September 17, 2024

Marquette University

Decarbonization Study

Acknowledgements

This work was initiated by Tim Tharp and David Nowacek, who were inspired by their students to make a serious effort to reduce Marquette University's carbon emissions. This study was made possible by contributions from many people, only some of whom are acknowledged here.

This work was funded by the Public Service Commission (PSC) Energy Innovation Grant Program (EIGP), Award Number EIGP-2022-15. The EIGP is funded by a grant awarded by the Department of Energy. Marquette University provided matching funds and substantial administrative and technical support.

The grant application was submitted by four partners: Marquette University, the Church of the Gesu, the Near West Side Partners (NWSP), and the Menomonee Valley Partners (MVP). Each of these organizations made critical contributions to this work, including networking, administrative support, and creative input. Tim Tharp and David Nowacek were co-PI's for this grant.

Marquette staff, particularly from the division of Facilities, Planning, & Management, provided key data and guidance of various sorts.

Heidi Bostic and Jeanne Hossenlopp corralled matching funds and institutional support without which this grant would not have come together.

WE Energies provided valuable input and support, and we particularly thank Paul Spicer for productive conversations and input. The Milwaukee Metropolitan Sewerage District (MMSD) provided critical data for our analysis of Wastewater Heat Exchange.

Salas O'Brien performed the engineering for this study, informed by a year of weekly meetings with the PI's, a number of trips to campus, and multiple conversations with representatives of the four grant partners. Salas fields an amazing team. We thank them not only for their multi-dimensional expertise but also for the deep pleasure of working with them.

Our colleague in engineering, Anthony Bowman, gave so generously of his time and expertise that he collaborated effectively as a third PI.

Staff at Vyron put key substance behind some of our more consequential assumptions.

In addition, we would like to thank by name a number of key collaborators without whom this work would not have been possible:

Rana Altenburg, Eleanore Colton, Raymond Ellingen, Josh Hays, Rick Humphries, Mike Jahner, Andy LaFerriere, Zeyneb Magavi, Matt Magruder, Chelsea Malacara, Rob McKenna, Chris Merker, Kelsey Otero, Joe Pater, Mike Ribbich, Matt Ruddat, Jame Schaefer, Audrey Schulman, Kevin Shafer, Jen Smith, Parker Stokosa, Lora Strigens, Kurt Thomas, Brian Urlaub, Jeff Urlaub, Mike Walters, and Corey Zetts.

Marquette University

EXECUTIVE SUMMARY

“[O]ur responses have not been adequate, while the world in which we live is collapsing and may be nearing the breaking point.” These are the words of Pope Francis in his recent Apostolic Exhortation, *Laudato Deum* (Oct. 4, 2023). He links the cry of the Earth to “the irresponsible lifestyle connected with the Western model” and with the United States in particular. He calls on “all people of good will” to respond to the threat of climate change through swift and substantial action.

Marquette University is a Catholic, Jesuit institution and therefore has a responsibility to heed the Pope’s call in a timely fashion. This responsibility goes far beyond adding a few solar panels where and when it is convenient to do so. In the words of Pope Francis, “We must move beyond the mentality of appearing to be concerned but not having the courage needed to produce substantial changes.”

The Intergovernmental Panel on Climate Change (IPCC) has identified the likely impacts of climate change at different levels of global warming. Based upon these findings, the international community has agreed to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. The IPCC has further determined what is required to meet this target, which can be summarized succinctly: We must reduce emissions aggressively, achieving a reduction of 50% by 2030 and net-zero by 2050 (from 2020 levels). If humanity must reach these targets globally, Marquette has a responsibility to at least achieve the same targets locally.

Marquette University needs to commit to advancing sustainability through a comprehensive decarbonization strategy. We have undertaken a year-long study to develop a cost-effective strategy that will achieve these goals. In this implementation paper, we recommend a strategy to achieve the required emission reduction for campus. Not only is the IPCC target achievable, but aggressively pursuing emissions reduction is also fiscally advantageous to Marquette.

The Recommended Strategy

Our analysis of Marquette's energy uses, existing infrastructure, and area resources has identified a particular infrastructure recommendation. The recommendation includes building out a district high temperature (170°F) hot water network, parallel to the existing chilled water network; purchasing commercially available heat pumps to supply the hot water and chilled water networks; and coupling these heat pumps to nearby thermal sources and sinks (notably a major sewer line running beneath campus).

The details of the recommended strategy (and how it was determined) are explained throughout the rest of this report. We include a suggested first phase of the strategy, enabled by a strategic reallocation of capital investments (which have already been identified by the university as needed) on steam leg 5.

The Recommended Strategy is comprised of five key elements. While each element has independent utility, their impact is much stronger when implemented together. Taken as a whole, the Recommended Strategy is financially advantageous compared to Marquette’s Business-As-Usual operation.

The Five Key Elements of the Recommended Strategy are:

1. Reduce Energy Demand
2. Modernize Marquette's Thermal Energy Infrastructure
3. Strategically Reallocate Capital Renewal Dollars
4. Sequence the Transition Opportunistically
5. Maintain and Build New Partnerships

1. **Reduce Energy Demand:** Demand-Side Reduction is pivotal because investments in reducing demand often pay themselves back quickly and reduce the scale of subsequent supply-side investments. Marquette's Department of Facilities Planning and Management (FP&M) has regularly worked to reduce energy demand when opportunities present themselves. Energy conservation measures (ECMs) already being implemented by FP&M are detailed later (see page 16). Our recommendation includes increasing this effort to achieve an overall 25% reduction in energy use, through a program of energy conservation funded at the level of $2 million per year for 10 years.
2. **Modernize Marquette's Thermal Energy Infrastructure:** Marquette's campus is currently heated by a steam system that is powered by natural gas at the WE Energies' Valley Power Plant. The recommended strategy would modernize this infrastructure, reducing carbon emissions in two important ways: First, a modern thermal infrastructure system could greatly reduce energy consumption (by ~25%) by taking advantage of simultaneous heating and cooling loads. Second, this system would be able to take advantage of local, renewable, low-carbon energy sources, notably by exchanging heat with a large sewer main running under campus (see page 20-23).
3. **Strategically Reallocate Capital Renewal Dollars**: Marquette already spends approximately $4 million annually on its thermal capital infrastructure. (See page 11 for analysis of these regular expenditures.) Many of these dollars could be spent more strategically simply by making slightly different choices when components or systems need to be replaced. Further, judiciously chosen projects can unlock substantial federal support, effectively stretching our existing deferred maintenance budgets by an additional 40%. Through these mechanisms, strategic reallocation of planned capital expenditures can continue to meet short term needs while also enabling the roll-out of modern thermal infrastructure able to meet Marquette's 21st century needs.
4. **Sequence the Transition Opportunistically:** The recommended strategy proposes an initial pilot project, commencing on Steam Leg 5, to begin the build-out of a district hot water network to service all of campus. As the pilot project demonstrates feasibility and scalability, additional steam legs can undergo similar conversion. Pilot networks would then be expanded, joined, and linked to ground source and wastewater heat recovery technologies to achieve decarbonization.
5. **Maintain and Build New Partnerships:** To rapidly achieve such a comprehensive solution, the Recommended Strategy proposes exploration of partnership opportunities with WE Energies and other third parties, especially the Milwaukee Metropolitan Sewerage District (MMSD) to access renewable thermal energy in a sewer main. Such partnerships would support infrastructure development and leverage external expertise and resources, thereby enhancing the financial and operational viability of the decarbonization efforts.

Life-cycle Cost Comparison

The following chart (Figure 1) presents a comparison of net present costs and greenhouse gas (GHG) emissions for Marquette University under three different scenarios: Business-As-Usual (BAU), the Recommended Strategy without an Investment Tax Credit (ITC), and the Recommended Strategy with ITC.

In the Business-As-Usual (BAU) scenario, the net present cost is $420.23 million. This scenario assumes the continuation of current systems and energy sources, resulting in 2050 Scope 1 and 2 emissions of 20,000 metric tons of CO_2 equivalent ($MTCO_2e$), compared to 52,600 $MTCO_2e$ in 2024.[1] The costs are distributed across operations and maintenance (O&M), commodities, and capital expenditures (CAPEX), reflecting the ongoing expenses of maintaining the status quo.

The second scenario, referred to as the Recommended Strategy, projects a net present cost of $433.56 million. This scenario involves a significant infrastructure upgrade to a 4-pipe heating system operating at 170°F, which reduces GHG emissions to 3,000 $MTCO_2e$ by 2050, assuming a net-zero grid. Most of the higher CAPEX is offset by lower commodity purchases. The amount not offset represents a net investment in carbon reduction, and risk avoidance, which eliminates 85% of Marquette's emissions that would remain even under the assumption of a net-zero grid in 2050.

The third scenario, the Recommended Strategy with ITC, presents a net present cost of $353.23 million, making it the most cost-effective option when accounting for investment tax credits. This scenario also achieves GHG emissions of 3,000 $MTCO_2e$ by 2050 with a net-zero grid. The ITC significantly lowers the overall cost by offsetting part of the capital investment, while maintaining the benefit of lower commodity costs.

Operation and maintenance (O&M) costs are assumed to be unchanged across the three scenarios. This is a conservative assumption: campus transformations such as that proposed here typically result in an overall decrease of O&M costs.

Overall, the chart demonstrates that while the BAU scenario incurs the lowest upfront capital costs, it leads to the highest long-term costs and emissions. In contrast, the Recommended Strategy, particularly with ITC, offers substantial long-term savings and significant reductions in GHG emissions, highlighting the financial and environmental advantages of investing in sustainable infrastructure upgrades. Additional financial break-even and sensitivity analyses are explored in more detail in the report's body (pages 34-36).

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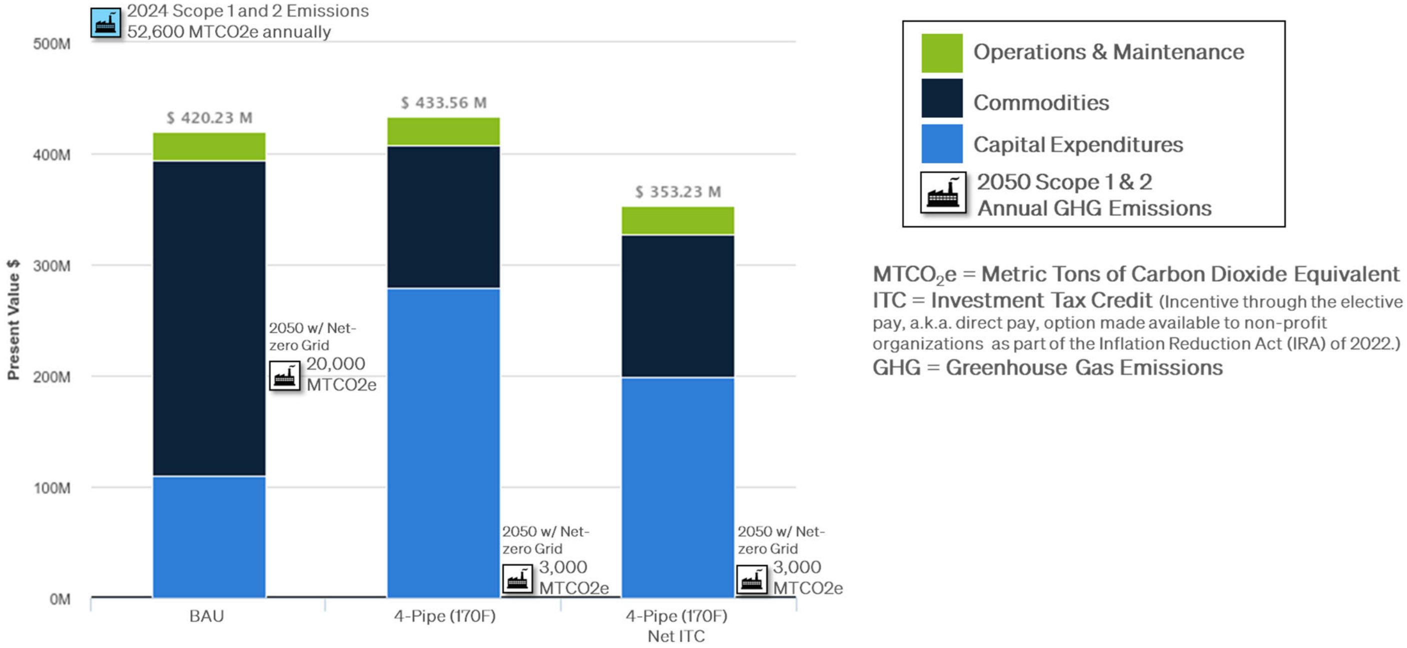
[1] This reduction is due solely to the assumption that the grid decarbonizes at a rapid pace, reaching net zero by 2050. All scenarios make this assumption.

Figure 1 Life-Cycle Cost Comparison



MTCO$_2$e = Metric Tons of Carbon Dioxide Equivalent
ITC = Investment Tax Credit (Incentive through the elective pay, a.k.a. direct pay, option made available to non-profit organizations as part of the Inflation Reduction Act (IRA) of 2022.)
GHG = Greenhouse Gas Emissions

In summary, our analysis shows that pursuing the Recommended Strategy in full will save campus $67 million over 30 years. The strategy can be fully funded by effectively reallocating funds from commodity purchases to infrastructure investment. A broad range of financing options is available to facilitate this reallocation.

BUSINESS AS USUAL

Marquette Community

This roadmap involves strategies that affect not only Marquette University's campus, but also the surrounding community and businesses that interact with the campus. The campus and community are linked by the utility that provides energy to both, making the utility a key strategic partner.

Marquette University is served by WE Energies steam for heating. The WE Energies steam system in Milwaukee is a district energy system that provides steam for heating and industrial processes to around 370 customers in the downtown area.[2] The steam is produced at the Valley Power Plant, where natural gas is burned to co-generate electricity and steam for heating purposes The steam is extracted from the power plant then distributed through a network of underground pipes extending from Mitchell Street north to West Vliet Street and from Lake Michigan west to 19th Street.[3]

This steam system supports a variety of applications, including space heating, water heating, food processing, and industrial sterilization. Recently, WE Energies has been investing in infrastructure improvements, such as constructing a new regulating station and improving flood resiliency. In addition,

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[2] "Key Facts - We Energies"

[3] "Downtown Milwaukee's Steam System a Hidden 125-Year-Old Source of Heat, Power"

to enhance the efficiency and reliability of the system, operations were recently consolidated in a new steam headquarters at the Valley Power Plant.[4] The system has faced challenges, including steam tunnel flooding incidents in 2020 and 2021, which required significant repairs and upgrades to maintain service continuity.[5]

Future Considerations for WE Energies Steam Supply

There are several factors affecting the price of steam for Marquette, most notably fluctuations in the price of natural gas (the Valley Plant's fuel), upkeep of plant equipment and distribution infrastructure, and changes in sales volume on the steam system.

