Technical Appendix
Middle Village Microgrid Project

The proposed project aligns with the priority greenhouse gas reduction measures outlined in the Priority Climate Action Plan submitted to the Environmental Protection Agency in February 2024 by the Midwest Tribal Energy Resource Association (MTERA) on behalf of all 35 tribes in EPA Region 5. This PCAP was developed in partnership with the eight participating Tribes listed below, under the guidance of MTERA board members representing 26 member Tribes, including the Menominee Indian Tribe of Wisconsin.

- Bad River Band of Lake Superior Chippewa (Wisconsin)
- Fond du Lac Band of Lake Superior Chippewa (Minnesota)
- Grand Portage Band of Lake Superior Chippewa (Minnesota)
- Ho-Chunk Nation (Wisconsin)
- Lac Courte Oreilles Band of Lake Superior Chippewa Indians (Wisconsin)
- Leech Lake Band of Ojibwe (Minnesota)
- Minnesota Chippewa Tribe
- Oneida Nation of Wisconsin

These eight Tribes, comprising nearly a quarter of all Midwest Tribes, exhibit a mix of characteristics including size, location, economic resources, energy resources, and population density, and are intended to be an indicative sample of all Midwest Tribes that permits the findings in the PCAP to be extrapolated to all 35 Tribes in the MTERA ecosystem. While the quantitative findings from the in-depth analysis of the eight Tribes' data cannot be considered directly representative of all Midwest Tribes due to Tribal-specific limitations, including varying building stock and unique eGRID emissions factors that vary throughout EPA Region 5, the qualitative analysis provided in the PCAP paired with an understanding of the Menominee Nation's specific circumstances provides a meaningful synopsis.

GHG Reduction Estimate Methods

The MTERA PCAP derives average carbon dioxide per kilowatt hour rates by geographic region from the EPA's 2020 eGRID database. eGRID data reflect direct emissions of carbon dioxide, methane, and nitrous oxide, though direct methane and nitrous oxide emissions, weighted by global warming potential. The rates quoted in the PCAP cover the eGRID regions MROW, MROE, and RFCW, and range from 1,003 to 1,592 pounds CO_2e per megawatt-hour. The weighted average of geographic regions where tribal projects were studied was 1,213 pounds CO_2e per megawatt-hour.

The eGRID database has been updated to 2022. The Menominee Indian Tribe of Wisconsin is located in the MROE region, which has an average emissions rate in the 2022 eGRID database of 1,480 pounds CO_2e per megawatt-hour in 2022, versus 1,513 pounds CO_2e per megawatt-hour in the 2020 database.

For the purposes of the CPRG grant program, which requires describing reductions caused by the project through 2050, a somewhat more complex analysis is necessary. To estimate greenhouse gas emissions avoided by the project, it is necessary to visualize the future effects of the project, which reduces emissions primarily by causing fossil fuel generators in other parts of the Midwest to reduce their output.[1] eGRID average emission rates are a mixture of fossil and non-fossil generation. Since the marginal cost of generating renewable electricity is close to zero, operators will preferentially reduce output from fossil plants first.

The EPA distributes the AVERT model, which estimates emissions reductions as if a project had been in operation in 2022. For this project, we used AVERT to examine reductions from its Central Region (comprising much of the Midwest). The model processes site-specific hourly PV production generated by PVWatts. However, AVERT does not have any built-in capacity to estimate impacts of battery storage projects.

Tools Used

- US Environmental Protection Agency. *AVoided Emissions and geneRation Tool (AVERT)*
  https://www.epa.gov/avert
- US Environmental Protection Agency. *Emissions and Generation Resource Integrated Database (eGRID)*
  https://www.epa.gov/egrid
- National Renewable Energy Laboratory. *Energy Analysis: Cambium*
  https://www.nrel.gov/analysis/cambium.html
- National Renewable Energy Laboratory. *PVWatts Calculator* (US Department of Energy)
  https://pvwatts.nrel.gov/
- National Renewable Energy Laboratory. *SCENARIO VIEWER :: DATA DOWNLOADER*. (US Department of Energy)
  https://scenarioviewer.nrel.gov/
- XENDEE Microgrid Decision Support Platform
  https://xendee.com/

[1] The power plants reducing output as a result of this project are not in Wisconsin: they are in Kansas, Nebraska, Oklahoma, Texas, Missouri, North Dakota, and Arkansas.

