Gerlach Solar Energy Initiative

Conceptual Plan for 1.256 MW Solar Energy Project

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Introduction

The Gerlach Solar PV Project proposal outlines the design and implementation of a 1.256 MW solar photovoltaic plant in Gerlach, NV. This project is an initiative to address the current and future electricity needs of the Gerlach community, aiming to enhance energy independence and promote environmental sustainability through advanced solar technology.

It is important to note that this proposal is based on preliminary estimates. Upon selecting the specific site location, further detailed analysis and design will be required to refine the project parameters and ensure optimal implementation. Upon final site selection, it is suggested to conduct a comprehensive geotechnical survey to assess soil and subsoil conditions, ensuring the ground can support the mounting structures. A topographical survey would be beneficial to provide accurate land mapping, identifying any terrain variations that could affect the PV module layout and installation. A thorough shading analysis might be necessary to study potential shading from nearby structures, vegetation, and landscape features throughout the year, optimizing panel placement. Additionally, a microclimate assessment is recommended to evaluate local weather patterns, wind speeds, and potential extreme weather events to ensure the robustness of the system design.

An Environmental Impact Assessment (EIA) should be conducted to identify and mitigate potential impacts on the local ecosystem to ensure minimal disruption and develop strategies for habitat preservation. Water management strategies should be evaluated to prevent erosion and manage rainwater effectively, particularly during the construction phase. Plans for noise and dust control are suggested to minimize the impact on nearby residents and ecosystems.

In the design optimization phase, refining the layout of PV modules and mounting structures to maximize solar exposure and land use efficiency would be beneficial. It is advisable to design the electrical system meticulously, including the optimal routing of cabling and the strategic placement of inverters and transformers to minimize losses and ensure safety. Structural designs should ensure that mounting structures can withstand local wind loads, snow loads, and other environmental stresses. Detailed planning for battery storage systems is suggested to ensure reliable backup power and efficient load management.

Refining cost estimates based on site-specific data through financial and economic analyses would be prudent, accounting for potential adjustments due to unexpected site conditions. Assessing the economic impact on the local community might highlight the project's benefits. The project costs have been calculated using benchmarks provided by the National Renewable Energy Laboratory (NREL) for Q1 2023. [1] However, it is important to note that costs might have changed, and exact calculations would be necessary upon finalizing the design.

Community engagement should be a continuous process, involving regular stakeholder meetings to gather input and address concerns. Public information sessions could help keep the community informed about project progress, expected benefits, and any potential disruptions.

Project Overview

Location

The proposed solar photovoltaic (PV) plant is planned for Gerlach with its favorable geographical and climatic conditions that are ideal for solar energy production. Although the specific site location within Gerlach has not yet been determined, the general area offers significant advantages for the deployment of a solar PV plant.

Gerlach, situated in northwestern Nevada, is an excellent candidate for solar energy projects. The geographical coordinates of Gerlach are approximately 40.65° N latitude and -119.36° W longitude. [2] This positioning allows the region to receive abundant sunlight throughout the year, crucial for the efficiency and effectiveness of solar PV systems.

The town's altitude is approximately 1198 meters (3930 feet) above sea level. [2] This elevation is beneficial for solar energy production as higher altitudes generally experience less atmospheric interference, resulting in higher solar irradiance. Additionally, the cooler temperatures at higher elevations can improve the efficiency of solar panels, which typically perform better at lower temperatures. [3]

As illustrated in Figure 1, the town of Gerlach has high solar irradiation, but is surrounded by federally owned lands that are managed by the Bureau of Land Management (BLM). A recent evaluation by the BLM to identify sites for a high potential to develop solar energy identified the region just south of Gerlach (the green region in Figure 1) as having excellent potential due to the land features, proximity to the power grid, and distance from critical habitat for various animal species.

While these general conditions make Gerlach a promising location for a solar PV plant, the final site selection will require detailed site-specific analysis. This analysis will include assessments of land suitability, shading, topography, and local climate patterns to ensure optimal placement and performance of the solar PV system. By leveraging the favorable conditions of Gerlach and conducting thorough site evaluations, the project aims to maximize solar energy production and contribute significantly to the community's energy needs.

