Geothermal Excellence

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Table of Contents

1.0 Introduction 1
2.0 Methodology 1
3.0 Geothermal Conceptual Model Development 2
  3.1 Regional Geology 3
    3.1.1 Bedrock Geology 3
    3.1.2 Surficial Geology 4
  3.2 Hydrogeology 5
  3.3 Geochemistry 7
  3.4 Subsurface Thermal Properties and Heat Transfer 8
  3.5 Ground Conditions at the Study Areas 8
4.0 Hydrogeologic and Seasonal Storage Evaluation of ATES and BTES 9
  4.1 ATES Evaluation 9
  4.2 BTES Evaluation 9
5.0 Conceptual GHX Design 10
  5.1 City of Oneonta 11
  5.2 Oneonta Railyards 13
  5.3 SUNY Oneonta 15
6.0 References 17

List of Figures

Figure 1 – Study areas, nearby wells and data sources used in the GCM 2
Figure 2 - Geothermal Conceptual Site Model Development Process 3
Figure 3 - Regional bedrock geology 4
Figure 4 – Regional surficial geology 5
Figure 5 - Glacial aquifer map showing confined and unconfined aquifer extents 6
Figure 6 - Geologic cross section D-D' at Oneonta community heat pump study area 7
Figure 7 - Imbalanced heating-only GHX discharge loads for City of Oneonta 11
Figure 8 - City of Oneonta modeled GHX temperatures 12

Figure 9 - City of Oneonta/ Neahwa Park conceptual GHX layout 12
Figure 10 - Imbalanced GHX charge and discharge loads at Oneonta Railyards 13
Figure 11 - Oneonta Railyards modeled GHX temperatures 14
Figure 12 - Oneonta Railyards minimum and maximum supply temperature 25-year trend 14
Figure 13 - Oneonta Railyards conceptual GHX layout 14
Figure 14 - Charging and Discharging Thermal Loads to BTES at SUNY Oneonta 15
Figure 15 - SUNY Oneonta modeled BTES temperatures 15
Figure 16 - SUNY Oneonta minimum and maximum supply temperature 25-year trend 16
Figure 17 - SUNY Oneonta conceptual BTES borefield layout 16

List of Tables

Table 1 - Thermal Response Test results from nearby geothermal test bore 8
Table 2 - Summary of GHX Sizing and Modeled Performance Data 10
Table 3 - Estimated base and peak loads for Oneonta Railyards 13

Appendices

Appendix A – EED Output Reports

1.0 Introduction

Underground Energy, LLC (UE) prepared this Geothermal Assessment Report for Ramboll as part of the Oneonta Community Heat Pump Study project in Oneonta, New York. The project was funded by NYSERDA, who awarded three scoping study grants to the City of Oneonta, Oneonta Railyards, and SUNY Oneonta. This report summarizes geothermal ground conditions in the Oneonta area and is intended to inform all three applicants regarding geothermal conditions and recommended conceptual Earth couple designs to inform their decision making regarding renewable heating and cooling potential at their respective sites. UE's work for this study focused on characterizing ground conditions to identify appropriate Earth coupling alternatives and formed the basis for conceptual design of ground heat exchangers at the community scale.

2.0 Methodology

UE developed a Geothermal Conceptual Model (GCM) during the first phase of this project (completed in December 2022) to characterize ground conditions and subsurface heat transfer mechanisms to facilitate conceptual design of Earth-coupled, low-temperature community-scale heating and cooling systems. Based on the GCM and load estimates provided by Ramboll, UE utilized Earth Energy Designer (EED) software to simulate monthly load data and develop conceptual design of ground heat exchangers (GHXs) using Borehole Thermal Energy Storage where applicable. The EED output reports are included in Appendix A.

Significant efforts by the City of Oneonta, the USGS, and students at SUNY Oneonta have been undertaken to characterize the ground conditions in Oneonta. Much of this work culminated in a 2022 report on the 2022 glacial geology and hydrogeology of the Oneonta area (see references in Section 6.0). The digital datasets published from the report were used in our analysis of geothermal conditions in the area. Figure 1 depicts the three study areas and the data sources that were used to develop the GCM.

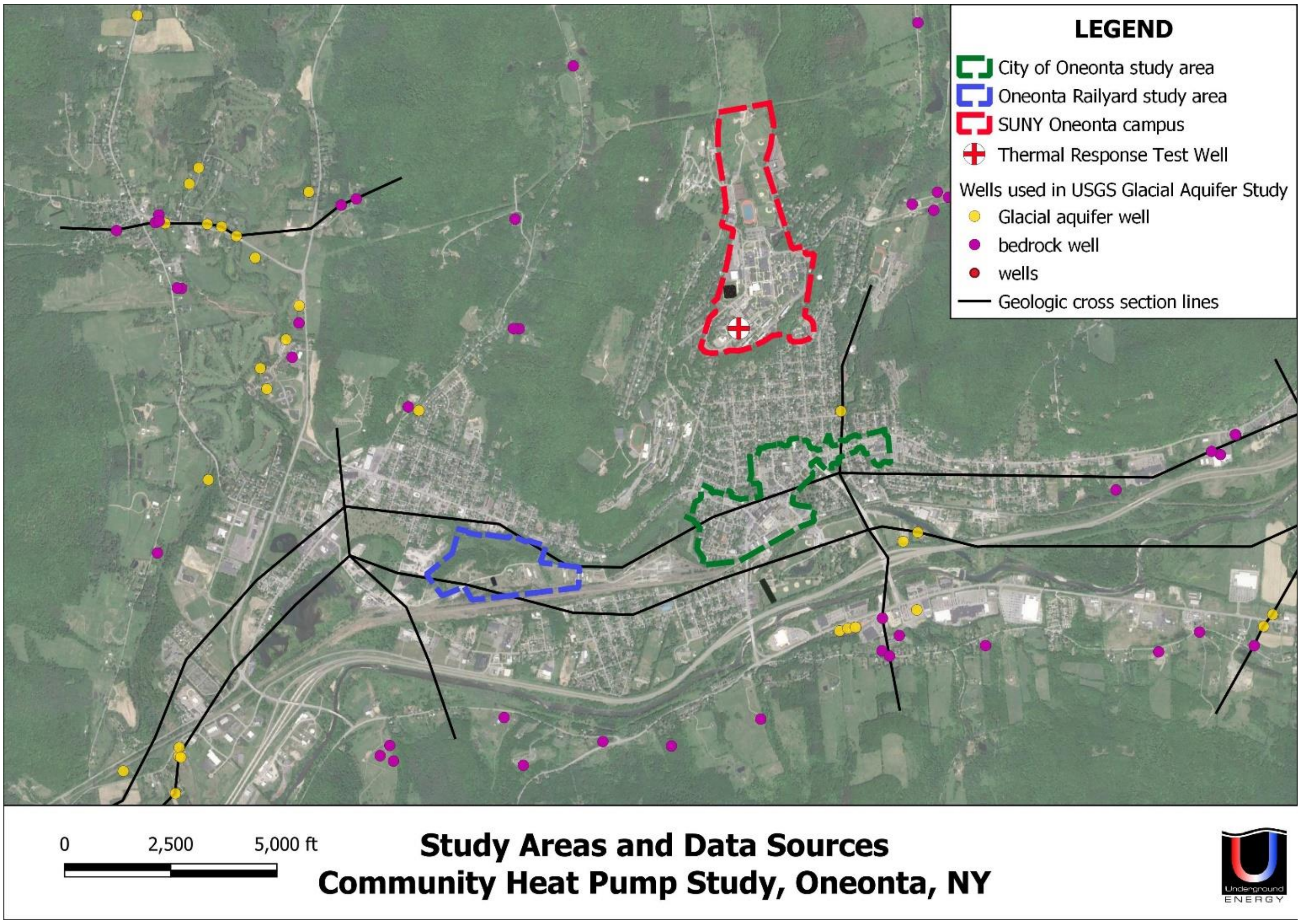
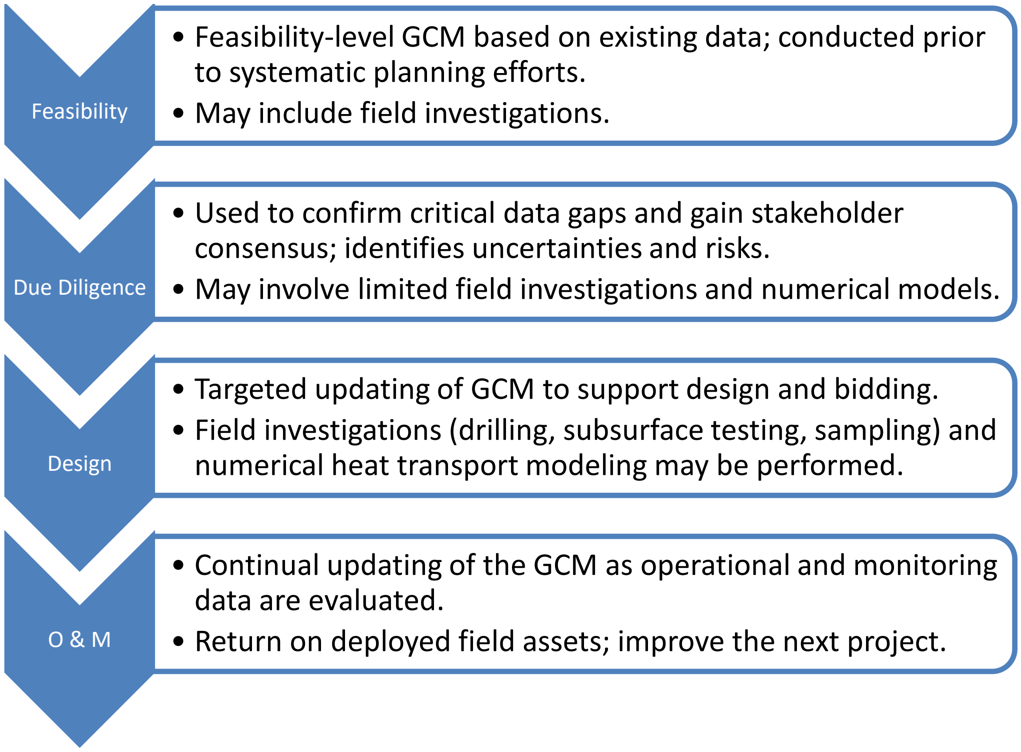


Figure 1 – Study areas, nearby wells and data sources used in the GCM

3.0 Geothermal Conceptual Model Development

Underground Energy developed a feasibility-level GCM for the Oneonta area. A GCM is a graphical and written summary of what is known or hypothesized about ground conditions at a site as they pertain to development of an earth-coupled heating and cooling project. The GCM process is graphically depicted in Figure 2 below.



Feasibility

- Feasibility-level GCM based on existing data; conducted prior to systematic planning efforts.
- May include field investigations.

Due Diligence

- Used to confirm critical data gaps and gain stakeholder consensus; identifies uncertainties and risks.
- May involve limited field investigations and numerical models.

Design

- Targeted updating of GCM to support design and bidding.
- Field investigations (drilling, subsurface testing, sampling) and numerical heat transport modeling may be performed.

O & M

- Continual updating of the GCM as operational and monitoring data are evaluated.
- Return on deployed field assets; improve the next project.

Figure 2 - Geothermal Conceptual Site Model Development Process

3.1 Regional Geology

3.1.1 Bedrock Geology

Bedrock in the Oneonta area is comprised of upper-Devonian-aged horizontally bedded sedimentary rocks comprised of shale, siltstone, sandstone and conglomerate. The Genesee Group includes the Oneonta Formation bedrock comprised of up to 300 feet of shale and secondarily sandstone and conglomerate. The Oneonta Formation is underlain by sandstone, siltstone and shale of the Unadilla, Laurens, New Lisbon and Gilboa Formations. A regional bedrock geologic map is presented below as Figure 3.

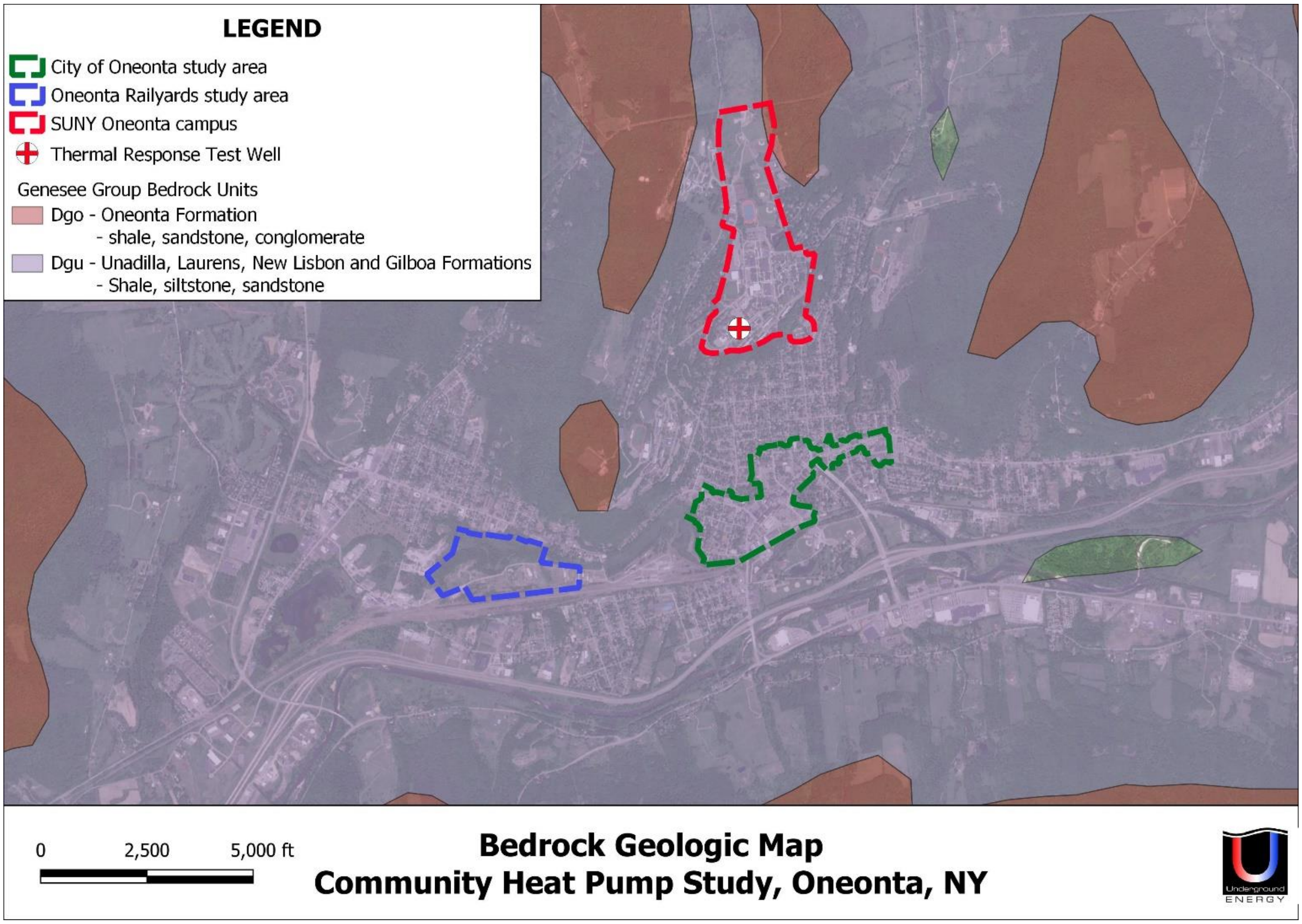


Figure 3 - Regional bedrock geology

3.1.2 Surficial Geology

The surficial geology of the Oneonta area is characterized by unconsolidated glacial deposits that were deposited over the bedrock during advance and retreat of the Laurentide Ice sheet. During Wisconsin and previous glacial advances, the bedrock surface was scoured to significant depth along the northeast-southwest trending Susquehanna River valley and its tributaries. These deeply incised bedrock valleys were filled with a complex sequence of ice-contact, outwash and lacustrine deposits during glacial retreat as meltwater created alluvial features and deltas in glacial lakes. A regional surficial geologic map is presented as Figure 4.

The base of the surficial deposits is glacial till deposited during glacial advance. The till is derived primarily from shale and siltstone and is therefore composed primarily by densely compacted silt and clay and shale fragments. A relatively thin veneer of glacial till covers bedrock in most upland locations, and the till is buried beneath glaciolacustrine and glacial outwash deposits in the scoured bedrock valleys.

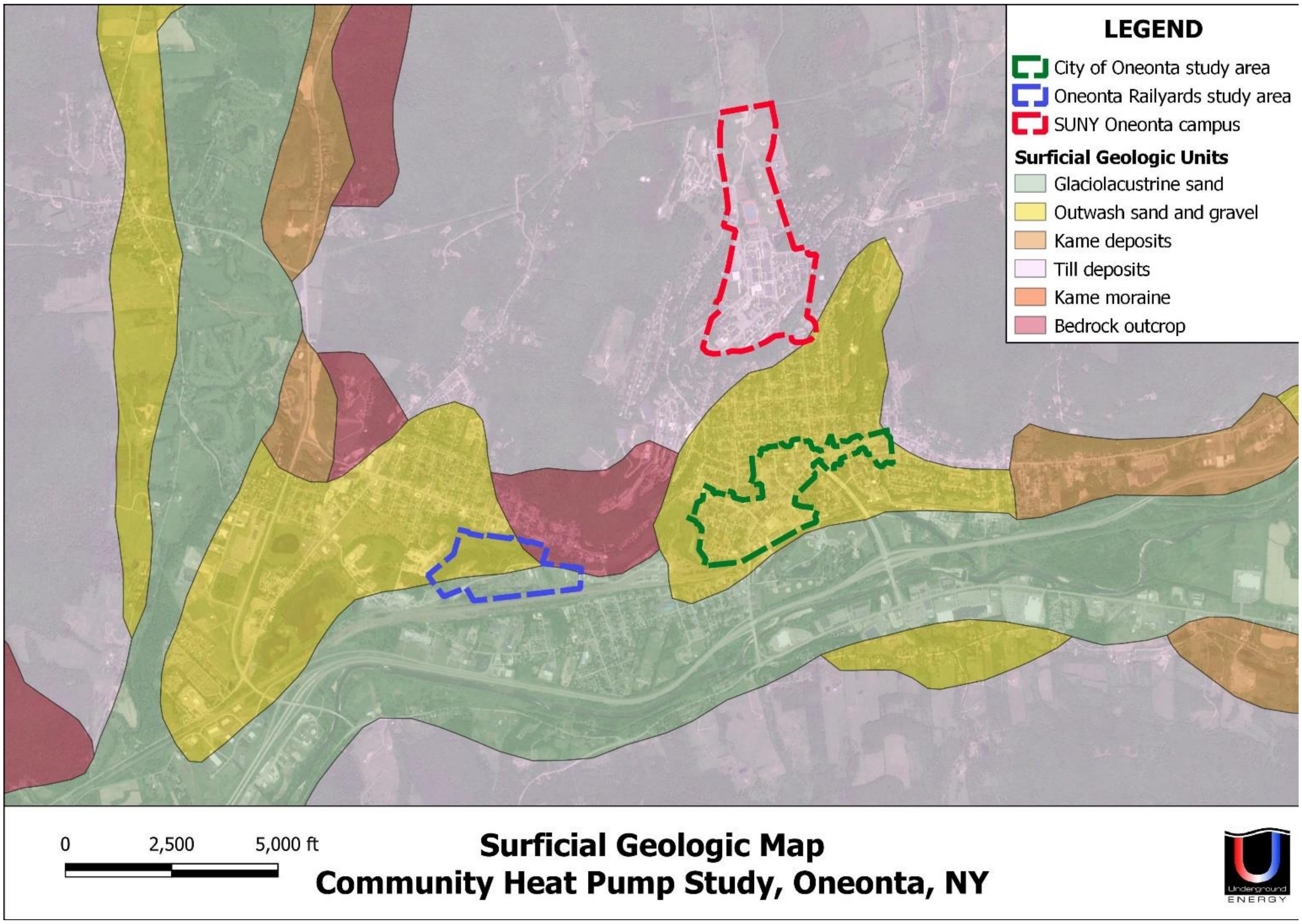


Figure 4 – Regional surficial geology

3.2 Hydrogeology

The primary hydrogeologic feature of the Oneonta area is the glacial aquifer that occurs within the Susquehanna River valley and its tributaries where glacial deposits filled the valley with more than 400 feet of fine- to course-grained sediments during glacial retreat. A map depicting the extent of the glacial aquifer is provided as Figure 5. Figure 6 is a north-south geologic cross section reproduced from Heisig and Fleisher (2022) near the Oneonta community heat pump study area. These figures and the well logs from which they were constructed depict a complex system of highly permeable glacial sand and gravel deposits adjacent to valley walls and overlain by less permeable glaciolacustrine deposits. The data suggest that the sand and gravel deposits in some areas are present to depths over 400 feet. Highly permeable and transmissive esker deposits may be present in at the very bottom of the bedrock valley.