The life-cycle cost comparison between Business-As-Usual (BAU) and the Recommended Strategy has assumed a long-term steam price escalation rate of 5%. It is important to contextualize this estimate as conservative when compared to actual increases since 2019. In 2019, Marquette paid $10.12 per unit of steam. By 2024 the price had risen to $16.08, which is an average annual rate of increase of 11.8% relative to 2019. Given that this rate of increase is over twice as fast as assumed in our comparison, we provide additional sensitivity analysis at the end of the report. To summarize that analysis, the Recommended Strategy with ITC is less expensive than Business-As-Usual, even at the conservative steam escalation rate of 5%. At 6% or more escalation, the Recommended Strategy is less expensive even without the ITC. And at an escalation rate of 11% (roughly what Marquette has seen these last 5 years), the savings of the Recommended Strategy (with or without the ITC) over Business-As-Usual are in excess of $200 million.

Valley Power Plant Considerations

The Valley Power Plant, which has a dual purpose of providing both steam and electricity, plays a critical role in the local energy landscape. As renewable energy penetration in the grid increases, the economic value of this plant for mitigating intermittency becomes more significant. However, its economic value for producing steam is diminishing. In consequence, finding a way to serve Marquette's thermal load in a manner that is decoupled from steam might enable more economical operation of the Valley Plant.

Opportunities for the future

Thus, as Marquette seeks to reduce its carbon footprint and control its future thermal energy costs, and as WE Energies seeks the highest economic use of the Valley Plant, a harmony of interests may emerge suggesting Marquette should explore potential partnership opportunities with WE Energies and other third parties to develop sustainable thermal energy alternatives. By collaborating on initiatives like district hot water networks, ground source heat pumps, and wastewater heat recovery systems, Marquette can ensure a resilient and future-proof energy infrastructure. Both the existing infrastructure and number and diversity of neighboring businesses and structures make a new sort of district energy system a practical and financially responsible prospect for Marquette and WE.

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[4] "Friday Photos: We Energies Readies New Steam HQ at Valley Power Plant"

[5] “Steam Tunnel Flood Repairs Will Cost Over $60 Million”

WE Energies has expressed interest in supporting Marquette's effort to decarbonize its energy supply. We Energies is engaged and willing to continue conversations regarding ways for MU to lower its carbon footprint, ideas for improving the district energy system, as well as further studying the technical and commercial aspects of this study's recommendations, including a variety of ownership and operation scenarios in order to help MU achieve its energy related goals.

For more details, visit the sources: Urban Milwaukee, TMJ4 News, Journal Sentinel, WE Energies District Energy, WE Energies Key Facts, Urban Milwaukee on Rate Hikes.

Existing Conditions

All buildings that are owned and operated by Marquette and which are located on the core campus and its periphery are included in the scope of our project roadmap. The scope of this roadmap currently includes 74 buildings (approximately 12 million GSF), with consideration for future expansion possibly beyond MU.

The building stock includes academic buildings, athletic, dormitory, residential, and support facilities. The structures range in age and condition, the earliest being St. Joan of Arc Chapel, built in 1429 and the latest in 2024. Over one third of the building stock was built in the last thirty years. The latest buildings include the College of Business Administration, College of Nursing, Wellness and Helfaer Recreation Building, and Lemonis Student Success Center, all built in the last two years (2023-2024).

Figure 2 Marquette Existing Distribution Map

The campus is predominately heated using district steam purchased from WE Energies (Figure 2 Marquette Existing Distribution Map above). Several peripheral buildings have stand-alone heating and cooling systems, including the 313 Building in the valley and some of the northwesterly university housing: Mashuda, O'Donnell, Campus Town East and West.

The campus is cooled by a district chilled water (CHW) system (Figure 2 above) consisting of two plants interconnected by a common 2-pipe distribution. Plants are located at Clark Hall (the old College of Nursing) and Eckstein Hall (the Law School). The Clark Hall plant includes (3) 1,350-ton electric centrifugal chillers with evaporative cooling tower cells on the roof. The Eckstein Hall plant includes (2) 1,350-ton electrical centrifugal chillers with evaporative cooling tower cells on the roof. Several peripheral campus buildings not on the district chilled network include Mashuda, O'Donnell, Campus West and East apartments, and the 313 Building in the valley. All these buildings have stand-alone systems (AC units/heat pumps) that contribute significantly to maintenance costs.

The Salas team was able to put together an analysis of steam and electricity usage using data provided by the University from fiscal year 2019. This year represented the most reliable pre-pandemic data with student population and occupancy rates mirroring future projections for the university.

The analysis of the data included an assessment of system loss. It is important to understand thermal losses, and where they occur in the system, to develop a complete understanding of costs, GHG emissions, and the heating and cooling needs of buildings on campus. District steam delivered to campus for heating purposes may be coupled with additional losses in the campus distribution network and at the building level. These losses need to be accounted for when developing the thermal profile because they represent purchased thermal energy that isn’t used to condition a building. Similarly, when considering carbon emissions, the generation and distribution losses from Valley Power Plant to the campus may not play into the heating profile of the campus but they still represent input energy (fossil fuels) that are burned as part of the process of creating and delivering the product to end-users. Steam losses totaled roughly 20% from distribution and conversion in the buildings and electricity losses totaled 5% from transmission and 14% from chilled water generation and space cooling.

Using monthly steam and electricity consumption, the team put together a thermal profile that shows the campus thermal load throughout the year (Figure 3). This is an hourly representation of monthly data that Salas obtained from Marquette for a typical year of operation. Steam and chilled water data were converted using a proprietary tool that distributes monthly totals across each hour of the month based on occupancy schedule assumptions and ambient temperature observations. [6] The result is an hour-by-hour estimate of thermal needs, both heating and cooling, sourced from actual observed monthly total heating and cooling needs as measured and recorded by Marquette.

During the information gathering phase of the study, the Salas team received valuable insight from Marquette facilities staff regarding annual operations of the campus chilled water plants. Based on these discussions, it was assumed that the chilled water system is brought online around April and will operate through October at which time the system is shut down until the next spring. This is illustrated in the cooling profile and contributes to the large cliffs that are observed between months of activity and inactivity.

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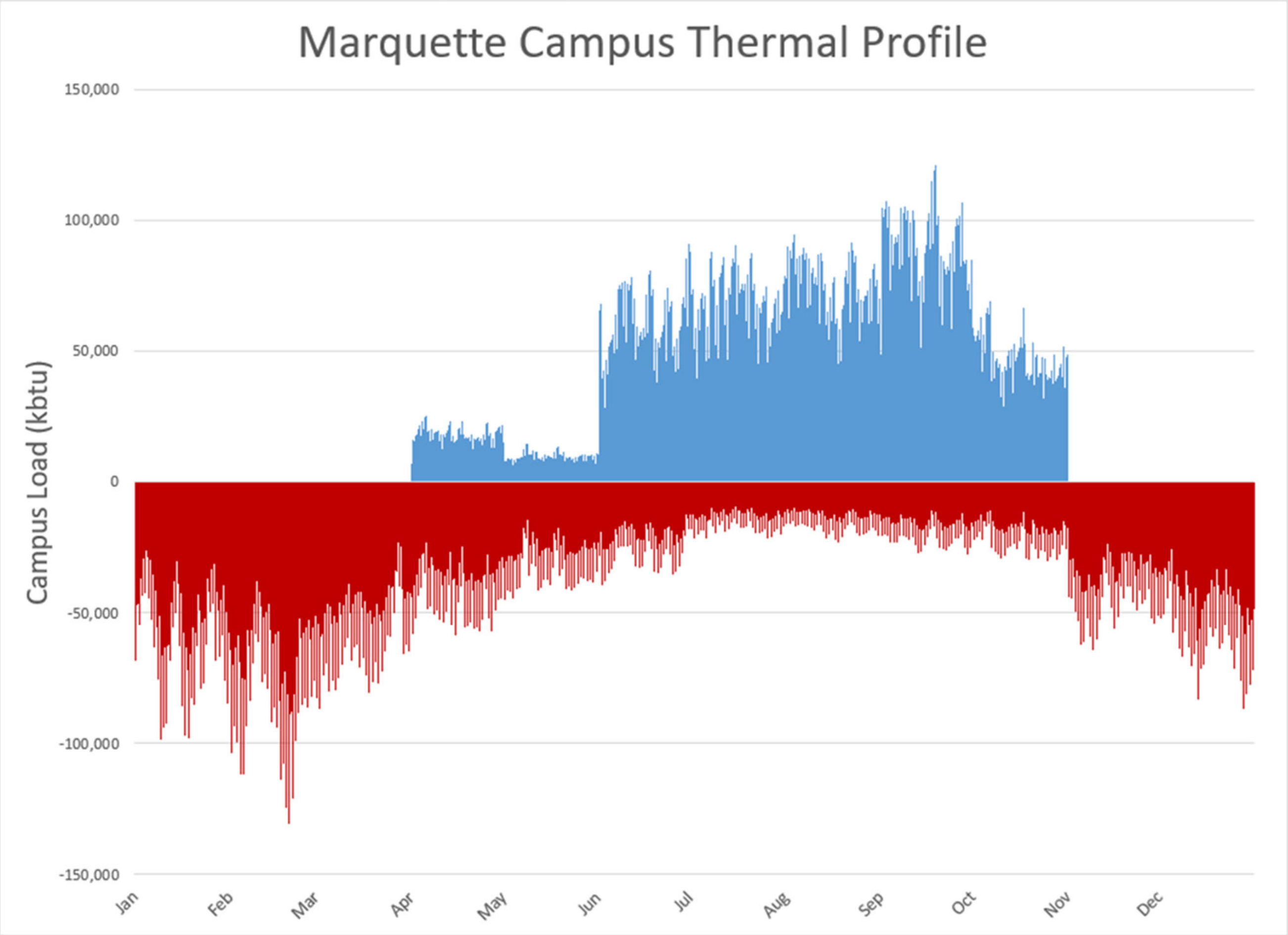
[6] There are several embedded assumptions in the conversion of monthly to hourly data. This is especially true when estimating chilled water load from electrical energy data as was done for this study. The chilled water load fluctuation that is seen in the spring months is likely due to changes in the base electrical load, or electrical load not associated with chilled water production, as students prepare for and progress through the end of the semester. For the purposes of the feasibility study, accuracy of hourly load(s) is not as important as total load for the calendar year. Therefore, while there may be some misrepresentation of actual cooling load on an hourly basis it should not affect overall results or recommendations which are more heavily influenced by annual load.

Figure 3 Marquette Thermal Profile (2019)

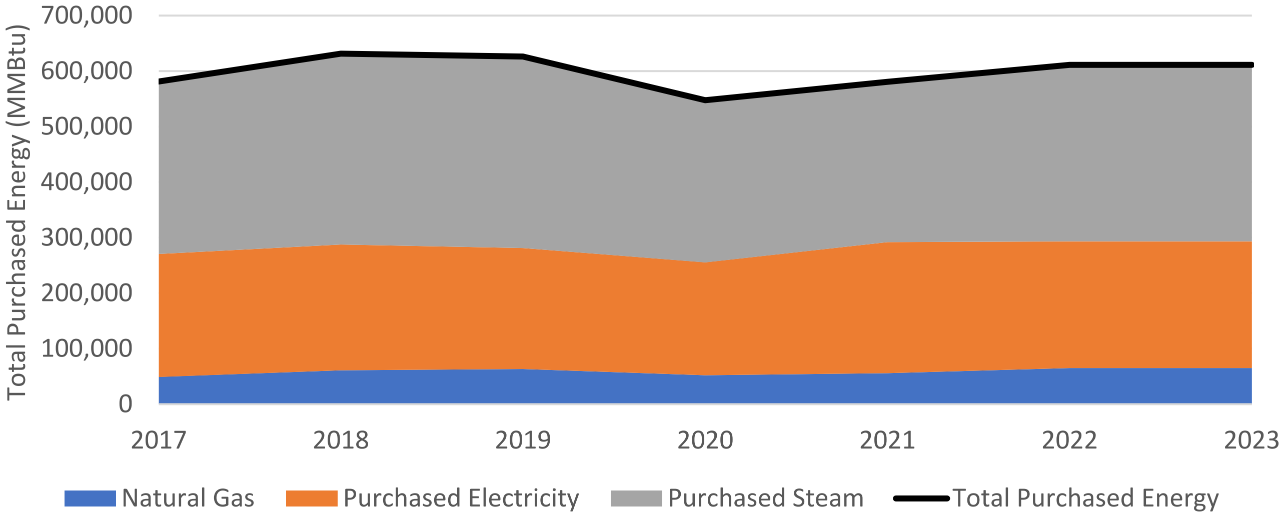


BAU Forecast

The Business-as-Usual (BAU) Forecast models Marquette University's projected emissions and costs if it continues to use its current equipment and energy sources. This model illustrates the carbon emissions and costs associated with stationary combustion, purchased electricity, and steam, encompassing the entire campus and its current building stock.

To forecast future energy consumption, we start with historical data. The chart below shows that the University has consistently purchased about 600 billion British Thermal Units (Btu) of energy annually, sourced from a mix of natural gas, electricity, and steam. This historical perspective is crucial for understanding future energy and emission trends.

Figure 4 Historical Energy Sources



Annually, Marquette University spends approximately $12 million on energy commodities, resulting in nearly 54,000 $MTCO_2e$ of greenhouse gas emissions. The table below breaks down the costs and GHG emissions by commodity, including the starting price and escalation rate used in the BAU model. This detailed breakdown helps in understanding the financial and environmental impact of the university's energy consumption, providing a clear view of the current expenses and future projections.

Table 1 BAU Purchased Energy Commodities [7]

	Annual Purchases (MMBtu)	Annual Cost (2024$)	Starting Price	Escalation Rate	GHG Emissions ($MTCO_2e$)	Scope
Natural Gas	65,000	$540,000	$8.50/MMBtu	2.0%	3,500	Scope 1
Purchased Electricity	230,000	$6,940,000	$105.80/MWh	2.0%	32,700	Scope 2
Purchased Steam	320,000	$4,260,000	$16.20/Mlb	4.0%	17,700	Scope 2
Total Annual	615,000	$11,740,000			53,900	

The breakdown includes Scope 1 and Scope 2 emissions. Scope 1 emissions are emissions associated with onsite combustion. Scope 2 emissions are emissions associated with purchased electrical energy and off-site combustion associated with the production of district steam.[8] The BAU assumes that current systems and equipment will be replaced or rebuilt in-kind and that new buildings will utilize similar systems as older buildings that are retired. The escalation rate is a conservative

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[7] Due to the current grid mix, the purchased MMBTU of electricity is worse from an emissions perspective based on what was consumed/burned to create the electricity, as compared to burning natural gas to make steam.