Measure Implementation Assumptions

a. PV lifespan

The nominal lifespan for the photovoltaic panels should be at least 20-25 years, and most manufacturers offer 25-year warranties. However, normal aging would cause output to decline on average about 0.1% to 3% per year, with 0.5% annually being typical.[2]

b. Battery use and lifespan

The Tribe proposes to primarily use the combined solar PV and battery storage to provide 24-hour and bad-weather power, with, generally, daily charging and drawdown. To maximize battery life, typically deep discharges and full charging should be avoided, applying that usable capacity is about 70% of nameplate capacity. For the purposes of this analysis, we assume that 3 megawatt-hours per day are reserved for immediate use, and that available power generated greater than 3 megawatt-hours per day are stored, up to the capacity of the batteries while charging at a battery conserving rate.

One might reasonably expect the batteries to last ten years in daily service with capacity declining to 60-70% of total. There is an energy cost to charging and discharging capacity, which is typically about 15% of power used to charge the battery. Note that if the battery storage system is primarily used to provide additional reliability, it will undergo few annual charge cycles and last much longer.

GHG Reduction Estimate Assumptions

a. Long-range projections

The GHG reduction estimate methods described above implicitly assume that the Midwest's electricity future will be like the electricity past. This is a reasonable assumption for a year or two, but public policy, technological innovation, and market forces are interacting to make the Midwest's 2024 energy present have lower avoided emission rates than in 2020 or 2022, and avoided emission rates are likely to fall considerably over the life of the Middle Village Microgrid. An alternative approach would provide a more realistic estimate of long-term emissions reductions.

The National Renewable Energy Laboratory (NREL) produces annually updated U.S. regional electric power sector projections that include direct estimates of regional avoided fossil fuel emissions rates as part of their Cambium program.[3] NREL's estimates include a short-range marginal emissions rate and a long-term marginal emissions rate, covering the period through

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[2] Jordan, D. C., Kurtz, S. R., Van Sant, K., & Newmiller, J. (2016, July). Compendium of photovoltaic degradation rates. *Progress in Photovoltaics, 24*(7), pp. 978-989. Retrieved March 19, 2024, from https://onlinelibrary.wiley.com/doi/epdf/10.1002/pip.2744

[3] Cambium data sets (2023), National Renewable Energy Laboratory. https://www.nrel.gov/analysis/cambium.html

2050. The long-range estimate includes the power sector's long-term adjustment to a marginal change in electricity demand by building/retiring power generation capacity, and probably end-use adjustments as well. The short-range estimate holds capacity fixed.

In this application, the long-range estimate is best suited to providing a basis for making a single figure "levelized" annual average estimate over a period of years for a project built in a particular year, while the short-range estimate is more applicable to reductions occurring a single year. The Cambium short-range estimate for a project built in 2024 is 1,502 pounds CO_2 per megawatt-hour, which is not far from avoided emissions rate calculations for 2022. The long-range estimate for 2024 is 699 lbs. CO_2 per MWH, and 451 pounds per CO_2 per megawatt-hour for 2026.[4]

b. Night vs. day emission reductions

The MTERA PCAP pointed out that generation with higher emission rates ran at night, and using battery storage to deliver electricity at night would provide about 10% greater emission reduction per kilowatt-hour than electricity sold during the daytime. This may or may not be a property of the real world, but the AVERT model shows only about a 2.5% lower emission rates at night. Examining hourly short run marginal emissions rates in the Cambium 2022 dataset output showed an interesting pattern over time. The gap between night and overall emission rates is negligible at present, but rises rapidly over time, reaching 36% in 2045. This "night-to-total" ratio has been used to calculate emission reductions from using battery storage to provide power at night. This shift is due to the expected rapid growth of solar power, which should tend to suppress the normal daytime seasonal air conditioning peak experienced in most of the United States.

c. Input assumptions for modeling

A feasibility study prepared for the Tribe in October 2023 utilized a techno-economic modeling approach to optimize combinations of viable energy technologies in terms of their economic, sustainability, and resilience profiles. Designs for the microgrid were simulated with the intent of establishing two useful bookends: a baseline microgrid design to meet current Middle Village needs, and the maximum generation resources available for that design to expand in the coming years.