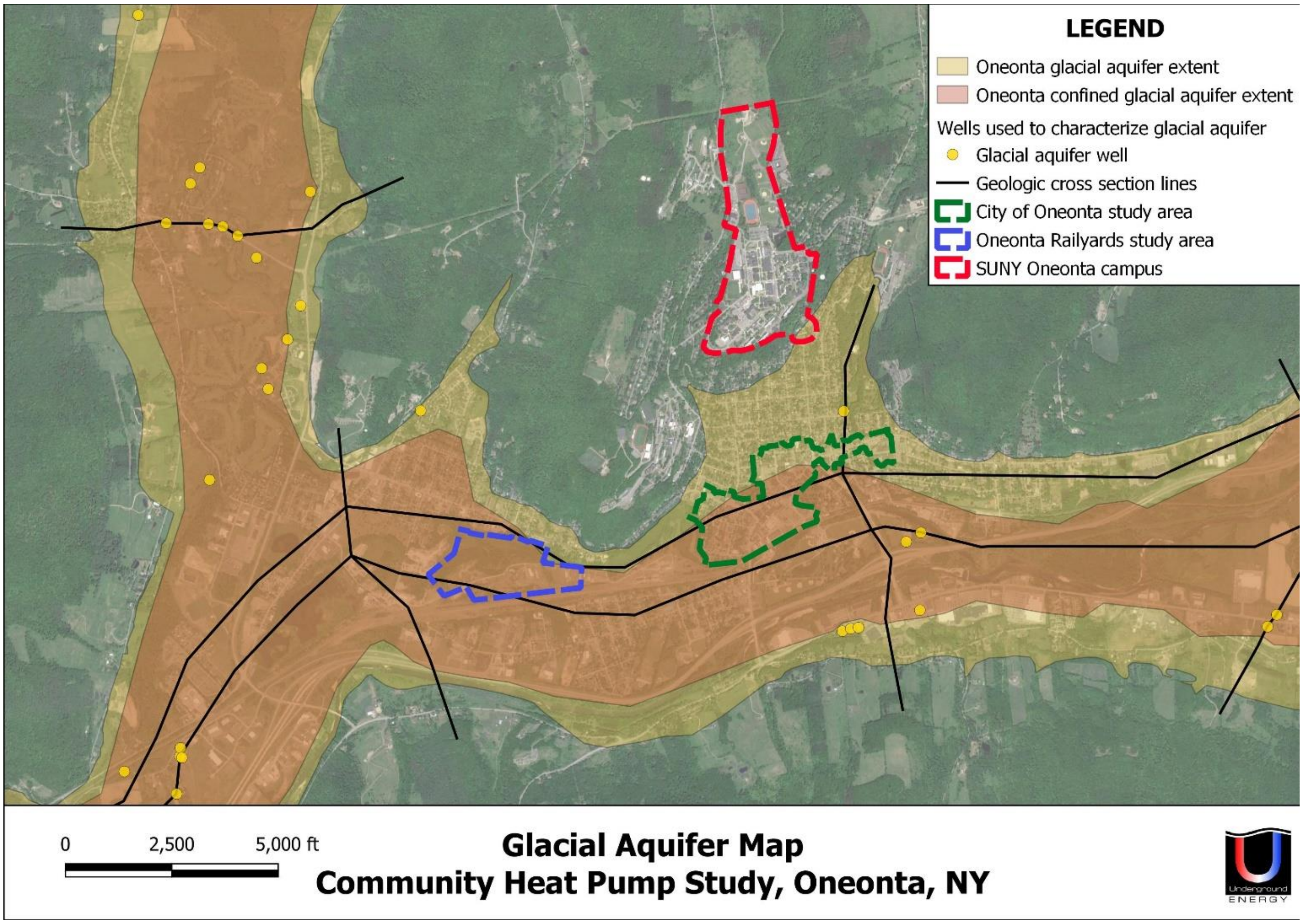


Figure 5 - Glacial aquifer map showing confined and unconfined aquifer extents

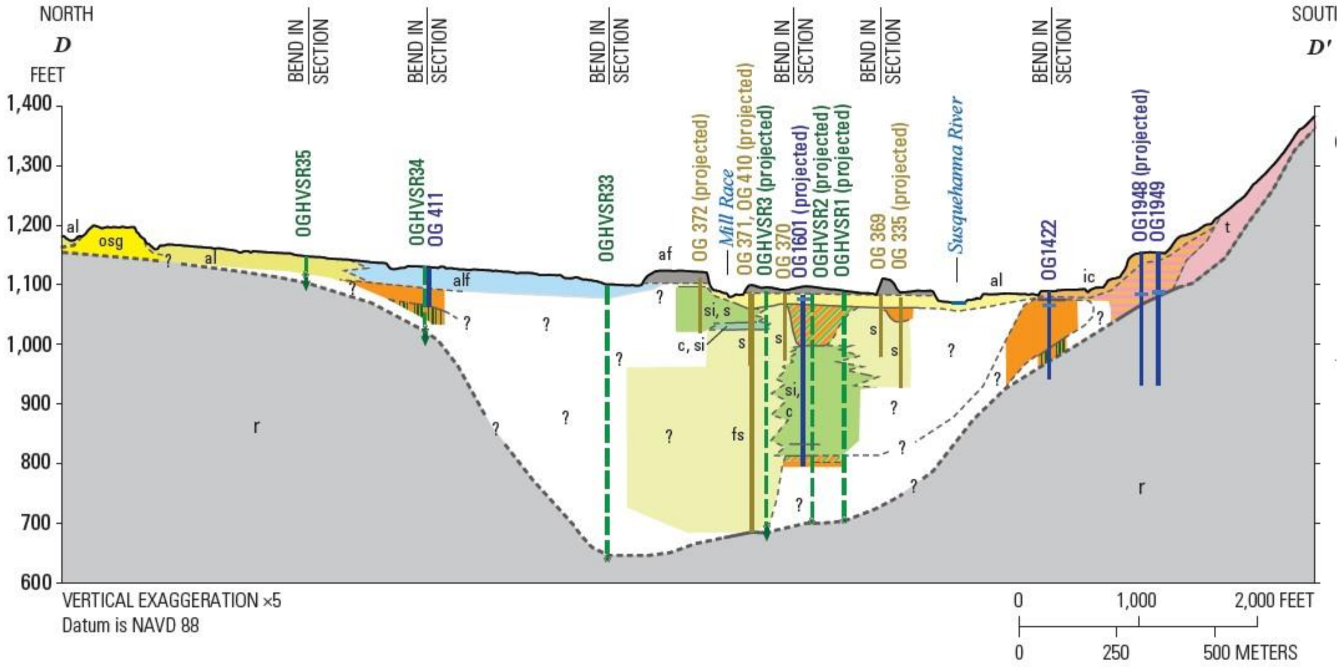


Figure 6 - Geologic cross section D-D' at Oneonta community heat pump study area

Our evaluation of available well specific capacity data and pumping test results indicated high to very high hydraulic conductivity values along with sufficient saturated thickness that could support Aquifer Thermal Energy Storage (ATES) at system flow rates of 250 gpm or more per well couplet.

3.3 Geochemistry

Groundwater in this hydrogeologic setting is characterized by freshwater in the surficial and uppermost bedrock units, with increasing salinity with depth within the shale bedrock. Moderate to elevated iron and manganese concentrations are characteristic of groundwater in glacial deposits.

Localized contamination of soil and groundwater from releases of oil and hazardous materials can complicate or render infeasible geothermal development projects. No geochemical conditions have been identified that would materially affect a closed-loop geothermal project.

Geochemical conditions can impair open-loop geothermal systems if well screens become fouled by precipitates. Best practices for open-loop geothermal systems are to minimize any oxygenation of the well system water, either from operation or by pumping oxygenated groundwater, because dissolved minerals can oxidize and precipitate in the presence of oxygen. As such, it is important to design and manage a well system to maintain reducing conditions and avoid withdrawal of near-surface groundwater that contains dissolved oxygen from near the water table and from induced infiltration from streams. Given the narrow (~3,500 feet wide) channel in which the confined portion of the glacial aquifer exists, along with the complex aquifer geometry and hydraulics, it may be difficult to avoid introduction of oxidizing groundwater at higher well system flow rates in relatively shallow wells. Geochemical conditions for open-loop applications are expected to improve with depth.

3.4 Subsurface Thermal Properties and Heat Transfer

A 500-foot-deep geothermal test bore was installed, and a thermal response test performed at the SUNY Oneonta Alumni Center in 2019. Those reported test results are summarized below in Table 1.

Table 1 - Thermal Response Test results from nearby geothermal test bore

Project	Well Depth (ft)	Thermal Conductivity (Btu/h·ft·°F)	Thermal Diffusivity (ft^2/d)	Formation Temperature (°F)
SUNY Oneonta Alumni Hall	500	1.76	1.33	49.8 – 51.2

UE's evaluation of Earth-coupling options will be performed in the context of two paradigms for how an Earth couple's function is considered: the Earth couple can be a heat source/sink, or, at scale, it can be a large thermal battery. The evaluation and selection of an optimized Earth couple requires an understanding of site-specific hydrogeologic conditions with respect to subsurface heat transfer by conduction and advection mechanisms. Advection-dominant hydrogeologic settings (permeable aquifers and high groundwater flux) are not well suited for seasonal thermal storage, but they can be highly effective as a heat sink/source. Conduction dominates in low permeability formations where groundwater flux and advective heat flow are minimal; and therefore, favorable conditions will exist for seasonal thermal energy storage.

The hydrogeologic data in Oneonta suggest that advective heat transfer from groundwater flow will be significant in the more permeable portions of the glacial aquifer, and insignificant in bedrock. Accordingly, all areas in Oneonta should be suitable for closed-loop geothermal systems. For open-loop systems, the high groundwater flux may limit seasonal storage efficiency for ATES systems, although high well flow rates could provide for substantial thermal capacity from a small number of wells.

3.5 Ground Conditions at the Study Areas

The SUNY Oneonta campus does not overlie an aquifer. The thermal response test from their 500-foot-deep geothermal test bore yielded a relatively high value of thermal conductivity. The thermal properties are significantly better than many other locations in upstate New York, where shale bedrock typically yield thermal conductivity values of 1.0 to 1.2 Btu/h·ft·°F. The boring log for this geothermal bore depicted 137 feet of glacial till overlying 43 feet of soft shale/clay, with the remainder of the bore in gray shale to its 500-foot completion depth. The relatively high thermal conductivity at this location suggests the bedrock there likely contains siltstone, sandstone, or conglomerate, as these rock types have more quartz and less clay than shale, which would improve formation thermal conductivity. Furthermore, because groundwater flux through the till and bedrock at SUNY Oneonta is expected to be minimal, ground conditions are very good for Borehole Thermal Energy Storage (BTES).

The Oneonta Railyards and City of Oneonta study areas both overlie the glacial aquifer and thus could utilize closed-loop or open-loop geothermal systems. Bedrock thermal properties in these areas should be similar to those reported at SUNY Oneonta. High groundwater flux in the glacial aquifer will also improve heat transfer to and from closed-loop geothermal bores, although seasonal storage efficiency will be decreased due to advective heat transport by groundwater flow.

4.0 Hydrogeologic and Seasonal Storage Evaluation of ATES and BTES

4.1 ATES Evaluation

UE evaluated potential applicability of ATES and BTES separately for the City of Oneonta, Oneonta Railyards, and SUNY Oneonta. Because the glacial aquifer is not present at the upland SUNY Oneonta campus location, ATES is not feasible there.

UE is of the opinion that ATES is technically feasible at the City of Oneonta and Oneonta Railyards locations based on aquifer hydraulics and system sizing, however, given the small size and highly complex nature of the glacial aquifer, it will be difficult and costly to characterize the aquifer sufficiently to ensure a reliable and efficient storage system design. Therefore, only closed-loop GHX options were considered in the conceptual GHX design for all three sites.

4.2 BTES Evaluation

In this report, we differentiate between a GHX and BTES as follows:

- GHX is synonymous with Earth couple and may involve any thermal interface between a geothermal system and the ground. The GHX may be designed to use the Earth as a heat sink or source, or as a thermal battery, or both.
- BTES is a type of large-scale closed-loop GHX designed as a thermal battery, to be charged and discharged seasonally.

The City of Oneonta and Oneonta Railyards sites both overlies the glacial aquifer. UE estimates that at these locations that the uppermost 30% to 50% of the 500-ft-deep borefield will be penetrate saturated silt, sand and gravel while the deeper portions of the borefield will be completed in shale. Conductive heat transfer and good conditions for seasonal storage will dominate the lower BTES field in shale, while advective heat transfer via groundwater flow will be the dominant heat transfer mechanism in the portion of the GHX that penetrates the glacial aquifer. The benefit of the glacial aquifer is that the GHX will have a higher thermal capacity than conduction-based design models predict, therefore it will be more resilient to imbalanced loads due to the “flushing” of excess heat or cold from the GHX by flowing groundwater, while a large volume of shale bedrock can store heat seasonally.

The SUNY Oneonta BTES would be completed entirely in shale bedrock, with good conditions for seasonal storage when the thermal loads at the borefield are annually balanced.

5.0 Conceptual GHX Design

UE developed a conceptual closed-loop GHX design for each site. A common Borehole Heat Exchanger (BHX) design was used for all sites:

- 6-in diameter bores in a hexagonal pattern;
- 1.25-in SDR 11 HDPE U-bend BHX; and
- 25% ethanol antifreeze solution.

A summary of the sizing and performance data for City of Oneonta, Oneonta Railyards and SUNY Oneonta concept design GHXs is presented below in Table 2.

Table 2 - Summary of GHX Sizing and Modeled Performance Data

Location	Oneonta City	Oneonta Railyards	SUNY Oneonta
No. Bores	344	75	225
Borefield Geometry	8 x 43	5 x 10	15 x 15
Bore Depth (ft)	350	500	500
Total Bore Length (ft)	120400	37500	112500
Bore Spacing (ft)	15	20	20
Ground Thermal Conductivity (Btu/h·ft·°F)	2.0	1.3	1.76
Grout / Backfill Thermal Conductivity (Btu/h·ft·°F)	1.8	1.2	1.2
Average Ground Temperature (°F)	50.6	50.6	50.6
Maximum Supply Temperature (°F)	50	80.9	60.6
Minimum Supply Temperature (°F)	36	45.8	33.0
Max. Recharge Specific Thermal Capacity (Btu/h·ft)	NA	101	95
Max. Discharge Specific Thermal Capacity (Btu/h·ft)	-104.6	-100	-100
Maximum Borefield Thermal Capacity (tons)	1049	313	938
Maximum Borefield Thermal Capacity (MW)	3.7	1.1	3.3

5.1 City of Oneonta

Ramboll's GHX load profile for City of Oneonta is highly imbalanced, only extracting heat from the ground between January into April, as shown in Figure 7. The heating-only load at the GHX reflects Ramboll's recommended approach that utilizes waste heat from the wastewater treatment plant for most of the year, supplemented by geothermal heat pumps during when supply from the plant alone is insufficient to meet modeled building loads. Given the imbalanced loads, UE recommends a GHX design that maximizes heat transfer by groundwater flow in the glacial aquifer. The operating principal assumes that if the bores are completed entirely in the permeable portions of the glacial aquifer, then groundwater flow will "wash away" a cold water plume that will be created in the aquifer by the during winter months, such that the GHX will begin the next heating season back at the ambient aquifer temperature of about 50 °F. This would require an average groundwater velocity in the borefield of greater than about 0.4 ft/d if the long axis of the borefield is oriented perpendicular to groundwater flow, a value that is exceeded in most glacial valley-fill aquifers. To optimize advective heat transfer UE recommends that, rather than using a thermally enhanced grout in the boreholes, the bores should be backfilled by allowing the glacial formation to naturally collapse into the borehole, which will allow groundwater to flow directly past the U-bend pipe, increasing heat transfer. Alternative borehole heat exchanger designs such as concentric (Rygan) or the Darcy heat exchanger could further enhance heat transfer and thermal capacity of the borefield.

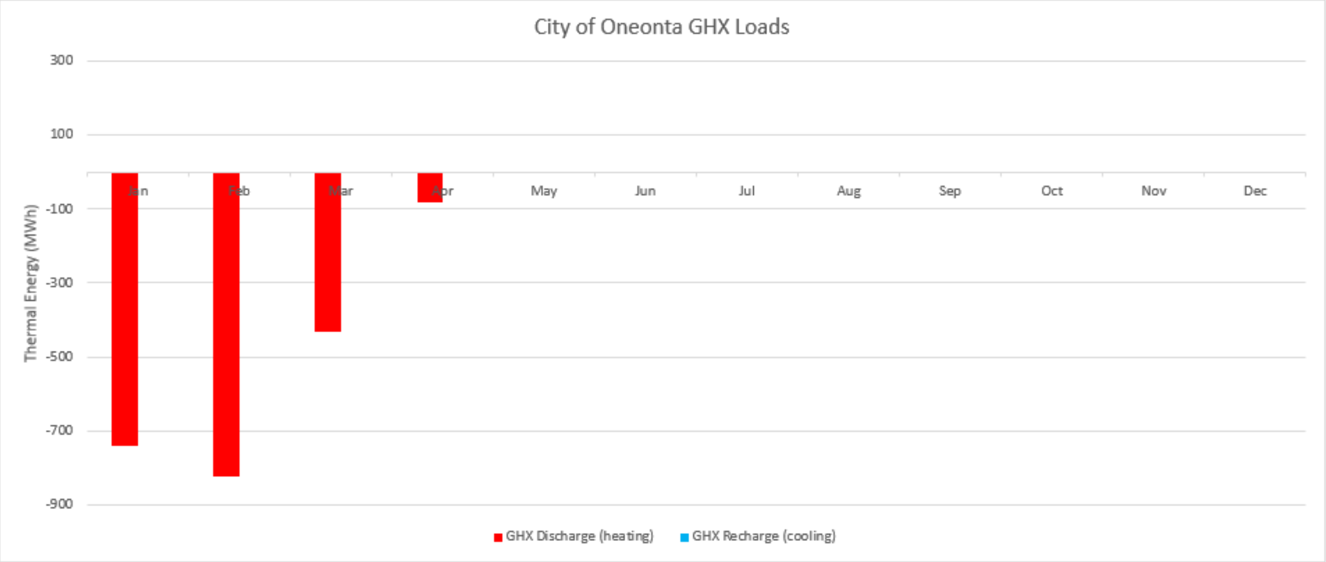


Figure 7 - Imbalanced heating-only GHX discharge loads for City of Oneonta

The simulated one-year supply temperatures for City of Oneonta/ Neahwa Park are depicted below in Figure 8. Figure 9 depicts a conceptual layout of the City of Oneonta GHX in Neahwa Park.