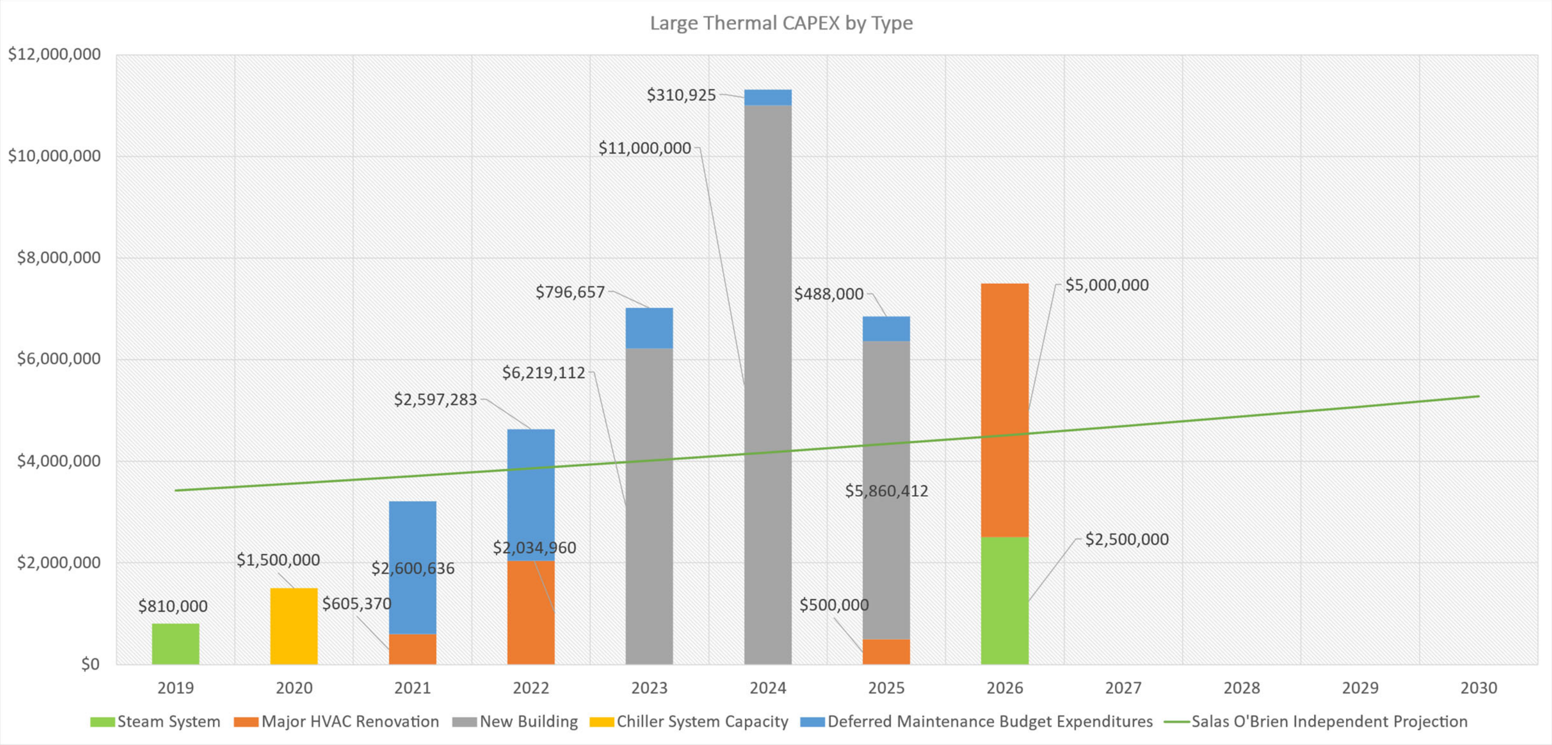
[8] Marquette is unusual in its Scope 1 emissions because the university purchases steam rather than burning natural gas.

estimate of increasing commodity costs. No growth is assumed in campus energy consumption or emissions.

The BAU financials also include major utility related capital expenditures (CAPEX) and annual operating expenses (OPEX) for the campus HVAC systems, including steam assets that are owned and maintained by the University. For this analysis, Salas O’Brien has developed an Independent Projection that is based on benchmarks from other higher education institutions.

Based on the system's size and complexity, we estimate that Marquette University should spend $4.2 million annually on CAPEX, escalating at 4% per year, and $1.2 million annually on OPEX, escalating at 2.5% per year. The embedded assumptions are based off Salas’ prior industry experience working with similar campuses on decarbonization plans. To calibrate these estimates, the primary investigators for this study evaluated actual and projected CAPEX over the past few years and the current capital plan at the University.[9] The chart below (Figure 5) illustrates the actual historical and projected CAPEX compared to the Salas O’Brien Independent Projection (see the green line in Figure 5 below). This illustrates that the independent projections are not unreasonable compared to actual and projected expenditures.

Figure 5 BAU Large Thermal CAPEX by Type Compared to BAU Estimates



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[9] Data are incomplete and therefore represent conservative values. For instance, deferred maintenance figures were not available for 2019 and 2020.

Table 2 presents Marquette University's historical and projected operating expenses (OPEX) and capital expenditures (CAPEX) for its energy systems from 2023 to 2050. It includes costs for purchased electricity, natural gas, steam, and distribution and HVAC operations and maintenance (O&M). The total operating expenses are projected to increase significantly, from $12.94 million in 2023 to $30.58 million by 2050. Additionally, CAPEX is detailed for future periods, highlighting substantial investments required to maintain and upgrade the energy infrastructure, totaling nearly $24.0 million for 2025-2029 alone.

The table also includes the White House social cost of carbon estimates, reflecting the monetary value of the long-term damage done by one ton of carbon dioxide emissions in a given year. These costs are projected to rise substantially, from $2.21 million in 2024 to $14.16 million by 2050, emphasizing the growing economic impact of greenhouse gas emissions. The starting White House social cost of carbon estimate is set at $51 per metric ton of CO2 equivalent ($MTCO_2e$). It encompasses various factors, including health impacts, property damage from increased flood risk, and changes in agricultural productivity due to climate change.

Although this externalized social cost doesn’t currently appear anywhere in Marquette’s ledger, these costs represent real impacts of the University’s emissions, and some state governments are enacting rules to ensure organizations adequately incorporate these costs into long-term decision-making. Understanding this cost helps quantify the environmental and societal impacts of carbon emissions, and the consideration of these external costs in our planning is one meaningful way for Marquette to respond to the call of Pope Francis.

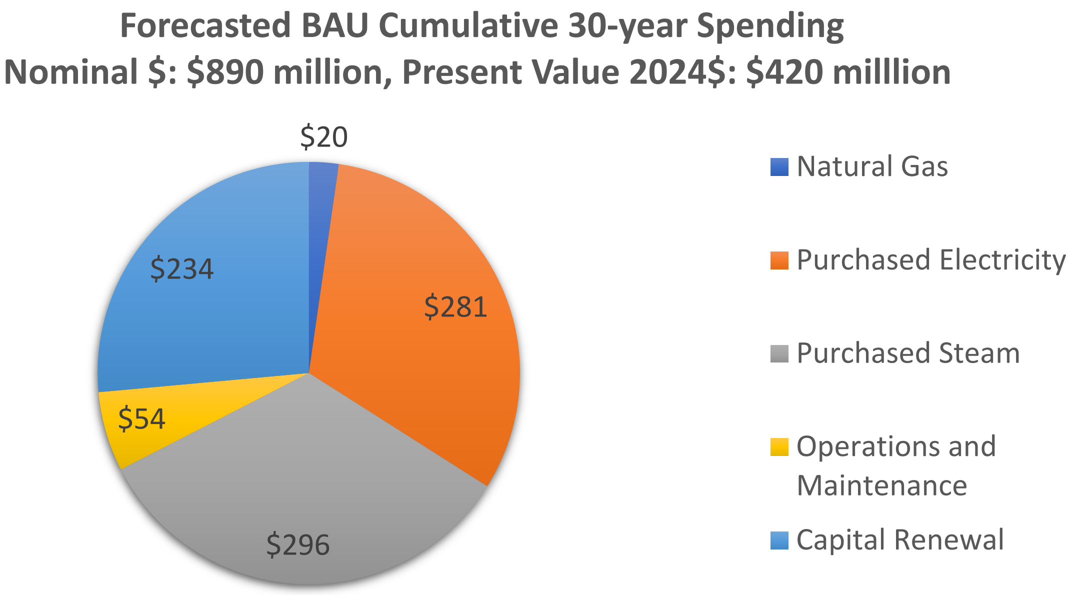
Table 2 BAU Utility Budget Forecast

	History	**Forecast**						
	2023	**2024**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Purchased Electricity	$6,940,000	$6,917,000	$7,056,000	$7,790,000	$8,601,000	$9,496,000	$10,484,000	$11,575,000
Purchased Natural Gas	$540,000	$497,000	$507,000	$560,000	$618,000	$682,000	$753,000	$831,000
Purchased Steam	$4,260,000	$4,454,000	$4,676,000	$5,968,000	$7,617,000	$9,722,000	$12,408,000	$15,836,000
Distribution and HVAC O&M	$1,200,000	$1,230,000	$1,261,000	$1,426,000	$1,614,000	$1,826,000	$2,066,000	$2,337,000
Total Operating Expense	**$12,940,000**	**$13,098,000**	**$13,500,000**	**$15,744,000**	**$18,450,000**	**$21,726,000**	**$25,711,000**	**$30,579,000**
Social Carbon Cost per White House	$2,205,000	$2,241,000	$2,330,000	$2,913,000	$3,884,000	$5,826,000	$11,652,000	$14,163,000
	2021-2023	**2024**	**2025-2029**	**2030-2034**	**2035-2039**	**2040-2044**	**2045-2049**	**2050-2053**
CAPEX	**$14,854,018**	**$4,171,000**	**$23,495,000**	**$28,585,000**	**$34,778,000**	**$42,313,000**	**$51,480,000**	**$49,106,000**

The BAU forecast should not be viewed as a prediction but as a modeling tool designed to help Marquette understand the likely implications of each proposed strategy, both individually and collectively. This approach provides a baseline scenario against which potential energy efficiency and decarbonization initiatives can be compared, aiding in strategic planning and decision-making.

This BAU forecast illustrates that the University is likely to spend nearly $900 million on the campus utility system over the next 30-years (Figure 6). The Recommended Strategy will illustrate opportunities to spend that same amount of money, or less, in a more strategic and environmentally impactful way.

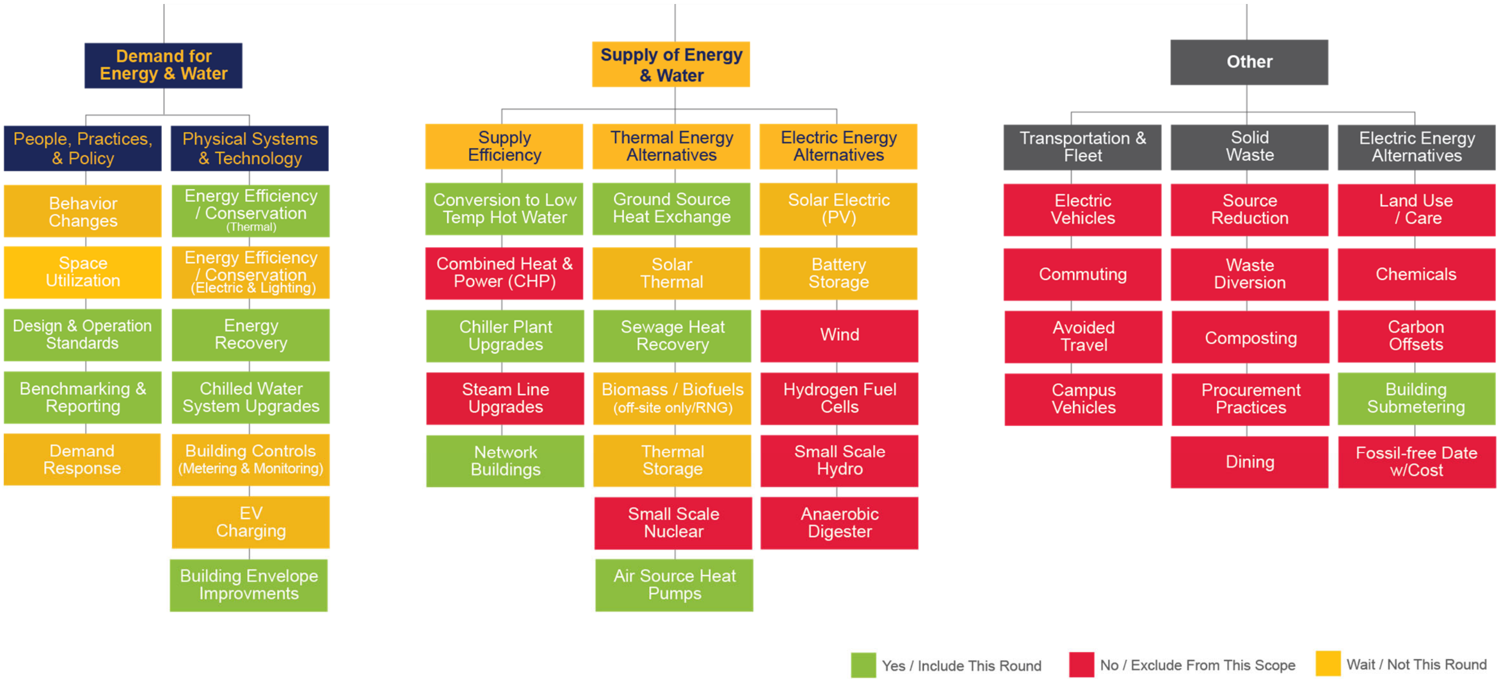
Figure 6 Forecasted BAU Cumulative 30-year Spending



CAPITAL REALLOCATION STRATEGY SELECTION

This study was guided by an ongoing conversation about goals and plausible initiatives. At the initial vision and criteria setting stage, the team went through the matrix (Figure 7) and immediately ruled out options that would not be actively considered in the present study.

Figure 8 Strategy Selection Matrix



In the subsequent evaluation of options phase, options that had been retained were assessed for maximum impact and benefit. Through modeling and scenario testing, the recommendations were determined.

Table 3 Decision Matrix with Key Criteria

Evaluation Criteria	**Weight**	Minimal Requirement	**Satisfactory Performance Threshold**
Capital Investment	35	Project financials must be consistent with Marquette's available cash flow, borrowing ability, and other planned capital projects. Payback time, Net Present Value, and rate of return are all useful indicators.	Identified 3rd party operator that fully finances project and reduces MU annual expenses. Acceptable profits for WE.
Annual Operating Expense			Current spending levels.
Maintenance			Current staffing levels.
Emissions reduction	25	Substantial reduction of GHG emissions.	100% electrification.
Scalability	15	Must not depend on carbon emissions of others to function (e.g. should not require use of steam condensate waste).	Demonstration inspires private utility investment.
WE Energies integration		WE is a willing partner for the MU project, able to publicly express support for an MU-driven campus transition.	WE sees opportunity for a successful business model that they want to expand to replace downtown steam system.
Ease of phasing	10	Business continuity.	Summer-only work.
Site Disruption		Two walking paths to each building preserved.	Less than 1 year of disruption, or summer only disruption.
Thermal Comfort	15	Comfort complaint tickets don't go up substantially.	Current comfort level, expanded service to buildings which currently have no cooling.
Total:	100		

Each potential strategy was assessed for feasibility based on cost, labor requirements, operational impact, external policies, and timing. The strategies found to be the most implementable and with potential to yield signification GHG emissions reductions were refined into campus-specific targets.

This study has been done in conversation with efforts that have already been made and are ongoing. In recent years, energy conservation measures including lighting and metering upgrades have been made. Our analysis identifies the success of these measures and proposes building on them.

Demand-Side Energy Reductions

Energy reduction on campus is identified through two main strategies: the supply side and the demand side. Supply-side energy reduction options are discussed further in the following section. The demand-side energy reduction is through building energy conservation measures (ECMs). These ECMs are modeled assuming a total campus reduction of 25%. The assumed 25% reduction is based on energy transition work seen on other similar campuses and can be accomplished through a variety of different measures from building to building. These ECMs can include upgraded building controls, energy recovery on outside air, LED lighting, and envelope measures just to name a few.

