

Charting the Path to Carbon Neutrality:
Sustainable Energy
Recommendations for Eau
Claire County

Prepared for

Matt Theisen, Eau Claire County Facilities Director

By

Andrew Zaiser, Shirley Obih, Owen Jonas

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WISCONSIN ENERGY INSTITUTE
UNIVERSITY OF WISCONSIN-MADISON

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Executive Summary

Eau Claire County of Wisconsin was motivated to reduce its energy consumption and greenhouse gas footprint in county facilities, especially the main administrative building located downtown Eau Claire. These buildings experience elevated energy consumption, making up about 91% of Eau Claire County energy government electricity usage.¹ The goal of this project was to recruit a team of students to provide recommendations to improve energy efficiency further, and reduce energy consumption and carbon emissions (particularly for the county courthouse and jail), investigate renewable energy projects/options to achieve the county's goal of carbon neutrality by 2050, assist in raising awareness to county staff and elected officials on the options the county can pursue to invest in the sustainability of county facilities. Through research and collaboration with Matt Thiesen, Eau Claire County Facilities Director, and Bu Wang, project advisor and professor of Civil Engineering, the list of suggested recommendations were as follows; installation of Light Emitting Diode (LED) bulbs and rooftop and parking lot solar panels, proper insulation of walls in these buildings, replacement of older HVAC models nearing expiration, transition from natural gas-sourced heating to Ground Source Heat Pump and/or Wastewater Heat pump, and installation of rooftop and parking lot solar as needed to reach net-zero carbon emissions from electricity consumption. Capital cost estimates for the ground source heat pump are approximately \$1,127,000, including installation. Solar costs can vary widely depending on the degree of grid decarbonization that occurs by 2050, but projections indicate costs will range between \$734,404.00 and \$1,515,686.00. Total capital cost will likely range from \$1,861,404.00 to \$2,642,686.00.

¹ Discussion with client and EnergyStar Portfolio manager data

Introduction

Climate Change and benefits of net-zero emissions

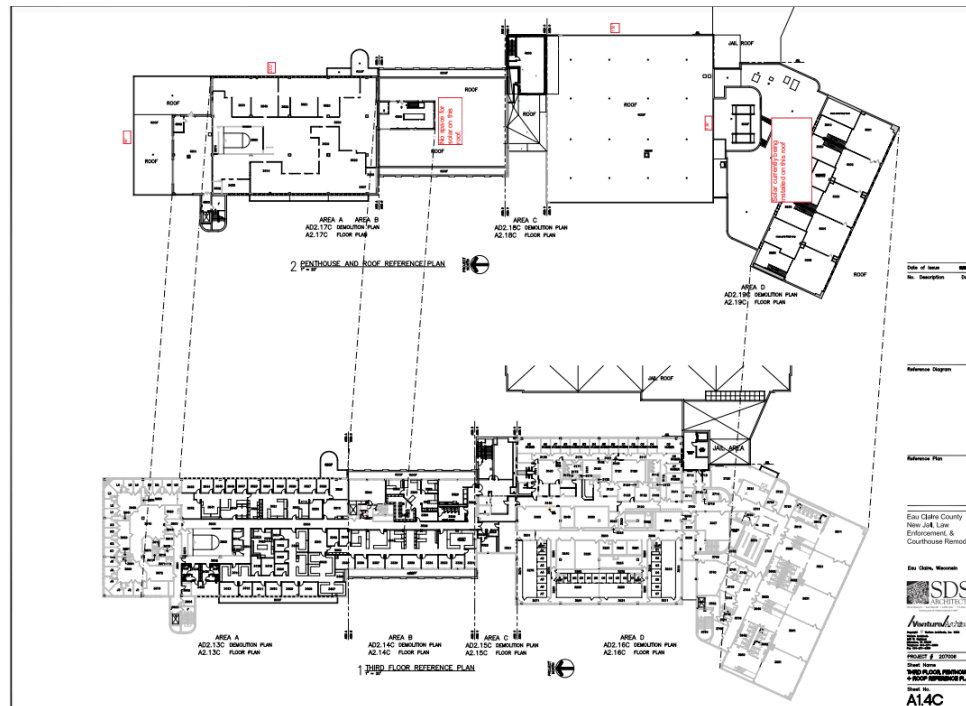
Climate change poses an existential threat to our planet, impacting ecosystems, economies, and human societies worldwide.² Embracing a net-zero approach is critical to mitigating its effects, particularly in the realm of energy and electricity consumption. By transitioning to renewable energy sources and implementing energy-efficient technologies, we not only reduce greenhouse gas emissions but also foster sustainability and resilience. The benefits of achieving net-zero emissions extend beyond environmental preservation to encompass economic advantages, including job creation, energy cost savings, and enhanced energy security. Moreover, by curbing our reliance on fossil fuels and embracing cleaner alternatives, we pave the way for a more sustainable and equitable future for generations to come.

Eau Claire County Goal

As stated in the executive summary, Eau Claire County sought to reduce energy consumption across the county courthouse and jail buildings located at 721 Oxford Ave Suite 2220 and 710 Second Ave., Eau Claire, WI 54703 respectively. Layouts of the buildings are shown in the figures below.

²*Effects of Climate Change—NASA Science*. Nasa. Retrieved May 7, 2024, from <https://science.nasa.gov/climate-change/effects/>

Figure 3: Layout of courthouse building with dimensions included. The red-text notation identifies portions of the building where rooftop will not be possible.⁵



In the interest of making progress toward the goal of carbon neutrality by 2050, Eau Claire County has already implemented some first-phase solutions. They include:

- Rooftop Solar: Currently, a 73 kW solar array is being installed in the south end of the courthouse building.
- Solar PPA (power purchasing agreement) with Xcel Energy
- Various Frequency Drive Chillers as a replacement for two 325 Ton building chillers
- Insulation of walls within the premises including roof repairs and resurfacing.

⁵ Provided by client

- Installation of occupancy sensors
- Removal of pneumatic controls and air compressors from the complex.
- Conversion of steam heat to hot water heat utilizing energy efficient boilers.

With these in mind, the team provided some other recommended solutions. They include additional rooftop and parking lot solar installations, replacement of natural gas sourced heating with ground source heat pumps. Some other recommendations were provided but discarded for lack of practicality to the current landscape available. These include:

Non-Viable Considered Solutions

Hydroelectric energy

This option was suggested as a plausible replacement for all or a portion of Eau Claire's energy consumption, due to the Eau Claire River, which sits approximately 100m from the buildings. However, this option was ultimately not chosen due to permitting issues and the presence of a dam 1 mile upstream, which might impact the availability and consistency of water flow downstream.⁶

Battery Storage

While battery storage is an extremely useful technology, and allows solar generation facilities to avoid the intermittency inherent in solar energy generation, it is still rapidly developing and remains a somewhat costly option to add to a solar array.⁷ Furthermore, Eau Claire County has expressed an

⁶ Per discussion with client

⁷ Lazard's Levelized Cost of Storage Version 7.0.

<https://www.lazard.com/media/42dnsswd/lazards-levelized-cost-of-storage-version-70-vf.pdf>.

interest in reaching net-zero, rather than fully serving its own electricity needs via renewable energy. Therefore, as long as enough renewable energy is generated to cover the amount of fossil fuel-generated electricity the county would otherwise have drawn on from the grid and any excess is sent to the grid to be used elsewhere, the county will have reached net-zero emissions.⁸ With this understanding, there is no need for battery storage. If the county decides it wants to generate 100% of its electricity on-site, or otherwise manage *when* it uses the electricity it generates on-site, then battery storage is a worthwhile option to explore.

Biomass/Bioenergy Electricity Generation

Biomass or bioenergy power generation was excluded from our analysis for one critical reason: there are no biomass or bioenergy generation facilities in the vicinity of Eau Claire's courthouse/jail complex.⁹ Our client indicated that - with other options available - they were not interested in taking the many steps required to build and operate a biomass power plant themselves.

Biomass/Bioenergy for Heating

This option was discounted for the same reasons that biomass/bioenergy was discounted as an option for electricity generation. It would be an expensive endeavor, as Eau Claire County would

⁸ What is net zero? The carbon emissions challenge | McKinsey.
<https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-net-zero>.

⁹ Mapping The Biomass Industry | Environmental Paper Network.
<https://environmentalpaper.org/biomass/mapping-bioenergy/>.

either need to construct and operate a biomass/bioenergy facility itself, or contract with another entity to do so. Both of these options would be more expensive than other far more convenient options.¹⁰

Off-site solar

Given the available on-site solar options, there is minimal justification for developing off-site solar generation capacity. While on-site solar does not require purchasing any property, nor does it require building and using additional transmission infrastructure, off-site solar does.¹¹ This leads to increased costs, and a lower net benefit to the client. There is one off-site location we discussed with the client, however, which is able to hold 100 KW of solar generation capacity. The critical flaw with this site is that it is served by a different electric utility than the courthouse/jail complex. This means that to use this site's solar generation, there would need to be inter-utility cooperation to transmit the electricity from off-site to the jail/courthouse complex. If this isn't possible, the energy generated there could still be sold to the grid, but it would be sold at the net metering rate, which is significantly lower than the retail rate paid by Eau Claire County.¹² Overall, this option - while reasonable - is inferior to on-site solar generation for the various reasons discussed previously, and has therefore been discounted.