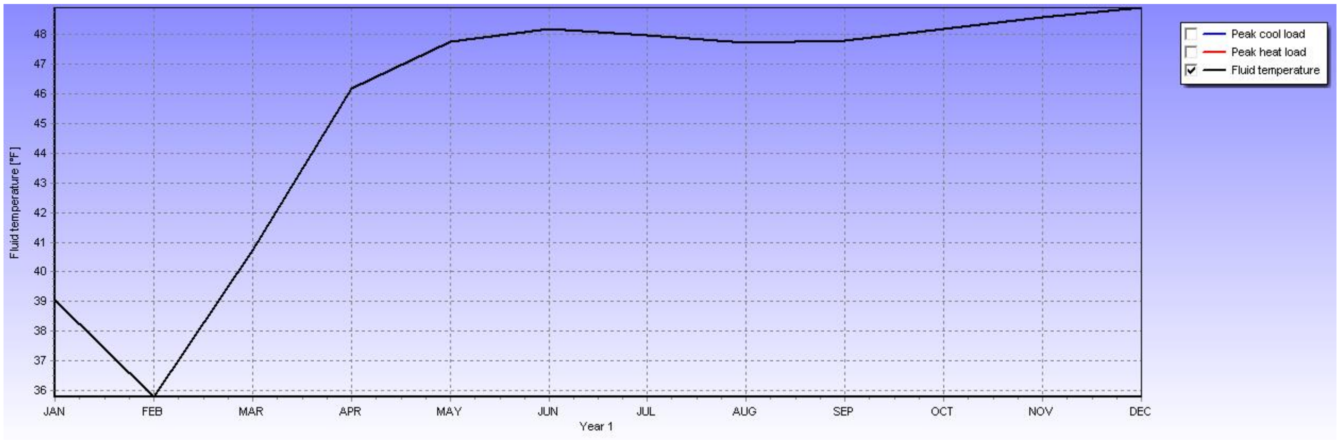


Figure 8 - City of Oneonta modeled GHX temperatures

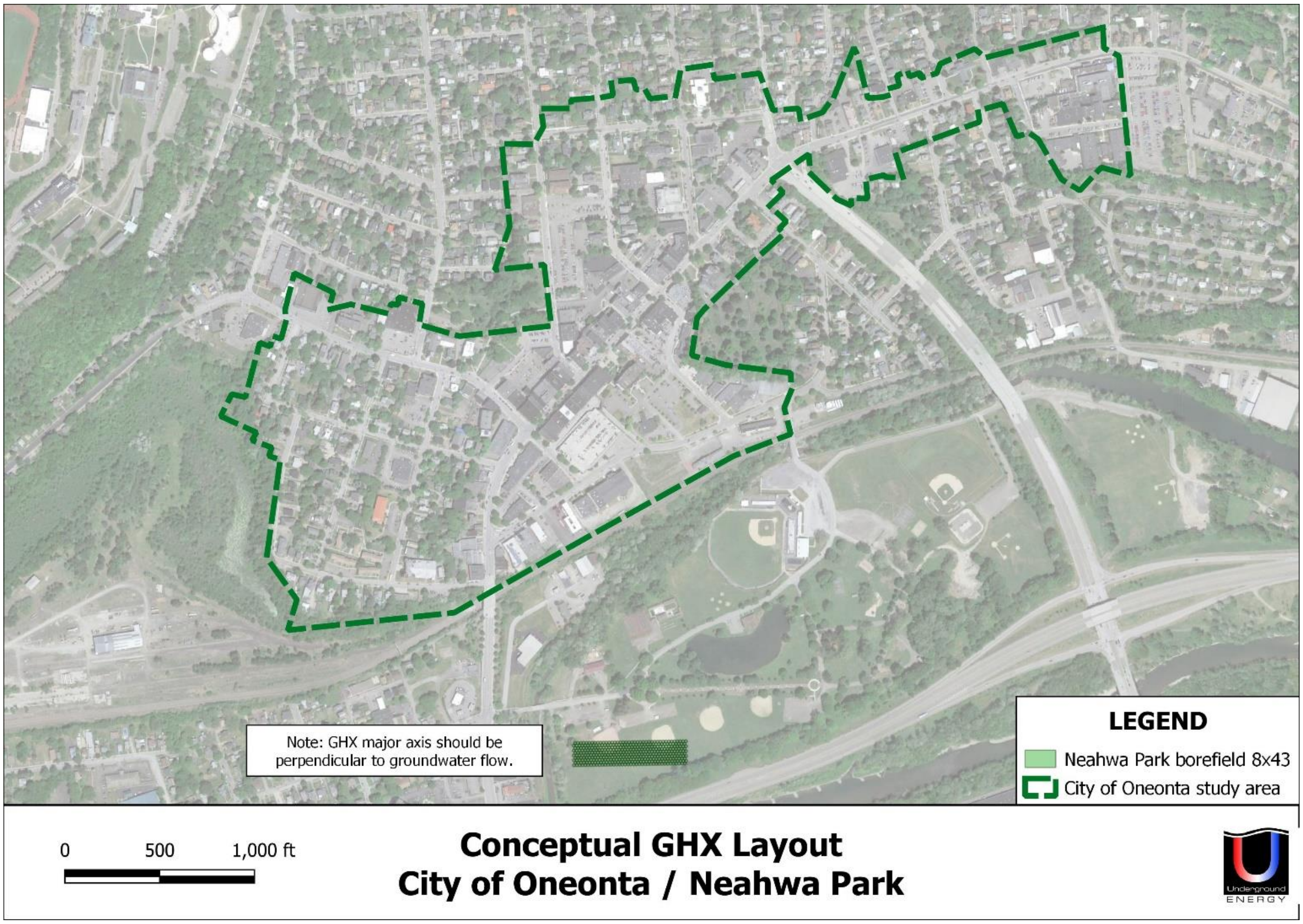


Figure 9 - City of Oneonta/ Neahwa Park conceptual GHX layout

5.2 Oneonta Railyards

Figure 10 summarizes the base GHX load estimates provided by Ramboll for the Oneonta Railyards site; base and peak loads are summarized in Table 3. The load is cooling dominant due to process heat rejection in addition to HVAC loads. This GHX could operate without antifreeze, or it could be integrated with other systems in Oneonta that require additional heat input.

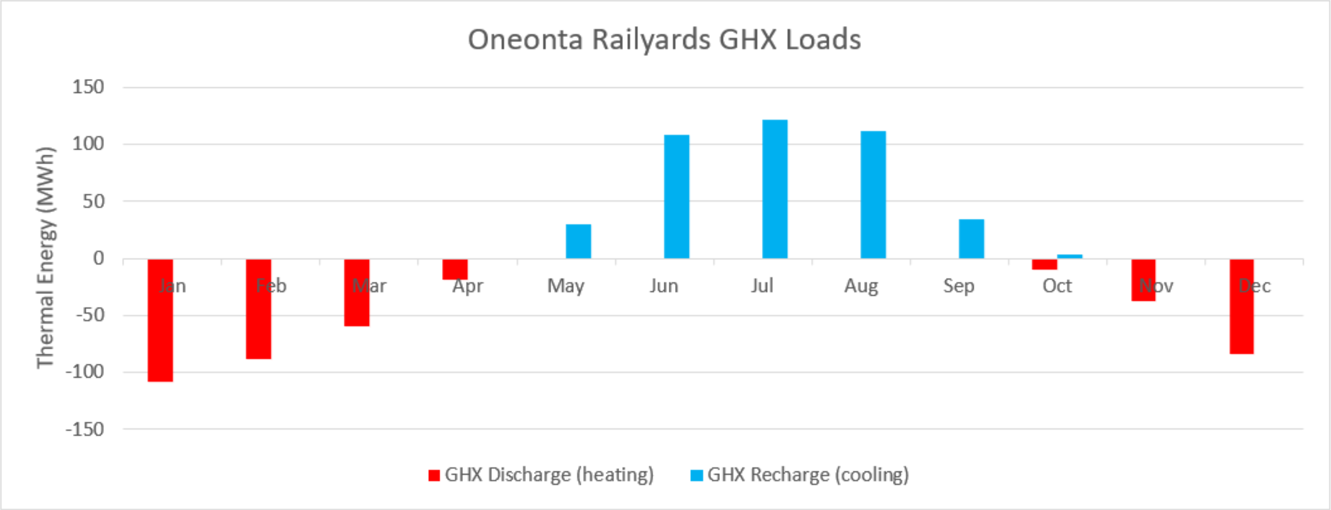


Figure 10 - Imbalanced GHX charge and discharge loads at Oneonta Railyards

Table 3 - Estimated base and peak loads for Oneonta Railyards

Monthly Loads at GHX

	Base Loads		**Peak Loads**			
Month	GHX Discharge (heating) (MWh)	GHX Recharge (cooling) (MWh)	GHX Discharge (heating) (kW)	Duration (hr)	GHX Recharge (cooling) (kW)	Duration (hr)
Jan	-109	0	225	472	0	0
Feb	-88	0	225	375	0	0
Mar	-59	0	225	253	0	0
Apr	-19	0	225	80	0	0
May	0	30	0	0	221	48
Jun	0	108	0	0	221	168
Jul	0	121	0	0	221	183
Aug	0	111	0	0	221	175
Sep	0	35	0	0	221	53
Oct	-10	3	225	40	0	0
Nov	-38	0	225	162	0	0
Dec	-84	0	225	356	0	0
Totals	**-407**	**407**	**1574**		**1107**	**627**

The simulated supply temperatures and 25-year min/max temperature trends for Oneonta Railyards are depicted below in Figure 11 and Figure 12.

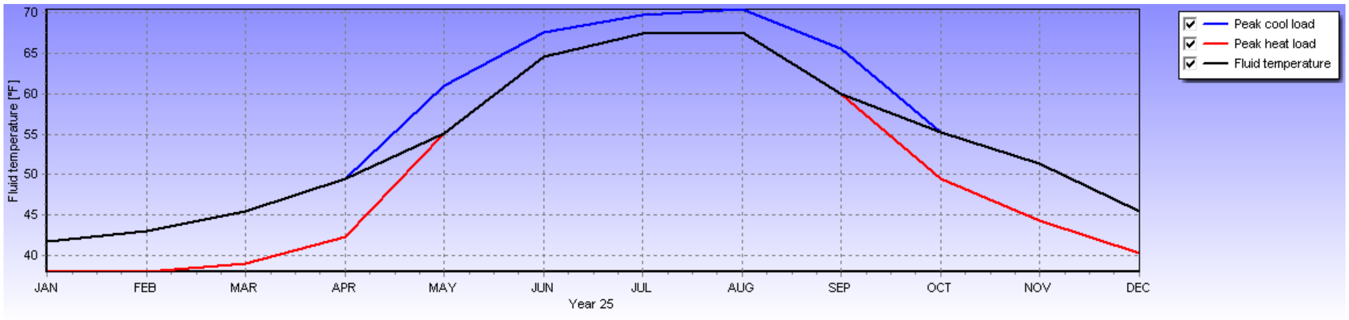


Figure 11 - Oneonta Railyards modeled GHX temperatures

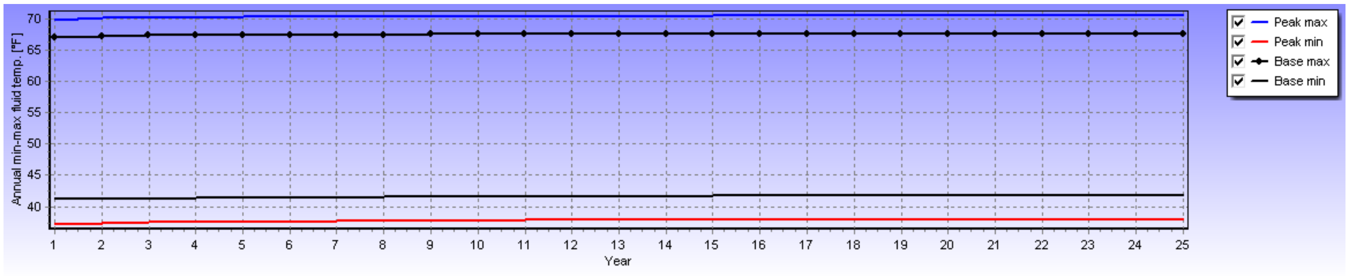


Figure 12 - Oneonta Railyards minimum and maximum supply temperature 25-year trend

Figure 13 - Oneonta Railyards conceptual GHX layout

5.3 SUNY Oneonta

Figure 14 summarizes the BTES load estimates for SUNY Oneonta provided by Ramboll. The load is about 10% heating (discharge) dominant.

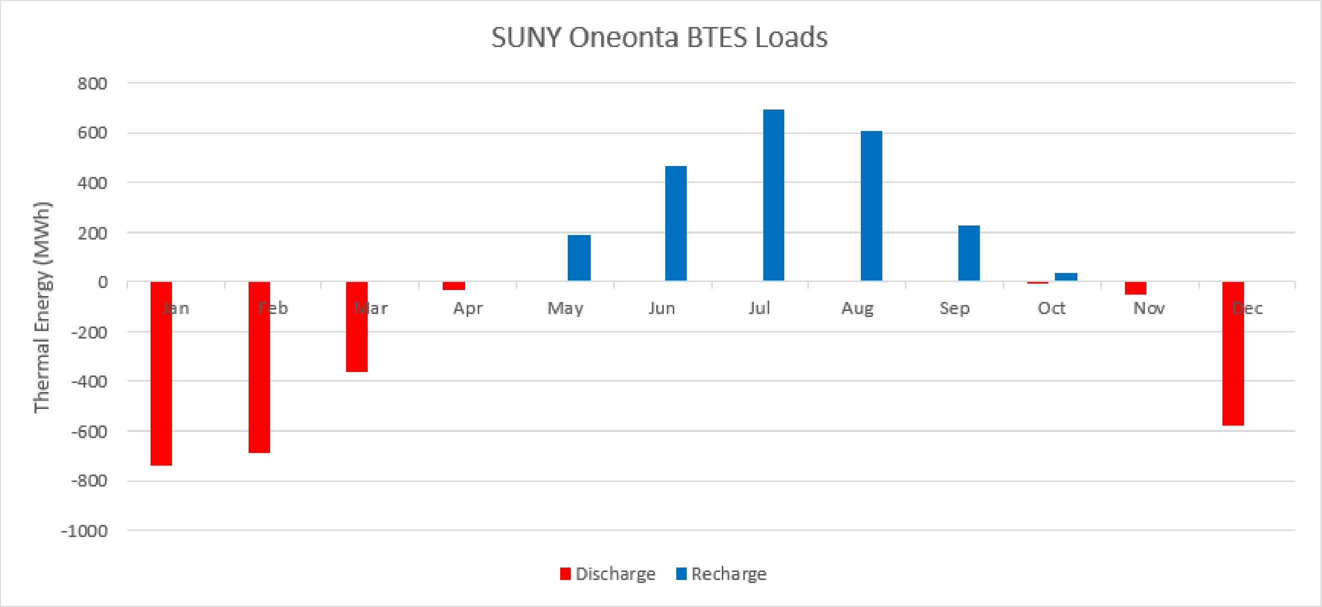


Figure 14 - Charging and Discharging Thermal Loads to BTES at SUNY Oneonta

The simulated supply temperatures and 25-year min/max temperature trends for SUNY Oneonta are depicted below in Figure 15 and Figure 16.

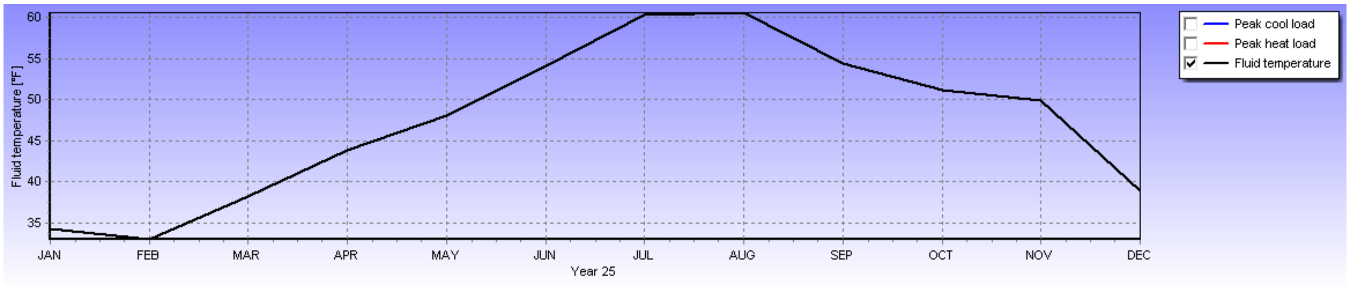


Figure 15 - SUNY Oneonta modeled BTES temperatures

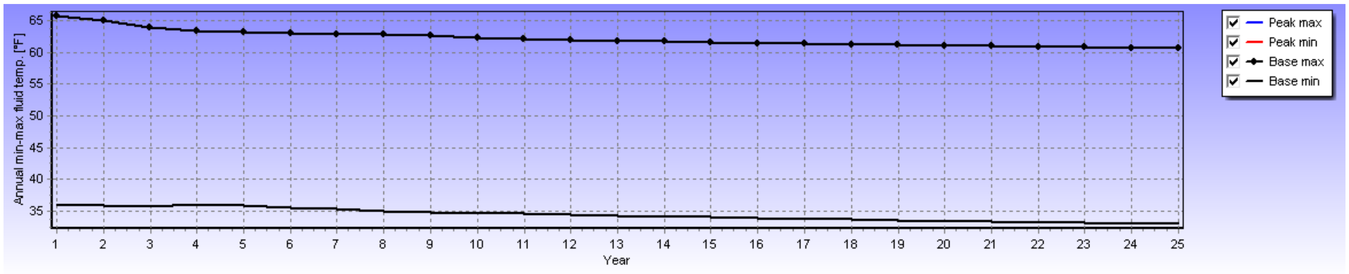


Figure 16 - SUNY Oneonta minimum and maximum supply temperature 25-year trend

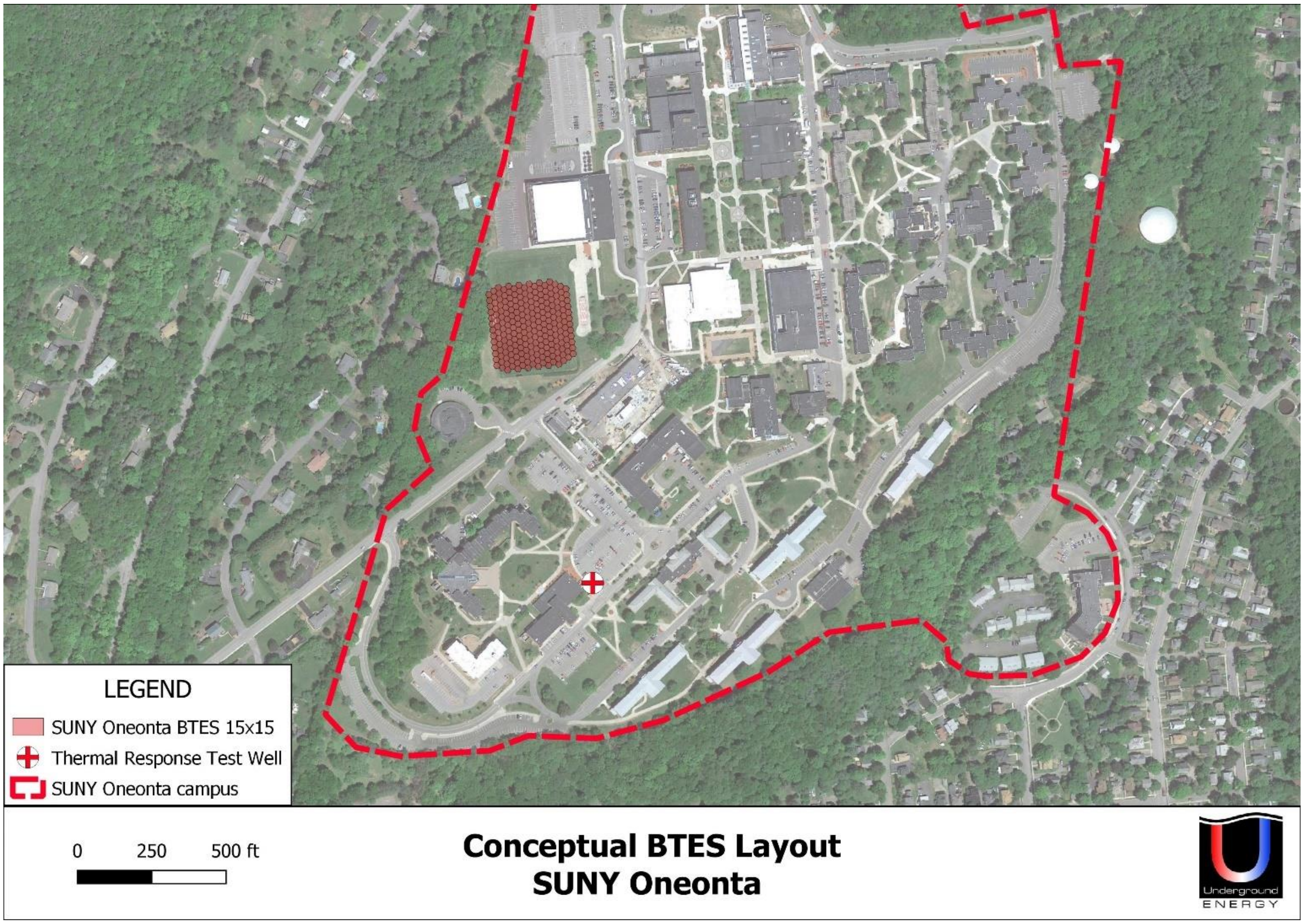


Figure 17 - SUNY Oneonta conceptual BTES borefield layout

6.0 References

City of Oneonta Department of Engineering, 2015, Aquifer testing plan Catella Wells #1 and #2.