Marquette has previously invested in several ECMs. Recent investments include high-efficiency LED lighting and new chilled water line sensors. LED lighting has typically been strategically deployed during larger building renovation projects, as these moments represent particularly cost-effective times to deploy new light fixtures. While energy has clearly been conserved through these projects, the cost savings cannot be readily measured due to a lack of building-level electricity meters.

Marquette has installed a set of building-level sensors on its chilled water network. These sensors are intended to detect malfunctions in individual buildings, allowing Facilities Planning & Management (FP&M) to locate and repair the cause. With regular analysis of the data, these chilled water network sensors could also be used to optimize operation of the chilled water network, allowing the chillers to spend more time operating at their most energy efficient settings.

While these improvements are welcome, there are still many more opportunities to reduce energy consumption on campus. For example, Marquette has not routinely invested in building envelope efficiency improvements (except for window replacements in a few buildings) or building exhaust heat recovery systems. Energy efficiency improvements such as these typically only occur as older buildings are retired and newer buildings with better performance replace them.

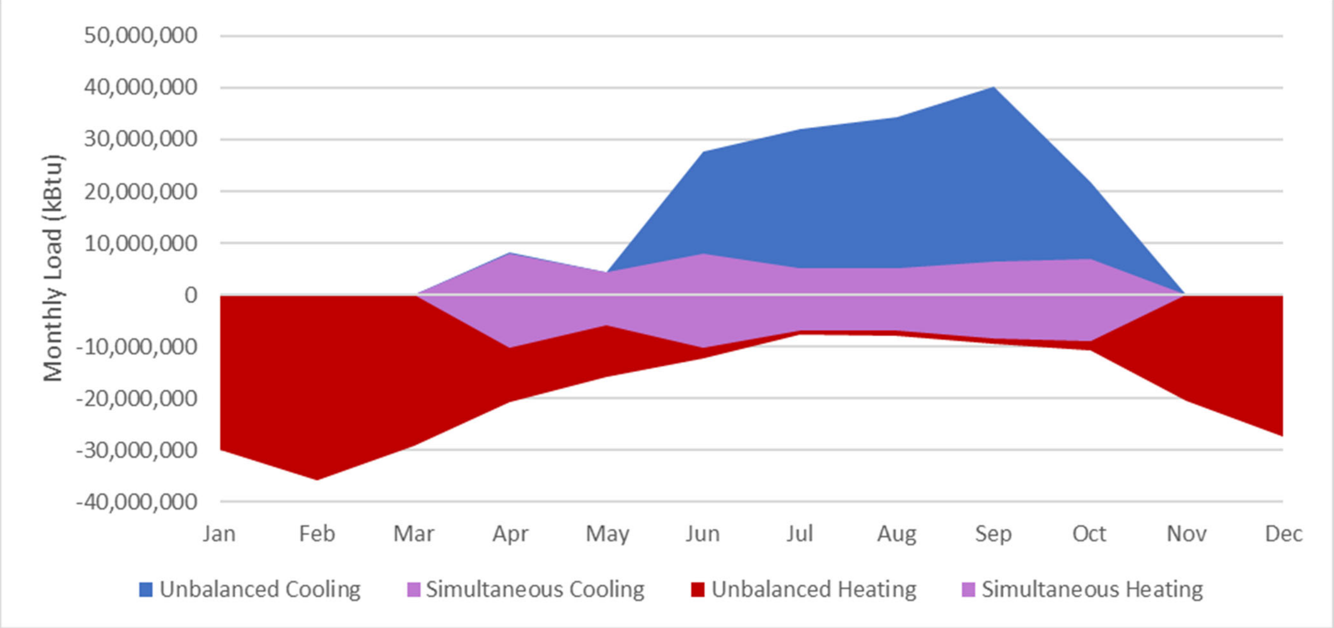
A program to pursue ECMs on campus is likely to yield a strong financial payback. Such a program would benefit greatly from the addition of a dedicated energy manager. (Although FP&M has requested the addition of such a position, funding has not yet been provided.) Such a position would allow greater utilization of existing data (from metering and the new chilled water network sensors) as well as energy efficiency payback monitoring.

Supply-Side Energy Reductions

There were several interesting avenues to explore from the supply side-strategies. Many of the strategies require interpreting the thermal profile of the campus and looking for ways to increase efficiency and opportunity to leverage the simultaneous load. Marquette's current system serves heating and cooling needs through separate systems; so, although the cooling system collects heat, that heat is exhausted as a waste when it could serve as a resource to meet simultaneous heating loads. Integrated systems (like the one proposed in this report) generate large efficiencies by connecting these simultaneous loads.

Figure 9 below shows the thermal profile at Marquette with the highlighted opportunity for simultaneous load. The pink region shows the potential Marquette has to share energy between networked buildings across campus, which would reduce fossil fuel usage for heating and reduce cooling tower water usage in the summer.

Figure 9 Marquette Thermal Profile with Simultaneous Load



Based on the refined set of solutions and key criteria matrix, the main strategies to be integrated into the analysis were supply efficiency strategies including conversion to low temperature hot water, chiller plant upgrades, and networking buildings. These were to be assessed alongside thermal energy alternatives including ground source heat exchange, wastewater heat exchange, and air/water source heat pumps. Table 4 lays out these options including benefits and consequences.

Table 4 Technologies Assessed

Technology	Pros	Cons
Conversion To Heating Hot Water	• Increases COP; reduces OPEX. • Reduces dependence on, with potential to eliminate, purchased steam.	• Requires building conversions. • Requires new infrastructure, site disruption
Chiller Plant Upgrades	• High COP and low OPEX • Opportunity to expand cooling on campus	• Could be high CAPEX • Doesn't support decarbonized heating.
Network Buildings	• High COP • Low OPEX	• Geographic constraints • Requires building conversions
Geo-Exchange	• High COP source for HHW • Low OPEX	• Very high CAPEX. • Requires green space. • Not cost effective for peak heating loads.
Wastewater Heat Exchange	• More cost competitive than vertical geo bores. • Has potential to outperform geo-exchange on COP basis for portions of the year.	• Capacity varies hourly and seasonally. • Thermal asset is owned and regulated by wastewater agency. • Not economical to cover peak heating loads.
Air/Water Source Heat Pumps	• Good for stand-alone applications • Enables LTHW and cooling source with good COP. • Technology is developing rapidly and widely used and supported	• Increases peak electricity demand. • Limited operating temperatures & decreased efficiencies at temperature extremes.

These strategies are not mutually exclusive. To maximize benefit of a system and increase phase-ability and resiliency, hybrid systems present a viable option. The analysis below includes each of the strategies discussed above.

Geo-Exchange

Geo-exchange systems have been a point of interest for Marquette since the decarbonization study began. These systems are comprised of electrically driven ground-source heat pumps (GSHP) coupled with a ground heat exchanger (GHE). When implemented they not only eliminate fossil fuel combustion but also, due to superior system efficiencies, reduce input energy required to heat and cool the campus buildings. The result is significant reduction in site carbon emissions over time especially when the greening of the grid is considered.

There are two broad categories of GHE that were investigated as part of this study. These included open- and closed-loop systems.

Open loop systems tap directly into local aquifers and thermal energy is exchanged with a working fluid via a heat exchanger. This can be accomplished using different methods, two of which were considered for this study. The first involves drilling extraction and re-injection wells which allow aquifer volume to be pumped from the aquifer through a heat exchanger located above grade and back into the aquifer. The second involves drilling a single well and lowering a heat exchanger with a dedicated pump directly into an aquifer. The ground water volume is pumped through the heat exchanger to transfer thermal energy to/from the working fluid. This is commonly referred to as a “down-the-hole” heat exchanger design.

Open-loop systems are beneficial when there is good local aquifer volume present and drillable area is minimal. Upon further investigation, Salas determined that re-injection wells are not allowed in the state of Wisconsin. While down-the-hole designs are permittable, the capacity per well is typically small and would require many wells to produce any meaningful amount of capacity. Well heads must also be located above grade for service and to adhere to regulatory requirements. A network of wells with down-the-hole heat exchangers would result in many exposed well heads at grade level.

Closed-loop systems rely on thermal energy transfer between the volume of earth surrounding a grid of vertical bores and a working fluid which is pumped through a piping network traversing and interconnecting the vertical bores. The largest caveat with this type of system is identifying space that can be used for integration of vertical bores. Existing parking lot and/or sidewalk in need of renovation and new construction projects present the excellent opportunity for vertical drilling as surface disruption is required regardless. Undesignated green space, such as vacant lots or open areas without existing landscaping, provide great opportunity as well.

A closed-loop GHE sized to handle the entirety of the Marquette heating load would require many acres of surface area for locating and drilling vertical bores. A system of this size would likely require more space than is available in the main portion of the campus bounded by I-94, W Wisconsin Avenue, and N 16th Street. This is especially true if there are areas that are deemed off-limits or if surface disruption in this area must be minimized.

Throughout the process, the Marquette team has expressed concern about the University approving a concept that requires major surface disruption on campus. With campus green space scarce, a GHE providing a meaningful amount of capacity would likely require common areas to be drilled and restored once installation is complete. This would include Central Mall at a minimum and would more than likely require the use of Westowne Square and/or Eckstein Common areas located adjacent to Alumni Memorial Union.

While geo-exchange is a promising addition to the Marquette campus, site selection for a closed-loop GHE will require a creative approach if the University is not willing to compromise on drilling locations and the need for intermittent surface disruption throughout campus. Alternative solutions to on-site drilling were briefly investigated as part of the study effort. Two reasonable alternatives were identified but require more detailed investigation if they are to be incorporated into the long-term decarbonization plan. These included a partnership with WE Energies in which local rights-of-way or other property assets are used for vertical bore integration or pursuit of other partnerships that could allow for access to and integration of vertical bores in property parcels near campus.

WE Energies Partnership

The Marquette team has conveyed interest in a joint venture for a WE Energies-owned thermal network that would supplement and ultimately replace existing district steam. One such discussion targeted on-site space and surface disruption concerns for vertical bore integration. Propositioning WE Energies as a thermal partner could provide access to rights-of-way and/or other parcels of property for vertical drilling and bore installation. WE could invest capital to secure ownership of these assets and offer this thermal service to a broader network of customers, not just to Marquette. This would enable WE to retain their existing thermal district customers while simultaneously transitioning the steam side of their business to a renewable low-carbon source. Such a partnership would also substantially reduce Marquette's required capital outlay.

Neighboring Parcels

If Marquette is unwilling to locate enough vertical bores on-site, it may be possible to pursue other partnerships that would allow access to parcels of property near campus for vertical bore integration. Utilization of parcels could be through direct purchase or a below-grade lease agreement with a third-party owner. One such relationship could be established with Menomonee Valley Partners who are actively involved in redevelopment projects along the Menomonee River. There are two parcels that will offer considerable opportunity for drillable space. The Kneeland Site is roughly 7 acres and located on the north side of the Menomonee River across from the Valley Power plant. The City Lights & Materials Recovery Facility (MRF) site is roughly 12 acres, located on the north side of the Menomonee River, and has a direct route of access to the campus via N 16th Street.

Figure 10 Menomonee Valley Land

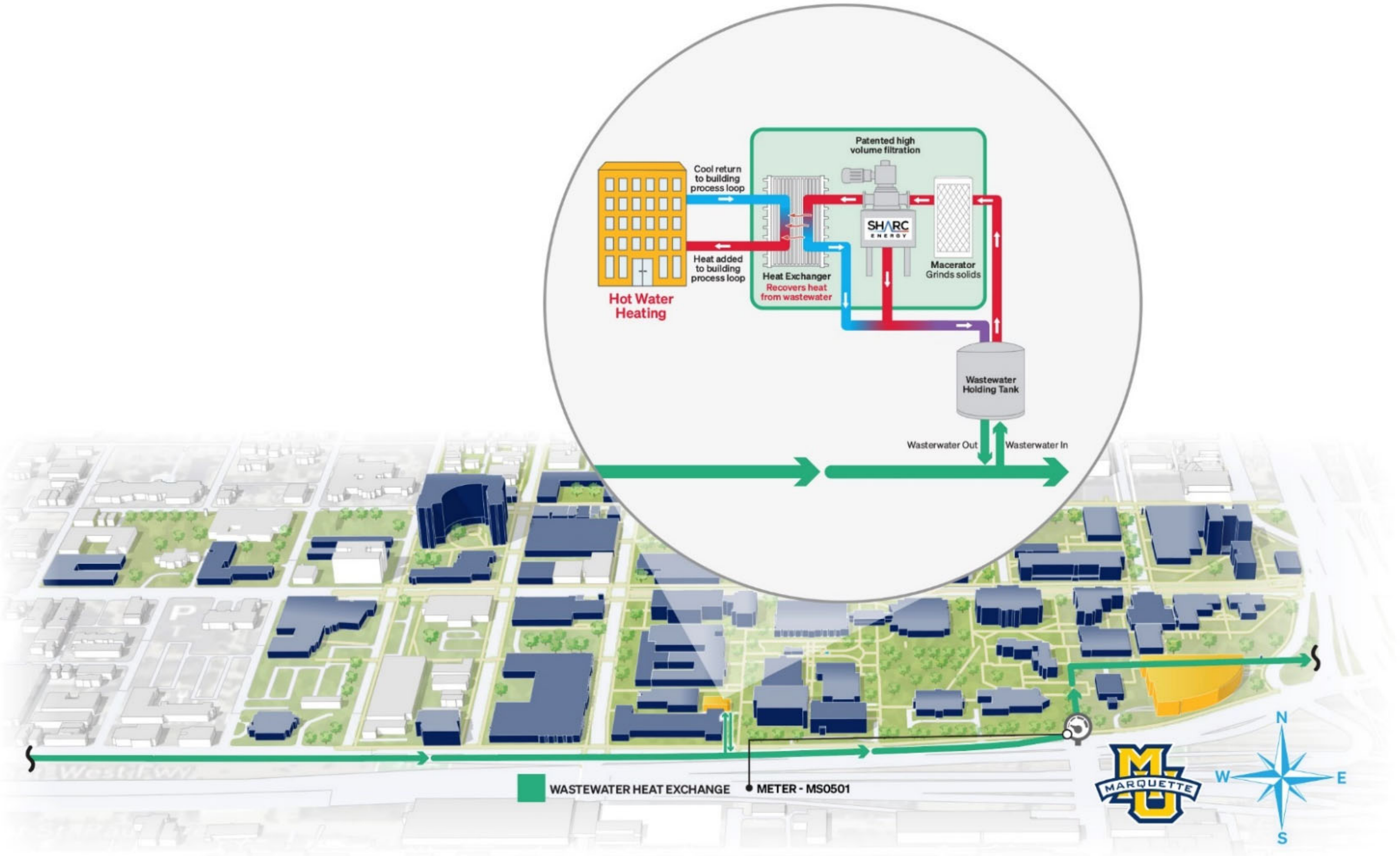
Wastewater Heat Exchange

Wastewater heat exchange (WWHX) systems work under the same principle as geo-exchange in that thermal energy can be extracted from and rejected to the wastewater volume. A typical configuration involves locating a side stream holding tank or wet well in proximity to an existing main. Flow is diverted from the main to the tank where a solids separation process yields a liquid that can exchange thermal energy with a working fluid via heat exchanger. Thermally exhausted liquids are recombined with solids and deposited back in the main downstream of the extraction point. This process is repeated continually to facilitate as much thermal exchange as is possible between the working fluid of the heat pump system and the wastewater flow.