¹⁰Renewable Power Generation Costs in 2022.

<https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022> (2023).

¹¹Larsen, P. H. A method to estimate the costs and benefits of undergrounding electricity transmission and distribution lines. *Energy Economics* 60, 47–61 (2016).

¹²Xcel Energy - WI_Solar_Net_Metering_Info_Sheet.

https://www.xcelenergy.com/staticfiles/xcel-responsive/Working%20With%20Us/Renewable%20Developers/WI_Solar_Net_Metering_Info_Sheet_vFinal.pdf.

Carbon Credits

Based on the budget preferences of our client, purchasing carbon credits to offset continued emissions was deemed to be non-preferable. With a larger capital budget than operating budget, and the ability to issue bonds for capital projects, the client indicated that single large capital purchases would be better for the county, rather than engaging in ongoing, annual purchases of carbon credits.

On-site wind

On-site wind was never considered a viable option, and was removed as a possible alternative early in our process. The turbines that could generate the amount of electricity demanded by the complex, even in the best-case scenario, would not fit on the courthouse/jail complex roof or in the parking lot area.¹³ Furthermore, permitting issues can arise with wind energy in more densely populated areas like downtown Eau Claire, with complaints brought up regarding perceived safety or aesthetics issues with the turbines.¹⁴ With far better options available, we were able to discount on-site wind as an option

Off-site wind

While off-site wind is a more realistic option than on-site wind, it still has multiple critical flaws that make it an untenable choice for the county's renewable electricity needs. Firstly, for any off-site wind option, Eau Claire County would either need to purchase or lease property on which to

¹³<https://products.mywindpowersystem.com/shop/500kw-3mw/winwind-wwd-1-1mw-wind-turbine-class/#:~:text=1MW%20Industrial%20Wind%20Turbine&text=and%20For%20environmentally%20size%20limited,at%20lower%20wind%20speed%20sites>.

¹⁴ WINDEXchange: Wisconsin 30-Meter Residential-Scale Wind Resource Map.
<https://windexchange.energy.gov/maps-data/247>.

construct wind turbines, increasing costs. If Eau Claire wanted to avoid these costs, it would need to enter into a power purchase agreement with a wind energy provider, which brings various complications as well.¹⁵ For example, this would be an ongoing expense, rather than a one-time capital expense as our client indicated was preferable. In either situation, Eau Claire would have to ensure that the electricity generated off-site could get to the courthouse/jail complex, bringing further technical difficulties - especially if the generation was newly built, requiring additional work to connect to transmission infrastructure. As Eau Claire is an area with a low level of wind resource, the complications are not worth the benefits of wind generation.¹⁶

Air-source heat pump

Air source heat pumps (ASHP) are a widely used, economical option for building heating and cooling in the majority of places. However, their one major flaw is an inability to operate efficiently at cold temperatures, and an inability to operate at all once a temperature threshold is reached. Inefficient operation begins at -2 degrees fahrenheit, while operation cannot continue below -22 degrees fahrenheit¹⁷. Given that Eau Claire spends 28 days on average below zero, the county would likely need to rely on backup heat generation supplied by natural gas to heat the courthouse/jail complex during these frigid days¹⁸. This would defeat the purpose of electrifying heating systems, and is a problem that other heat pump types - like ground source heat pumps - do not have.

¹⁵ Oct 20, 2007. Chapter 13: Power Purchase Agreement. Windustry
https://www.windustry.org/community_wind_toolbox_13_power_purchase_agreement.

¹⁶ WINDEXchange: Wisconsin 30-Meter Residential-Scale Wind Resource Map. <https://windexchange.energy.gov/maps-data/247>.

¹⁷ Safa, A. A., Fung, A. S., & Kumar, R. (2015). Comparative thermal performances of a ground source heat pump and a variable capacity air source heat pump systems for sustainable houses. *Applied Thermal Engineering*, 81, 279–287. <https://doi.org/10.1016/j.applthermaleng.2015.02.039>

¹⁸ Schaefer, M. (2020, February 20). *Eau Claire's 4th coldest low of the winter this morning was just the 14th time below zero*. WQOW.
https://www.wqow.com/weather/eau-claire-s-4th-coldest-low-of-the-winter-this-morning-was-just-the-14th/article_b4837b5b-3ea4-5db1-a7e1-17d9720d16fa.html

Viable Solutions

Rooftop Solar

Given the large surface area available on the courthouse/jail complex roof, along with the technology's maturity, low cost, and available incentives, rooftop solar is a highly viable option to provide at least a large portion of Eau Claire County's jail/courthouse complex's electricity needs.¹⁹ Of the 108,681 square feet of roof space in the jail/courthouse complex, approximately 53,084 square feet is usable for rooftop solar. With our calculations showing approximately 59 square feet needed per kW of solar capacity in this location, the roof of the courthouse/jail complex has a potential capacity of 900 KW of nameplate capacity. With a capacity factor of 17.3%, the effective capacity of a full-rooftop solar array could reach up to approximately 150 kW. This is a significant amount of capacity given that the total electricity capacity needs of this complex after a conversion from natural gas heat to GSHP would be between 660 and 710 KW, working out to approximately 21-23% of total electricity demand. Assuming Wisconsin's fossil fuel share of grid mix is ~22% or less, a rooftop array could bring the courthouse/jail complex to net-zero emissions. Additionally, the Inflation Reduction Act includes a provision that provides a 30% tax Investment Tax Credit (ITC) to offset the cost of installing solar panels.²⁰ This provision includes public entities like Eau Claire County, and would significantly decrease the cost of all solar options.

¹⁹ Lazard's LCOE 2023. <https://www.lazard.com/media/typdgxmm/lazards-lcoeplus-april-2023.pdf>.

²⁰ Inflation Reduction Act Extends and Modifies Tax Credits for Solar Projects. McGuireWoods <https://www.mcguirewoods.com/client-resources/alerts/2023/2/inflation-reduction-act-extends-and-modifies-tax-credits-for-solar-projects/>.

Parking Lot Solar

While rooftop solar should be able to meet a large portion of Eau Claire County's electricity needs, there are a range of possible decarbonization outcomes in which it cannot generate enough electricity to allow Eau Claire County to reach net-zero emissions. In these scenarios, the best option to bridge the gap - taking into account all options - is installing solar panels above parking stalls in the courthouse/jail complex parking lot. This would allow vehicles to use the stalls while also providing electricity to the complex. There are 472 parking spaces in all lots serving the courthouse/jail complex, of which 228 meet the requirements for the installation of parking lot solar. For example, 36 spaces are shaded by the complex itself, making them unsuitable for solar generation due to the limited insolation they would receive throughout the day. Furthermore, Lot A, which contains 197 spaces, is already earmarked to be converted to a parking structure, so it will not be available to be used for solar. The remaining 11 spaces, while potentially usable, were determined to be non-ideal during discussions with the client. These spaces have been discounted for the purpose of our analysis.

Based on the City of Eau Claire's zoning ordinances, parking spaces must be 18 feet by 9 feet, which represents 162 square feet available for solar generation above each parking space.²¹ Altogether, there are 36,936 square feet of space available for solar generation in the complex's parking lots. Added together with the available rooftop space, there is a grand total of 90,020 square feet available. With these parameters established, we must now analyze whether that amount of square footage is enough to meet the complex's energy needs. This question, however, depends on how much of its energy Eau

²¹ Eau Claire Zoning Code Ch 18.25: OFF-STREET PARKING AND LOADING REQUIREMENTS.
<https://www.eauclairewi.gov/home/showpublisheddocument/44675/638422052438070000>.

Claire County can get from the grid via renewable sources. This, in turn, will depend on how quickly the grid decarbonizes.

Ground Source Heat Pump

An effective alternative to air source heat pumps, are ground source heat pumps (GSHP), which involves extracting heat from underground for building heating and cooling. Within every GSHP system, there are three main components: the heat pump unit itself that serves as the medium between indoor and below-ground temperatures, an air conditioning unit that manages building heating and cooling loads, and the heat exchange systems themselves that are installed underground and are responsible for extracting the heat that will be used to heat or cool the building²². Where various types of GSHP systems differ, is the third component, changing how heat from underground is extracted. Open GSHP systems use heat directly from groundwater, whereas closed system GSHPs are separated from the soil and contain high density circulation pipes carrying a heating medium, which tends to be a water-antifreeze solution²³. For the purposes of this project we recommend using a 30% Propylene Glycol solution, which has been used in similar projects.