Geothermal Resource Technologies Inc., April 2019, Formation thermal conductivity test and data analysis, SUNY Oneonta, Alumni Hall, Oneonta, NY.

Heisig, P.M., and Fleisher, P.J., 2022, Glacial geology and hydrogeology of valley-fill aquifers in the Oneonta area, Otsego and Delaware Counties, New York: U.S. Geological Survey Scientific Investigations Report 2022–5069, 35 p., 1 pl., https://doi.org/10.3133/sir20225069.

Heisig, P.M., and Izdebski, M.A., 2022, Horizontal-to-vertical spectral ratio soundings and depth-to-bedrock data for valley-fill aquifers in the Oneonta area, Otsego and Delaware Counties, New York, 2016 - 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P92NSO7T.

Heisig, P.M., and Fleisher, P.J., 2022, Geospatial datasets of the glacial geology and hydrogeology of valley-fill aquifers in the Oneonta area, Otsego and Delaware Counties, New York: U.S. Geological Survey data release, https://doi.org/10.5066/P9RCQS14.

Appendix A

EED Output Reports

```
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ONEONTA V1 US UNITS.DAT
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MEMORY NOTES FOR PROJECT
[]

QUICK FACTS
  Cost                              -
  Number of boreholes                    344
  Borehole depth                      350 ft
  Total borehole length                 1.204E5 ft


              D E S I G N    D A T A
              ======================

GROUND

  Ground thermal conductivity             2 Btu/(h·ft·°F)
  Ground heat capacity                34.29 Btu/(ft³·°F)
  Ground surface temperature              50.59 °F
  Geothermal heat flux                0.016 Btu/(h·ft²)

BOREHOLE

  Configuration:                      547 ("344 : 8 x 43 rectangle")
  Borehole depth                      350 ft
  Borehole spacing                     20 ft
  Borehole installation                 Single-U
  Borehole diameter                     5.98 inch
  U-pipe diameter                      1.66 inch
  U-pipe thickness                     0.15 inch
  U-pipe thermal conductivity             0.24 Btu/(h·ft·°F)
  U-pipe shank spacing                   3.15 inch
  Filling thermal conductivity            1.8 Btu/(h·ft·°F)
  Contact resistance pipe/filling         0.017 (h·ft·°F)/Btu

THERMAL RESISTANCES

  Borehole thermal resistances are calculated.
  Number of multipoles                    10
  Internal heat transfer between upward and downward channel(s) is considered.

HEAT CARRIER FLUID

  Thermal conductivity                    0.25 Btu/(h·ft·°F)
  Specific heat capacity                 1.02 Btu/(lb·°F)
  Density                           59.93 lb/ft³
  Viscosity                         0.0051 lb/(ft·s)
  Freezing point                       5 °F
  Flow rate per borehole                 7.93 US gal/min
```

```
BASE LOAD

  Seasonal performance factor (DHW)         1
  Seasonal performance factor (heating)    9999
  Seasonal performance factor (cooling)    9999

  Monthly energy values [MBtu]
  Month        Heat load      Cool load   Ground load
   JAN          2521            0        2521
   FEB          2803            0        2803
   MAR          1478            0        1478
   APR           278            0         278
   MAY             0            0           0
   JUN             0            0           0
   JUL             0            0           0
   AUG             0            0           0
   SEP             0            0           0
   OCT             0            0           0
   NOV             0            0           0
   DEC             0            0           0
           -------       ------     -------
   Total        7080            0        7079

PEAK LOAD

  Monthly peak powers [kBtu/h]
  Month         Peak heat    Duration     Peak cool   Duration [h]
   JAN            0          0            0         0
   FEB            0          0            0         0
   MAR            0          0            0         0
   APR            0          0            0         0
   MAY            0          0            0         0
   JUN            0          0            0         0
   JUL            0          0            0         0
   AUG            0          0            0         0
   SEP            0          0            0         0
   OCT            0          0            0         0
   NOV            0          0            0         0
   DEC            0          0            0         0

  Number of simulation years              1
  First month of operation              JAN


            C A L C U L A T E D   V A L U E S
            ==================================

  Total borehole length                 1.204E5 ft


THERMAL RESISTANCES

  Borehole therm. res. internal          0.58 (h·ft·°F)/Btu
```

```
  Reynolds number                      2329
  Thermal resistance fluid/pipe          0.02632 (h·ft·°F)/Btu
  Thermal resistance pipe material         0.1306 (h·ft·°F)/Btu
  Contact resistance pipe/filling        0.0173 (h·ft·°F)/Btu

  Borehole therm. res. fluid/ground        0.1424 (h·ft·°F)/Btu

  Effective borehole thermal res.        0.1471 (h·ft·°F)/Btu

 SPECIFIC HEAT EXTRACTION RATE [Btu/(h·ft)]

  Month         Base load    Peak heat   Peak cool
   JAN          94.09          0          0
   FEB          104.6          0          0
   MAR            55.17          0          0
   APR           10.38          0          0
   MAY               0          0          0
   JUN             0          0          0
   JUL             0          0          0
   AUG              0          0          0
   SEP             0          0          0
   OCT              0          0          0
   NOV              0          0          0
   DEC              0          0          0

 BASE LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

   Year       1
   JAN     39.03
   FEB     35.79
   MAR      40.73
   APR     46.19
   MAY      47.76
   JUN     48.19
   JUL     47.97
   AUG      47.7
   SEP     47.78
   OCT     48.16
   NOV      48.56
   DEC     48.89

  BASE LOAD: YEAR  1
  Minimum mean fluid temperature  35.79 °F at end of FEB
  Maximum mean fluid temperature  48.89 °F at end of DEC


 PEAK HEAT LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

   Year       1
   JAN     39.03
   FEB     35.79
   MAR      40.73
   APR     46.19
```

```
  MAY     47.76
  JUN    48.19
  JUL    47.97
  AUG     47.7
  SEP    47.78
  OCT    48.16
  NOV     48.56
  DEC    48.89

 PEAK HEAT LOAD: YEAR  1
 Minimum mean fluid temperature  35.79 °F at end of FEB
 Maximum mean fluid temperature  48.89 °F at end of DEC


PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

  Year       1
  JAN    39.03
  FEB    35.79
  MAR     40.73
  APR    46.19
  MAY     47.76
  JUN    48.19
  JUL    47.97
  AUG     47.7
  SEP    47.78
  OCT    48.16
  NOV     48.56
  DEC    48.89

 PEAK COOL LOAD: YEAR  1
 Minimum mean fluid temperature  35.79 °F at end of FEB
 Maximum mean fluid temperature  48.89 °F at end of DEC
```

```
EED 3.22 - www.buildingphysics.com - license for mark.worthington@underground-energy.com
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Railyards V1 US UNITS.DAT
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MEMORY NOTES FOR PROJECT
[]

QUICK FACTS
  Cost                                   -
  Number of boreholes                    50
  Borehole depth                      498.7 ft
  Total borehole length               2.494E4 ft


                D E S I G N   D A T A
                =====================

GROUND

  Ground thermal conductivity              1.3 Btu/(h·ft·°F)
  Ground heat capacity                   34.29 Btu/(ft³·°F)
  Ground surface temperature             50.59 °F
  Geothermal heat flux                   0.016 Btu/(h·ft²)

BOREHOLE

  Configuration:                      382 ("50 : 5 x 10 rectangle")
  Borehole depth                      498.7 ft
  Borehole spacing                      20 ft
  Borehole installation                 Single-U
  Borehole diameter                     5.98 inch
  U-pipe diameter                       1.66 inch
  U-pipe thickness                      0.15 inch
  U-pipe thermal conductivity              0.24 Btu/(h·ft·°F)
  U-pipe shank spacing                     3.15 inch
  Filling thermal conductivity             1.2 Btu/(h·ft·°F)
  Contact resistance pipe/filling          0.017 (h·ft·°F)/Btu

THERMAL RESISTANCES

  Borehole thermal resistances are calculated.
  Number of multipoles                   10
  Internal heat transfer between upward and downward channel(s) is considered.

HEAT CARRIER FLUID

  Thermal conductivity                     0.25 Btu/(h·ft·°F)
  Specific heat capacity                   1.02 Btu/(lb·°F)
  Density                             59.93 lb/ft³
  Viscosity                           0.0051 lb/(ft·s)
  Freezing point                          5 °F
  Flow rate per borehole                  7.93 US gal/min
```

```
BASE LOAD

 Seasonal performance factor (DHW)        1
 Seasonal performance factor (heating)    9999
 Seasonal performance factor (cooling)    9999

 Monthly energy values [MBtu]
 Month       Heat load     Cool load   Ground load
  JAN        372.1           0       372.1
  FEB        300.5           0       300.4
  MAR         201.4           0       201.4
  APR        64.87           0       64.86
  MAY            0        102.4      -102.4
  JUN          0        372.1      -372.2
  JUL          0        416.5      -416.6
  AUG           0        382.4      -382.4
  SEP          0        119.5      -119.5
  OCT        34.14        10.24        23.9
  NOV         129.7           0       129.7
  DEC        286.8           0       286.8
          -------       ------     -------
  Total      1390         1403      -13.94

PEAK LOAD

 Monthly peak powers [kBtu/h]
 Month        Peak heat   Duration     Peak cool   Duration [h]
  JAN        767.5        15           0        0
  FEB        767.5        13           0        0
  MAR         767.5        8           0        0
  APR        767.5        3           0        0
  MAY            0        0       755.9        2
  JUN          0        0       755.9        6
  JUL          0        0       755.9        6
  AUG           0        0       755.9        6
  SEP          0        0       755.9        2
  OCT        767.5        1           0        0
  NOV         767.5        5           0        0
  DEC        767.5        11           0        0

 Number of simulation years             25
 First month of operation              JAN


            C A L C U L A T E D   V A L U E S
            ===================================

 Total borehole length                 2.494E4 ft


THERMAL RESISTANCES

 Borehole therm. res. internal            0.7 (h·ft·°F)/Btu
```

```
  Reynolds number                          2337
  Thermal resistance fluid/pipe            0.02625 (h·ft·°F)/Btu
  Thermal resistance pipe material          0.1318 (h·ft·°F)/Btu
  Contact resistance pipe/filling          0.0173 (h·ft·°F)/Btu

  Borehole therm. res. fluid/ground         0.1698 (h·ft·°F)/Btu

  Effective borehole thermal res.          0.1777 (h·ft·°F)/Btu

 SPECIFIC HEAT EXTRACTION RATE [Btu/(h·ft)]

  Month           Base load    Peak heat   Peak cool
   JAN           67.07         101          0
   FEB           54.15         101          0
   MAR             36.3         101          0
   APR            11.69         101          0
   MAY            -18.46          0      -99.47
   JUN          -67.08           0      -99.47
   JUL          -75.08           0      -99.47
   AUG           -68.93           0      -99.47
   SEP          -21.54           0      -99.47
   OCT             4.31         101          0
   NOV            23.38         101          0
   DEC            51.69         101          0

 BASE LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

   Year       1        2        5       10       25
   JAN     41.17    41.31    41.48    41.59    41.76
   FEB     42.21    42.34    42.71    42.83    43.01
   MAR      44.65    44.58    45.07    45.23    45.42
   APR     48.63    48.58    49.03    49.22    49.41
   MAY      54.35    54.33    54.67    54.87    55.06
   JUN      63.9    64.05    64.26    64.44    64.62
   JUL     66.66    67.13    67.15    67.3    67.47
   AUG      66.9    67.19    67.34    67.44    67.61
   SEP     59.37    59.42    59.69    59.76    59.92
   OCT     54.82    54.62    54.95    55.04    55.2
   NOV      51.2    50.74    51.05    51.19    51.34
   DEC     45.29    44.9    45.17    45.34    45.49

  BASE LOAD: YEAR  25
  Minimum mean fluid temperature  41.76 °F at end of JAN
  Maximum mean fluid temperature  67.61 °F at end of AUG


 PEAK HEAT LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

   Year       1        2        5       10       25
   JAN     37.42    37.56    37.73    37.84    38.01
   FEB     37.16    37.29    37.66    37.78    37.96
   MAR      38.26    38.19    38.68    38.84    39.03
   APR     41.44    41.4    41.85    42.03    42.23
```

```
  MAY     54.35     54.33     54.67     54.87     55.06
  JUN      63.9     64.05     64.26     64.44     64.62
  JUL     66.66     67.13     67.15      67.3     67.47
  AUG      66.9     67.19     67.34     67.44     67.61
  SEP     59.37     59.42     59.69     59.76     59.92
  OCT     49.02     48.82     49.15     49.24      49.4
  NOV     44.22     43.76     44.07      44.2     44.36
  DEC     40.12     39.74     40.01     40.18     40.33

 PEAK HEAT LOAD: YEAR  25
 Minimum mean fluid temperature  37.96 °F at end of FEB
 Maximum mean fluid temperature  67.61 °F at end of AUG


PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

  Year        1         2         5        10        25
  JAN     41.17     41.31     41.48     41.59     41.76
  FEB     42.21     42.34     42.71     42.83     43.01
  MAR     44.65     44.58     45.07     45.23     45.42
  APR     48.63     48.58     49.03     49.22     49.41
  MAY     60.26     60.23     60.58     60.78     60.97
  JUN     66.93     67.08     67.28     67.47     67.64
  JUL     68.94      69.4     69.43     69.58     69.75
  AUG     69.75     70.04     70.19      70.3     70.46
  SEP     65.05      65.1     65.37     65.44      65.6
  OCT     54.82     54.62     54.95     55.04      55.2
  NOV      51.2     50.74     51.05     51.19     51.34
  DEC     45.29      44.9     45.17     45.34     45.49

 PEAK COOL LOAD: YEAR  25
 Minimum mean fluid temperature  41.76 °F at end of JAN
 Maximum mean fluid temperature  70.46 °F at end of AUG
```

```
EED 3.22 - www.buildingphysics.com - license for mark.worthington@underground-energy.com
  Input file:C:\Users\markw\OneDrive\Desktop\UE\Projects\Ramboll\Oneonta\Deliverable\EED models\SUNY
ONEONTA V1 US units.DAT
  This output file: SUNY ONEONTA V1 US UNITS.OUT  Date: 9/20/2023 Time: 11:59:41 AM

MEMORY NOTES FOR PROJECT
[]

QUICK FACTS
  Cost                                -
  Number of boreholes                      225
  Borehole depth                      498.7 ft
  Total borehole length                 1.122E5 ft


               D E S I G N   D A T A
               =====================

GROUND

  Ground thermal conductivity              1.76 Btu/(h·ft·°F)
  Ground heat capacity                 34.29 Btu/(ft³·°F)
  Ground surface temperature              50.59 °F
  Geothermal heat flux                 0.016 Btu/(h·ft²)

BOREHOLE

  Configuration:                      708 ("225 : 15 x 15 rectangle")
  Borehole depth                      498.7 ft
  Borehole spacing                     20 ft
  Borehole installation                 Single-U
  Borehole diameter                     5.98 inch
  U-pipe diameter                      1.66 inch
  U-pipe thickness                     0.15 inch
  U-pipe thermal conductivity             0.24 Btu/(h·ft·°F)
  U-pipe shank spacing                    3.15 inch
  Filling thermal conductivity             1.2 Btu/(h·ft·°F)
  Contact resistance pipe/filling          0.017 (h·ft·°F)/Btu

THERMAL RESISTANCES

  Borehole thermal resistances are calculated.
  Number of multipoles                      10
  Internal heat transfer between upward and downward channel(s) is considered.

HEAT CARRIER FLUID

  Thermal conductivity                     0.25 Btu/(h·ft·°F)
  Specific heat capacity                  1.02 Btu/(lb·°F)
  Density                            59.93 lb/ft³
  Viscosity                          0.0051 lb/(ft·s)
  Freezing point                       5 °F
  Flow rate per borehole                  8 US gal/min
```

```
 BASE LOAD

  Seasonal performance factor (DHW)         1
  Seasonal performance factor (heating)     9999
  Seasonal performance factor (cooling)     9999

  Monthly energy values [MBtu]
  Month        Heat load      Cool load   Ground load
   JAN         2520           0        2519
   FEB         2359           0        2359
   MAR          1243           0        1243
   APR        105.8           0       105.8
   MAY            0         645.3      -645.4
   JUN          0         1601       -1601
   JUL          0         2359      -2359
   AUG            0         2069      -2069
   SEP          0         778.4      -778.5
   OCT        20.49        116.1      -95.61
   NOV          181            0       180.9
   DEC         1980            0        1980
          -------        ------     -------
   Total       8409          7569       838.3

 PEAK LOAD

  Monthly peak powers [kBtu/h]
  Month         Peak heat    Duration     Peak cool   Duration [h]
   JAN           0          0            0         0
   FEB           0          0            0         0
   MAR             0          0            0         0
   APR           0          0            0         0
   MAY             0          0            0         0
   JUN           0          0            0         0
   JUL           0          0            0         0
   AUG             0          0            0         0
   SEP           0          0            0         0
   OCT           0          0            0         0
   NOV             0          0            0         0
   DEC           0          0            0         0

  Number of simulation years              25
  First month of operation               JAN


             C A L C U L A T E D   V A L U E S
             ===================================

  Total borehole length                  1.122E5 ft


 THERMAL RESISTANCES

  Borehole therm. res. internal           0.67 (h·ft·°F)/Btu
```

```
  Reynolds number                    2350
  Thermal resistance fluid/pipe          0.02613 (h·ft·°F)/Btu
  Thermal resistance pipe material        0.1306 (h·ft·°F)/Btu
  Contact resistance pipe/filling        0.0173 (h·ft·°F)/Btu

  Borehole therm. res. fluid/ground       0.1682 (h·ft·°F)/Btu

  Effective borehole thermal res.        0.1762 (h·ft·°F)/Btu

 SPECIFIC HEAT EXTRACTION RATE [Btu/(h·ft)]

  Month         Base load    Peak heat   Peak cool
   JAN          100.9          0          0
   FEB          94.49          0          0
   MAR            49.77          0          0
   APR            4.24          0          0
   MAY           -25.85          0          0
   JUN          -64.14          0          0
   JUL          -94.5          0          0
   AUG           -82.88          0          0
   SEP          -31.18          0          0
   OCT            -3.83          0          0
   NOV             7.25          0          0
   DEC            79.31          0          0

 BASE LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

   Year       1        2        5       10       25
   JAN       37     36.82     37.27     36.03     34.33
   FEB    36.11     35.87     35.93     34.69     33.02
   MAR     41.19     40.96     41.03     39.87     38.22
   APR    47.84     46.82     46.61     45.56     43.89
   MAY     52.37     51.31     50.69     49.69     48.01
   JUN    58.91     57.94     56.81      55.8     54.14
   JUL    65.22     64.43     62.91     61.94     60.28
   AUG     65.7     64.95     63.23     62.24     60.59
   SEP    59.01     58.84     57.02     56.07     54.41
   OCT    54.97     55.38     53.66     52.78     51.11
   NOV     53.16     53.78     52.41      51.6     49.91
   DEC    41.78     42.38     41.47     40.67     38.99

  BASE LOAD: YEAR  25
  Minimum mean fluid temperature  33.02 °F at end of FEB
  Maximum mean fluid temperature  60.59 °F at end of AUG


 PEAK HEAT LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

   Year       1        2        5       10       25
   JAN       37     36.82     37.27     36.03     34.33
   FEB    36.11     35.87     35.93     34.69     33.02
   MAR     41.19     40.96     41.03     39.87     38.22
   APR    47.84     46.82     46.61     45.56     43.89
```

```
  MAY     52.37     51.31     50.69     49.69     48.01
  JUN     58.91     57.94     56.81      55.8     54.14
  JUL     65.22     64.43     62.91     61.94     60.28
  AUG      65.7     64.95     63.23     62.24     60.59
  SEP     59.01     58.84     57.02     56.07     54.41
  OCT     54.97     55.38     53.66     52.78     51.11
  NOV     53.16     53.78     52.41      51.6     49.91
  DEC     41.78     42.38     41.47     40.67     38.99

 PEAK HEAT LOAD: YEAR  25
 Minimum mean fluid temperature  33.02 °F at end of FEB
 Maximum mean fluid temperature  60.59 °F at end of AUG


PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month) [°F]

  Year        1         2         5        10        25
  JAN        37     36.82     37.27     36.03     34.33
  FEB     36.11     35.87     35.93     34.69     33.02
  MAR     41.19     40.96     41.03     39.87     38.22
  APR     47.84     46.82     46.61     45.56     43.89
  MAY     52.37     51.31     50.69     49.69     48.01
  JUN     58.91     57.94     56.81      55.8     54.14
  JUL     65.22     64.43     62.91     61.94     60.28
  AUG      65.7     64.95     63.23     62.24     60.59
  SEP     59.01     58.84     57.02     56.07     54.41
  OCT     54.97     55.38     53.66     52.78     51.11
  NOV     53.16     53.78     52.41      51.6     49.91
  DEC     41.78     42.38     41.47     40.67     38.99

 PEAK COOL LOAD: YEAR  25
 Minimum mean fluid temperature  33.02 °F at end of FEB
 Maximum mean fluid temperature  60.59 °F at end of AUG
```