WWHX is a financially and thermally competitive alternative to geo-exchange systems in locations where there is notable wastewater flow to tap into. Because space for vertical bores is scarce and the bores required to satisfy annual and peak campus heating is substantial, investigation into WWHX feasibility at Marquette started early in the study process.

The Salas team was able to trend seasonal temperature and flow fluctuations from infrastructure and meter data provided by the Milwaukee Metropolitan Sewerage District (MMSD). The trend analyses demonstrate the feasibility of a WWHX for campus.

Figure 11 Marquette Campus Map with Wastewater Heat Exchange Concept



The metered data provided by MMSD showed exciting thermal opportunity for mains traversing the southern edge of campus along W Clybourn Street. Flow and temperature data were obtained for Meter MS0501 located southeast of Eckstein Hall near I-94 along W Tory Hill Street. This meter is collecting data for a main that passes directly by Eckstein and could be intercepted here if heat pump equipment were installed in the existing cooling plant. Included below are graphical trends of the of flow and temperature.

Figure 12 Wastewater Flow in Sewer (2016)

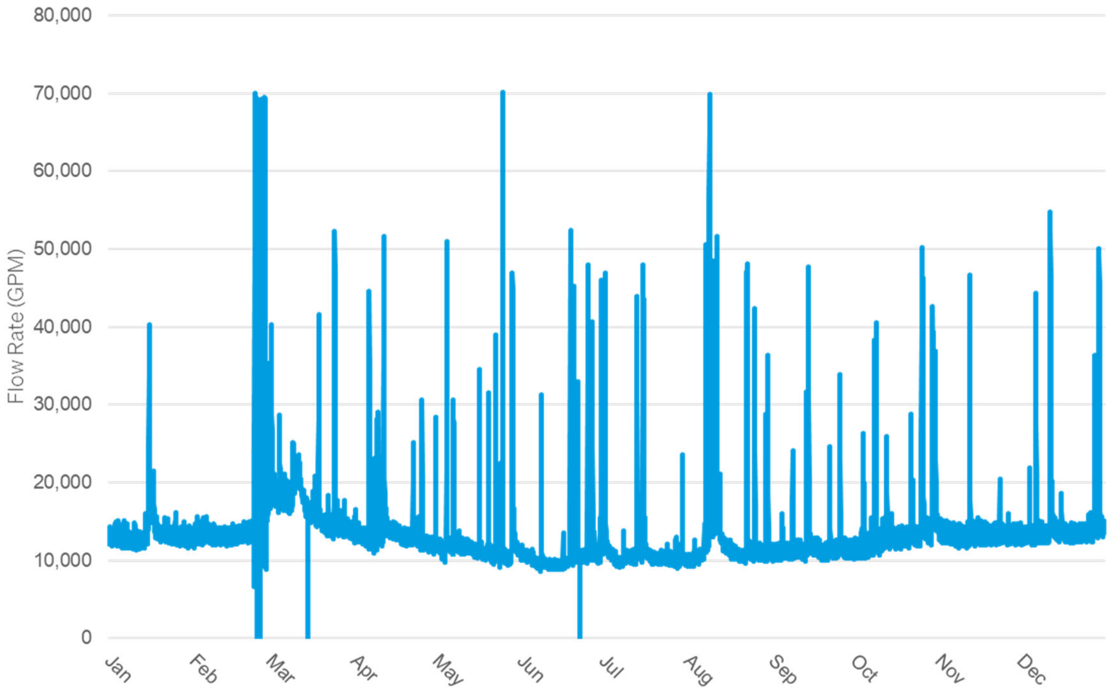
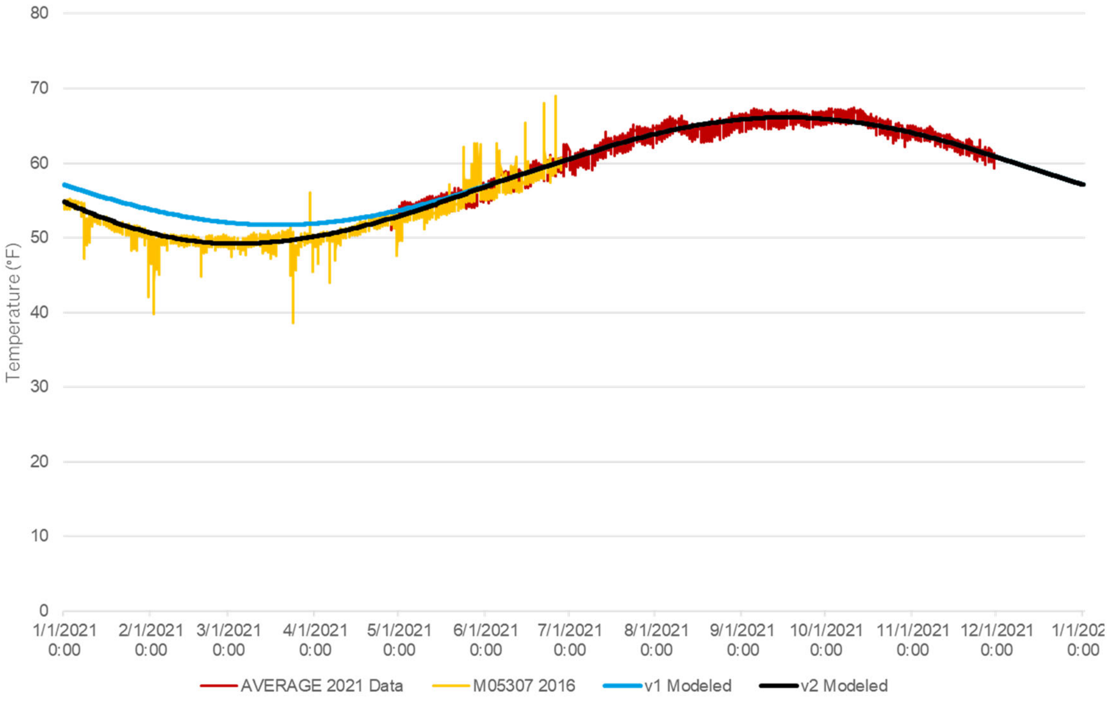


Figure 13 Wastewater Temperatures 2021 & 2016



A flow data set for 2016 was plotted to illustrate fluctuations over a typical calendar year. The data provided were in terms of water level within the pipe which could be translated to flow using a conversion method as prescribed by MMSD. WWHX systems rely on a steady flow from which thermal energy can be exchanged as connected buildings almost always require some level of space heating or cooling. The plot of flow data indicates that, except for a few outliers, the base flow in this section of the network is around 10,000 GPM. This was used as the basis for downstream assessment of feasibility.

Similarly, a plot was created for temperature of the wastewater flow during calendar years 2016 and 2021. Using data provided by MMSD, regression analysis was used to estimate a curve fit to represent the change in wastewater temperature over time. The plot indicates that the temperature ranges sinusoidally from around 50°F in the spring to 65°F in the fall.[10]

For the purposes of the study, it has been assumed that only a portion of the available wastewater flow through the W Clybourn Street main can be utilized for campus heating and cooling. The analysis has assumed a 10°F temperature differential for fluids entering and leaving the heat exchanger. Depending on the season, that would be either a 10°F rise or fall in the temperature of the fluid returned to the main to be mixed with non-diverted flow. The diverted flow represents a very small portion of the total returned to the treatment plant. Accordingly, it is expected that these relatively small temperature changes to a fraction of the total wastewater volume returned will be nearly non-detectable at the plant.

Distribution Systems: Technologies, Innovations, and Solutions Considered

When considering a viable long-term plan for Marquette, a variety of design criteria was investigated and evaluated. While campus cooling was a part of that evaluation, it was not as mission critical to decarbonization as heating. District steam service from Valley Power Plant represents Scope 2 emissions or the burning of fossil fuels off-site to satisfy campus heating needs. Transitioning from fossil fuel to electrically driven heating systems requires consideration of not only changes to the generation equipment already considered above, but also the distribution network and building equipment responsible for delivering and utilizing thermal energy in each building.

Distribution network design was investigated as part of the decarbonization study. Three network concepts were considered which included heating hot water, ambient loop, and a two-pipe switchover. Ambient loop and two-pipe switchover concepts utilize a common two-pipe supply/return network to transport thermal energy while the heating hot water concept would require a new supply/return network to supplement the existing chilled water network (four-pipe). The ambient loop and two-pipe switchover concepts reduce infrastructure investment by making use of the existing chilled water network; however, there are drawbacks, as illustrated in the case study of the AMU below.

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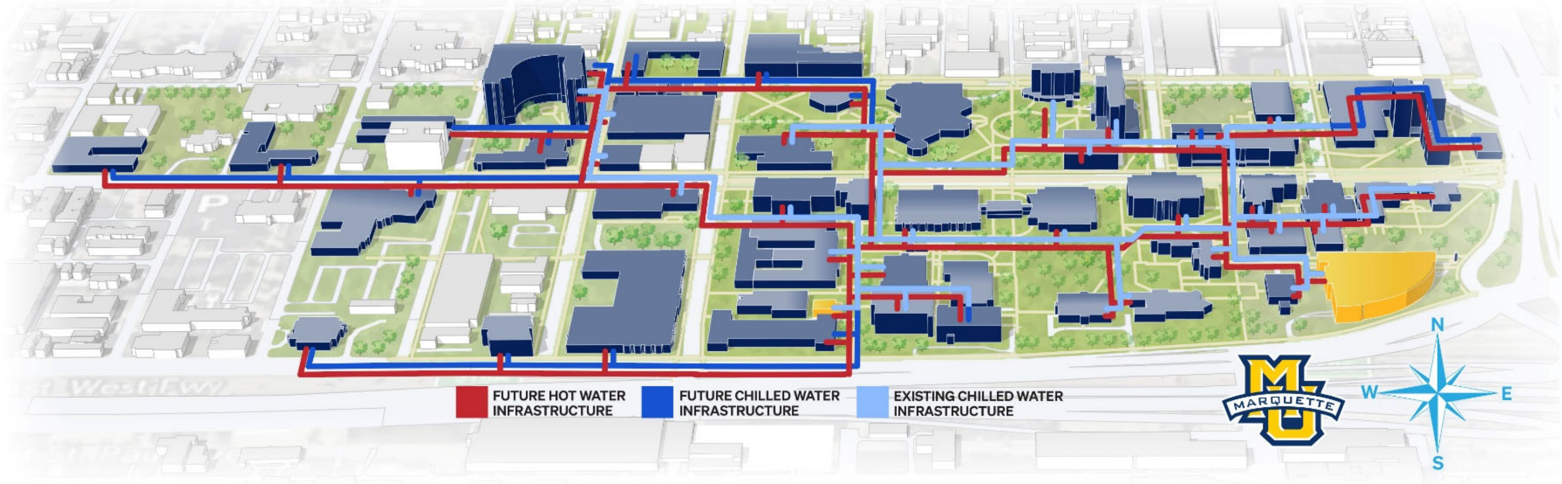
[10] The temperature readings are less than expected especially since it is understood that condensate from district steam customers is rejected to sanitary rather than returned to Valley Power Plant.

Option A: District High Temperature Heating Hot (HTHHW) Water Network

Figure 14 Option A: District Heating Hot Water Network



This distribution concept would retain Marquette’s existing chilled water network and start a new HTHHW (170°F) network at one of the existing chilled water plants and add heat pump capacity as buildings are converted and connected. The hot water loop would extend from the chilled water plant(s) and the team would locate and tie in thermal sink and source capacity. This option would address peak load and balance the loop with district steam and chilled water. This strategy could be completed as small districts or nodes that are interconnected over time.

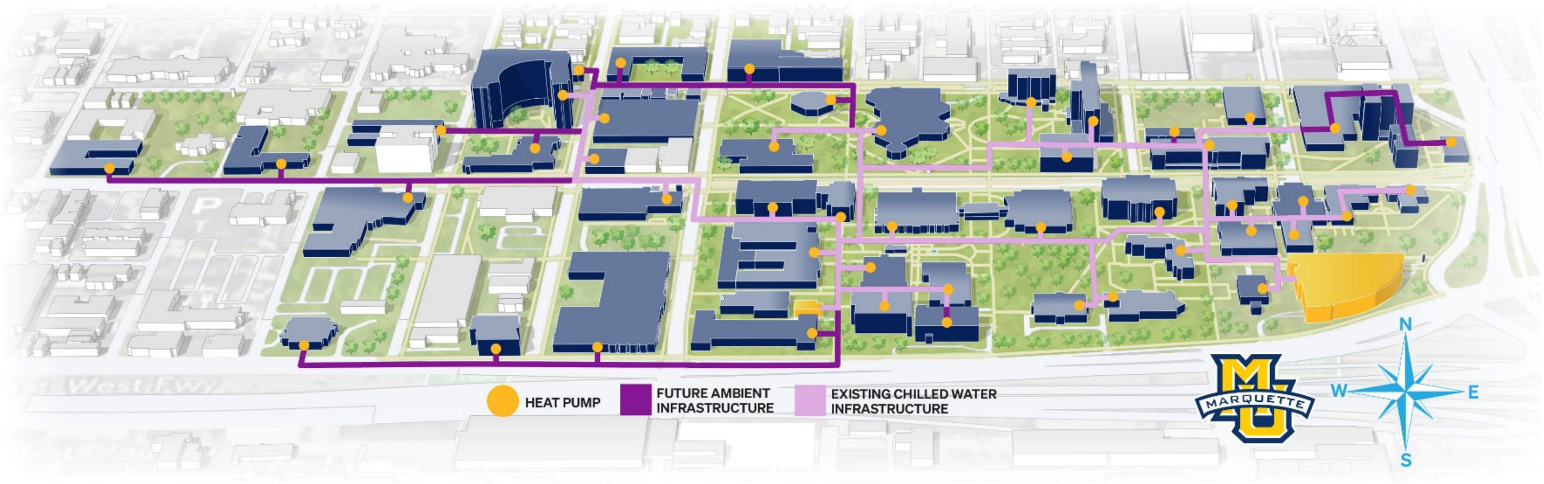
This configuration is the only one of the three to enable true simultaneous load cancellation between buildings. This means that a heat pump can be used to extract thermal energy from the chilled water return and reject it directly to the hot water supply. The other distribution networks can move thermal energy around in a similar manner but require a two-step process in which one set of heat pumps operates to remove thermal energy from a source and another set must operate to reject thermal energy to a sink. As a result, Option A offers a level of heating and cooling efficiency that is not attainable with an ambient loop or two-pipe switchover network.

The addition of the heating hot water network promotes centralized plant capacity. Centralized capacity yields benefits of diversity and economies of scale at the plant level; less total heat pump capacity is required at a smaller per unit capacity cost. Central plants also reduce maintenance costs with less equipment to service consolidated in fewer locations. Similarly, redundancy requirements can be satisfied in fewer locations which bolsters operational resiliency.