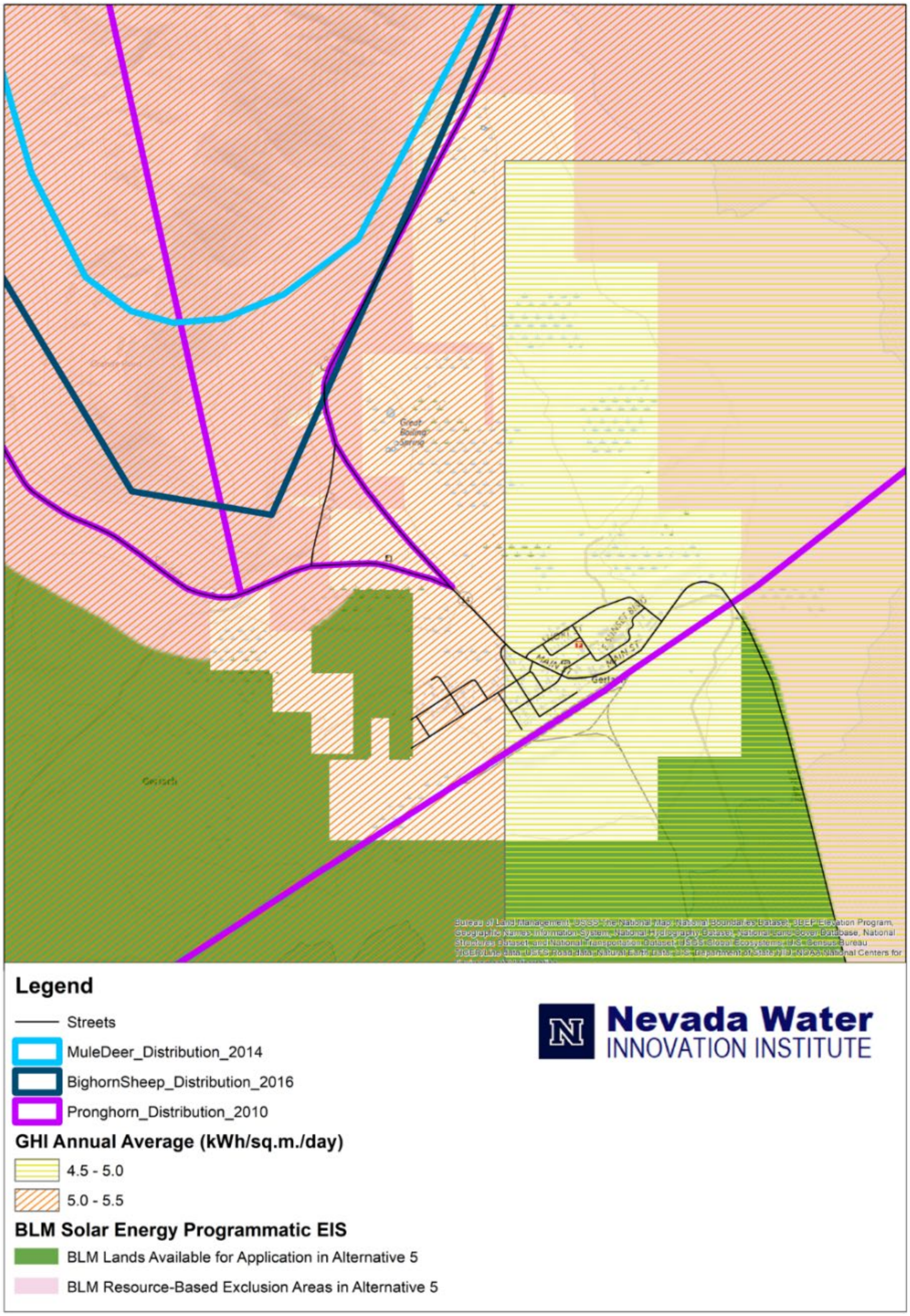

Figure 1. Solar Energy Potential in the Vicinity of Gerlach. Source: Nevada water Innovation Institute

Current and Future Electricity Consumption

Gerlach's current and future electricity consumption have been analyzed to ensure that the solar PV plant will meet the community's needs both now and in the future. The nZero energy audit, carried out in 2024, estimated the current total annual consumption for the community and across sectors (Table 1). As of the most recent data, Gerlach's total annual electricity consumption is approximately 1,987,507 kWh.