Within the subcategory of closed GSHP systems, there exists both vertical systems, which place the system in vertical boreholes, and horizontal systems, in which the system exists in a horizontally dug trench. Vertical systems tend to be more efficient and take up less space, but the initial cost to dig

²² Li, H. X., Okolo, D. E., Tabadkani, A., Arnel, T., Zheng, D., & Shi, L. (2023). An integrated framework of ground source heat pump utilization for high-performance buildings. *Scientific Reports*, 13(1), 371. <https://doi.org/10.1038/s41598-023-27704-2>

²³ Esen, H., Inalli, M., & Esen, M. (2007). A techno-economic comparison of ground-coupled and air-coupled heat pump system for space cooling. *Building and Environment*, 42(5), 1955–1965. <https://doi.org/10.1016/j.buildenv.2006.04.007>

the boreholes is generally higher than the cost of digging a horizontal trench, depending on what the land is currently being used for²⁴.

While the upfront cost of GSHP systems can be high, life-cycle analyses of these systems show that through lower energy costs and reductions in carbon dioxide emissions, these systems are more economically viable than traditional HVAC systems, and a return on the difference in the initial investment can occur just 12 years after installation²⁵.

In addition to being able to supply heating at extremely low temperatures, GSHPs also possess less efficiency variability than ASHPs. A study conducted in Ontario, Canada found that at both higher and lower temperatures the coefficient of performance (COP), which is a ratio of heating or cooling energy provided to energy (work) required, had a smaller range for GSHPs compared to ASHPs. At warmer temperatures (60-90 degrees Fahrenheit) ASHP's COP ranged from 4.7-5.7, whereas GSHP's COP ranged from 4.9-5.6 for cooling. At low temperatures (-2 to 48 degrees Fahrenheit), when providing heat, ASHP's COP ranged from 1.79-5.0, whereas GSHP's COP ranged from 3.05-3.44²⁶. While this means that ASHPs can be more efficient at certain temperatures, variability in how much energy is required based on the ambient air temperature leads to unpredictability in how much solar energy will be needed to power the system. As climate change worsens and temperatures become more and more unpredictable, having a more constant COP of the GSHP is the better option.

²⁴ Li, H. X., Okolo, D. E., Tabadkani, A., Arnel, T., Zheng, D., & Shi, L. (2023). An integrated framework of ground source heat pump utilization for high-performance buildings. *Scientific Reports*, 13(1), 371. <https://doi.org/10.1038/s41598-023-27704-2>

²⁵ Kwon, Y., Bae, S., Chae, H., & Nam, Y. (2023). Economic and performance analysis of ground source heat pump system for high-rise residential buildings considering practical applications. *Energy Reports*, 10, 4359–4373. <https://doi.org/10.1016/j.egy.2023.10.086>

²⁶ Safa, A. A., Fung, A. S., & Kumar, R. (2015). Comparative thermal performances of a ground source heat pump and a variable capacity air source heat pump systems for sustainable houses. *Applied Thermal Engineering*, 81, 279–287. <https://doi.org/10.1016/j.applthermaleng.2015.02.039>

Estimating the Size of the GSHP Required

To estimate the size of the GSHP system required to provide heating and cooling to Eau Claire County's courthouse and jail facility, we first had to determine how much energy was currently being used to provide heating and cooling for the facility. From data provided by Eau Claire County's EnergyStar Portfolio Management system, which provides information about how much energy the county consumed at their various government buildings, we found that this facility consumed 24,580,390,000 BTU total last year for heating and cooling. This equates to a system size that must cover 2,805,980.61 BTU/hour. Using Figure 4, a resource from Nordic Heating and Cooling, a large manufacturer of heat pumps in the United States, we estimated that a 280-ton heat pump system would cover the heating and cooling capacity that this facility requires. Differences in the size of the system required occur when comparing open loop to closed loop systems, and it is slightly more expensive to install a closed loop system. This difference in cost is made up for by the increased efficiency of closed loop systems, the lower maintenance costs, and the decreased likelihood of issues arising with the system. Closed loop systems also last longer than open loop systems²⁷. For these reasons, and the climate of Eau Claire County, we recommend installing the slightly more expensive, closed-loop system. In regards to the size and amount of vertical boreholes that need to be drilled, various similar projects have used 400-800 feet deep boreholes with diameters ranging from 4-6 inches, depending on the size of the heat pump required. It is standard to assume that 150 linear feet are needed for every ton of the heat pump system. Given that Eau Claire requires a 280 ton system, this

²⁷ *Pros and Cons of Geothermal Energy for Property Owners in NH, MA, and ME (800) 343-1411*. Comac Pump and Well. Retrieved May 6, 2024, from <https://www.comacpumpandwell.com/geothermal-energy/pros-and-cons>

means 42,000 linear feet are required. This means that any combination of number of boreholes and borehole depth that results in 42,000 feet would service the heating and cooling needs of the jail/courthouse complex in Eau Claire County. We recommend drilling 70 boreholes at 600 feet deep, with a maximum diameter of 6 inches. These boreholes should be spaced 20 feet apart. If the 70 boreholes are arranged in a square array, this would result in a space required of 22,400 square feet. At the jail/courthouse complex in Eau Claire County parking lot A has 197 spaces with each space being 162 feet²⁸. This results in a space of more than 30,000 square feet which would be more than large enough to accommodate the heat exchange system. In addition, this lot is currently earmarked to be turned into a parking structure. It is worth exploring if the ground source heat pump and parking structure can be constructed at the same time, as the combination could decrease the overall construction costs for both projects. Given that this is dependent on parallel timelines of two different projects, another option should be available. The space available in parking lots E and F is more than enough to build the heat exchange system required for this project. In addition, both of these spaces could be converted back into parking lots after the construction of the heat exchange system, as has occurred in similar projects²⁹.

²⁸ Eau Claire Zoning Code Ch 18.25: OFF-STREET PARKING AND LOADING REQUIREMENTS.

<https://www.eauclairewi.gov/home/showpublisheddocument/44675/638422052438070000>.

²⁹ Thao, K., Bremer, A., & Schuenke, M. (2023). *Village of McFarland New Community Center Net Zero Energy Predesign Report*. <https://www.mcfarland.wi.us/DocumentCenter/View/2858/McFarland-Community-Center-Report-2023?bidId=>

Figure 4: Standard Capacity Ratings for Ground Source Heat Pumps

Standard Capacity Ratings for Open Loop (60Hz)											
Performance Rating Conditions	Model	Tons	Flow (GPM)	Outdoor dP (psi)	Heating Capacity (Btu/hr)	Input Energy (Watts)	COPh (Heating)	Cooling Capacity (Btu/hr)	Input Energy (Watts)	COPc (Cooling)	EER
Open Loop Heating EWT 104°F Cooling EWT 54°F	W-150	12	36	2.0	153,800	10,386	4.34	156,300	7,242	6.33	21.6
	W-185	15	48	2.3	207,300	13,871	4.38	188,800	8,711	6.36	21.7
	W-240	20	60	2.7	274,500	17,625	4.56	253,900	11,890	6.26	21.4
	W-300	23	72	2.7	316,900	19,360	4.80	297,700	13,330	6.54	22.3
	W-400	30	100	2.8	408,600	25,970	4.61	393,000	18,190	6.33	21.6
	W-500	40	120	4.0	569,800	36,465	4.58	493,500	23,005	6.28	21.4
	W-600	50	150	4.4	683,400	42,630	4.70	620,000	29,055	6.25	21.3
	W-800	65	190	4.6	850,600	54,885	4.54	796,400	37,335	6.25	21.3
	W-900	70	210	4.7	914,800	59,500	4.51	872,500	41,600	6.15	21.0
	W-1000	81	225	4.6	1,076,100	74,774	4.22	981,700	47,213	6.10	20.8
Standard Capacity Ratings for Closed Loop (60Hz)											
Closed Loop Heating EWT 104°F Cooling EWT 54°F 35% Propylene Glycol	W-150	12	36	2.7	115,100	10,067	3.35	140,700	9,085	4.55	15.5
	W-185	15	48	2.9	155,400	13,308	3.42	172,300	11,054	4.57	15.6
	W-240	20	60	3.3	197,900	16,790	3.45	224,600	14,635	4.50	15.4
	W-300	23	72	3.7	231,000	18,650	3.66	272,500	15,960	5.00	17.1
	W-400	30	100	3.5	291,700	24,915	3.43	365,300	22,070	4.85	16.6
	W-500	40	120	5.5	423,900	36,400	3.41	474,600	29,055	4.79	15.5
	W-600	50	150	5.9	478,900	41,150	3.41	578,000	36,415	4.65	15.9
	W-800	65	190	6.0	612,500	52,910	3.39	743,800	47,030	4.63	15.8
	W-900	70	210	6.2	683,500	57,600	3.48	802,000	52,300	4.50	15.3
	W-1000	81	225	5.9	808,900	72,771	3.26	900,300	58,812	4.49	15.3