Data sources were input into a cloud-based modeling platform, XENDEE, which runs millions of simulations to solve for a least-cost solution that is responsive to resilience and economic constraints. An analysis of potential fuel sources indicated that a combination of solar PV, battery energy storage systems (BESS), and diesel or propane generation is ideally suited for the Middle Village Microgrid. This asset mix is consistent with a clear industry trend toward those complementary technologies and was selected in XENDEE to serve as the basis for techno-economic modeling.

[4] "Reference: Modeled Marginal Emission Rates Over Time" output table in AVERT 4.2

Every microgrid option simulated was required to be capable of sustaining a full two-week utility outage and to provide at least 85% of the load via local renewable generation. The two-week outage is significant because it emulates more of a steady-state and longer-term, back-up system. The outage is simulated to occur at the worst possible time, i.e., during low PV generation or high seasonal loads. During those times, 125% of load was simulated to create a critical margin, understanding that these emergency scenarios may involve people sheltering in place. A baseline of 85% renewables was selected because targeting 100% renewables requires a considerable overbuild of PV and storage to get through extended cloudy days in winter. It typically makes economic sense to have a generator on hand to carry load during those times.

A Loads Analysis introduced the question of how to manage future load increases in the context of microgrid planning. To understand the question better, the centralized microgrid was simulated with the maximum amount of PV available at the substation field (4.43 MW), and then modeled different load growth scenarios. The analysis found that the annual PV energy produced (≈ 4GWh annually) could support a roughly four-fold load increase at Middle Village. The 4.43MW PV system would include corresponding increases in energy storage and generator sizing.

Reference Case Scenario

The base GHG emissions inventory completed by MTERA for the CPRG PCAP is a record of quantified emissions by source measured in carbon dioxide equivalent (CO_2e). GHGs quantified account for the following three gasses: carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O). Emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) were not estimated to be emitted in traceable amounts. In cases where data inputs were not available to collect, proxy data was calculated from a representative boundary.

Data is based on GHG inventories provided by the eight participating Tribes and has been extrapolated by population data provided by MTERA to demonstrate the emissions of all 35 MTERA Tribes. The scaling factor was determined by taking the sum total of population on Tribal Lands for all 35 MTERA Tribes and dividing by the eight-Tribe subset.

Total GHG emissions from the eight-Tribe subset are 403,000 $MTCO_2e$ and extrapolated total emissions for all 35 MTERA Tribes are 972,000 $MTCO_2e$. Most of the greenhouse gas emissions produced come from the Transportation and Buildings sectors, while less than 1% of emissions are from Waste.

The buildings included in the GHG inventory were limited to Tribal-owned commercial buildings and residential buildings (single-family and multifamily) that Tribal members reside in. While some Tribes only included residential buildings with Tribal members, other Tribes included all residential buildings within the Reservation regardless of occupant.

For all buildings, the first priority was to use utility data provided by the Tribal members. When this was not available, proxy data was used to estimate building energy use based on building typology, size, and location. For single-family homes, if utility data was not provided, the U.S. Energy Information Administration (EIA) 2020 Residential Energy Consumption Survey (RECS)[5] was used as a proxy. For commercial buildings, if utility data was not provided, the U.S. EIA 2018 Commercial Buildings Energy Consumption Survey (CBECS)[6] results and data were used as a proxy. For electricity use in commercial buildings, electricity consumption and conditional energy intensity by census division was used.

Activity Data

Based on an analysis using the National Renewable Energy Laboratory's PVWatts calculator, a four-megawatt photovoltaic plant located on Menominee Tribal lands should generate peak output of about 3.3 megawatts (AC) of usable power, and about 5.44 million kilowatt-hours (AC) of usable electricity annually.[7] Based on an analysis of similar photovoltaic projects in the area, PVWatts calculated the range of likely output from a four-megawatt array at this location of 5.2 to 5.7 million kilowatt-hours.