Table 1. 2022 Total Energy Consumption Across All Buildings in Gerlach, NV - Source: nZero

2022 Total Energy Consumption Across All Buildings	
Residential Electricity (kWh)	1,187,058
Non-Residential (kWh)	800,449
Residential Propane (Gallons)	30,795
Residential Wood (MMBTu)	2,299
Non-Residential Propane (Gallons)	67,776

Note: kWh = Kilowatt hours; MMBTu = million British Thermal unit

Forecasting future electricity consumption is crucial for ensuring that the Gerlach Solar PV Project can meet the long-term energy needs of the community. To provide a comprehensive view of expected energy demand for the Gerlach Solar PV Project, we can use two forecasting methods: the Compound Annual Growth Rate (CAGR) and the Exponential Growth Model. Below is an explanation of how each method is used along with their respective formulas and calculations.

The Compound Annual Growth Rate (CAGR) is a useful measure for understanding the mean annual growth rate of electricity consumption over a specified period. Based on national trends and local growth patterns, the following estimates provide a comprehensive view of expected energy demand.

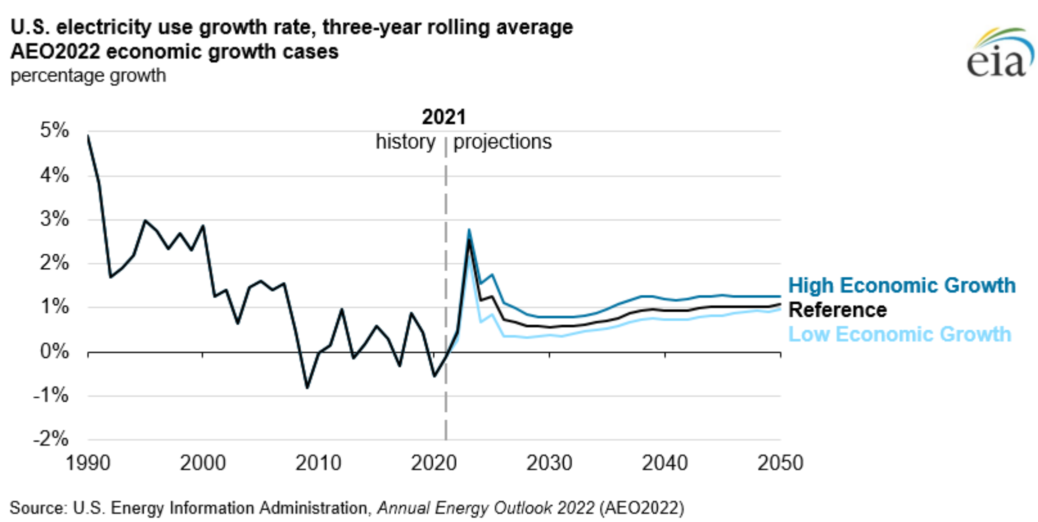

Figure 2. The U.S. annual average electricity growth rate remains below 1% for much of the projection period. Source: eia

Scenarios of Future Energy Demand

We consider four scenarios of future energy demand in order to determine the size of solar array required to meet Gerlach electricity demands (Table 2). These scenarios include a) no growth, b) no growth with 25% reduction through conservation, c) US national average growth (an increase of 0.3% annually), and d) US national average growth and 25% conservation. Under each of these scenarios, the energy demand is projected out 26 years to determine the required capacity of the system proposed.

The conservation scenarios assume that 25% energy savings are achieved through improvements to buildings and electronics within residential and commercial structures. According to the National Residential Efficiency Measures Database, maintained by the US Department of Energy, average energy reductions are approximately 10% through insulation and air sealing measures, 15% through window upgrades, 5% through thermostat controls, and 11 to 27% through reflective cooling roofs. Additional use solutions such as shading, whole house fans, and energy efficient electronics can achieve additional savings. Based on these potential savings, a net energy reduction of 25% across the community was selected as a conservative long-term goal.