The heating hot water network will require significant site disruption. Existing direct buried chilled water infrastructure will need to be supplemented with heating hot water supply and return. Direct buried refers to site infrastructure located below grade without additional projection such as tunnel or duct bank. This will likely involve a combination of surface trenching and directional drilling installation techniques. Capital investments in materials and labor to build out the network will be required which will offset a portion of the operational cost savings generated from expected increases in operational efficiency.

Option B: Ambient Loop Network

Figure 15 Option B: Ambient Loop Network



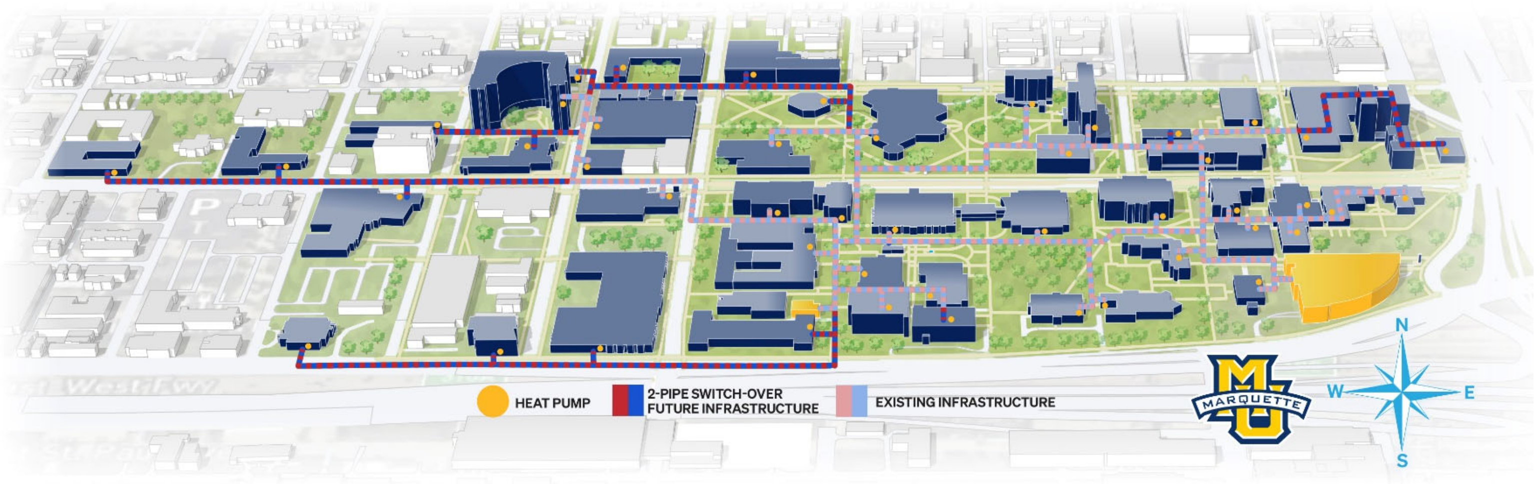
This concept, initially favored by the Marquette team, would repurpose the chilled water (CHW) network as an ambient loop. The strategy would involve converting each building to low temperature heating hot water (LTHHW) and installing heat pump capacity in each building sized to handle peak heating and cooling load. Then as above, the team would locate and tie in thermal sink and source capacity to temper the ambient loop. The district steam and CHW thermal rejection assets would remain to temper the ambient loop. In the future, this would need to be addressed or replaced to fully disconnect from steam.

The ambient loop would utilize the existing chilled water network thus minimizing surface disruption. While it is assumed that most of the existing piping would not need to be replaced, it is recommended that a hydraulic model be completed to evaluate the constraints of the existing system, especially in areas where downstream load is expected to increase, and existing pipe capacity may not be adequate in the future. Because ambient loop temperatures will remain in a temperate range throughout the year, the existing piping material(s) are not expected to be an issue. Therefore, investments to the existing network, beyond future expansions, would be minimal.

An ambient loop would require extensive spends at the building level. Heat pump capacity and any redundancy must be satisfied at each building individually in lieu of a central location. This does not allow Marquette to take advantage of economies of scale in heat pump pricing afforded by larger capacity units. Installation of electrically driven heat pumps would also increase stress on the electrical system capacity; for many buildings this may necessitate a service upgrade. Finally, the smaller, building-level, heat pumps are not capable of the high temperature lifts that larger, centralized heat pumps can accomplish. Thus, the ambient loop option would necessitate high-cost conversions of in-building heat distribution equipment to ensure LTHHW could be utilized effectively.

Option C: 2-pipe Switchover Network

Figure 16 Option C: 2-pipe Switchover Network



Like Option B, this option would utilize the existing CHW network as-is during the cooling season and repurpose the network to supply HHW, or “switch-over”, during the heating season. The team would install heat pump capacity at each building sized to handle summer re-heating load. There would also be installed heat pump capacity at existing plants to provide seasonal hot and chilled water. Again, the team would locate and tie in thermal sink and source capacity to temper the ambient loop. At first, the district steam and CHW thermal rejection assets could remain to temper the ambient loop. In the future, this would need to be addressed or replaced to fully disconnect from steam.

A 2-pipe switchover network would reduce capital investment and surface disruption by repurposing the existing chilled water network. This repurposing assumes that pipes in the existing CHW network could handle the 140°F+ temperatures flowing through the network during the heating season. If this assumption holds, a 2-pipe switchover would offer a lower-cost path for campus conversion to heating hot water. This system would allow most of the heat plant capacity to be centralized, ensuring that economies of both scale and redundancy would be attained.

However, if the assumption that existing pipe could handle 140°F+ heating hot water does *not* hold for major sections of the existing CHW network, then these sections would need to be replaced. It is expected that replacement would require substantial capital investment and increase surface disruption as compared to the ambient loop, but still be less than that required by a new heating hot water network.

The 2-pipe switchover will inherently have thermal comfort issues if the plant capacity is centralized. Accordingly, this system will require the addition of a small simultaneous heat pump in each of the connected buildings to handle summer heating load for reheat and/or domestic hot water heating. In most cases, the capacity required is expected to be small enough that there is not concern about electrical upgrades; however, it may be necessary for some of the larger buildings with significant reheat loads. Additional investigation would be required.

Case Studies to Inform Distribution System Choice

Three conversion cost case studies for existing campus buildings were performed by Vyron at the request of Marquette. The campus buildings that were selected as case study candidates included Alumni Memorial Union (AMU), Eckstein Hall, and the Gesu-Parish Center. The purpose of the studies was to independently assess and verify conversion cost assumptions that were being held by the Salas team as part of the overall cost estimate and financial assessment. Those assumptions were based on Salas' professional experience and recent project budget costs which support the conclusion that adapting existing buildings in heating dominant climates to a lower temperature source requires significant investment into building conversions to ensure space setpoints can be maintained to satisfy occupant comfort.

A conversion cost case study was completed for AMU and shared with the Salas team as a means of comparison against assumptions held to date. Results have been summarized and included in Table 5. Vyron found that in-kind replacement of the existing steam equipment would cost roughly the same as converting the building to HTHHW (180F). An incremental savings of roughly $70,000 was realized when pursuing the hot water conversion in lieu of steam replacement. Converting to LTHHW at 130°F supply was found to have a significant capital cost add. Two scenarios were evaluated at LTHHW, and both were found to be in the range of 50% higher than the HTHHW option: increasing the capital expenditure by over $2,000,000.

This finding was especially significant because it meant that even under the fortuitous scenario of building mechanicals already needing replacement, this clean slate still greatly favored a heat distribution network at higher temperatures (HHW @ 180F). This finding greatly tipped the evaluation of system alternatives because it meant that the Marquette team's initial preference for an ambient loop (which would mean smaller, distributed heat pumps only capable of LTHHW @ 130F) would be much more expensive even under an auspicious building conversion scenario.

Table 5 AMU Conversion Cost Study Results

	STEAM COST	HHW 180F	HHW 130F (Alt A)	HHW 130F (Alt B)
AHU	$1,184,851	$1,165,633	$1,171,536	$
VAV	$56,297	$56,297	$73,251	$
BASEBOARD	$125,053	$125,053	$704,660	$838,809
TOTAL MATERIAL	$1,366,201	$1,346,984	$1,949,447	$2,083,596
TOTAL MATERIAL + INSTALL	**$4,781,705**	**$4,714,442**	**$6,823,064**	**$7,292,585**

Many of the existing buildings on campus utilize district steam to temper a HTHHW loop via steam-to-hot water heat exchangers. It is understood that design heating hot water supply temperatures typically range from 180°F to 200°F depending on the building. A district HTHHW network at 170°F would minimize capital expenditure for conversions as buildings with existing hot water loops will function at a slightly lower supply for most of the heating season. This design will enable Marquette to evolve their system over time by collectively lowering heating hot water supply temperature and increasing operational efficiency as building renovations permit. Salas recommends stress tests be performed in the winter to identify and replace any terminal equipment that is unable to maintain space set point on a design heating day.

IMPLEMENTING THE RECOMMEDED STRATEGY

The preceding analyses culminated in three layers of strategies which should build on each other. Although each has individual merit, the benefit will be maximized with all three.

Optimize Demand-Side Investment

The first layer of the strategy is to identify projects that maximize the efficiency of existing systems and promise rapid payback, thus providing capital flow for future projects. These projects represent the foundational layer that will create necessary but insufficient changes to position the campus to take on longer term decarbonization efforts. These solutions are relatively low-cost and low-effort foundational improvements. The focus is on demand-side savings opportunities via Energy Conservation Measures (ECMs).

Implementing ECMs in buildings is crucial for reducing energy consumption, lowering operational costs, and minimizing environmental impact. Key strategies include improving insulation to reduce heat loss and gain, thereby enhancing thermal efficiency. Upgrading to energy-efficient windows and doors can significantly reduce energy use by minimizing drafts and maintaining indoor temperatures. Installing programmable thermostats and advanced HVAC systems ensures optimal heating and cooling performance tailored to occupancy patterns. Additionally, switching to LED lighting and incorporating daylighting designs can reduce electricity usage for lighting. Marquette's recent investments include high efficiency LED lighting and new chilled water line sensors. Utilizing renewable energy sources, such as solar panels, further offsets energy consumption and promotes sustainability. Regular maintenance of equipment and adopting smart building technologies for real-time monitoring and control also contribute to more efficient energy use. MU has already made progress on implementing ECMs, detailed above (page 16).

A budgeting mechanism or agreement with administration to reinvest the savings from energy efficiency projects into future initiatives will enable this effort to create a sustainable funding cycle. For example, Weber State University has successfully implemented a revolving green fund, where savings from completed energy projects are reinvested into new sustainability projects.[11] This approach ensures a continuous cycle of improvements and financial sustainability.

The University of California system has also demonstrated the effectiveness of reinvesting savings from energy efficiency projects. Their initiatives have avoided over $300 million in utility costs, showcasing the financial benefits of sustainable investments.[12]

By establishing a structured budgeting mechanism that reinvests energy savings, universities can ensure ongoing funding for future decarbonization and sustainability projects. This strategy not only enhances financial efficiency but also promotes long-term environmental stewardship and resilience.

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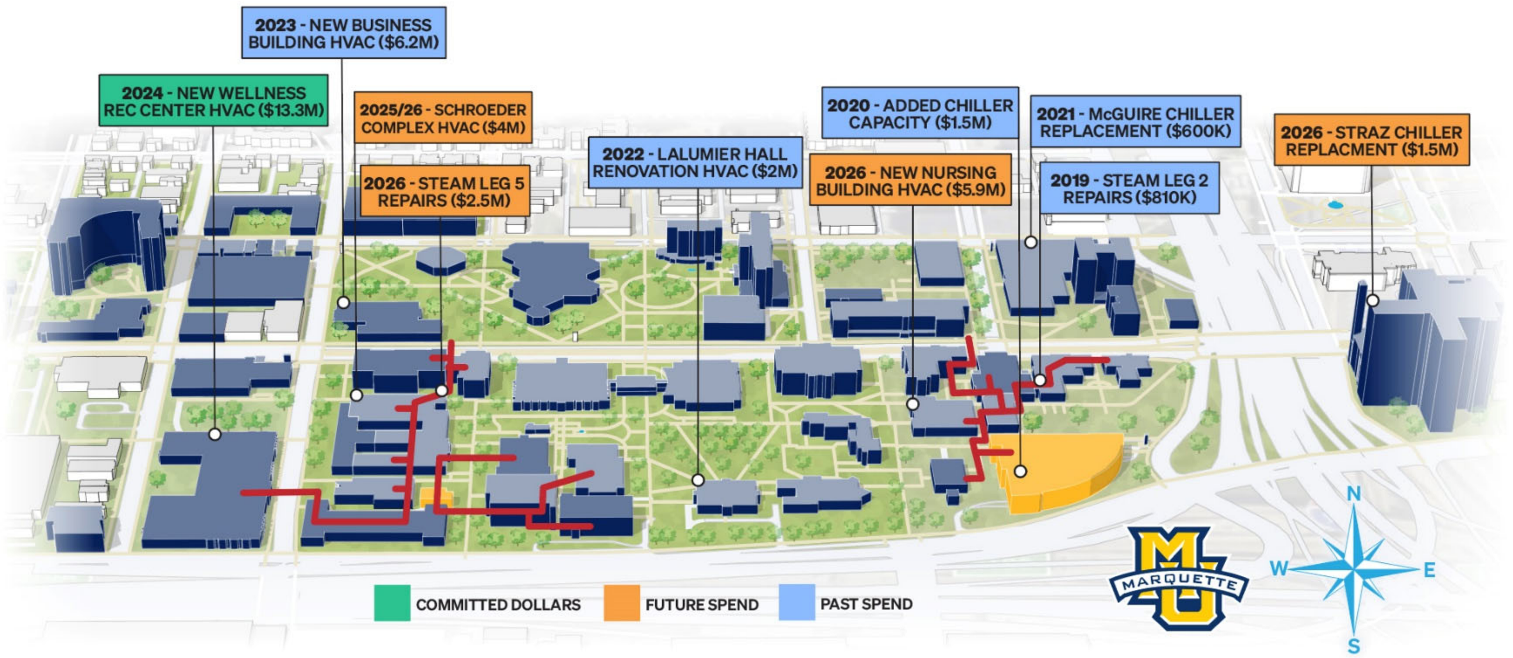
[11] "WSU's Climate Action Plan"

[12] "Energy Efficiency Programs Save UC $21 Million a Year"

Strategic Capital Renewal Allocation

Figure 17 Historic and Planned Campus Projects



The second layer of the recommended strategy is the identification of strategic renewal opportunities which would enable a wider range of supply-side strategies and facilitate a gradual and manageable transition to a decarbonized campus that can be flexible as the campus transitions and evolves.