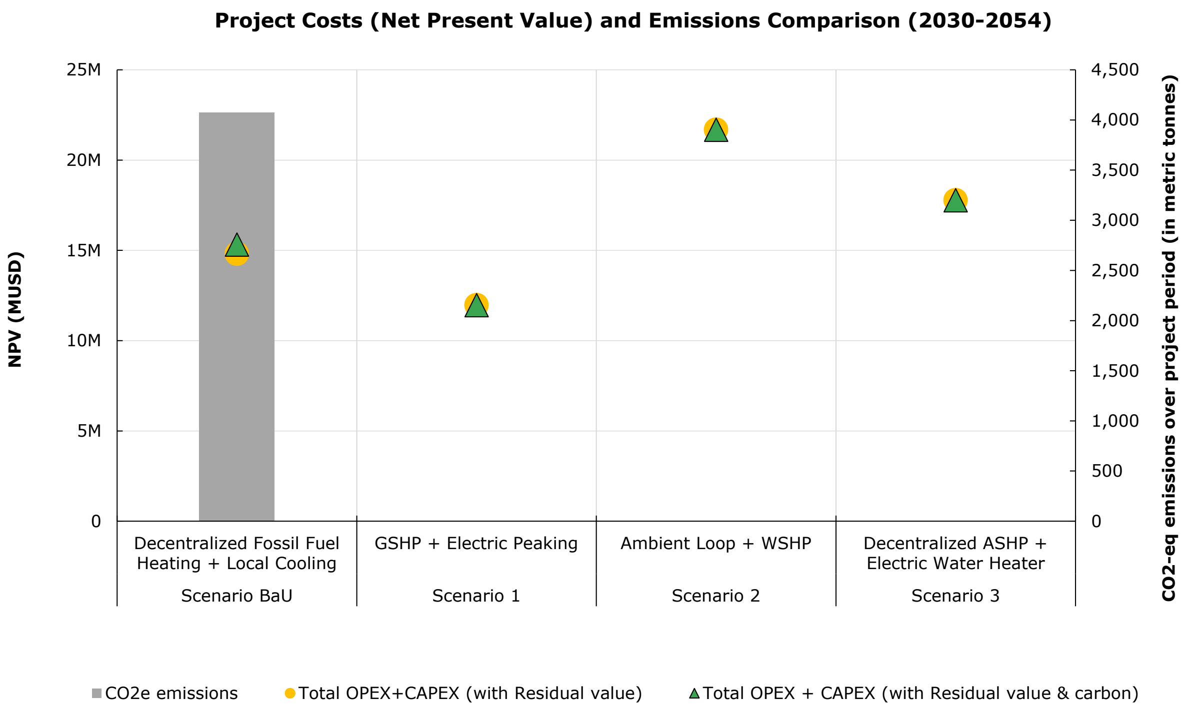
Appendix E. Techno-Economic Analysis

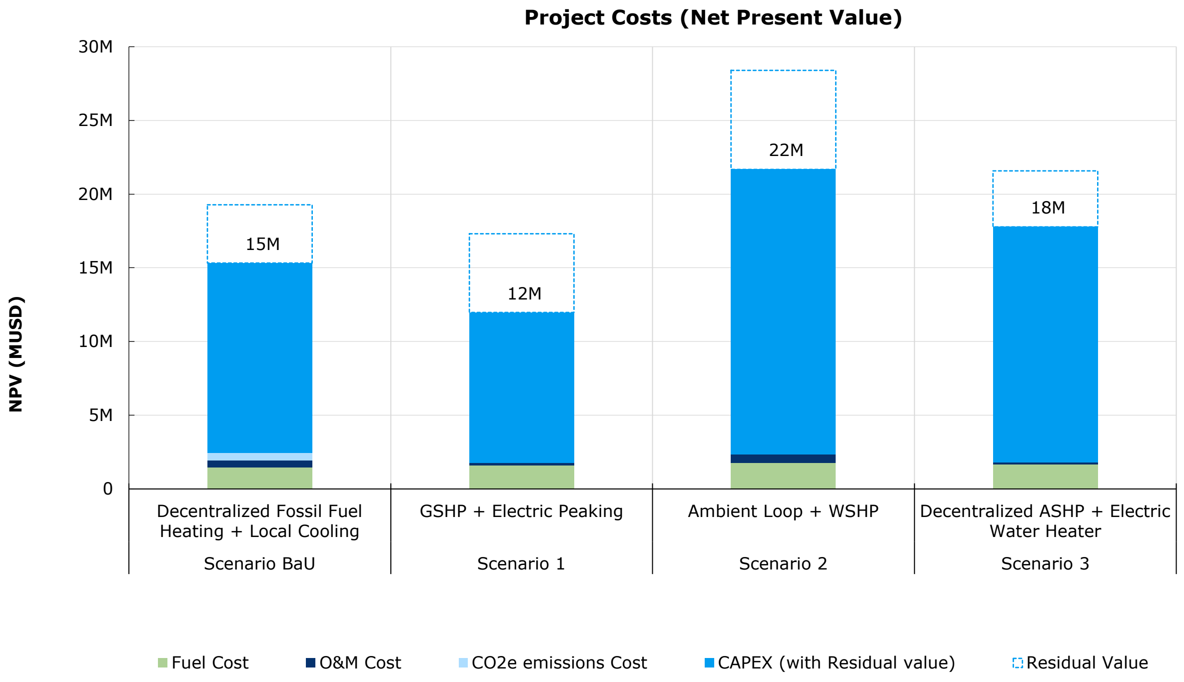
TECHNICAL DATA	Units	Scenario BaU	Scenario 1	Scenario 2	Scenario 3
		Decentralized Fossil Fuel Heating + Local Cooling	GSHP + Electric Peaking	Ambient Loop + WSHP	Decentralized ASHP + Electric Water Heater
Space Heating (SH) Demand	MWh	728	728	728	728
Domestic Hot Water (DHW) Demand	MWh	18	18	18	18
Network Losses (Heat Storage Loss)	MWh	-	9	-	-
Total Heat Demand	MWh	***746***	***755***	***746***	***746***
Total Cooling Demand	MWh	***1,811***	***1,811***	***1,811***	***1,811***
Heating Production					
Centralized ASHP	MWh	-	-	-	-
Centralized GSHP	MWh		711	-	-
Centralized Electric boiler	MWh		26	-	-
Decentralized indv. WSHP	MWh	-		746	-
Decentralized electric boiler	MWh	18	18	-	18
Decentralized fossil fuel boiler	MWh	728	-	-	-
Decentralized ASHP	MWh	-	-		728
Total Heating Production	MWh	***746***	***755***	***746***	***746***
Cooling Production					
Centralized ASHP*	MWh	-	-		-
Centralized GSHP	MWh	-	192.5	-	-
Decentralized indv. WSHP	MWh	-	-	192.5	-
Decentralized water source chiller(process cooling)	MWh	1,619	1,619	1,619	1,619
Decentralized air source chiller	MWh	193	-	-	-
Decentralized ASHP	MWh		-	-	193
Total Cooling Production	MWh	***1,811***	***1,811***	***1,811***	***1,811***
Fuel Consumption					
Centralized ASHP*	MWh-el	-	-	376	-
Centralized GSHP	MWh-el	-	272	-	-
Centralized Electric boiler	MWh-el	-	26	-	-
Decentralized indv. WSHP	MWh-el	-	-	270	-
Decentralized electric boiler	MWh-el	18	18	-	18
Decentralized fossil fuel boiler	MWh-f	899	-	-	-
Decentralized ASHP	MWh-el	-	-	-	399
Decentralized water source chiller(process cooling)	MWh-el	579	579	309	579
Decentralized air source chiller	MWh-el	57	-	-	-
Electricity for uses other than heating/cooling	MWh-el	709	709	709	709
Total Fuel Consumption	MWh	***2,262***	***1,605***	***1,664***	***1,705***
CO2e Emissions					
Centralized ASHP	tons CO2e	-	-	-	-
Centralized GSHP	tons CO2e	-	-	-	-
Centralized Electric boiler	tons CO2e	-	-	-	-
Decentralized indv. WSHP	tons CO2e	-	-	-	-
Decentralized electric boiler	tons CO2e	-	-	-	-
Decentralized fossil fuel boiler	tons CO2e	4,070	-	-	-
Decentralized ASHP	tons CO2e	-	-	-	-
Decentralized air cooled chiller/water source chiller	tons CO2e	-	-	-	-
Decentralized DX	tons CO2e	-	-	-	-
Electricity for uses other than heating/cooling	tons CO2e	-	-	-	-
Total CO2e Emissions	tons CO2e	***4,070***	***-***	***-***	***-***

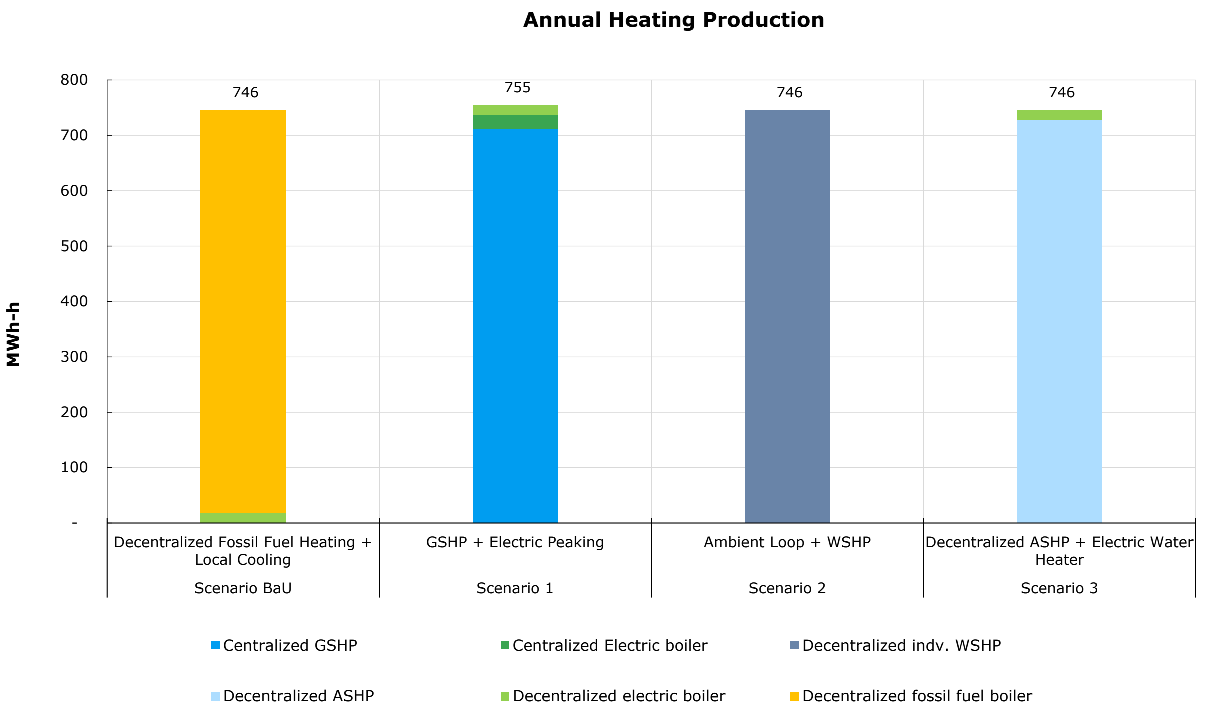
*Centralized ASHP in Scenario 3 is used as the heating source for building level WSHP. The heating and cooling productions of the system are all counted under Decentralized individual WSHP.

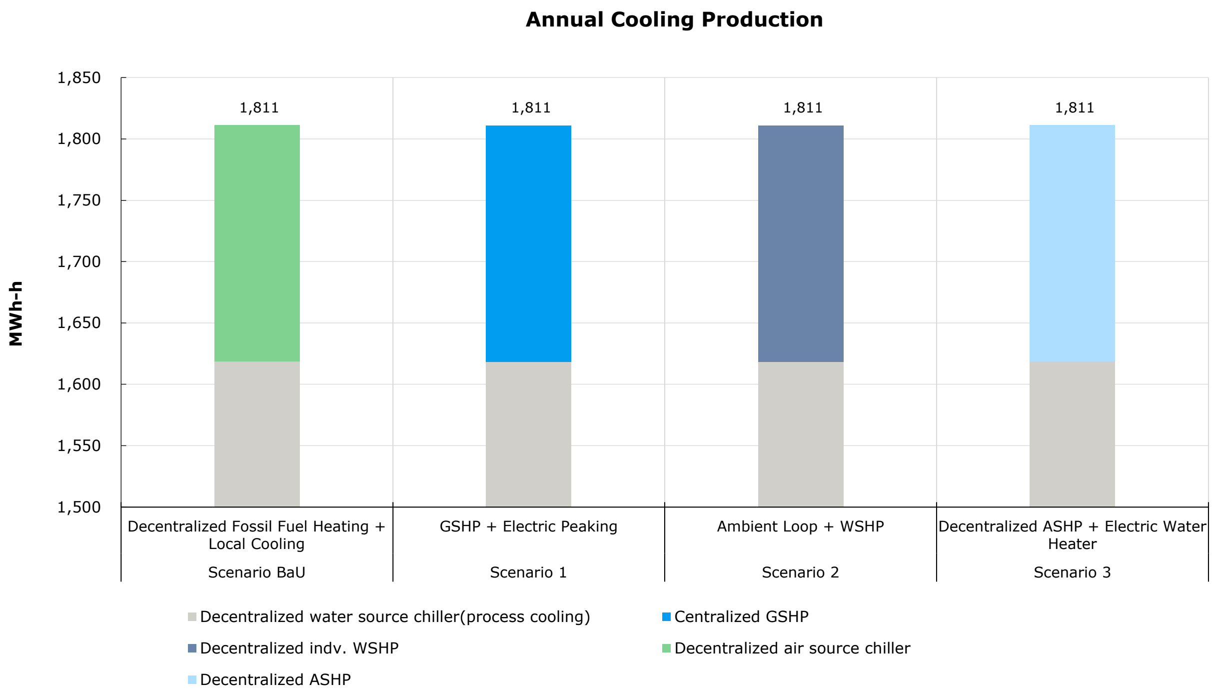
CAPEX	Scenario BaU Decentralized Fossil Fuel Heating + Local Cooling	Scenario 1 GSHP + Electric Peaking	Scenario 2 Ambient Loop + WSHP	Scenario 3 Decentralized ASHP + Electric Water Heater
Campus Distribution and Heat Exchangers (SH/SC)	-	4,563,765	3,803,291	-
Centralized Heat Pumps	-	906,997	356,060	-
Geothermal Wellfield	-	3,509,876	3,509,876	-
Electric Boilers	-	254,604	-	-
Natural Gas Boilers	5,705,502	787,417	4,532,533	4,532,533
Thermal Energy Storage	78,385	1,241,526	210,658	210,658
DHW (HX For Centralized/Local DHW For Ambient and decentralized)	85,778	85,778	272,482	85,778
Decentralized Heat Pumps/Air Cooled Chiller	3,040,466	-	6,549,341	7,096,385
Electrical Infrastructure Upgrades	795,682	723,762	858,835	899,736
Central Energy Plant Construction	-	767,064	613,652	-
Process cooling	1,264,278	1,593,345	1,515,812	1,264,278
Total	**$ 10,970,090**	**$ 14,434,134**	**$ 22,222,541**	**$ 14,089,369**