The growth scenarios were determined using a conservative annual growth rate of 0.3% [4]. This projection considers the steady but slow increase in energy demand due to population growth, economic activities, and technological advancements within the community. The 0.3% growth rate is aligned with the U.S. annual average electricity growth rate, which remains below 1% for much of the projection period, as reported by the U.S. Energy Information Administration (EIA). [5] This rate also considers ongoing efficiency gains in energy consumption within buildings, driven by improvements in energy-efficient technologies and practices.

Table 2. Estimated Energy Demand in 2048 under growth and no-growth scenarios, with and without energy conservation measures implemented.

	No Conservation	**25% Conservation**
No Growth	1,987,507 kWh	1,490,630 kWh
Growth (0.3%)	2,148,488 kWh	1,611,002 kWh

Design Objectives

The design of the solar energy system will be developed to meet the following design objectives. These objectives will then be implemented to determine the size and characteristics of the solar farm based on site characteristics and component recommendations.

Primary Objective

The primary objective of this project is to design and implement a solar photovoltaic (PV) plant to meet 100% of the town of Gerlach's current and future electricity needs (Table 2). This includes integrating a battery backup system capable of providing at least one full day of power to ensure continuous electricity supply even during periods of low solar irradiance.

- **Capacity**: Capacity to be determined based on 26-year (2048) energy demand scenarios.
- **Energy Independence**: Provide 100% of the town's electricity from solar energy.
- **Battery Backup**: Ensure at least 24 hours of power availability through an integrated battery storage system.

Secondary Objectives

These objectives focus on maximizing efficiency, minimizing environmental impact, ensuring durability, and integrating advanced smart-grid technologies.

Maximize Energy Production Efficiency

- **Optimal Design**: Utilize advanced PV modules, efficient inverters, and optimal tilt angles based on the geographical and climatic conditions of Gerlach to maximize solar energy capture and conversion efficiency.
- **Smart-Grid Integration**: Implement smart-grid technologies such as demand response systems and real-time energy monitoring to optimize energy distribution and usage.

Minimize Environmental Impact

- **Clean Energy**: Replace fossil fuel-based energy with clean, renewable solar power to significantly reduce greenhouse gas emissions and the overall carbon footprint of the town.
- **Sustainable Materials**: Use environmentally friendly and sustainable materials to construct and maintain the solar plant.
- **Land Use**: Optimize the land area occupied by the solar plant to minimize disruption to the local ecosystem and maintain the rural landscape of Gerlach.

Ensure Ease of Maintenance and Durability

- **Robust Design**: Use high-quality, durable materials for PV modules, mounting systems, and other components to ensure longevity and reduce the frequency of maintenance.
- **Maintenance Accessibility**: Design the layout to include adequate spacing for easy access to all components for inspection, cleaning, and repairs.

- **Local Training**: Provide training for local personnel to handle routine maintenance and troubleshooting, ensuring quick response times and minimal downtime.

Integrate Smart-Grid Elements for Efficiency

- **Smart Meters**: Install smart meters in individual buildings to enable real-time energy usage monitoring and management.
- **Home Energy Management Systems (HEMS)**: Implement HEMS to optimize household energy consumption, reducing wastage and improving overall efficiency.
- **Battery Storage**: Integrate battery storage systems for energy storage and backup, ensuring a stable and reliable energy supply even during periods of low solar generation.
- **Three-Phase Power Supply**: Install three-phase inverters and transformers to provide necessary power to businesses requiring three-phase electricity, ensuring reliable and efficient energy supply for commercial operations.

Site Sunlight Analysis

Solar Irradiance & Meteorological Data

Solar irradiance is a critical factor in determining the feasibility and potential output of a solar PV plant. The data for Gerlach has been sourced from NASA, the NREL's PVWatts calculator [6], PVGIS [7] platform of the ©European Union, and other reliable tools like Meteonorm 8.