This layer focuses on leveraging deferred maintenance investments to uncover project opportunities and updating design standards to maximize future benefits. The goal is to proactively invest in infrastructure upgrades that support future decarbonization objectives, enhance campus resilience, and ensure long-term sustainability and cost savings. This includes converting in-building steam systems to low-temperature hot water systems while addressing deferred maintenance. These system renewals offer future-proofing benefits by enabling compatibility with a wider range of energy supply options, such as heat pumps and other renewable technologies, beyond traditional steam. For example, the University of Virginia has prioritized maintenance projects to reduce their backlog and secure dedicated funding, while MIT has committed $250 million over three years for deferred maintenance to support its sustainability goals.[13] [14]

Part of campus thermal infrastructure is funded out of the Minor Capital Budget (MCB). Up through 2018, the MCB included a category called “Annual Maintenance”. The 2018 budget acknowledged that, “Many more deferred maintenance projects exist than funding or staffing will accommodate”. In accord with this declared state of affairs, in 2019 Marquette’s "Annual Maintenance" category was renamed "Deferred Maintenance," and has remained a top-line category in the Minor Capital Budget ever since.

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[13] “A New Plan to Fix Old Buildings”

[14] “Addressing Deferred Maintenance: MIT’s maintenance backlog”

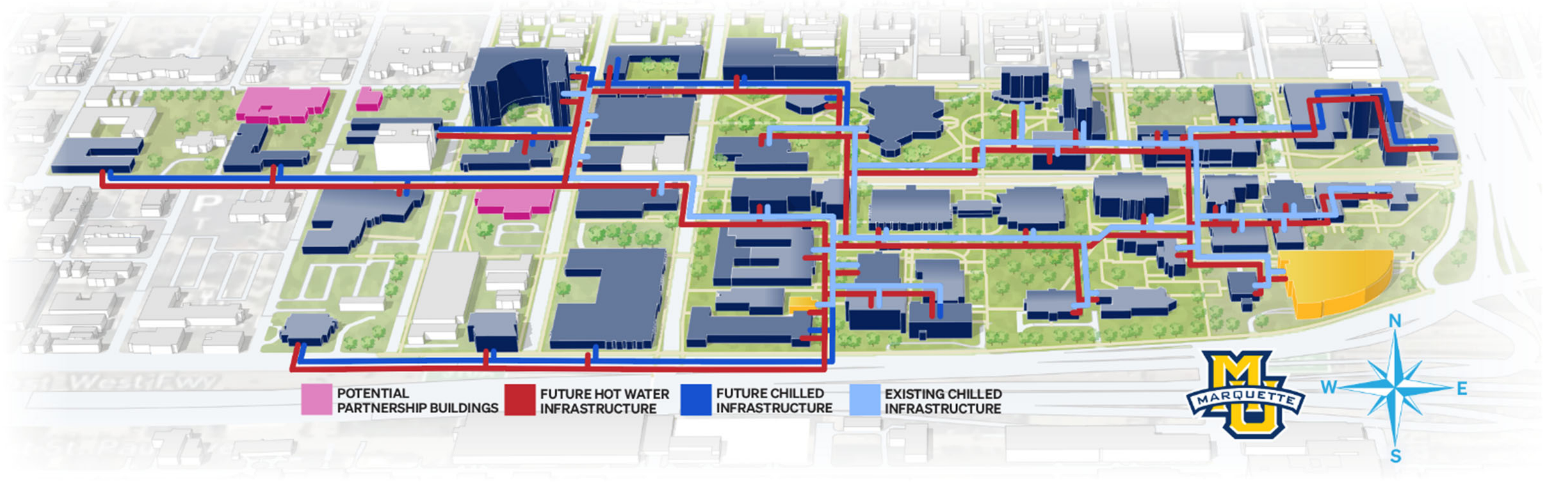
"Deferred Maintenance" allocations cover various expenditures, with only some related to thermal infrastructure, which are extracted and graphed in Figure 5. In 2021, a new subcategory, "Deferred Maintenance Backlog Reduction," was introduced to address the growing backlog of deferred maintenance.

Each year, both Facilities Planning and Management and the Office of Residence Life identify and prioritize projects in their respective backlogs (academic and residential buildings). A portion of these is then funded out of the appropriated "Deferred Maintenance Backlog Reduction" budget. In 2021, $9.4 million in needed thermal capital maintenance was identified, with 29.2% funded. In 2022, $8.6 million was identified, with 33.9% funded. Over these two years, just under a third of the deferred thermal capital maintenance was addressed. This fraction seems to have decreased in recent years due to funds being redirected to large new building projects (see Figure 5).

To implement this strategy effectively, the facilities team should work closely with administration to conduct facility condition assessments (FCAs), secure dedicated funds for capital renewal, and develop agreements to reinvest savings from energy efficiency projects into future initiatives. This proactive approach not only addresses immediate infrastructure needs but also positions universities for long-term sustainability and decarbonization.[15]

Pilot Project + District Hot Water Network

Figure 18 Transformation Enabler Map



Ultimately, the analysis from this study shows that building out a district high temperature (170°F) hot water network is the most effective and tailorable path for Marquette decarbonization. This strategy will substantially reduce carbon emissions while also maximizing financial benefits and minimizing future risk. This should begin with a pilot project followed by a phased implementation of the long term decarbonization plan. This pilot project would serve as a “proof of concept” for the larger campus

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[15] “Maintaining a large University Campus: Capital Renewal”

transformation effort and would target an area of opportunity to be expanded upon in the following decarbonization work.

Discussions with Marquette around capital planning and deferred maintenance budgets have revealed that significant capital allocations have been or are planned to be made for steam distribution and chilled water system improvements in the sciences district of the campus. These target leg 5 of the existing steam distribution system as well as the Clark Hall chilled water plant, both of which serve the science buildings located in this section of the campus.

Capital improvement allocations for leg 5 of the steam system are already anticipated in the 2026 Minor Capital Budget. However, any investments made to maintain steam distribution to buildings on this leg could be repurposed to fund the installation of a partial heating hot water loop extending from the Clark Hall chiller plant. Similarly, planned investment in the evaporative cooling tower (heat rejection) or other chilled water assets could be used instead to purchase heat pump capacity. Instead of rejecting thermal energy to the atmosphere via cooling towers, a heat pump can be used to capture and repurpose thermal energy to satisfy heating load in neighboring buildings via a heating hot water loop. An effort should be made to determine which buildings in this area of campus have summer heating loads.

The Clark Hall chilled water plant is near a large wastewater main running in parallel to W. Clybourn Street. The long term decarbonization plan includes a recommendation to intercept volume from the wastewater main in proximity to Clark Hall and in an additional location near the Eckstein Hall chilled water plant. In lieu of locating wastewater heat exchange assets solely at Eckstein, supplemental assets could be located at the Clark Hall plant to provide a thermal source and help to develop a heating hot water network to replace steam service for the buildings on leg 5. Having distributed plants and assets serving a common network will enable a more controlled growth of the heating hot water network over time while promoting long-term system redundancy/resiliency as the plants are fully integrated and connected.

The long term decarbonization plan seeks to expand both the reach of the heating hot water network and thermal resources over time. A pilot project originating at Clark Hall would expand to serve the buildings on leg 5 of the steam distribution network to start. Once these buildings are connected to a heating hot water network, the steam service and distribution no longer need to be maintained. This asset could either be removed or abandoned in place. The Clark Hall plant would expand outwards by extending the heating hot water distribution to other legs of the steam distribution network. Expansion of the network will require the existing plant chillers to be replaced with heat pump capacity and supplemented with additional source capacity. The wastewater heat exchange system could continue to expand and operate in parallel with a geo-exchange system located in green space adjacent to the plant.

A parallel approach can be taken at the Eckstein Hall chiller plant. A heating hot water loop could be created to serve buildings on a common steam leg near the chilled water plant. The advantage with the Eckstein plant is that there is already vacant space that can be used to add heat pump capacity without disrupting or replacing the existing plant assets. With a significant wastewater main running right next to the building, a thermal exchange system (SHARC) could be deployed to serve a majority of the heating and cooling needs in this area. As the system expands and the loads served increase, the wastewater exchange asset can expand and be supplemented with GHE. Vertical bores would, ideally, be located near the Eckstein plant. If green space disruption is problematic, Salas recommends targeting surface parking and sidewalk areas for drilling.

Salas engaged SHARC Energy to discuss system design options using the information obtained from MMSD and the thermal profile that was developed for the Marquette campus. The intent was to optimize system design to handle as much of the annual campus heating load as possible. The remaining annual and peak load in excess of SHARC capacity would be handled with supplemental source-side technologies such as GHE, air-source heat pump, or other conventional electrically driven assets.

Preliminary design included a total system capacity of roughly 63,000,000 Btu/hr via processing capacity up to 14,000 GPM of wastewater flow. This could be accomplished via (12) SHARC Model 880 or (6) SHARC Model 1212 units. Note that the SHARC models are not indicative of capacity; each offers a range of potential capacities based on a range of possible flows and operational temperature differential. A minimum storage capacity of 189,000 gallons was recommended. This is a significant amount of storage volume and, much like the GHE, will require notable surface disruption if the storage tanks are to be buried adjacent to one or both existing chilled water plants.

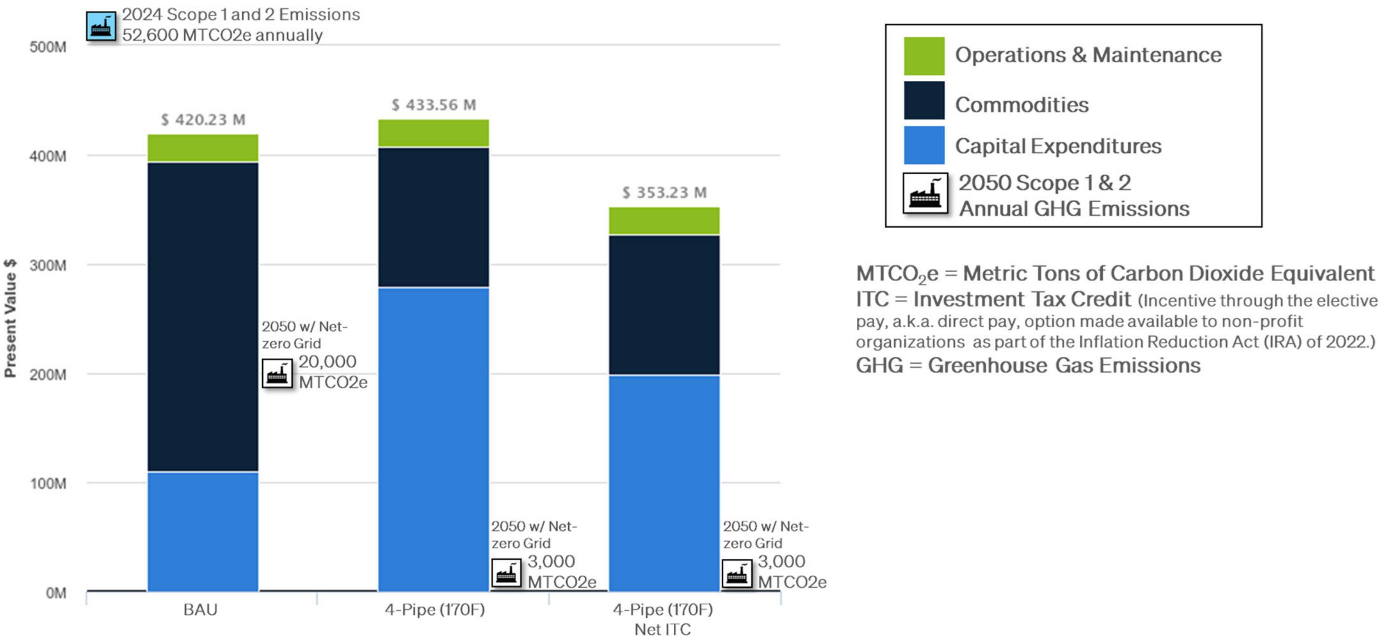
Heat exchange with wastewater flow via the proposed SHARC system can provide over 90% of the unbalanced campus heating. Unbalanced heating refers to the amount of campus heating left after simultaneous loads have been satisfied via moving thermal energy from functions that require cooling to functions that simultaneously need heating. Only a small portion of the total annual heating load (<5%) will be left to be satisfied with supplemental sources. Similarly, over 75% of the unbalanced cooling load could be satisfied via the proposed SHARC system leaving only 14% of the total annual cooling to be handled with conventional plant.

Comparative Life-cycle Cost Analysis

Overview of Scenarios

The life-cycle cost comparison for Marquette University considers three different scenarios: Business-As-Usual (BAU), the Recommended Strategy without Investment Tax Credit (ITC), and the Recommended Strategy with ITC. The BAU scenario shows a net present cost of $420.23 million, reflecting the ongoing expenses of maintaining current systems and energy sources. In contrast, the Recommended Strategy without ITC projects a slightly higher net present cost of $433.56 million but offers significant environmental benefits by reducing greenhouse gas (GHG) emissions to 3,000 metric tons of CO_2 equivalent ($MTCO_2e$) by 2050. The most advantageous option, the Recommended Strategy with ITC, presents a net present cost of $353.23 million, again achieving emissions of 3,000 $MTCO_2e$ by 2050. This scenario highlights the financial and environmental benefits of leveraging investment tax credits.

Figure 19 Life-Cycle Cost Comparison

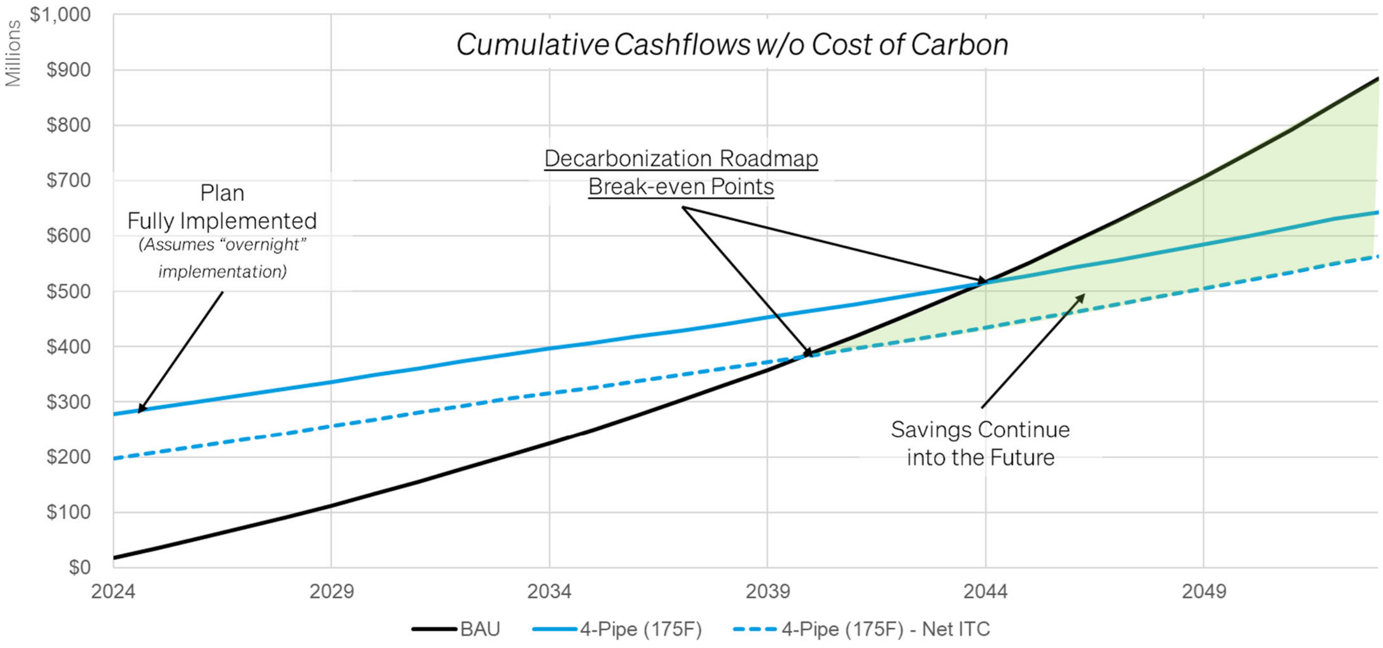


$MTCO_2e$ = Metric Tons of Carbon Dioxide Equivalent
ITC = Investment Tax Credit (Incentive through the elective pay, a.k.a. direct pay, option made available to non-profit organizations as part of the Inflation Reduction Act (IRA) of 2022.)
GHG = Greenhouse Gas Emissions

Break-Even Analysis

The break-even analysis below shows that the Recommended Strategy, even with significant upfront costs, offers a payback period of less than 20 years when comparing the Cumulative Cashflows w/o Cost of Carbon. The analysis, depicted with an "overnight implementation" model, illustrates the benefits of this strategy. The solid blue line represents the Recommended Strategy without ITC, while the dashed blue line represents the same strategy with ITC. The investment payback period ranges from 16 to 20 years, which exceeds the typical returns from the university’s endowment, making it a prudent financial decision.