PVWatts does not estimate the impact of snow covering the surface of the panels. A simple estimate of snow losses reduces electrical output by about 1.5-percent on an annual basis, concentrated in December-February, for a smaller total of 5.35 million kilowatt-hours annually.[8]

Projected Annual Energy Generation, as Estimated by PVWatts, based on 2022 data:

Measure	Generation MWH (AC)
1. Microgrid (4 MW PV / 16 MWH Battery)	5,440
2. Commercial solar (4 x 50 kW PV/200 kwh Battery)	272
3. Residential solar (73 x 10 kW PV)	1,015

[5] 2020 Residential Energy Consumption Survey. (2020). U.S. Energy Information Administration. Retrieved February 24, 2024, from https://www.eia.gov/consumption/residential/data/2020/

[6] 2018 Commercial Buildings Energy Consumption Survey. (2018). U.S. EIA. Retrieved February 24, 2024, from https://www.eia.gov/consumption/commercial/data/2018/

[7] This estimate uses all default parameters (i.e, open rack, fixed array, standard modules, 96-percent inverter efficiency, 97-percent availability), with the exception of tilt angle, which was set to 34-degrees, close to optimal for Middle Village's latitude. PVWatts provides weather data averaged over several recent years from a gridded, interpolated data set, based on weather observations from nearby stations, notably Green Bay, WI.

[8] Based on average weather calculated for nearby Shawano, WI, the Menominee Reservation typically experiences snow in November-April, with about two days per month of active snow precipitation in December and January, and 0.1 days of snow in April. Average snow accumulation is about 100 mm (4"), and peak accumulation is about 250 mm (9"). We assume that a snow day will cause PV output to cease for that day, and resume the following day, which can be modeled as a percentage of the number of snow days for the months affected by snow.

GHG Emissions Reduced

Annual Emission Reductions over the life of the project:

(Thousand Metric Tons of Carbon Dioxide and Carbon Dioxide Equivalent)

Emissions Avoided	**2026**	**2027**	**2028**	**2029**	**2030**	**2035**	**2040**	**2045**
4 MW Solar Array	333	1,203	1,115	1,087	1,056	1,137	1,642	1,529
PV Via Battery Storage	413	1,337	1,161	1,064	975	755		
0.2 MW Commercial Solar		31	105	99	93	87	81	76
PV Via Battery Storage		4	14	12	11	8		
0.72 MW Residential Solar			118	418	391	358	302	281
Total Combustion CO2 Reductions	**745**	**2,575**	**2,513**	**2,680**	**2,526**	**2,345**	**2,026**	**1,886**
Combustion Methane & N2O	1	2	2	2	2	2	1	1
Total Direct Reductions	**746**	**2,577**	**2,515**	**2,682**	**2,528**	**2,347**	**2,027**	**1,887**
Pre-Combustion CH4 & N20	468	1,577	1,500	1,454	1,246	877	569	480
All Emission Reductions	**1,214**	**4,154**	**4,015**	**4,137**	**3,774**	**3,224**	**2,596**	**2,366**

Cumulative Emission Reductions 2025-2030 and 2025-2050:

GHG Reduction Measure	**Magnitude of Reductions 2025-2030**	**Magnitude of GHG Reductions 2025-2050**
4 MW Solar Array	4,793	29,558
PV Via Battery Storage	413	10,526
SUBTOTAL Measure 1	9,442	40,084
4 x 50 kW PV Commercial Solar	326	1,831
PV Via Battery Storage	42	104
SUBTOTAL Measure 2	368	1,935
73 x 10 kW PV Residential Solar	927	7,001
SUBTOTAL Measure 3	927	7,001
Total Combustion CO2 Reductions	**11,038**	**49,020**
Combustion Methane & N2O	9	36
Total Direct Reductions	**11,048**	**49,057**
Pre-Combustion CH4 & N20	6,245	18,715
All Emission Reductions	**17,293**	**67,771**

(Thousand Metric Tons of Carbon Dioxide and Carbon Dioxide Equivalent)