As illustrated in Figure 3, the NASA model for solar radiation in Gerlach was slightly less than the NREL model. This is due to the NASA model use of downward rather than angled irradiance. The annual average solar radiation in Gerlach is 4.98 kWh/m²/day (kWh/m^2/day [8]) to 5.60 kWh/m²/day [6]. Both these models indicate that Gerlach has a strong potential for solar energy generation due to the high level of solar irradiance .

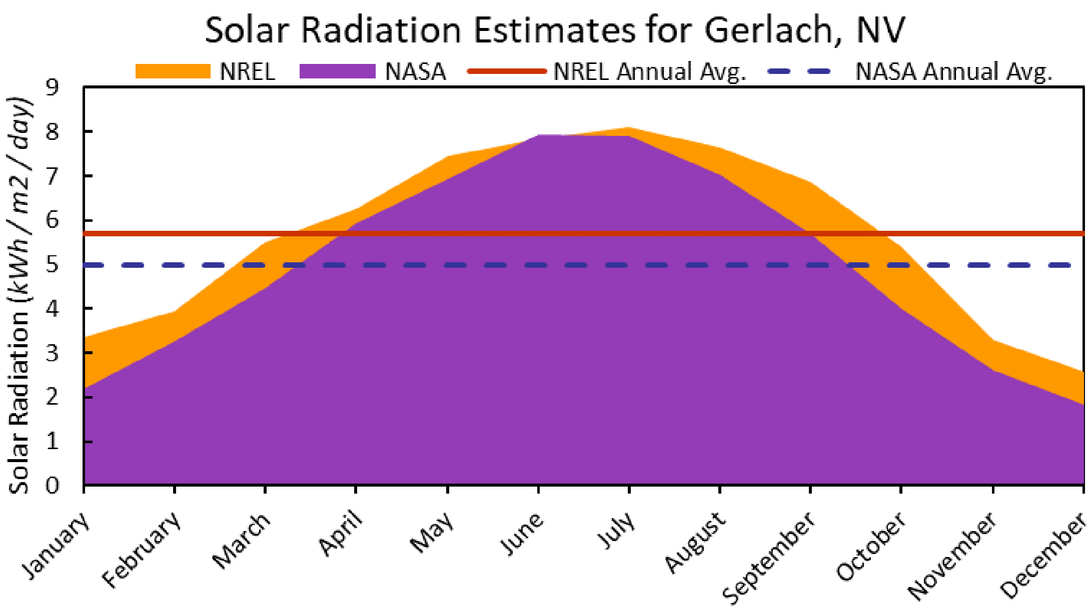

Figure 3. Solar Radiation by month, estimates from NREL [6] and NASA [8]

Solar Insolation

The duration of peak sun hours is an essential component to determine the capacity of the solar farm that is required to meet Gerlach's electricity demands. Figure 4 presents the average astronomical sunshine duration (hours) and the average peak sun hours on a monthly basis. Gerlach receives an annual average of 5.8 hours of peak sunlight per day, referred to as the solar insolation. The longer duration of the peak sunlight in the summer months is beneficial for maximizing the output of the solar PV plant. Understanding sun hours is crucial for determining the amount of solar radiation needed to achieve the desired power output from a solar PV system. Sun hours refer to the duration an area receives maximum sunlight, which directly impacts the efficiency and energy yield of the solar panels. [9]