Estimating the Cost of the Ground Source Heat Pump System

To estimate the cost of the Ground Source Heat Pump system, we first consulted with several distributors near Wisconsin. These estimates ranged from \$261,000 on the low end³⁰, to \$610,000 on the high end³¹. To get a more accurate estimate of the cost of the heat pump itself, we consulted with Mike Walters of Salas O'Brien who worked on the heat pump system at the Epic Systems campus in Verona, Wisconsin. Mike informed us that cost estimates for heat pump systems in Wisconsin are generally budgeted at \$2,000/ton. Therefore, given the size of the system that we recommend, 280 tons, we estimate the cost of the heat pump itself to be \$560,000. Due to differences in installation costs based on geographic location, we also consulted Mike on how much it would cost to install a ground source heat exchange system using vertical boreholes in Wisconsin, as he had previously worked

³⁰ W-Series Large Commercial (12-81 tons). *Rocky Ridge Geo - Geothermal Heat Pumps*. Retrieved May 6, 2024, from <https://rockyridgegeo.com/product/w-series-commercial/>

³¹ *W Series Commercial Water to water Geothermal Heat pump. 50T*. Hydro Solar. Retrieved May 6, 2024, from https://hydrosolar.ca/products/copy-of-water-to-water-geothermal-heat-pump-w-series-w600hp-dpp-r410a?variant=34799671574689&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_campaign=gs-2018-12-17&utm_source=google&utm_medium=smart_campaign&gad_source=1&gclid=Cj0KCOiA5rGuBhCnARIsAN11vgTgK4toqsYRtn181w-

on a similar project. Mike informed us that capital costs for the ground source heat exchange system are roughly \$25/linear foot and that each ton requires about 150 feet. Using this calculation, our installation costs for the vertical geothermal heat exchange system come out to \$1,050,000. Therefore, our overall cost estimate for the purchase and installation of the closed loop vertical geothermal heat pump is \$1,610,000. After incorporating the 30% Investment Tax Credit for which GSHP's are eligible, this number falls to \$1,127,000. This number does include some degree of uncertainty, as different construction companies and different heat pump distributors will charge different prices. In addition, the price of heat pumps themselves is changing quickly, so depending on when the system is installed, the overall cost will change.

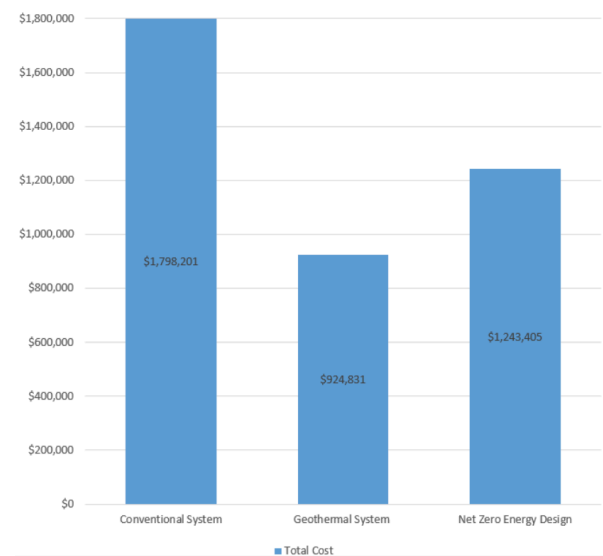
Similar Projects

McFarland Community Center

In the fall of 2023, the Village of McFarland, Wisconsin renovated its existing Municipal Center into a new Community Center and used a geothermal heat pump system and energy from solar photovoltaics to achieve net zero carbon emissions for this facility. The building is much smaller than the Eau Claire courthouse-jail facility at just 60,000 square feet and therefore has a much smaller energy demand, but the strategies that they used to construct this new facility are directly applicable to Eau Claire's case. Figure 5 shows McFarland's cost estimates for their facility, broken down by the cost of the geothermal heat pump, and the entire net-zero system which includes the installation of solar panels. These estimates are consistent with our estimates of the cost of converting Eau-Claire's courthouse-jail facility to a net-zero facility, they only differ in that the size of the geothermal system

required is smaller and the amount of solar energy needed is less. The report from McFarland's Community Center also explains that the village made use of the 30% Investment Tax Credit under the Inflation Reduction Act to decrease the capital costs of their project. Meanwhile, air source heat pumps do not qualify for this same tax credit, thus the incentive to install a GSHP over an ASHP is even greater³².

Figure 5: Cost Estimates for McFarland Community Center Project



Bedrock Energy

In Texas, a geothermal heat pump startup, Bedrock Energy, just completed a commercial heat pump installation for a 30,000 square foot mixed-use building complex on the Penn Field campus. Co-founder and CEO of Bedrock, Joselyn Lai explained that their mission is to “expand the addressable, serviceable market’ for geothermal heating and cooling so that even buildings in dense areas can harvest energy hiding below the surface”. The Penn Field campus project used a vertical

³² Thao, K., Bremer, A., & Schuenke, M. (2023). *Village of McFarland New Community Center Net Zero Energy Predesign Report*. <https://www.mcfarland.wi.us/DocumentCenter/View/2858/McFarland-Community-Center-Report-2023?bidId=>

closed-loop system, similar to the one that we propose for Eau Claire County, citing a lack of space as the reason for the vertical system as opposed to a horizontal one, and the energy efficiency as the reason for the closed-loop geothermal system as opposed to a different option such as an air-source heat pump. Lai also explains that Bedrock Energy is exploring strategies for becoming more affordable and efficient including drilling fewer, deeper boreholes, as they explore future projects in Texas ³³.

Proposed Scenarios

The state of Wisconsin has set the same goal as Eau Claire County - to reach net-zero carbon emissions by 2050.³⁴ If it reaches that goal, Eau Claire will not need any on-site electricity generation capacity to reach net-zero on its own. As long as its heating system is electrified, it should be able to draw on a net-zero grid for all of its power needs, thereby reaching net-zero emissions. However, there is no guarantee that Wisconsin will reach that goal, so we have explored multiple grid decarbonization scenarios to provide a broader picture of possible outcomes. Each scenario explores the grid mix in 2050 based on four different decarbonization rates. The four rates, and the related scenarios are: Full decarbonization by 2050, full decarbonization by 2075, full decarbonization by 2100, and no further decarbonization. This provides a range of outcomes from most to least-optimistic, allowing Eau Claire County to see the full picture. In all of these scenarios, Eau Claire will need to convert from a gas-powered heating system to electric-powered ground-source heat-pumps, so we were able to hold the GSHP part of our analysis steady.

³³ Gallucci, M. (2024, April 29). *Geothermal heat pumps are helping clean up city buildings*. Canary Media.

<https://www.canarymedia.com/articles/geothermal/geothermal-heat-pumps-are-helping-clean-up-city-buildings>

³⁴ Wisconsin Office of Sustainability & Clean Energy Clean Energy Plan. <https://osce.wi.gov/pages/cleanenergyplan.aspx>.

For each scenario, we calculated the percentage of total electricity generation provided by renewable and fossil-fuel sources using the EPA's eGRID dataset. Using these percentages, and data provided on the overall electricity demand by the courthouse/jail complex, we were able to calculate the total amount of renewable energy the complex's rooftop and parking lot solar systems would have to generate in order to reach net-zero in each scenario. Then, utilizing NREL's System Advisor Model (SAM), we ran simulations to calculate the system's size, capital costs, net present value, electricity savings in year one, and other key outcome data points. Those data points are outlined in the table below, and further details on the simulations' inputs can be found in Appendix A.

Proposed Alternatives

To make the analysis more accurate, various grid decarbonization rates have been incorporated to break down multiple potential scenarios encompassing the potential range of outcomes. Each scenario's analysis also incorporates a range of coefficients of performance for the ground-source heat pump:

Scenario 1: Business As Usual - No decarbonization past this point.

Scenario 2: 100% Grid Decarbonization by 2100

Scenario 3: 100 Grid Decarbonization by 2075

Scenario 4: 100% Grid Decarbonization by 2050. This is the State of Wisconsin's goal, and would mean that Eau Claire County could reach its goal of net-zero by 2050 without installing any solar (as the grid would already be net-zero). To add further context, we found optimistic and pessimistic

decarbonization rates based on recent historical grid mix data in Wisconsin, and have included those in the graphs below our simulation tables.

Coefficient of Performance Range for GSHP: 3 - 4.5 - 6

Electricity Demand Note: Eau Claire County is currently installing a rooftop solar array with a 73 kW nameplate capacity. We have subtracted the generation capacity of this array from Eau Claire County's electricity demand in each scenario.