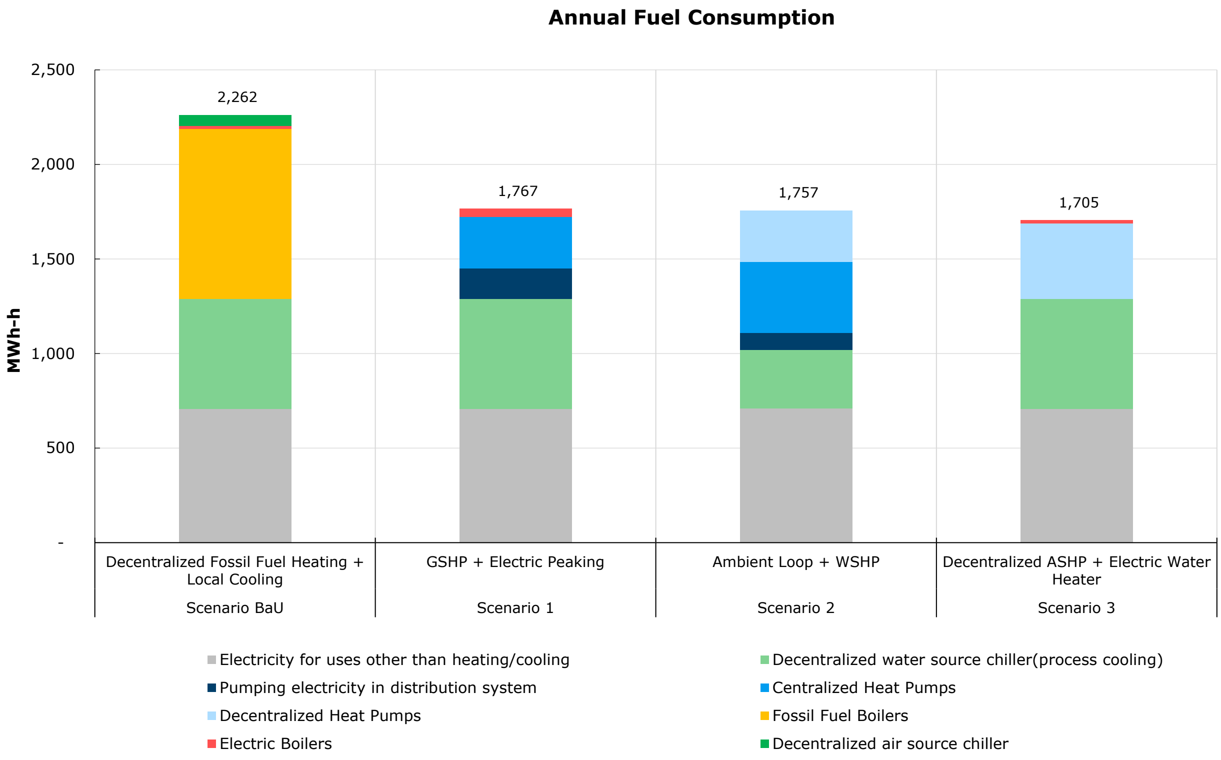
NPV COSTS	Scenario BaU	Scenario 1	Scenario 2	Scenario 3
	Decentralized Fossil Fuel Heating + Local Cooling	GSHP + Electric Peaking	Ambient Loop + WSHP	Decentralized ASHP + Electric Water Heater
Fuel Cost				
Centralized ASHP	-	-	389,929	-
Centralized GSHP	-	192,682	-	-
Centralized Electric boiler	-	21,038	-	-
Decentralized indv. WSHP	-	-	279,957	-
Decentralized electric boiler	18,909	-	-	18,909
Decentralized fossil fuel boiler	166,641	-	-	-
Decentralized ASHP	-	-	-	413,251
Decentralized air cooled chiller	58,770	-	-	-
Process cooling unit	488,188	488,188	260,103	488,188
Pumping electricity in distribution system	-	168,162	96,071	-
Electricity for uses other than heating/cooling	734,771	734,771	734,771	734,771
Total Fuel Cost	***1,467,279***	***1,604,841***	***1,760,831***	***1,655,119***
Variable O&M Cost				
Centralized ASHP	-	-	87,769	-
Centralized GSHP	-	34,580	-	-
Centralized Electric boiler	-	430	-	-
Decentralized indv. WSHP	-	-	-	-
Decentralized electric boiler	-	-	-	-
Decentralized fossil fuel boiler	-	-	-	-
Decentralized ASHP	-	-	-	-
Decentralized air cooled chiller	-	-	-	-
Process cooling unit	-	-	-	-
Pumping electricity in distribution system	-	-	-	-
Electricity for uses other than heating/cooling	-	-	-	-
Total Variable O&M Cost	***-***	***35,010***	***87,769***	***-***
Fixed O&M Cost				
Centralized ASHP	-	-	50,793	-
Centralized GSHP	-	19,048	-	-
Centralized Electric boiler	-	6,984	-	-
Decentralized indv. WSHP	-	-	303,560	-
Decentralized electric boiler	3,434	-	-	3,434
Decentralized fossil fuel boiler	114,354	-	-	-
Decentralized ASHP	-	-	-	17,359
Decentralized air cooled chiller	223,758	-	-	-
Process cooling unit	124,995	124,995	124,995	124,995
Pumping electricity in distribution system	-	-	-	-
Electricity for uses other than heating/cooling	-	-	-	-
Total Fixed O&M Cost	***466,542***	***151,027***	***479,348***	***145,788***
CO2e Cost				
Imported Electricity	-	-	-	-
Natural Gas	513,088	-	-	-
Total CO2e Cost	***513,088***	***-***	***-***	***-***
CAPEX				
Campus Distribution and Heat Exchangers (SH/SC)	-	4,563,765	3,803,291	-
Centralized Heat Pumps	-	906,997	553,202	-
Geothermal Wellfield	-	3,509,876	3,509,876	-
Electric Boilers	-	395,571	-	-
Natural Gas Boilers	8,864,500	787,417	7,042,087	6,968,993
Thermal Energy Storage	78,385	1,241,526	210,658	210,658
DHW (HX For Centralized/Local DHW For Ambient and decentralized)	140,836	140,836	447,378	140,836
Decentralized Heat Pumps/Air Cooled Chiller	4,992,026	-	6,667,803	9,611,033
Electrical Infrastructure Upgrades	795,682	723,762	858,835	899,736
Central Energy Plant Construction	-	767,064	613,652	-
Process cooling	1,964,278	2,475,542	2,355,081	1,943,890
Total CAPEX Cost	***16,835,706***	***15,512,356***	***26,061,863***	***19,775,146***
Residual Value				
Campus Distribution and Heat Exchangers (SH/SC)	-	(2,281,882)	(1,901,645)	-
Centralized Heat Pumps	-	-	(147,856)	-
Geothermal Wellfield	-	(1,316,204)	(1,316,204)	-
Electric Boilers	-	(105,726)	-	-
Natural Gas Boilers	(2,369,249)	-	(1,882,165)	(1,949,168)
Thermal Energy Storage	-	(206,921)	-	-
DHW (HX For Centralized/Local DHW For Ambient and decentralized)	(18,353)	(18,353)	(58,299)	(18,353)
Decentralized Heat Pumps/Air Cooled Chiller	(650,520)	-	(39,487)	(838,216)
Electrical Infrastructure Upgrades	(397,841)	(361,881)	(429,418)	(449,868)
Central Energy Plant Construction	-	(383,532)	(306,826)	-
Process cooling	(525,000)	(661,647)	(629,451)	(543,689)
Total Residual Value	***(3,960,962)***	***(5,336,146)***	***(6,711,351)***	***(3,799,294)***
Total Net Present Value	**15,321,652**	**11,967,089**	**21,678,460**	**17,776,760**

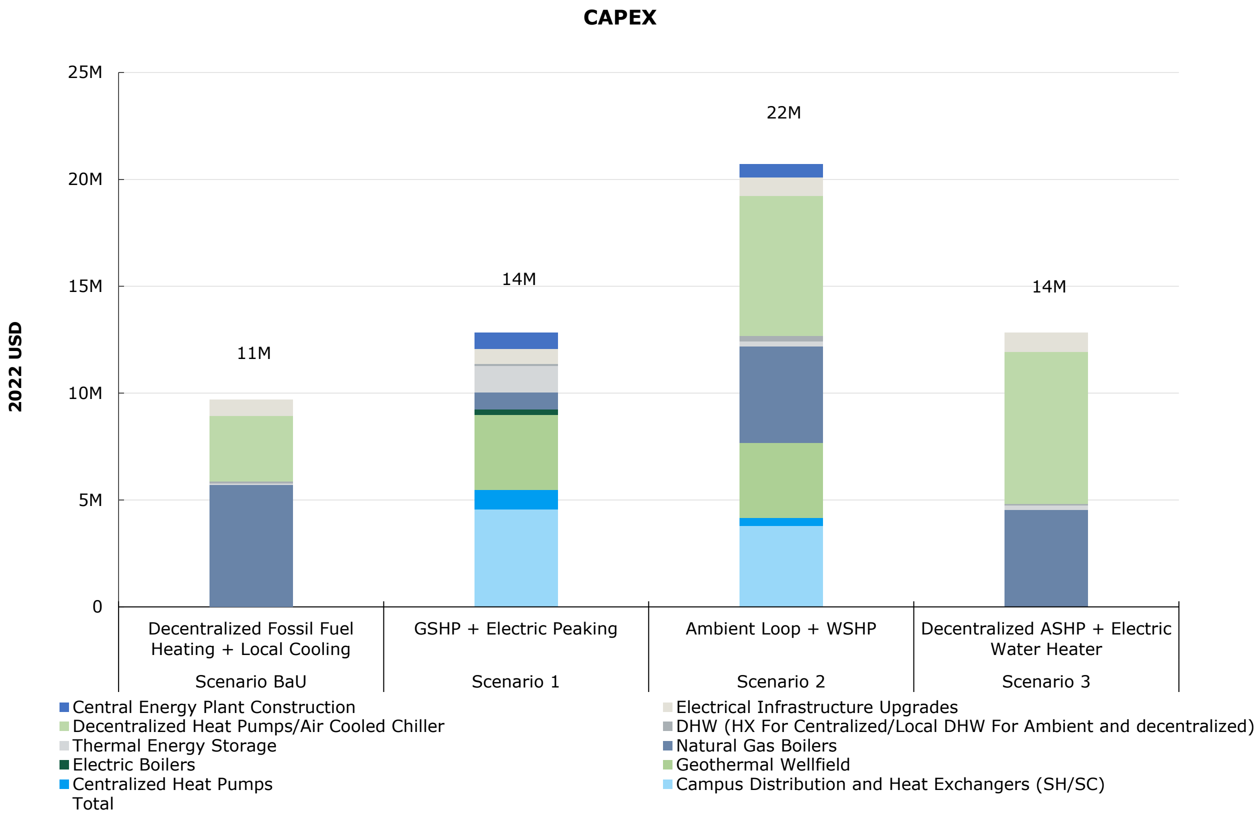

Project Costs (Net Present Value) and Emissions Comparison (2030-2054)
NPV (MUSD)
25M
20M
15M
10M
5M
0
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
CO2-eq emissions over project period (in metric tonnes)
Decentralized Fossil Fuel Heating + Local Cooling
Scenario BaU
GSHP + Electric Peaking
Scenario 1
Ambient Loop + WSHP
Scenario 2
Decentralized ASHP + Electric Water Heater
Scenario 3
CO2e emissions
Total OPEX+CAPEX (with Residual value)
Total OPEX + CAPEX (with Residual value & carbon)


Project Costs (Net Present Value)
NPV (MUSD)
30M
25M
20M
15M
10M
5M
0
15M
12M
22M
18M
Decentralized Fossil Fuel Heating + Local Cooling
Scenario BaU
GSHP + Electric Peaking
Scenario 1
Ambient Loop + WSHP
Scenario 2
Decentralized ASHP + Electric Water Heater
Scenario 3
Fuel Cost
O&M Cost
CO2e emissions Cost
CAPEX (with Residual value)
Residual Value


Annual Heating Production
MWh-h
800
700
600
500
400
300
200
100
-
746
755
746
746
Decentralized Fossil Fuel Heating + Local Cooling
Scenario BaU
GSHP + Electric Peaking
Scenario 1
Ambient Loop + WSHP
Scenario 2
Decentralized ASHP + Electric Water Heater
Scenario 3
Centralized GSHP
Centralized Electric boiler
Decentralized indv. WSHP
Decentralized ASHP
Decentralized electric boiler
Decentralized fossil fuel boiler


Annual Cooling Production
MWh-h
1,850
1,800
1,750
1,700
1,650
1,600
1,550
1,500
1,811
1,811
1,811
1,811
Decentralized Fossil Fuel Heating + Local Cooling
Scenario BaU
GSHP + Electric Peaking
Scenario 1
Ambient Loop + WSHP
Scenario 2
Decentralized ASHP + Electric Water Heater
Scenario 3
Decentralized water source chiller(process cooling)
Centralized GSHP
Decentralized indv. WSHP
Decentralized air source chiller
Decentralized ASHP


Annual Fuel Consumption
MWh-h
2,500
2,000
1,500
1,000
500
-
2,262
1,767
1,757
1,705
Decentralized Fossil Fuel Heating + Local Cooling
Scenario BaU
GSHP + Electric Peaking
Scenario 1
Ambient Loop + WSHP
Scenario 2
Decentralized ASHP + Electric Water Heater
Scenario 3
Electricity for uses other than heating/cooling
Decentralized water source chiller(process cooling)
Pumping electricity in distribution system
Centralized Heat Pumps
Decentralized Heat Pumps
Fossil Fuel Boilers
Electric Boilers
Decentralized air source chiller


CAPEX
2022 USD
25M
20M
15M
10M
5M
0
11M
14M
22M
14M
Decentralized Fossil Fuel Heating + Local Cooling
Scenario BaU
GSHP + Electric Peaking
Scenario 1
Ambient Loop + WSHP
Scenario 2
Decentralized ASHP + Electric Water Heater
Scenario 3
Central Energy Plant Construction
Electrical Infrastructure Upgrades
Decentralized Heat Pumps/Air Cooled Chiller
DHW (HX For Centralized/Local DHW For Ambient and decentralized)
Thermal Energy Storage
Natural Gas Boilers
Electric Boilers
Geothermal Wellfield
Centralized Heat Pumps
Campus Distribution and Heat Exchangers (SH/SC)
Total

Appendix F. Scenario Cost Estimates

PROJECT SUMMARY	TOTAL COST
SCENARIO BAU	$ 10,970,090
SCENARIO 1	$ 14,434,134
SCENARIO 2	$ 22,222,541
SCENARIO 3	$ 14,089,369

SCENARIO BAU SUMMARY

PROJECT SUMMARY	TOTAL MATERIAL	TOTAL LABOR	TOTAL COST	% OF TOTAL
Thermal Distribution	$ 0	$ 0	$ 0	0%
Centralized Heat Pumps	$ 0	$ 0	$ 0	0%
Centralized Water Cooled Chiller	$ 0	$ 0	$ 0	0%
Geothermal Wellfield	$ 0	$ 0	$ 0	0%
Electric Boilers	$ 0	$ 0	$ 0	0%
Natural Gas Boilers	$ 984,199	$ 2,269,970	$ 3,254,169	40%
Thermal Energy Storage	$ 18,451	$ 26,256	$ 44,707	1%
DHW	$ 17,164	$ 31,760	$ 48,924	1%
Decentralized units	$ 765,659	$ 968,490	$ 1,734,149	21%
Electrical	$ 201,550	$ 252,272	$ 453,822	6%
Central Energy Plant Construction	$ 0	$ 0	$ 0	0%
Process Cooling	$ 699,489	$ 21,600	$ 721,089	9%
SUBTOTAL - SCENARIO 1			**$ 6,256,860**	
General Conditions	15%		$ 938,529	
Overhead and Profit	10%		$ 719,539	
Design Contingency	20%		$ 1,582,986	
Bid Contingency	5%		$ 474,896	
Phasing	10%		$ 997,281	
TOTAL - SCENARIO 1			**$ 10,970,090**	

Scenario BaU Detail

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
NATURAL GAS BOILERS						
Natural gas boiler-office	2 EA	$13,050.00	$26,100	$80,000.00	$160,000	$186,100
Natural gas boiler-non-refrigerated warehouse with fine sotrage	2 EA	$14,500.00	$29,000	$80,000.00	$160,000	$189,000
Natural gas boiler- Non-refrigerated Warehouse with Heating Only Storage	2 EA	$12,470.00	$24,940	$80,000.00	$160,000	$184,940
Natural gas boiler - refrigerated warehouse	2 EA	$14,210.00	$28,420	$80,000.00	$160,000	$188,420
Natural gas boiler- light manufacturing	2 EA	$33,640.00	$67,280	$80,000.00	$160,000	$227,280
Boiler breaching and venting	5 LS	$50,000.00	$250,000	$100,000.00	$500,000	$750,000
Direct digital control of boilers (est 15 pts each)	10 EA	$15,000.00	$150,000	$22,500.00	$225,000	$375,000
Heating hot water system components	1 LS	$100,000.00	$100,000	$30,720.00	$30,720	$130,720
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	400 SF	$5.50	$2,200	$10.40	$4,160	$6,360
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
TOTAL NATURAL GAS BOILERS			**$984,199**		**$2,269,970**	**$3,254,169**
DECENTRALIZED UNITS						
Air source chiller - office	2 EA	$96,250.00	$192,500	$5,400.00	$10,800	$203,300
Air source chiller-non-refrigerated warehouse with fine sotrage	2 EA	$37,500.00	$75,000	$5,400.00	$10,800	$85,800
Air source chiller- Non-refrigerated Warehouse with Heating Only Storage	2 EA	$3,750.00	$7,500	$5,400.00	$10,800	$18,300
Air source chiller - refrigerated warehouse	2 EA	$5,000.00	$10,000	$5,400.00	$10,800	$20,800
Chilled water system components	1 LS	$100,000.00	$100,000	$75,000.00	$75,000	$175,000
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
- 6" diameter	1,000 LF	$64.60	$64,600	$116.50	$116,500	$181,100
thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
- 6" diameter	1,000 LF	$9.80	$9,800	$23.70	$23,700	$33,500
TOTAL DECENTRALIZED UNITS			**$765,659**		**$968,490**	**$1,734,149**

DESCRIPTION	QUANTITY	MATERIAL		LABOR		TOTAL
		UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	
ELECTRICAL						
Electrical connection at HVAC equipment including means of disconnect, conduit and circuiting back to source power panel						
- Air Source Chiller Connections	8 EA	$2,500.00	$20,000	$3,920.00	$31,360	$51,360
- Circulator Connections	16 EA	$1,250.00	$20,000	$2,352.00	$37,632	$57,632
- Natural Gas Boilers	8 EA	$2,500.00	$20,000	$3,920.00	$31,360	$51,360
- Domestic Water Heaters	5 EA	$750.00	$3,750	$1,960.00	$9,800	$13,550
- Process Cooling Chillers	4 EA	$3,200.00	$12,800	$4,280.00	$17,120	$29,920
testing, commissioning, etc)	1 ALLOW	$125,000.00	$125,000	$125,000.00	$125,000	$250,000
TOTAL ELECTRICAL			**$201,550**		**$252,272**	**$453,822**
DOMESTIC HOT WATER TANKS						
storage tank 2 - office	1 EA	$1,585.03	$1,585	$2,160.00	$2,160	$3,745
storage tank 2-non-refrigerated warehouse with fine sotrage	2 EA	$792.52	$1,585	$2,160.00	$4,320	$5,905
storage tank 2- Non-refrigerated Warehouse with Heating Only Storage	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
storage tank 2- light manufacturing	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
Domestic water piping, above slab, copper type L, 2" diameter	240 LF	$36.60	$8,784	$23.40	$5,616	$14,400
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter	240 LF	$3.80	$912	$16.00	$3,840	$4,752
Direct digital control of domestic water tank (est 2 pts each)	5 EA	$800.00	$4,000	$1,200.00	$6,000	$10,000
TOTAL DOMESTIC HOT WATER TANKS			**$18,451**		**$26,256**	**$44,707**
DOMESTIC WATER ELECTRIC HEATERS						
Electric water heater - office	1 EA	$1,350.00	$1,350	$2,160.00	$2,160	$3,510
Electric water heater -non-refrigerated warehouse with fine sotrage	2 EA	$450.00	$900	$2,160.00	$4,320	$5,220
Storage	1 EA	$300.00	$300	$2,160.00	$2,160	$2,460
Electric water heater - light manufacturing	1 EA	$150.00	$150	$2,160.00	$2,160	$2,310
Domestic water piping, above slab, copper type L, 2" diameter	160 LF	$36.60	$5,856	$33.30	$5,328	$11,184
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter	160 LF	$3.80	$608	$22.70	$3,632	$4,240
Direct digital control of domestic water heat heaters (est 4 pts each)	5 EA	$1,600.00	$8,000	$2,400.00	$12,000	$20,000
TOTAL DOMESTIC WATER ELECTRIC HEATERS			**$17,164**		**$31,760**	**$48,924**
PROCESS COOLING						
Water cooled chiller for freezer	2 EA	$63,977.66	$127,955	$5,400.00	$10,800	$138,755
Water cooled chiller for cooling dock	2 EA	$285,766.86	$571,534	$5,400.00	$10,800	$582,334
TOTAL PROCESS COOLING			**$699,489**		**$21,600**	**$721,089**