Figure 20



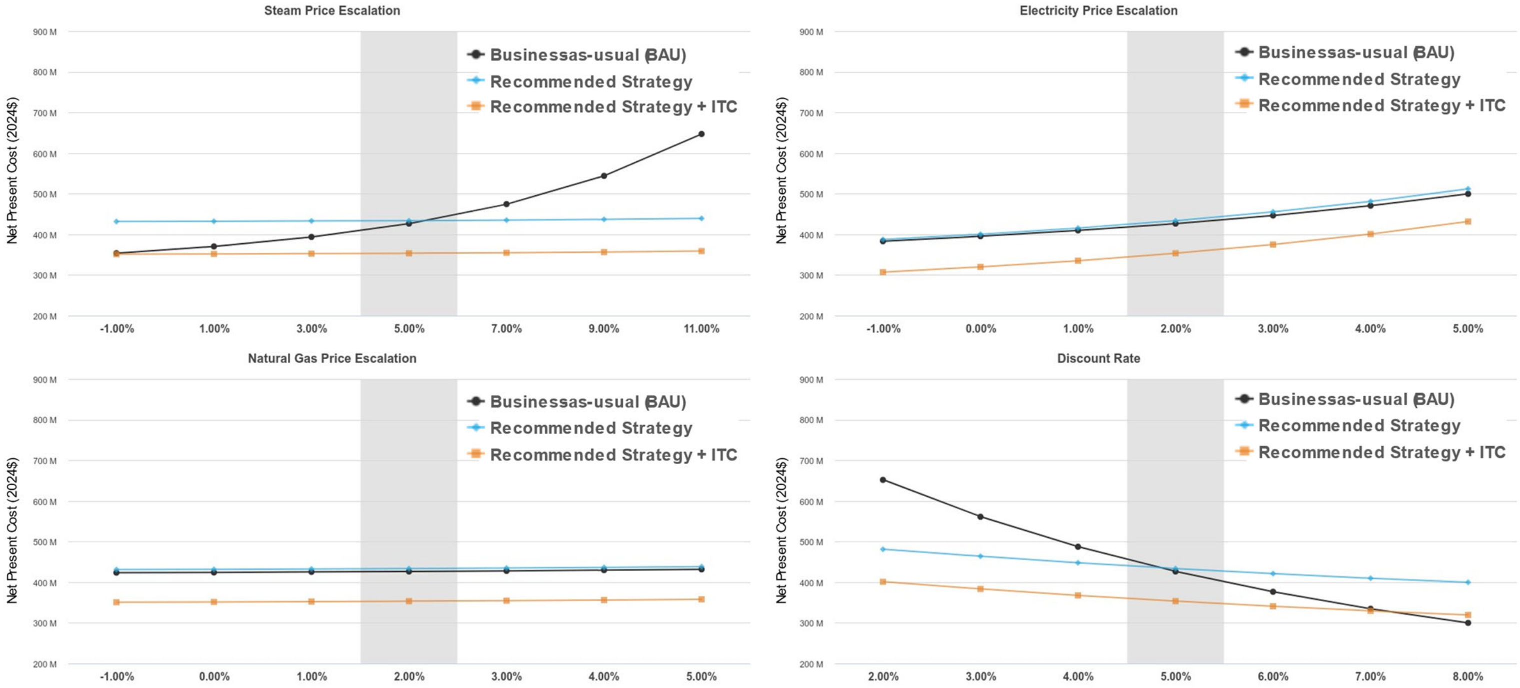
Conclusion

This comprehensive life-cycle cost analysis demonstrates that while the BAU scenario incurs the lowest upfront costs, it results in the highest long-term expenses and emissions. In contrast, the Recommended Strategy, particularly with ITC, offers substantial long-term savings and significant reductions in GHG emissions. This strategic investment not only aligns with Marquette University's sustainability goals but also provides a financially sound approach to future-proofing the university against rising energy and carbon costs. This future-proofing is evident in the following sensitivity analysis.

Sensitivity Analysis

The sensitivity analysis below emphasizes the impact of steam price escalation on the overall costs. The black line represents the BAU scenario, the blue line represents the Recommended Strategy without ITC, and the orange line represents the Recommended Strategy with ITC. A key sensitivity is the steam price escalation. At a 5% cost escalation, the BAU and Recommended Strategy without ITC costs are essentially equivalent. However, if steam prices escalate faster than 5% per year (they have escalated in excess of 11% per year over the last five years), the Recommended Strategy significantly mitigates this risk. Conversely, the BAU scenario remains highly exposed to this substantial risk.

Figure 21 Sensitivity Analysis

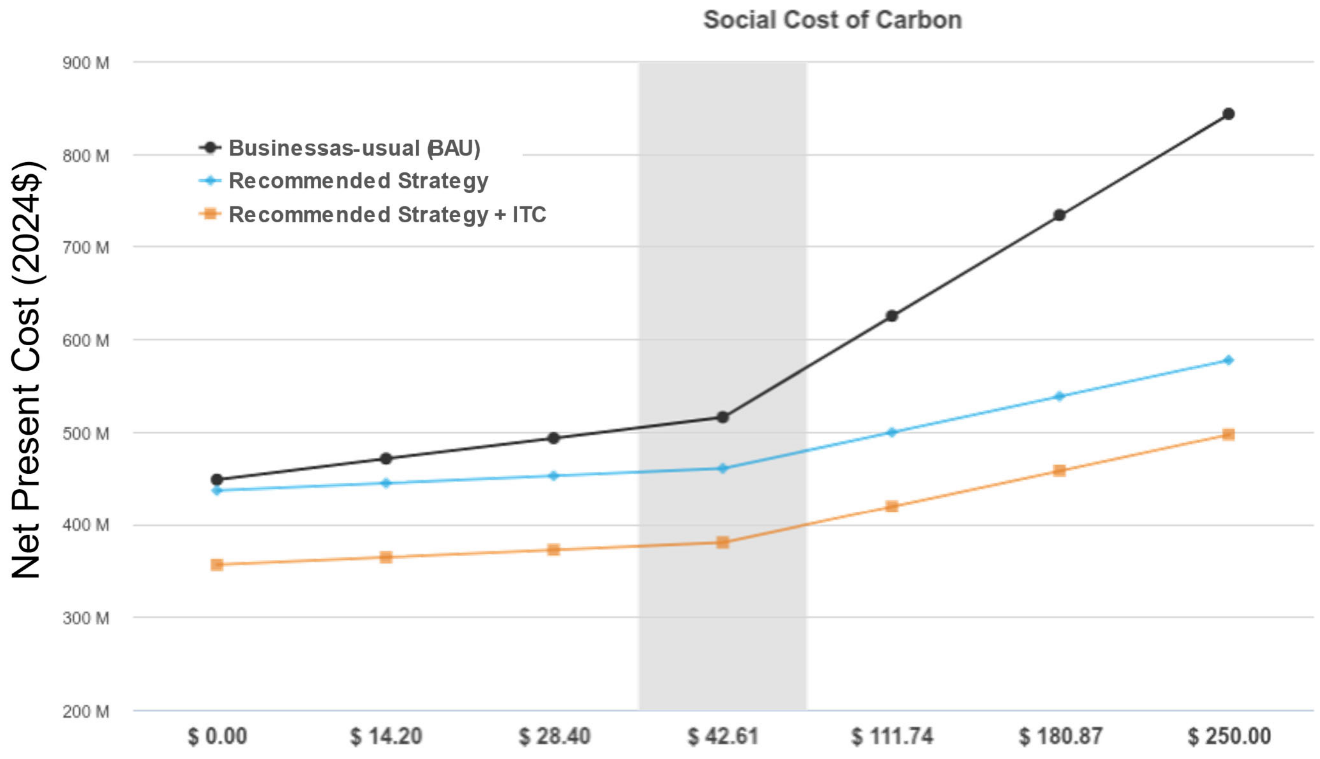


The analysis shows little sensitivity to the price escalation rates for electricity and natural gas. In the case of electricity, this is because total electricity purchases under the Recommended Strategy are not substantially higher than total electricity purchases under the BAU scenario. (Most of Marquette’s electricity is not used for HVAC applications, so price escalation similarly impacts both scenarios.) In the case of natural gas, there is little sensitivity because direct natural gas purchases represent only a small fraction of purchased energy under all scenarios. Sensitivity to the assumed discount rate is also shown. Since the Recommended Strategy uses an up-front investment to replace recurring commodity purchases, the Recommended Strategy is most favorable at lower discount rates.

Sensitivity Analysis with Social Cost of Carbon

Finally, the team created a sensitivity analysis incorporating the social cost of carbon. With zero cost of carbon, the BAU and Recommended Strategy (without ITC) lines are nearly identical. However, as real-world examples from New York City and Boston show carbon costs exceeding $250 per metric ton, the BAU scenario's exposure to these costs becomes a significant financial risk.[16] The Recommended Strategy mitigates this risk by transitioning to a lower-carbon energy source, thereby reducing exposure to escalating carbon costs and enhancing fiscal responsibility.

Figure 22 Sensitivity Analysis with Social Cost of Carbon



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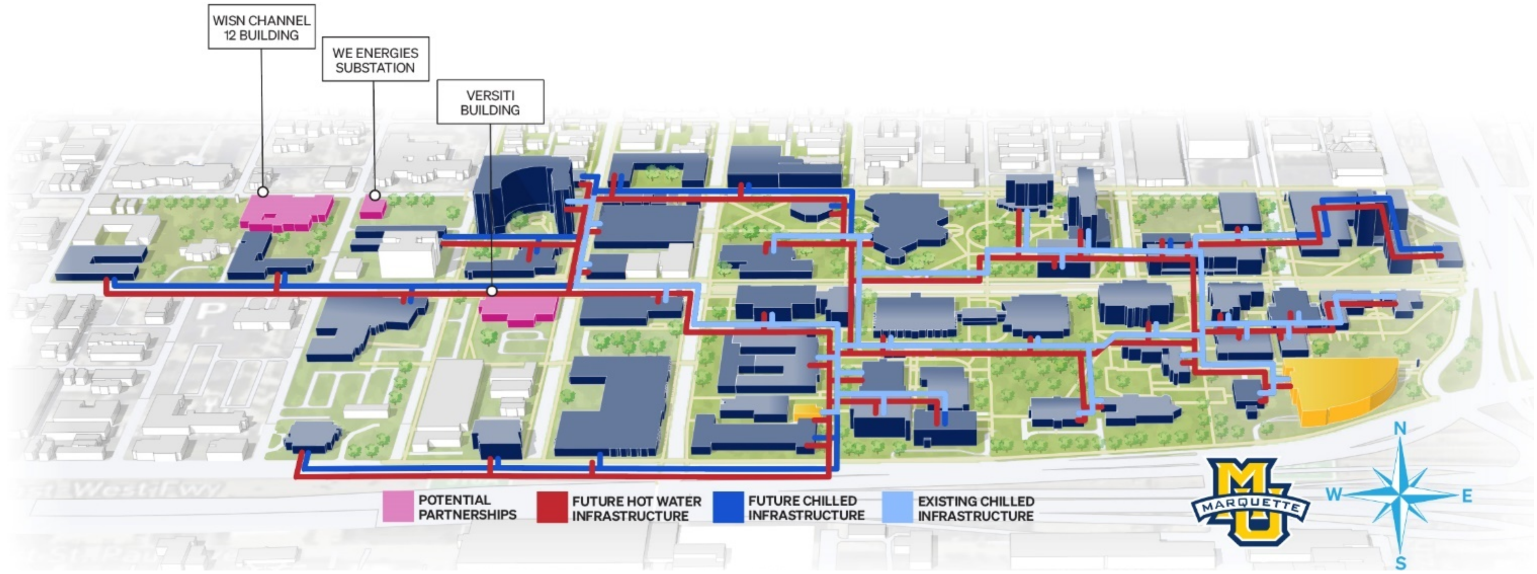
[16] https://www.nyc.gov/assets/buildings/local_laws/ll97of2019.pdf https://www.thecrimson.com/article/2023/7/7/Cambridge-net-zero-2035/

THE PATH AHEAD

Figure 23 Decarbonization Roadmap with Potential Future Partnerships



The recommended strategy presents an opportunity for Marquette to start on a path of progress, to “Be the Difference.” This path is paved by five key elements, and Marquette has already taken some steps in this direction. Following this path also sets the stage for future neighboring community decarbonization, either through direct integration into the proposed infrastructure, or by developing new district energy plans following Marquette’s model. Figure 22 shows the Marquette Decarbonization Roadmap with potential future connections to our community neighbors (shown in pink). Though not part of Marquette’s campus, these structures are located ideally to tie into the district hot water network and benefit from the system as well.

Campus decarbonization is not only socially and fiscally responsible, but also rapidly becoming a key factor in students' choice of school, with increasing local pressure to adopt sustainable practices. As Pope Francis emphasized in *Laudato Deum*, "our responses have not been adequate, while the world in which we live is collapsing and may be nearing the breaking point." Marquette University, as a Catholic, Jesuit institution, has a profound responsibility to heed this call and take swift and substantial action. Embarking on this journey will put Marquette at the forefront of higher education institutions aiming to do their part for decarbonization.

The international community, guided by the IPCC, has set ambitious targets to limit global warming to 1.5°C above pre-industrial levels, necessitating a 50% reduction in emissions by 2030 and achieving net zero by 2050. Marquette University has a duty to meet, if not exceed, these targets within our campus. Our comprehensive decarbonization strategy, detailed in this implementation paper, is not only a blueprint for achieving these necessary reductions but also a testament to fiscal responsibility. By prioritizing investments in building demand reduction, reallocating capital expenditures to facilitate the transition to high-efficiency supply systems, and forming strategic partnerships to enhance energy sustainability, Marquette University is committed to leading by example. This approach ensures that we not only fulfill our moral and social responsibilities but also set a standard for the broader academic and local community, reinforcing that sustainability and fiscal prudence are not mutually exclusive but indeed complementary.

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