Figure 6: Power and capital cost requirement to achieve each of the four scenarios

Table 1a) Scenario 1

	No New Decarb COP 6	No New Decarb COP 4.5	No New Decarb COP3
KW Needed	295.6112664	316.3925088	357.9549937
Capacity Needed to deliver this (based on 17.3 CF of FirstSolar Module used in SAM)	1708.74	1828.86	2069.10
M^2	9344.16	10009.44	11324.88
SqFt	100579.60	107740.61	121899.88
% of Available Roof Area Occupied	189.47%	202.96%	229.64%
% of Available Roof and Parking Lot Area Occupied	111.73%	119.69%	135.41%
Parking Stalls Required	293	337	425
Total Capital Cost (Solar+GSHP)	\$4,345,879.00	\$4,575,055.00	\$5,028,198.00

Table 1b) Scenario 2

	2100 Decarb COP 6	2100 Decarb COP 4.5	2100 Decarb COP3
KW Needed	190.826874	204.5436602	231.9772327

Capacity Needed to deliver this (based on 17.3 CF of FirstSolar Module used in SAM)	1103.05	1182.33	1340.91
M^2	6032.88	6471.36	7333.20
SqFt	64937.32	73888.58	83328.09
% of Available Roof Area Occupied	122.33%	139.19%	156.97%
% of Available Roof and Parking Lot Area Occupied	72.14%	82.08%	92.57%
Parking Stalls Required	73	128	187
Total Capital Cost (Solar+GSHP)	\$3,205,208.00	\$3,356,256.00	\$3,653,143.00

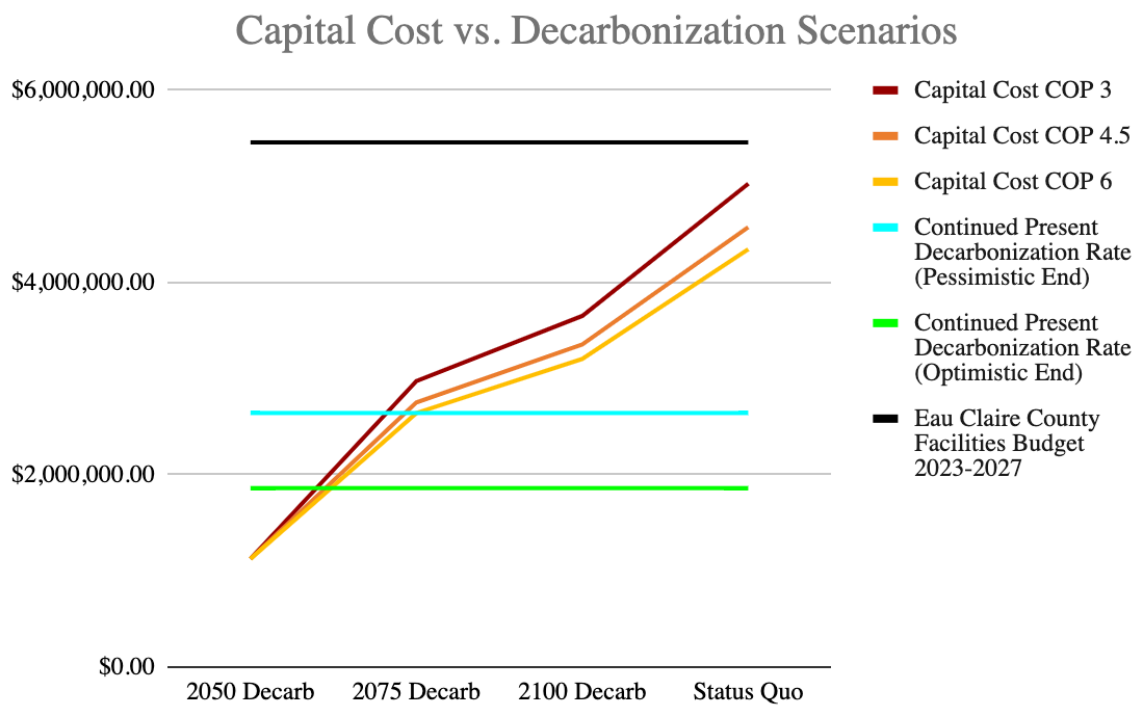
Table 1c) Scenario 3

	2075 Decarb COP 6	2075 Decarb COP4.5	2075 Decarb COP 3
KW Needed	139.1243429	149.3553976	169.8175069
Capacity Needed to deliver this (based on 17.3 CF of FirstSolar Module used in SAM)	804.19	863.33	981.60
M^2	4399.92	4717.44	5367.60
SqFt	47360.30	55172.31	62170.56
% of Available Roof Area Occupied	89.22%	103.93%	117.12%
% of Available Roof and Parking Lot Area Occupied	52.61%	61.29%	69.06%
Parking Stalls Required	0	13	56

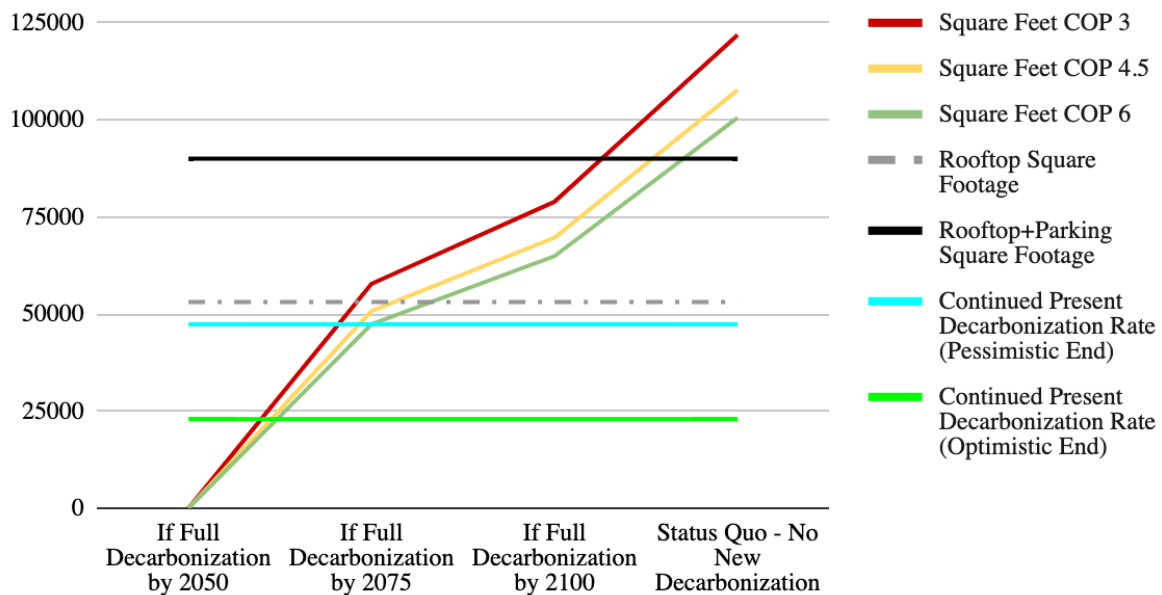
Total Capital Cost (Solar+GSHP)	\$2,642,686.00	\$2,752,065.00	\$2,976,032.00
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Figure 7: Square Footage and capital cost requirement to achieve each of the four scenarios

(Heating)



Solar PV Square Footage Requirements vs. Decarbonization Scenarios



Scenario Analyses

Scenario 1 Analysis

Scenario 1 can be considered the “worst-case scenario” for this analysis. In this scenario, we assume that Wisconsin’s grid mix is the same in 2050 as it is now. With the fossil fuel share of the grid mix remaining at 46%, there is simply not enough space available between the courthouse/jail complex’s roof and parking lots for the capacity need to reach net-zero. Even if the ground-source heat pump’s coefficient of performance is on the high end - at 6, for example - the complex would need more than 10,000 additional square feet than it has in order to meet the requisite capacity. This would involve a minimum of 320 parking spaces - 92 more than are available - along with full utilization of

available rooftop space. In this scenario, then, net-zero is not possible without adding off-site generation, further reducing energy consumption, buying carbon credits, or a combination of the three. One option could be to continue the current practice of purchasing renewable energy from Xcel. Maintaining the present level of 165 kW of generation capacity could, in tandem with rooftop and parking lot solar, make net-zero a possibility even at the current grid mix.

On the other hand, our analysis found that - due to compensation from net metering, along with energy savings - adding additional capacity to the solar array leads to an increase in the system's net present value. While it requires a higher upfront capital investment, the overall value of the system increases over its lifetime.

Assuming the county wants to minimize the amount of off-site generation, energy consumption reduction, and carbon credit purchases needed, this scenario would involve installing the maximum amount of solar that the roof and parking lots could hold. This would cost 2,864,698, and result in 263 kW of capacity. Added to this cost would be the capital and installation costs of the GSHP, which would cost \$1,127,000. In total, we estimate a total cost of approximately 3,991,698.