SCENARIO 1 SUMMARY

PROJECT SUMMARY	TOTAL MATERIAL	TOTAL LABOR	TOTAL COST	% OF TOTAL
Thermal Distribution	$ 1,310,109	$ 1,292,863	$ 2,602,972	32%
Centralized Heat Pumps	$ 390,888	$ 126,423	$ 517,312	6%
Centralized Water Cooled Chiller	$ 0	$ 0	$ 0	0%
Geothermal Wellfield	$ 1,244,860	$ 757,020	$ 2,001,880	24%
Electric Boilers	$ 83,715	$ 61,500	$ 145,215	2%
Natural Gas Boilers	$ 211,728	$ 237,380	$ 449,108	5%
Thermal Energy Storage	$ 559,166	$ 148,946	$ 708,112	9%
DHW	$ 17,164	$ 31,760	$ 48,924	1%
Decentralized units	$ 0	$ 0	$ 0	0%
Electrical	$ 184,050	$ 228,752	$ 412,802	5%
Central Energy Plant Construction	$ 250,000	$ 187,500	$ 437,500	5%
Process Cooling	$ 876,374	$ 32,400	$ 908,774	11%
SUBTOTAL - SCENARIO 1			**$ 8,232,599**	
General Conditions	15%		$ 1,234,890	
Overhead and Profit	10%		$ 946,749	
Design Contingency	20%		$ 2,082,848	
Bid Contingency	5%		$ 624,854	
Phasing	10%		$ 1,312,194	
TOTAL - SCENARIO 1			**$ 14,434,134**	

Scenario 1 Centralized Detail

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
THERMAL DISTRIBUTION AND HEAT EXCHANGERS						
Chilled water heat exchangers for buildings	5 EA	$32,000.00	$160,000	$3,240.00	$16,200	$176,200
Hot water heat exchangers for buildings	5 EA	$28,200.00	$141,000	$3,240.00	$16,200	$157,200
Pumps, end suction base mounted, 82 feet head, including VFDs and accessories	3 EA	$10,000.00	$30,000	$5,400.00	$16,200	$46,200
Direct digital control of heat exchangers (est 8 pts each)	10 EA	$3,200.00	$32,000	$4,800.00	$48,000	$80,000
Direct digital control of pumps (est 5 pts each)	3 EA	$2,000.00	$6,000	$3,000.00	$9,000	$15,000
Isolation valves, automatic	40 EA	$745.00	$29,800	$810.00	$32,400	$62,200
Flow meters, ultrasonic	10 EA	$1,500.00	$15,000	$1,080.00	$10,800	$25,800
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	10 EA	$875.00	$8,750	$270.00	$2,700	$11,450
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	1,600 LF	$32.00	$51,192	$80.80	$129,280	$180,472
- 3" diameter	560 LF	$33.90	$18,984	$88.20	$49,392	$68,376
- 4" diameter	LF	$48.40	$0	$103.40	$0	$0
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	1,600 LF	$6.90	$11,040	$14.70	$23,520	$34,560
- 3" diameter	560 LF	$7.30	$4,088	$15.40	$8,624	$12,712
- 4" diameter	LF	$8.30	$0	$18.60	$0	$0
Chilled water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC, (80 lf per HX)						
- 2-1/2" diameter	640 LF	$32.00	$20,477	$80.80	$51,712	$72,189
- 3" diameter	560 LF	$33.90	$18,984	$88.20	$49,392	$68,376
- 4" diameter	1,280 LF	$48.40	$61,952	$103.40	$132,352	$194,304
- 6" diameter	LF	$64.60	$0	$116.50	$0	$0
Chilled water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	640 LF	$6.90	$4,416	$14.70	$9,408	$13,824
- 3" diameter	560 LF	$7.30	$4,088	$15.40	$8,624	$12,712
- 4" diameter	1,280 LF	$8.30	$10,624	$18.60	$23,808	$34,432
- 6" diameter	LF	$9.80	$0	$23.70	$0	$0
Dual-temperature, buried hydronic piping, EN-253, 10-guage, steel, welded, factory applied polyurethane foam with exterior HDPE jacket including integral leak detection cable						
- 2" diameter	92 LF	$26.40	$2,429	$70.90	$6,523	$8,952
- 2-1/2" diameter	1,400 LF	$37.50	$52,500	$73.60	$103,040	$155,540
- 3" diameter	LF	$39.80	$0	$76.50	$0	$0
- 4" diameter	1,645 LF	$47.30	$77,809	$82.20	$135,219	$213,028
- 5" diameter	163 LF	$56.30	$9,177	$85.70	$13,969	$23,146
- 6" diameter	LF	$62.80	$0	$91.40	$0	$0
- 8" diameter	LF	$108.00	$0	$98.50	$0	$0
- 10" diameter	LF	$156.60	$0	$107.10	$0	$0
- 12" diameter	LF	$195.20	$0	$110.40	$0	$0
- 16" diameter	LF	$281.40	$0	$133.60	$0	$0
Site utilities earthwork including excavation, select backfill and disposal on site (6' wide by 5' deep trench)	11,000 CY	$48.80	$536,800	$35.80	$393,800	$930,600
TOTAL THERMAL DISTRIBUTION AND HEAT EXCHANGERS			**$1,310,109**		**$1,292,863**	**$2,602,972**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
GROUND SOURCE HEAT PUMPS						
ground source heat pumps, with split condensers located on the exterior of the central energy plant	2 EA	$191,932.97	$383,866	$58,320.00	$116,640	$500,506
Direct digital control of GSHP (est 12 pts each)	1 EA	$4,800.00	$4,800	$7,200.00	$7,200	$12,000
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	200 SF	$5.50	$1,100	$8.80	$1,760	$2,860
Earthwork including excavation, select backfill and disposal on site for tank pad	23 CY	$48.80	$1,122	$35.80	$823	$1,946
TOTAL GROUND SOURCE HEAT PUMPS			**$390,888**		**$126,423**	**$517,312**
GEOTHERMAL WELLFIELD						
Wellfield piping, includes vertical piping within the wellfield and distribution connecting each well, 500' depth	1 LS	$937,500	$937,500	$562,500	$562,500	$1,500,000
Wellfield water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC, (from wellfield to pumps)						
- 12" diameter	600 LF	$193.10	$115,860	$155.20	$93,120	$208,980
Pumps, end suction base mounted, 20 ft hd, including VFDs and accessories	3 EA	$48,500.00	$145,500	$10,800.00	$32,400	$177,900
Direct digital control of pumps (est 5 pts each)	3 EA	$2,000.00	$6,000	$3,000.00	$9,000	$15,000
Direct digital control of wellfield (est 100 pts each, (wellfield in different section)	1 LS	$40,000.00	$40,000	$60,000.00	$60,000	$100,000
TOTAL GEOTHERMAL WELLFIELD			**$1,244,860**		**$757,020**	**$2,001,880**
ELECTRIC BOILERS						
Boiler, electric, serving the hot water system	1 EA	$26,614.70	$26,615	$11,260.07	$11,260	$37,875
Direct digital control of boilers (est 15 pts each)	1 EA	$6,000.00	$6,000	$9,000.00	$9,000	$15,000
Heating hot water system components	1 LS	$50,000.00	$50,000	$40,000.00	$40,000	$90,000
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	200 SF	$5.50	$1,100	$6.20	$1,240	$2,340
TOTAL ELECTRIC BOILERS			**$83,715**		**$61,500**	**$145,215**
NATURAL GAS BOILERS						
Boiler, fuel oil, serving the hot water system	1 EA	$44,528.45	$44,528	$80,000.00	$80,000	$124,528
Boiler breaching and venting	1 LS	$50,000.00	$50,000	$100,000.00	$100,000	$150,000
Direct digital control of boilers (est 15 pts each)	1 EA	$15,000.00	$15,000	$22,500.00	$22,500	$37,500
Heating hot water system components	1 LS	$100,000.00	$100,000	$30,720.00	$30,720	$130,720
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	400 SF	$5.50	$2,200	$10.40	$4,160	$6,360
TOTAL NATURAL GAS BOILERS			**$211,728**		**$237,380**	**$449,108**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
DOMESTIC HOT WATER TANKS						
storage tank 2 - office	1 EA	$1,585.03	$1,585	$2,160.00	$2,160	$3,745
storage tank 2-non-refrigerated warehouse with fine sotrag	2 EA	$792.52	$1,585	$2,160.00	$4,320	$5,905
storage tank 2- Non-refrigerated Warehouse with Heating (	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
storage tank 2- light manufacturing	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
Domestic water piping, above slab, copper type L, 2" diameter	240 LF	$36.60	$8,784	$23.40	$5,616	$14,400
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter	240 LF	$3.80	$912	$16.00	$3,840	$4,752
Direct digital control of domestic water tank (est 2 pts each)	5 EA	$800.00	$4,000	$1,200.00	$6,000	$10,000
TOTAL DOMESTIC HOT WATER TANKS			**$18,451**		**$26,256**	**$44,707**
THERMAL STORAGE TANKS						
storage	1 EA	$453,054.98	$453,055	$3,240.00	$3,240	$456,295
Piping, above slab, copper type L, 2" diameter (50 lf per tank)	2,150 LF	$36.60	$78,690	$33.40	$71,810	$150,500
Piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter (50 lf per tank)	2,150 LF	$3.80	$8,170	$21.60	$46,440	$54,610
Direct digital control of domestic water tank (est 2 pts each)	1 EA	$800.00	$800	$1,200.00	$1,200	$2,000
TOTAL THERMAL STORAGE TANKS			**$540,715**		**$122,690**	**$663,405**
DOMESTIC WATER ELECTRIC HEATERS						
Electric water heater - office	1 EA	$1,350.00	$1,350	$2,160.00	$2,160	$3,510
Electric water heater -non-refrigerated warehouse with fine sotrage	2 EA	$450.00	$900	$2,160.00	$4,320	$5,220
Electric water heater - Non-refrigerated Warehouse with Heating Only Storage	1 EA	$300.00	$300	$2,160.00	$2,160	$2,460
Electric water heater - light manufacturing	1 EA	$150.00	$150	$2,160.00	$2,160	$2,310
Domestic water piping, above slab, copper type L, 2" diameter	160 LF	$36.60	$5,856	$33.30	$5,328	$11,184
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter	160 LF	$3.80	$608	$22.70	$3,632	$4,240
Direct digital control of domestic water heat heaters (est 4 pts each)	5 EA	$1,600.00	$8,000	$2,400.00	$12,000	$20,000
TOTAL DOMESTIC WATER ELECTRIC HEATERS			**$17,164**		**$31,760**	**$48,924**
DECENTRALIZED UNITS						
	EA	$0.00	$0	$0.00	$0	$0
TOTAL DECENTRALIZED UNITS			**$0**		**$0**	**$0**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
ELECTRICAL						
Electrical connection at HVAC equipment including means of disconnect, conduit and circuiting back to source power panel						
- Ground Source Heat Pumps	2 EA	$2,500.00	$5,000	$3,920.00	$7,840	$12,840
- Circulator Connections	20 EA	$1,250.00	$25,000	$2,352.00	$47,040	$72,040
- Natural Gas Boilers	1 EA	$2,500.00	$2,500	$3,920.00	$3,920	$6,420
- Electric Boilers	1 EA	$2,500.00	$2,500	$3,920.00	$3,920	$6,420
- Domestic Water Heaters	5 EA	$750.00	$3,750	$1,960.00	$9,800	$13,550
- Thermal Borefield Pumps	3 EA	$1,250.00	$3,750	$2,352.00	$7,056	$10,806
- Thermal Distribution Pumps	3 EA	$1,250.00	$3,750	$2,352.00	$7,056	$10,806
- Process Cooling Chillers	4 EA	$3,200.00	$12,800	$4,280.00	$17,120	$29,920
Miscellaneous electrical work (removals, equipment, feeders, terminations, testing, commissioning, etc)	1 ALLOW	$125,000.00	$125,000	$125,000.00	$125,000	$250,000
TOTAL ELECTRICAL			**$184,050**		**$228,752**	**$412,802**
CENTRAL ENERGY PLANT						
Pre-engineered metal building including foundations, slab, insulated metal building, including all MEP infrastructure needed for personnel operations	2,500 SF	$100.00	$250,000	$75.00	$187,500	$437,500
TOTAL CENTRAL ENERGY PLANT			**$250,000**		**$187,500**	**$437,500**
PROCESS COOLING						
water cooled chiller for freezer	2 EA	$63,977.66	$127,955	$5,400.00	$10,800	$138,755
water cooled chiller for cooling doc	2 EA	$285,766.86	$571,534	$5,400.00	$10,800	$582,334
heat rejection unit	2 EA	$88,442.71	$176,885	$5,400.00	$10,800	$187,685
Heating hot water system components	1 LS	$15,000.00	$15,000	$20,000.00	$20,000	$35,000
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC, (80 lf per HX)						
- 2-1/2" diameter	100 LF	$32.00	$3,200	$80.80	$8,080	$11,280
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	100 LF	$6.90	$690	$14.63	$1,463	$2,153
Direct digital control of domestic water heat ASHPs (est 12 pts each)	3 EA	$4,800.00	$14,400	$7,200.00	$21,600	$36,000
TOTAL PROCESS COOLING			**$876,374**		**$32,400**	**$908,774**

SCENARIO 2 SUMMARY

PROJECT SUMMARY	TOTAL MATERIAL	TOTAL LABOR	TOTAL COST	% OF TOTAL
Thermal Distribution	$ 1,062,535	$ 1,106,696	$ 2,169,231	17%
Centralized Heat Pumps	$ 134,978	$ 68,103	$ 203,081	2%
Centralized Water Cooled Chiller	$ 0	$ 0	$ 0	0%
Geothermal Wellfield	$ 1,244,860	$ 757,020	$ 2,001,880	16%
Electric Boilers	$ 0	$ 0	$ 0	0%
Natural Gas Boilers	$ 823,529	$ 1,761,630	$ 2,585,159	20%
Thermal Energy Storage	$ 60,104	$ 60,046	$ 120,150	1%
DHW	$ 21,412	$ 134,000	$ 155,412	1%
Decentralized units	$ 1,595,118	$ 2,140,340	$ 3,735,458	29%
Electrical	$ 214,050	$ 275,792	$ 489,842	4%
Central Energy Plant Construction	$ 200,000	$ 150,000	$ 350,000	3%
Process Cooling	$ 832,153	$ 32,400	$ 864,553	7%
SUBTOTAL - SCENARIO 1			**$ 12,674,766**	
General Conditions	15%		$ 1,901,215	
Overhead and Profit	10%		$ 1,457,598	
Design Contingency	20%		$ 3,206,716	
Bid Contingency	5%		$ 962,015	
Phasing	10%		$ 2,020,231	
TOTAL - SCENARIO 1			**$ 22,222,541**	