Scenario 2 Analysis

Scenario 2 assumes Wisconsin's grid decarbonizes at a constant rate that would result in full decarbonization by 2100. This is far slower than Wisconsin's goal, but can be considered a more reasonable pessimistic scenario than Scenario 1. A complete pause in decarbonization is highly unlikely at this point, leading us to explore this scenario as well. In this scenario, more capacity (191kW-232W) is needed than the roof can provide alone. However, regardless of the coefficient of performance of the

installed GSHP, adding parking lot solar as a supplementary option will provide enough square footage to accommodate the required capacity of solar panels. In the lowest COP scenario, 88% of combined rooftop and parking lot capacity is required, while in the highest COP scenario, only 72% of combined capacity is required. Assuming rooftop space is exhausted before any parking lot solar is installed, this scenario would require between 73 and 160 parking spaces to be utilized. This is fewer than the 228 available spaces. Ultimately, our analysis demonstrates that using parking lot solar in conjunction with rooftop solar provides adequate capacity for Eau Claire County to reach net-zero in its courthouse/jail complex using exclusively on-site solar generation and a ground-source heat pump. Scenario 3, our more optimistic scenario, further drives this home.

Scenario 3 Analysis

Scenario 3 takes a look at a more optimistic scenario where Wisconsin fails to reach net-zero by 2050, but has a path to net-zero by 2075. This scenario is the closest to our projections of Wisconsin's grid mix in 2050 while still requiring slightly more capacity than that estimate, providing a breakdown of what Eau Claire County could reasonably need to do to be beyond sure it will reach net-zero by 2050. In this scenario, between 89% and 109% of available rooftop square footage is required to reach the necessary capacity, while only 53% to 64% of available combined rooftop and parking lot square footage is required. This is very achievable, with rooftop installations encompassing the majority of installed capacity, and parking lot solar installations filling in any additional capacity gaps. Assuming rooftop space is exhausted before any parking lot solar is installed, the range of parking spaces needed for in this scenario is 0-29 - far below the 228 available.

Scenario 4 Analysis

Scenario 4 is the “best-case scenario” for the county. In this scenario, Wisconsin’s grid fully decarbonizes by 2050, which means that as long as the courthouse/jail complex’s heating system is electrified, no on-site renewable generation is needed to reach net-zero. Therefore, the overall cost for rooftop and parking lot solar generation would be 0. The only cost for the county would be installation of the ground-source heat pump, which is \$1,127,000. This is the lowest-cost scenario, and requires the least amount of effort to reach net-zero.

Alternative Breakdowns

Regardless of the path forward, a ground-source heat pump will need to be installed for net-zero to be achievable. However, there are multiple paths forward in terms of solar installations. The most aggressive approach would be to install both the GSHP and as much solar as possible, filling the usable rooftop and parking lot space as soon as possible. This would maximize the net present value of the solar installation, result in the highest savings on electricity bills, and allow the county to reach net-zero as quickly as possible. However, it is by far the most expensive option upfront and could result in the county installing far more solar than is needed to reach net-zero. Additionally, parking lot solar installations could be more disruptive to county employees and visitors.

The second option is to utilize all available rooftop space for solar, but not install any parking lot solar. This will allow the county to reach net-zero under the most reasonable and optimistic scenarios, doing so as quickly as is financially prudent, while minimizing the potential disruption caused by parking lot solar installation and lowering upfront costs compared to the first option.

The final option is the most conservative, and involves tracking decarbonization trends and installing just enough rooftop solar to reach net-zero by 2050 once it becomes more clear how much will be needed. This will minimize upfront costs, but will also result in the lowest energy cost savings over the long term. It would also be the slowest of the three options in terms of reaching net-zero.

Goals-alternatives matrix

	Reach Net-Zero Quickly	Reach Net-Zero Cheaply with minimal construction	Maximize Energy Savings
Fill Rooftop & Parking Lot Capacity with Solar	High	Low	High
Fill rooftop with enough solar to reach net-zero based on our estimate	Medium	Medium	Medium
Continue tracking decarbonization trends, installing only enough to reach net-zero right before 2050	Low	High	Low

Recommendation

Based on the above analysis, we recommend Eau Claire install a ground-source heat pump as soon as is prudent. Even without any change to the grid mix, a heat pump will result in significant energy savings, and pave the way towards net-zero regardless of the decision made on solar installations. Our recommendation on the solar array side of things is more complicated, however.

Based on historical data, and assuming a consistent rate of decarbonization, we estimate that Wisconsin's grid mix will be between 12% to 19% fossil fuels in 2050.³⁵ Given this, Eau Claire County would need to offset 12%-19% of its electricity usage with renewable energy generated on-site in order to reach net-zero. This is equivalent to 67-140 kW of capacity, depending on the coefficient of performance of the heat pump selected. In turn, this would require between approximately 23,000 and 47,500 square feet for a solar array, taking into account the 17.3% capacity factor of the panel we used in our simulations and the level of insolation Eau Claire receives. With 53,000 square feet available on the Eau Claire County complex's rooftop, we recommend Eau Claire County install solar panels on the entirety of its available rooftop space, at a pace that makes the most sense financially. This may involve waiting for interest rates to drop, or installing panels as soon as possible to maximize energy cost savings. It could also involve installing panels in phases, with a "wait-and-see" approach that improves the accuracy of decarbonization rate predictions, allowing the county to install only the panels it needs to reach net-zero. If Wisconsin accelerates its decarbonization, that could reduce costs significantly, and if it fails to continue its current decarbonization rate, the county could fully utilize its rooftop space and add additional panels in its available parking lots. With 90,020 square feet available

³⁵ Historical eGRID Data | US EPA. <https://www.epa.gov/egrid/historical-egrid-data>.

for solar panels between the rooftop and parking spaces, Eau Claire has a significant amount of space available beyond that which we project will be needed.

Further Questions/Research

Given the rapid improvements in clean technologies, uncertainty regarding future incentives, and climate change, various technologies that were not included in our analysis as options could become relevant for a future iteration of this analysis. For example, wastewater-source heat pumps - using wastewater from the complex itself - are still too expensive and new to recommend. However, given the large amount of water needed for the complex, they could become a cheaper alternative to a GSHP once the technology has matured further. Air-source heat pumps, an option we explicitly stated would not work in Eau Claire's climate due to their decreased performance in extremely cold weather, could become a viable option if climate change continues, raising the lowest temperatures Eau Claire experiences each year.³⁶

Additionally, technologies that were recommended could be improved further, reducing overall electricity needs and - by extension - reducing the total square footage needed for the solar array we recommended. For example, GSHPs could increase their COP in the future, leading to lower electricity needs for the same amount of heating and cooling. Another possibility is the increase of solar panels' efficiency or capacity factor, increasing the amount of electricity a panel can produce per square foot in an array. Both of these would lower the size of the solar array required to reach net-zero emissions.

³⁶ Fitzpatrick, M. C. & Dunn, R. R. Contemporary climatic analogs for 540 North American urban areas in the late 21st century. *Nat Commun* 10, 614 (2019).

Furthermore, GSHPs and solar PV could both see further decreases in hardware and installation costs. Decreasing these costs would not affect the size of either needed to meet Eau Claire's needs, but it would increase the net benefits of reaching net-zero.

Lastly, it remains to be seen how quickly the grid will decarbonize. Ideally, our estimate will prove to be a conservative one, and Eau Claire will either be able to reach net-zero with even fewer capital expenditures or will be able to go beyond net-zero, returning excess generation to the grid to further lower its energy bills and help other consumers get closer to net-zero.

Conclusion

Considering the various scenarios analyzed in this report, our recommendation for Eau Claire County is to prioritize the installation of a ground-source heat pump (GSHP) for electrical heating. While ASHPs were ruled out due to low winter temperatures, the viability of alternative options like ASHPs or water-source heat pumps should be periodically reassessed, especially given potential future temperature changes due to climate variability.

In terms of solar installations, the report outlines several scenarios based on Wisconsin's grid decarbonization rates. While the "worst-case scenario" (Scenario 1) suggests challenges in achieving net-zero solely through on-site solar generation, reasonable and optimistic scenarios show that it could be feasible. It's recommended that the county utilize available rooftop space for solar installations to minimize upfront costs and disruptions while ensuring progress toward net-zero emissions.

In conclusion, there is great emphasis on the importance of flexibility and continued monitoring of technological advancements, grid decarbonization trends, and climate change impacts. By staying informed and adapting strategies accordingly, Eau Claire County can optimize its efforts to reach net-zero emissions while maximizing energy savings and minimizing environmental impact.

Appendix A: Solar Simulation Methodology

To calculate square footage requirements, net present value, and capital cost of solar arrays in each scenario, we utilized the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM), a renewable energy system simulator. In each scenario, we found the capacity required to generate the average electricity load required by the jail/courthouse complex, taking into account the capacity factor of the selected module and other system losses.

The specifications we utilized in our simulations are as noted below. If a specific variable is not noted below, we have left it at its default setting as recommended in SAM.