Scenario 2 Ambient loop Detail

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
AIR SOURCE HEAT PUMPS						
AS heat pumps, with split condensers located on the exterior of the central energy plant	1 EA	$127,955.31	$127,955	$58,320.00	$58,320	$186,275
Direct digital control of ASHP (est 12 pts each)	1 EA	$4,800.00	$4,800	$7,200.00	$7,200	$12,000
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	200 SF	$5.50	$1,100	$8.80	$1,760	$2,860
Earthwork including excavation, select backfill and disposal on site for tank pad	23 CY	$48.80	$1,122	$35.80	$823	$1,946
TOTAL AIR SOURCE HEAT PUMPS			**$134,978**		**$68,103**	**$203,081**
GEOTHERMAL WELLFIELD						
Wellfield piping, includes vertical piping within the wellfield and distribution connecting each well, 500' depth	1 LS	$937,500	$937,500	$562,500	$562,500	$1,500,000
Wellfield water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC, (from wellfield to pumps)						
- 12" diameter	600 LF	$193.10	$115,860	$155.20	$93,120	$208,980
Pumps, end suction base mounted, 20 ft hd, including VFDs and accessories	3 EA	$48,500.00	$145,500	$10,800.00	$32,400	$177,900
Direct digital control of pumps (est 5 pts each)	3 EA	$2,000.00	$6,000	$3,000.00	$9,000	$15,000
Direct digital control of wellfield (est 100 pts each, (wellfield in different section)	1 LS	$40,000.00	$40,000	$60,000.00	$60,000	$100,000
TOTAL GEOTHERMAL WELLFIELD			**$1,244,860**		**$757,020**	**$2,001,880**
NATURAL GAS BOILERS						
Natural gas boiler-office	1 EA	$13,050.00	$13,050	$80,000.00	$80,000	$93,050
Natural gas boiler-non-refrigerated warehouse with fine sotrage	1 EA	$14,500.00	$14,500	$80,000.00	$80,000	$94,500
Natural gas boiler- Non-refrigerated Warehouse with Heating Only Storage	1 EA	$12,470.00	$12,470	$80,000.00	$80,000	$92,470
Natural gas boiler - refrigerated warehouse	1 EA	$14,210.00	$14,210	$80,000.00	$80,000	$94,210
Natural boiler- light manufacturing	1 EA	$33,640.00	$33,640	$80,000.00	$80,000	$113,640
Boiler breaching and venting	5 LS	$50,000.00	$250,000	$100,000.00	$500,000	$750,000
Direct digital control of boilers (est 15 pts each)	5 EA	$15,000.00	$75,000	$22,500.00	$112,500	$187,500
Heating hot water system components	1 LS	$100,000.00	$100,000	$30,720.00	$30,720	$130,720
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	800 SF	$5.50	$4,400	$10.40	$8,320	$12,720
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
TOTAL NATURAL GAS BOILERS			**$823,529**		**$1,761,630**	**$2,585,159**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
DOMESTIC HOT WATER TANKS						
DHW storage tank 2 - office	1 EA	$1,585.03	$1,585	$2,160.00	$2,160	$3,745
DHW storage tank 2-non-refrigerated warehouse with fine sotrage	2 EA	$792.52	$1,585	$2,160.00	$4,320	$5,905
DHW storage tank 2- Non-refrigerated Warehouse with Heating Onl	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
DHW storage tank 2- light manufacturing	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
Domestic water piping, above slab, copper type L, 2" diameter	240 LF	$36.60	$8,784	$23.40	$5,616	$14,400
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter	240 LF	$3.80	$912	$16.00	$3,840	$4,752
Direct digital control of domestic water tank (est 2 pts each)	5 EA	$800.00	$4,000	$1,200.00	$6,000	$10,000
TOTAL DOMESTIC HOT WATER TANKS			**$18,451**		**$26,256**	**$44,707**
DOMESTIC HOT WATER HEAT PUMPS						
DHW WSHP 2 - office	1 EA	$1,656	$1,656	$21,600.00	$21,600	$23,256
DHW WSHP 2-non-refrigerated warehouse with fine sotrage	2 EA	$552	$1,104	$21,600.00	$43,200	$44,304
DHW WSHP 2- Non-refrigerated Warehouse with Heating Only Stoı	1 EA	$368	$368	$21,600.00	$21,600	$21,968
DHW WSHP 2- light manufacturing	1 EA	$184	$184	$21,600.00	$21,600	$21,784
Domestic water piping, above slab, copper type L, 2" diameter	250 LF	$36.60	$9,150	$33.30	$8,325	$17,475
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter (40 lf per heater)	250 LF	$3.80	$950	$22.70	$5,675	$6,625
Direct digital control of domestic water HPs (est 4 pts each)	5 EA	$1,600.00	$8,000	$2,400.00	$12,000	$20,000
TOTAL DOMESTIC HOT WATER HEAT PUMPS			**$21,412**		**$134,000**	**$155,412**
THERMAL STORAGE TANKS						
Thermal storage tank- office	1 EA	$15,533.31	$15,533	$3,240.00	$3,240	$18,773
Thermal storage tank-non-refrigerated warehouse with fine sotrage	1 EA	$6,102.37	$6,102	$3,240.00	$3,240	$9,342
Thermal storage tank - Non-refrigerated Warehouse with Heating O	1 EA	$924.60	$925	$2,160.00	$2,160	$3,085
Thermal storage tank- refrigerated warehouse	1 EA	$924.60	$925	$2,160.00	$2,160	$3,085
Thermal storage tank- light manufacturing	1 EA	$4,068.25	$4,068	$3,240.00	$3,240	$7,308
Piping, above slab, copper type L, 2" diameter (50 lf per tank)	250 LF	$36.60	$9,150	$33.40	$8,350	$17,500
Piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter (50 lf per tank)	250 LF	$3.80	$950	$21.60	$5,400	$6,350
Direct digital control of storage tank (est 2 pts each)	5 EA	$800.00	$4,000	$1,200.00	$6,000	$10,000
TOTAL THERMAL STORAGE TANKS			**$41,653**		**$33,790**	**$75,443**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
AMBIENT WATER LOOP DISTRIBUTION						
Pumps, end suction base mounted, including VFDs and accessories	3 EA	$10,000.00	$30,000	$5,400.00	$16,200	$46,200
Direct digital control of pumps (est 5 pts each)	3 EA	$2,000.00	$6,000	$3,000.00	$9,000	$15,000
Isolation valves, automatic	20 EA	$745.00	$14,900	$810.00	$16,200	$31,100
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Ambient piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC, (80 lf per HX)						
- 2-1/2" diameter	240 LF	$32.00	$7,679	$80.80	$19,392	$27,071
- 3" diameter	480 LF	$33.90	$16,272	$88.20	$42,336	$58,608
- 4" diameter	1,360 LF	$48.40	$65,824	$103.40	$140,624	$206,448
- 6" diameter	1,280 LF	$64.60	$82,688	$116.50	$149,120	$231,808
Buried hydronic piping, HDPE pipe with leak detection	0					
- 2-1/2" diameter	0 LF	$45.80	$0	$70.90	$0	$0
- 4" diameter	0 LF	$60.20	$0	$82.20	$0	$0
- 5" diameter	1,953 LF	$66.10	$129,093	$85.70	$167,372	$296,465
- 6" diameter	LF	$72.90	$0	$91.40	$0	$0
- 8" diameter	984 LF	$95.40	$93,874	$98.50	$96,924	$190,798
- 10" diameter	0 LF	$125.30	$0	$107.10	$0	$0
- 12" diameter	390 LF	$154.20	$60,138	$110.40	$43,056	$103,194
- 14" diameter	LF	$187.90	$0	$133.60	$0	$0
- 16" diameter	LF	$228.40	$0	$133.60	$0	$0
- 22" diameter	LF	$400.00	$0	$177.50	$0	$0
Site utilities earthwork including excavation, select backfill and disposal on site (6' wide by 5' deep trench)	11,090 CY	$48.80	$541,192	$35.80	$397,022	$938,214
TOTAL AMBIENT WATER LOOP DISTRIBUTION			**$1,062,535**		**$1,106,696**	**$2,169,231**
DECENTRALIZED HEAT PUMPS						
WSHP-office	2 EA	$70,840	$141,680	$21,600.00	$43,200	$184,880
WSHP-non-refrigerated warehouse with fine sotrage	2 EA	$46,000	$92,000	$21,600.00	$43,200	$135,200
WSHP- Non-refrigerated Warehouse with Heating Only Storage	2 EA	$39,560	$79,120	$21,600.00	$43,200	$122,320
WSHP - refrigerated warehouse	2 EA	$45,080	$90,160	$21,600.00	$43,200	$133,360
WSHP- light manufacturing	2 EA	$106,720	$213,440	$32,400.00	$64,800	$278,240
Direct digital control of WSHP (est 12 pts each)	10 EA	$4,800.00	$48,000	$7,200.00	$72,000	$120,000
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	800 SF	$5.50	$4,400	$8.80	$7,040	$11,440
Heating hot water system components	9 LS	$15,000.00	$135,000	$20,000.00	$180,000	$315,000
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	800 SF	$5.50	$4,400	$10.40	$8,320	$12,720
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
Chilled water system components	1 LS	$100,000.00	$100,000	$75,000.00	$75,000	$175,000
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Chilled water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
- 6" diameter	1,000 LF	$64.60	$64,600	$116.50	$116,500	$181,100
Chilled water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
- 6" diameter	1,000 LF	$9.80	$9,800	$23.70	$23,700	$33,500
TOTAL DECENTRALIZED HEAT PUMPS			**$1,595,118**		**$2,140,340**	**$3,735,458**
ELECTRICAL						
Electrical connection at HVAC equipment including means of disconnect, conduit and circuiting back to source power panel						
- Water Source Heat Pumps	10 EA	$2,500.00	$25,000	$3,920.00	$39,200	$64,200
- Air Source Heat Pumps	1 EA	$2,500.00	$2,500	$3,920.00	$3,920	$6,420
- Circulator Connections	20 EA	$1,250.00	$25,000	$2,352.00	$47,040	$72,040
- Natural Gas Boilers	5 EA	$2,500.00	$12,500	$3,920.00	$19,600	$32,100
- Domestic Water Heater HPs	5 EA	$750.00	$3,750	$1,960.00	$9,800	$13,550
- Thermal Borefield Pumps	3 EA	$1,250.00	$3,750	$2,352.00	$7,056	$10,806
- Thermal Distribution Pumps	3 EA	$1,250.00	$3,750	$2,352.00	$7,056	$10,806
- Process Cooling Chillers	4 EA	$3,200.00	$12,800	$4,280.00	$17,120	$29,920
Miscellaneous electrical work (removals, equipment, feeders, terminations, testing, commissioning, etc)	1 ALLOW	$125,000.00	$125,000	$125,000.00	$125,000	$250,000
TOTAL ELECTRICAL			**$214,050**		**$275,792**	**$489,842**
CENTRAL ENERGY PLANT						
Central energy plant, block construction, including all MEP infrastructure needed for personnel operations	2,000 SF	$100.00	$200,000	$75.00	$150,000	$350,000
TOTAL CENTRAL ENERGY PLANT			**$200,000**		**$150,000**	**$350,000**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
PROCESS COOLING						
water cooled chiller for freezer	2 EA	$63,977.66	$127,955	$5,400.00	$10,800	$138,755
water cooled chiller for cooling doc	2 EA	$285,766.86	$571,534	$5,400.00	$10,800	$582,334
heat rejection unit	2 EA	$66,332.03	$132,664	$5,400.00	$10,800	$143,464
Heating hot water system components	1 LS	$15,000.00	$15,000	$20,000.00	$20,000	$35,000
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC, (80 lf per HX)						
- 2-1/2" diameter	100 LF	$32.00	$3,200	$80.80	$8,080	$11,280
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	100 LF	$6.90	$690	$14.63	$1,463	$2,153
Direct digital control of domestic water heat ASHPs (est 12 pts each)	3 EA	$4,800.00	$14,400	$7,200.00	$21,600	$36,000
TOTAL PROCESS COOLING			**$832,153**		**$32,400**	**$864,553**

SCENARIO 3 SUMMARY

PROJECT SUMMARY	TOTAL MATERIAL	TOTAL LABOR	TOTAL COST	% OF TOTAL
Thermal Distribution	$ 0	$ 0	$ 0	0%
Centralized Heat Pumps	$ 0	$ 0	$ 0	0%
Centralized Water Cooled Chiller	$ 0	$ 0	$ 0	0%
Geothermal Wellfield	$ 0	$ 0	$ 0	0%
Electric Boilers	$ 0	$ 0	$ 0	0%
Natural Gas Boilers	$ 823,529	$ 1,761,630	$ 2,585,159	18%
Thermal Energy Storage	$ 60,104	$ 60,046	$ 120,150	1%
DHW	$ 17,164	$ 31,760	$ 48,924	0%
Decentralized units	$ 2,153,568	$ 1,893,900	$ 4,047,468	29%
Electrical	$ 224,050	$ 289,120	$ 513,170	4%
Central Energy Plant Construction	$ 0	$ 0	$ 0	0%
Process Cooling	$ 699,489	$ 21,600	$ 721,089	5%
SUBTOTAL - SCENARIO 1			**$ 8,035,960**	
General Conditions	15%		$ 1,205,394	
Overhead and Profit	10%		$ 924,135	
Design Contingency	20%		$ 2,033,098	
Bid Contingency	5%		$ 609,929	
Phasing	10%		$ 1,280,852	
TOTAL - SCENARIO 1			**$ 14,089,369**	

Sc3 Decentralized Detail

DESCRIPTION	QUANTITY	MATERIAL		LABOR		
		UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
NATURAL GAS BOILERS						
Natural gas boiler-office	1 EA	$13,050.00	$13,050	$80,000.00	$80,000	$93,050
Natural gas boiler-non-refrigerated warehouse with fine sotrage	1 EA	$14,500.00	$14,500	$80,000.00	$80,000	$94,500
Natural gas boiler- Non-refrigerated Warehouse with Heating Only Storage	1 EA	$12,470.00	$12,470	$80,000.00	$80,000	$92,470
Natural gas boiler - refrigerated warehouse	1 EA	$14,210.00	$14,210	$80,000.00	$80,000	$94,210
Natural boiler- light manufacturing	1 EA	$33,640.00	$33,640	$80,000.00	$80,000	$113,640
Boiler breaching and venting	5 LS	$50,000.00	$250,000	$100,000.00	$500,000	$750,000
Direct digital control of boilers (est 15 pts each)	5 EA	$15,000.00	$75,000	$22,500.00	$112,500	$187,500
Heating hot water system components	1 LS	$100,000.00	$100,000	$30,720.00	$30,720	$130,720
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	800 SF	$5.50	$4,400	$10.40	$8,320	$12,720
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
TOTAL NATURAL GAS BOILERS			**$823,529**		**$1,761,630**	**$2,585,159**
DOMESTIC HOT WATER TANKS						
storage tank 2 - office	1 EA	$1,585.03	$1,585	$2,160.00	$2,160	$3,745
storage tank 2-non-refrigerated warehouse with fine sotrage	2 EA	$792.52	$1,585	$2,160.00	$4,320	$5,905
storage tank 2- Non-refrigerated Warehouse with Heating Only Storage	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
storage tank 2- light manufacturing	1 EA	$792.52	$793	$2,160.00	$2,160	$2,953
Domestic water piping, above slab, copper type L, 2" diameter	240 LF	$36.60	$8,784	$23.40	$5,616	$14,400
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter	240 LF	$3.80	$912	$16.00	$3,840	$4,752
Direct digital control of domestic water tank (est 2 pts each)	5 EA	$800.00	$4,000	$1,200.00	$6,000	$10,000
TOTAL DOMESTIC HOT WATER TANKS			**$18,451**		**$26,256**	**$44,707**
THERMAL STORAGE TANKS						
storage tank- office	1 EA	$15,533.31	$15,533	$3,240.00	$3,240	$18,773
storage tank-non-refrigerated warehouse with fine sotrage	1 EA	$6,102.37	$6,102	$3,240.00	$3,240	$9,342
storage tank - Non-refrigerated Warehouse with Heating Only Storage	1 EA	$924.60	$925	$2,160.00	$2,160	$3,085
storage tank- refrigerated warehouse	1 EA	$924.60	$925	$2,160.00	$2,160	$3,085
storage tank- light manufacturing	1 EA	$4,068.25	$4,068	$3,240.00	$3,240	$7,308
Piping, above slab, copper type L, 2" diameter (50 lf per tank)	250 LF	$36.60	$9,150	$33.40	$8,350	$17,500
Piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter (50 lf per tank)	250 LF	$3.80	$950	$21.60	$5,400	$6,350
Direct digital control of storage tank (est 2 pts each)	5 EA	$800.00	$4,000	$1,200.00	$6,000	$10,000
TOTAL THERMAL STORAGE TANKS			**$41,653**		**$33,790**	**$75,443**

		MATERIAL		LABOR		
DESCRIPTION	QUANTITY	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	TOTAL
DOMESTIC WATER ELECTRIC HEATERS						
electric water heater - office	1 EA	$1,350.00	$1,350	$2,160.00	$2,160	$3,510
electric water heater -non-refrigerated warehouse with fine sotrage	2 EA	$450.00	$900	$2,160.00	$4,320	$5,220
electric water heater - Non-refrigerated Warehouse with Heating Only Storage	1 EA	$300.00	$300	$2,160.00	$2,160	$2,460
electric water heater - light manufacturing	1 EA	$150.00	$150	$2,160.00	$2,160	$2,310
Domestic water piping, above slab, copper type L, 2" diameter	160 LF	$36.60	$5,856	$33.30	$5,328	$11,184
Domestic water piping fiberglass insulation with all service jacket, 1" thickness for copper piping, 2" diameter (40 lf per heater)	160 LF	$3.80	$608	$22.70	$3,632	$4,240
Direct digital control of domestic water heat heaters (est 4 pts each)	5 EA	$1,600.00	$8,000	$2,400.00	$12,000	$20,000
TOTAL DOMESTIC WATER ELECTRIC HEATERS			**$17,164**		**$31,760**	**$48,924**
DECENTRALIZED AIR SOURCE HEAT PUMPS						
ASHP-office	2 EA	$144,375.00	$288,750	$7,020.00	$14,040	$302,790
ASHP-non-refrigerated warehouse with fine sotrage	2 EA	$93,750.00	$187,500	$7,020.00	$14,040	$201,540
ASHP- Non-refrigerated Warehouse with Heating Only Storage	2 EA	$80,625.00	$161,250	$7,020.00	$14,040	$175,290
ASHP - refrigerated warehouse	2 EA	$91,875.00	$183,750	$7,020.00	$14,040	$197,790
ASHP- light manufacturing	2 EA	$203,000.00	$406,000	$7,020.00	$14,040	$420,040
Heating hot water system components	9 LS	$15,000.00	$135,000	$20,000.00	$180,000	$315,000
4" concrete slab, vapor barrier, 6x6 6/6 welded wire mesh, 6" stone base, bulkheads and edge forms, finish, cure and protect	800 SF	$5.50	$4,400	$10.40	$8,320	$12,720
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Heating hot water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
Heating hot water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
Chilled water system components	1 LS	$100,000.00	$100,000	$75,000.00	$75,000	$175,000
Flow meters, ultrasonic	5 EA	$1,500.00	$7,500	$1,080.00	$5,400	$12,900
Temperature transmitters	20 EA	$150.00	$3,000	$135.00	$2,700	$5,700
Differential pressure switch	5 EA	$875.00	$4,375	$270.00	$1,350	$5,725
Chilled water piping, welded black steel, schedule 40, on yoke & roll hanger assemblies, 10' OC						
- 2-1/2" diameter	3,200 LF	$32.00	$102,384	$80.80	$258,560	$360,944
- 3" diameter	2,400 LF	$33.90	$81,360	$88.20	$211,680	$293,040
- 4" diameter	1,200 LF	$48.40	$58,080	$103.40	$124,080	$182,160
- 6" diameter	1,000 LF	$64.60	$64,600	$116.50	$116,500	$181,100
Chilled water fiberglass pipe insulation with all service jacket, 1-1/2" thickness for iron piping						
- 2-1/2" diameter	3,200 LF	$6.90	$22,080	$14.70	$47,040	$69,120
- 3" diameter	2,400 LF	$7.30	$17,520	$15.40	$36,960	$54,480
- 4" diameter	1,200 LF	$8.30	$9,960	$18.60	$22,320	$32,280
- 6" diameter	1,000 LF	$9.80	$9,800	$23.70	$23,700	$33,500
TOTAL DECENTRALIZED AIR SOURCE HEAT PUMPS			**$2,153,568**		**$1,893,900**	**$4,047,468**

DESCRIPTION	QUANTITY	MATERIAL		LABOR		TOTAL
		UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	
ELECTRICAL						
Electrical connection at HVAC equipment including means of disconnect, conduit and circuiting back to source power panel						
- Water Source Heat Pumps	10 EA	$2,500.00	$25,000	$3,920.00	$39,200	$64,200
- Air Source Heat Pumps	8 EA	$2,500.00	$20,000	$3,920.00	$31,360	$51,360
- Circulator Connections	20 EA	$1,250.00	$25,000	$2,352.00	$47,040	$72,040
- Natural Gas Boilers	5 EA	$2,500.00	$12,500	$3,920.00	$19,600	$32,100
- Domestic Water Heater Electric	5 EA	$750.00	$3,750	$1,960.00	$9,800	$13,550
- Process Cooling Chillers	4 EA	$3,200.00	$12,800	$4,280.00	$17,120	$29,920
Miscellaneous electrical work (removals, equipment, feeders, terminations, testing, commissioning, etc)	1 ALLOW	$125,000.00	$125,000	$125,000.00	$125,000	$250,000
TOTAL ELECTRICAL			**$224,050**		**$289,120**	**$513,170**
PROCESS COOLING						
Water-cooled chiller for freezer	2 EA	$63,977.66	$127,955	$5,400.00	$10,800	$138,755
Water-cooled chiller for cooling doc	2 EA	$285,766.86	$571,534	$5,400.00	$10,800	$582,334
TOTAL PROCESS COOLING			**$699,489**		**$21,600**	**$721,089**

Endnotes

[1] NYSEG Electric Rate Summary May 2022: https://www.nyseg.com/documents/40132/5899296/NYSEG%2BElectric%2BRate%2BSummary%2BMay%2B2022%2BNPRB211.pdf/692e2ee9-e221-913a-b020-94c522e5a43a?version=1.0&t=1654867260084

[2] NYSEG ISO Maps: https://www.nyseg.com/w/iso-maps?p_l_back_url=%2Fsearch%3Fq%3Diso

[3] Consumer Price Index Historical Data (U.S. Table): https://www.bls.gov/regions/mid-atlantic/data/consumerpriceindexhistorical_us_table.htm
2021 average CPI = 255.7, 2022 average CPI = 292.7, 14.47% inflation rate from 2019 to 2022

[4] NYISO 2021 State of the Market Report: https://www.nyiso.com/documents/20142/2223763/NYISO-2021-SOM-Full-Report-5-11-2022-final.pdf

[5] USGS Water Data for Pennsylvania: https://waterdata.usgs.gov/pa/nwis/current/?type=temp

[6] Carrier Ecodesign Technical Data Sheet (30WG 020): https://eto.carrier.com/litterature/Ecodesign/10244_TDS_SCOP_09_2019_30WG_020_190.pdf

[7] New York State Department of Environmental Conservation (DEC) VOC Applicator Certification Form: https://www.dec.ny.gov/docs/administration_pdf/vocapp23.pdf

[8] Consumer Price Index Historical Data (U.S. Table): https://www.bls.gov/regions/mid-atlantic/data/consumerpriceindexhistorical_us_table.htm
2020 average CPI = 258.8, 2022 average CPI = 292.7, 13.1% inflation rate from 2020 to 2022

[9] Design contingency is related to the project’s progress. In early stages, when details are still being defined, the contingency is higher. As the project progresses, the contingency usually decreases.

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

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New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

NEW YORK STATE | NYSERDA