- **Location & Weather File:** 721 Oxford Ave, Eau Claire, WI 54703
- **Module:** First Solar Inc, FS-6460-P-I³⁷
 - **Capacity Factor:** 17.3
- **Inverter:** CSI Solar Co Ltd, CSI-255K-T800GL02-U [800V]
- **Desired A/C to DC Ratio:** ~1.1³⁸
- **Discount Rate:** 3.5%
- **Inflation Rate:** 3%³⁹

³⁷ We chose an American-manufactured solar module for this installation

³⁸ BSE 367 note from Prof. Troy Runge: "A typical inverter is sized to provide around a 1.2 DC/AC ratio...However, if you had a choice of either going higher or lower on this ratio, it is likely better to be a bit lower"

https://canvas.wisc.edu/courses/346320/pages/solar-pv-systems?module_item_id=5618861

³⁹ CPI Home : U.S. Bureau of Labor Statistics. Bureau of Labor Statistics

- **Debt %:** 100%
- **Loan Term:** 25 years
- **Loan Interest Rate:** 3.5%
- **Analysis Period:** 25 years
- **Investment Tax Credit:** 30%
- ⁴⁰**Net Metering Compensation:** 0.0299\$/kWh⁴¹
- **Electric Load:** Peak and Average Load taken from Portfolio Manager
- **Additional Notes:**
 - Our analysis takes into account the 73 kW solar PV array currently being installed on the roof, removing that capacity need from the total capacity required to reach net-zero
 - Our analysis does not include the 165 kW of solar energy capacity being currently being purchased from Xcel. Our discussions indicated that ongoing expenses were undesirable, and we therefore crafted our analysis to minimize these.

<https://www.bls.gov/cpi/>. (Inflation currently sits at 3.5%, but, per the below citation, the Fed's goal is 2% inflation. We chose 3% to split the difference, erring on the side of current inflation but assuming it lowers somewhat)

What Would Happen If the Fed Raised Its Inflation Target? | Chicago Booth Review.
<https://www.chicagobooth.edu/review/what-would-happen-if-fed-raised-its-inflation-target>.

⁴⁰ Lyle, J. The Inflation Reduction Act – What public entities need to know. PublicCEO

<https://www.publicceo.com/2024/02/the-inflation-reduction-act-what-public-entities-need-to-know/> (2024).

⁴¹Xcel Energy - WI_Solar_Net_Metering_Info_Sheet.

[\">https://www.xcelenergy.com/staticfiles/xe-responsive/Working%20With%20Us/Renewable%20Developers/WI_Solar_Net_Metering_Info_Sheet_vFinal.pdf\](https://www.xcelenergy.com/staticfiles/xe-responsive/Working%20With%20Us/Renewable%20Developers/WI_Solar_Net_Metering_Info_Sheet_vFinal.pdf)

Appendix B: Heat Pump Cost Calculation Methodology

$$T_c = I_c + S_c - \text{Tax Credit}$$

$$I_c = HE_c \times L_T \times T$$

$$I_c = \$25.00 \times 150 \text{ ft} \times 280 \text{ tons}$$

$$I_c = \$1,050,000$$

$$S_c = \$2,000/\text{ton} \times T$$

$$S_c = \$2,000/\text{ton} \times 280 \text{ tons}$$

$$S_c = \$560,000$$

$$\text{Tax Credit} = (I_c + S_c) \times 0.30$$

$$\text{Tax Credit} = \$483,000$$

$$T_c = \$1,050,000 + \$560,000 - \$483,000$$

$$T_c = \$1,127,000$$

$$T_c = \text{Total cost of heat pump}$$

$$I_c = \text{Cost of installation of geothermal system}$$

$$S_c = \text{Cost of heat pump system itself}$$

$$HE_c = \text{Capital cost of heat exchanger} = \$25.00/\text{linear foot}$$

$$L_T = \text{Length of heat exchanger per ton} = 150 \text{ feet/ ton}$$

$$T = \text{tons in heat pump system}$$

Appendix C: Discussion of State & Federal Incentives

Both solar PV installations and ground-source heat pumps are eligible for up to an Investment Tax Credit worth up to 30% of the total cost of the system. We have incorporated these incentives into our analysis of each system's cost. These incentives stem from the Inflation Reduction Act, with provisions lasting until at least 2032. Other than these incentives, however, we were conservative in our assumptions and did not include any incentives in order to provide a realistic or slightly pessimistic, rather than overly optimistic, view of potential costs. It is our view that it is better to be pleasantly surprised by lower costs, than to experience unexpected overruns. Furthermore, our analysis is only a snapshot in time, and we recommend that Eau Claire County do its due diligence on all potentially available incentives and relevant costs before proceeding with these installations.

Appendix D: Solar Capacity Requirement Calculations

Calculated Average Yearly Consumption		
Average Electricity Consumption		Average Gas Consumption
Sum the above two averages		
Converted that sum to the average generation capacity needed for total consumption		
Calculated generation capacity needed for remaining % of total consumption otherwise coming from fossil fuels in each scenario		
Divided by Capacity Factor of chosen solar panel to find total nameplate capacity needed to average the needed generation		
Subtracted 73 kW nameplate array already being installed		

Appendix E:

Grid Mix Projections Calculations:

2100 Decarb:

$$EmissionsNew\% = -.006096 * (\Delta year) + .4633$$

2075 Decarb:

$$EmissionsNew\% = -.0090849 * (\Delta year) + .4633$$

2050 Decarb:

$$EmissionsNew\% = -.0178192307692 * (\Delta year) + .4633$$

Projected Mix Step 1:

	Coal	Oil	Gas	Other Fossil	Total Fossil % of Grid Mix	Change in Grid Mix YoY	Average Change Since 2008	Average Change Past 10 Years	Average Change past 5 Years
2002					0				
2003					0				
2004					0				
2005					0				
2006					0.00%				
2007	70.99%	0.50%	4.96%	0.23%	76.68%				
2008	70.04%	0.33%	3.68%	0.19%	74.24%	-3%			
2009	69.09%	0.15%	2.40%	0.16%	71.80%	-3%			
2010	65.26%	0.15%	3.16%	0.13%	68.70%	-4%			
2011	63.05%	0.14%	4.08%	0.14%	67.40%	-2%			
2012	60.83%	0.13%	5.00%	0.14%	66.11%	-2%			
2013	59.62%	0.11%	4.10%	0.17%	66.11%	0%			
2014	58.40%	0.10%	3.20%	0.20%	61.90%	-6%			
2015	55.55%	0.15%	4.95%	0.10%	60.75%	-2%			
2016	52.70%	0.20%	6.70%	0.00%	59.60%	-2%			
2017	52.25%	0.15%	7.35%	0.00%	59.75%	0%			
2018	51.80%	0.10%	8.00%	0.00%	59.90%	0%			
2019	43.90%	0.10%	11.20%	0.00%	55.20%	-8%			
2020	38.20%	0.10%	10.90%	0.00%	49.20%	-11%			

2021	39.60%	0.20%	10.60%	0.10%	50.50%	3%			
2022	38.00%	0.10%	8.30%	0.10%	46.50%	-8%	-3%	-4%	-5%

Note: Yellow-highlighted years were years with unavailable historical data. We have averaged the year before and year after to create estimates

Based on the above data, we found that historical data indicates an annual rate of decarbonization between 3% and 5%. Taking 3% per year as the pessimistic scenario and 5% as the optimistic scenario, we found each the estimated grid mix for both scenarios. Using an annual percentage change allowed us to take into account that low-hanging fruit will likely be addressed first, with rates slowing down as we approach 0% fossil fuel in the grid mix.

Projected Mix Step 2a: Optimistic Scenario (5% Decarbonization Rate per Year)

	Coal	Oil	Gas	Other Fossil	Total Fossil % of Grid Mix
2023	36%	0%	8%	0%	44%
2024	34%	0%	8%	0%	42%
2025	33%	0%	7%	0%	40%
2026	31%	0%	7%	0%	38%
2027	30%	0%	7%	0%	36%
2028	28%	0%	6%	0%	35%
2029	27%	0%	6%	0%	33%
2030	26%	0%	6%	0%	32%
2031	25%	0%	5%	0%	30%
2032	23%	0%	5%	0%	29%
2033	22%	0%	5%	0%	27%
2034	21%	0%	5%	0%	26%
2035	20%	0%	4%	0%	25%
2036	19%	0%	4%	0%	24%
2037	18%	0%	4%	0%	22%
2038	17%	0%	4%	0%	21%

2039	17%	0%	4%	0%	20%
2040	16%	0%	3%	0%	19%
2041	15%	0%	3%	0%	18%
2042	14%	0%	3%	0%	18%
2043	14%	0%	3%	0%	17%
2044	13%	0%	3%	0%	16%
2045	12%	0%	3%	0%	15%
2046	12%	0%	3%	0%	14%
2047	11%	0%	2%	0%	14%
2048	11%	0%	2%	0%	13%
2049	10%	0%	2%	0%	13%
2050	10%	0%	2%	0%	12%

Projected Mix Step 2b: Pessimistic Scenario (3% Decarbonization Rate per Year)

	Coal	Oil	Gas	Other Fossil	Total Fossil % of Grid Mix
2023	37%	0%	8%	0%	45%
2024	36%	0%	8%	0%	44%
2025	34%	0%	8%	0%	42%
2026	33%	0%	7%	0%	41%
2027	32%	0%	7%	0%	39%
2028	31%	0%	7%	0%	38%
2029	30%	0%	7%	0%	37%
2030	29%	0%	6%	0%	36%
2031	28%	0%	6%	0%	35%
2032	27%	0%	6%	0%	34%
2033	27%	0%	6%	0%	32%
2034	26%	0%	6%	0%	31%
2035	25%	0%	5%	0%	30%
2036	24%	0%	5%	0%	29%
2037	23%	0%	5%	0%	28%
2038	23%	0%	5%	0%	28%
2039	22%	0%	5%	0%	27%
2040	21%	0%	5%	0%	26%
2041	20%	0%	4%	0%	25%
2042	20%	0%	4%	0%	24%
2043	19%	0%	4%	0%	23%
2044	19%	0%	4%	0%	23%

2045	18%	0%	4%	0%	22%
2046	17%	0%	4%	0%	21%
2047	17%	0%	4%	0%	21%
2048	16%	0%	4%	0%	20%
2049	16%	0%	3%	0%	19%
2050	15%	0%	3%	0%	19%

References

- “CPI Home : U.S. Bureau of Labor Statistics.” n.d. Bureau of Labor Statistics. Accessed April 24, 2024. <https://www.bls.gov/cpi/>.
- “Eau Claire Zoning Code Ch 18.25: OFF-STREET PARKING AND LOADING REQUIREMENTS.” n.d. Accessed April 24, 2024. <https://www.eauclairewi.gov/home/showpublisheddocument/44675/638422052438070000>.
- Effects of Climate Change—NASA Science*. (n.d.). Nasa. Retrieved May 7, 2024, from <https://science.nasa.gov/climate-change/effects/>
- Esen, H., Inalli, M., & Esen, M. (2007). A techno-economic comparison of ground-coupled and air-coupled heat pump system for space cooling. *Building and Environment*, 42(5), 1955–1965. <https://doi.org/10.1016/j.buildenv.2006.04.007>
- Fitzpatrick, Matthew C., and Robert R. Dunn. 2019. “Contemporary Climatic Analogs for 540 North American Urban Areas in the Late 21st Century.” *Nature Communications* 10 (1): 614. <https://doi.org/10.1038/s41467-019-08540-3>.
- Gallucci, M. (2024, April 29). *Geothermal heat pumps are helping clean up city buildings*. Canary Media. <https://www.canarymedia.com/articles/geothermal/geothermal-heat-pumps-are-helping-clean-up-city-buildings>
- “Inflation Reduction Act Extends and Modifies Tax Credits for Solar Projects.” n.d.-a. McGuire Woods. Accessed May 7, 2024.

<https://www.mcguirewoods.com/client-resources/alerts/2023/2/inflation-reduction-act-extends-and-modifies-tax-credits-for-solar-projects/>.

Kwon, Y., Bae, S., Chae, H., & Nam, Y. (2023). Economic and performance analysis of ground source heat pump system for high-rise residential buildings considering practical applications. *Energy Reports*, 10, 4359–4373. <https://doi.org/10.1016/j.egyr.2023.10.086>

Larsen, Peter H. 2016. “A Method to Estimate the Costs and Benefits of Undergrounding Electricity Transmission and Distribution Lines.” *Energy Economics* 60 (November): 47–61. <https://doi.org/10.1016/j.eneco.2016.09.011>.

“Lazard’s LCOE 2023.” n.d. Accessed April 24, 2024.

<https://www.lazard.com/media/typdgxmm/lazards-lcoeplus-april-2023.pdf>.

“Lazard’s Levelized Cost of Storage Version 7.0.” n.d. Accessed April 24, 2024.

<https://www.lazard.com/media/42dnsswd/lazards-levelized-cost-of-storage-version-70-vf.pdf>.

Li, H. X., Okolo, D. E., Tabadkani, A., Arnel, T., Zheng, D., & Shi, L. (2023). An integrated framework of ground source heat pump utilisation for high-performance buildings. *Scientific Reports*, 13(1), 371. <https://doi.org/10.1038/s41598-023-27704-2>

Lyle, Jacob. 2024. “The Inflation Reduction Act – What Public Entities Need to Know.” PublicCEO. February 7, 2024. <https://www.publicceo.com/2024/02/the-inflation-reduction-act-what-public-entities-need-to-know/>.

“Mapping The Biomass Industry | Environmental Paper Network.” n.d. Accessed April 24, 2024. <https://environmentalpaper.org/biomass/mapping-bioenergy/>.

“NSP - NORTHERN STATES POWER COMPANY WISCONSIN -WISCONSIN ELECTRIC RATE BOOK.” n.d. Accessed April 24, 2024.

[https://www.xcelenergy.com/staticfiles/xcel-responsive/Archive/2We Section 2New.pdf](https://www.xcelenergy.com/staticfiles/xcel-responsive/Archive/2We%20Section%20New.pdf).

Oct 20, 2007. n.d. “Chapter 13: Power Purchase Agreement.” Windustry. Accessed April 24, 2024.

https://www.windustry.org/community_wind_toolbox_13_power_purchase_agreement.

Pros and Cons of Geothermal Energy for Property Owners in NH, MA, and ME (800) 343-1411. (n.d.).

Comac Pump and Well. Retrieved May 6, 2024, from

<https://www.comacpumpandwell.com/geothermal-energy/pros-and-cons>

“Renewable Power Generation Costs in 2022.” 2023. August 29, 2023.

<https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022>.

Safa, A. A., Fung, A. S., & Kumar, R. (2015). Comparative thermal performances of a ground source heat pump and a variable capacity air source heat pump systems for sustainable houses. *Applied Thermal Engineering*, 81, 279–287. <https://doi.org/10.1016/j.applthermaleng.2015.02.039>

Schaefer, M. (2020, February 20). Eau Claire’s 4th coldest low of the winter this morning was just the 14th time below zero. WQOW.

https://www.wqow.com/weather/eau-claire-s-4th-coldest-low-of-the-winter-this-morning-was-just-the-14th/article_b4837b5b-3ea4-5db1-a7e1-17d9720d16fa.html

Sim, M., & Suh, D. (2021). A heuristic solution and multi-objective optimization model for life-cycle cost analysis of solar PV/GSHP system: A case study of campus residential building in Korea.

Sustainable Energy Technologies and Assessments, 47, 101490.

<https://doi.org/10.1016/j.seta.2021.101490>

Thao, K., Bremer, A., & Schuenke, M. (2023). *Village of McFarland New Community Center Net Zero Energy Predesign Report*.

<https://www.mcfarland.wi.us/DocumentCenter/View/2858/McFarland-Community-Center-Report-2023?bidId=>

W Series Commercial Water to water Geothermal Heat pump. 50T. (n.d.). Hydro Solar. Retrieved May 6, 2024, from

https://hydrosolar.ca/products/copy-of-water-to-water-geothermal-heat-pump-w-series-w600hp-dpp-r410a?variant=34799671574689&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_campaign=gs-2018-12-17&utm_source=google&utm_medium=smart_campaign&gad_source=1&gclid=Cj0KCQIA5rGuBhCnARIsAN11vgTgK4toqsYRtn181w-Y3Ppy3Oxr5IhvtxZ1XBeRzhLmEukY5PjIM5AaAhdkEALw_wcB

W-Series Large Commercial (12-81 tons). (n.d.). *Rocky Ridge Geo - Geothermal Heat Pumps*. Retrieved May 6, 2024, from <https://rockyridgegeo.com/product/w-series-commercial/>

“What Is Net Zero? The Carbon Emissions Challenge | McKinsey.” n.d. Accessed April 24, 2024.

<https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-net-zero>.

“What Would Happen If the Fed Raised Its Inflation Target? | Chicago Booth Review.” n.d. Accessed April 24, 2024.

<https://www.chicagobooth.edu/review/what-would-happen-if-fed-raised-its-inflation-target>

“WINDEXchange: Wisconsin 30-Meter Residential-Scale Wind Resource Map.” n.d. Accessed April 24, 2024. <https://windexchange.energy.gov/maps-data/247>.

“Wisconsin Office of Sustainability & Clean Energy Clean Energy Plan.” n.d. Accessed April 24, 2024.

<https://osce.wi.gov/pages/cleanenergyplan.aspx>.

“Xcel Energy - WI_Solar_Net_Metering_Info_Sheet.” n.d. Accessed April 24, 2024.

https://www.xcelenergy.com/staticfiles/xcel-responsive/Working%20With%20Us/Renewable%20Developers/WI_Solar_Net_Metering_Info_Sheet_vFinal.pdf.