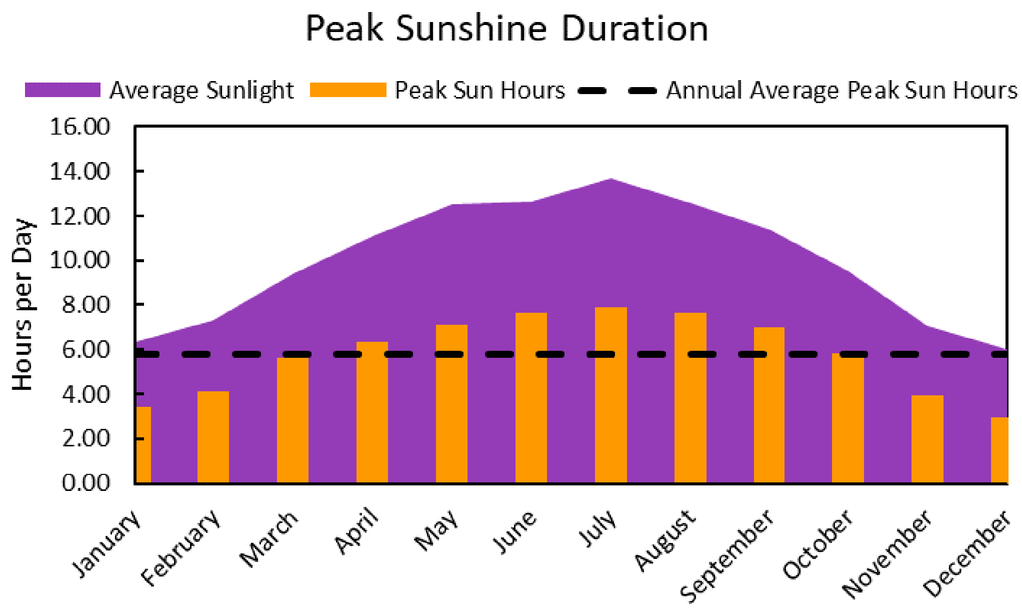

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Figure 4. Monthly averages for sunlight and peak sun hours in Gerlach, Nevada, with an annual average duration of peak sun light at 5.79 hours per day [Gerlach data from Footprinthero.com]

System Design

System Size

The Gerlach Solar PV Plant is designed to have a capacity to meet the current and future electricity demands of Gerlach, NV, based on the four scenarios of growth and conservation. Performance ratios, which characterize system inefficiencies, generally range from 0.75 to 0.85; a ratio of 0.75 was selected as a conservative estimate. The solar insolation for Gerlach was determined to be the annual average peak sun hours in Gerlach (Figure 4), which was 5.79 hours per day.

$$Capacity\ (kWh) = \frac{Annual\ Energy\ Output\ (kWh)}{Solar\ Insolation\ \left(\frac{h}{year}\right) \times Performance\ Ratio}$$

The scale of solar farm capacity under the growth and conservation scenarios ranged from approximately 1 MW to 1.4 MW (Table 3). Conservation was estimated to have the biggest impact, helping to reduce the capacity requirement by nearly one third. These results further demonstrate the recommendations of the energy audit, which identified that the highest return on investment for addressing a sizeable portion of Gerlach's energy needs could be achieved through conservation and use measures.

Table 3. System capacity requirements to meet energy demand in 2038 under four scenarios of growth and conservation.

Energy Demand Scenario for 2048	Estimated Energy Demand (kWh)	System Size (MW)
No Conservation, No Growth	1,987,507	1.25
25% Conservation, No Growth	1,490,630	0.94
Growth (0.3%), No Conservation	2,148,488	1.36
Growth (0.3%), 25% Conservation	1,611,366	1.02

PV Modules

The choice of photovoltaic (PV) modules is critical to the overall efficiency and performance of the solar plant. The project will utilize high-efficiency 400W peak modules. Characteristics of the PV modules recommended are described in Table 4.

Table 4. System capacity requirements to meet energy demand in 2038 under four scenarios of growth and conservation.

Characteristic/Operational Parameter	**Value**
Type	400W peak modules
Total Modules	3,140 modules
Dimensions	1 meter wide by 2 meters long (39 in/3.25 ft x 78 in/6.5 ft) [10]
Total Array Size	1.256 MW
Total Modules	Total Array Size / Module Watt Peak
Lifespan	The expected lifespan of these modules is approximately 25-30 years. [11]
Temperature Coefficient	-0.3%/°C, indicating the decrease in efficiency with each degree increase in temperature above 25°C. [12]
String Configuration	• **Connection:** Connection in Series configuration to increase the system voltage while keeping the current the same • **Estimated Total Strings:** 157 • **Modules per String:** 20
Array Configuration	• **Connection**: Parallel connection of strings • **Inverter Specifications**: The array configuration is designed to match the input specifications of high-efficiency inverters. • **Redundancy**: Parallel connection offers redundancy, ensuring that if one string fails, others continue to operate, maintaining overall system performance. • **Voltage Drop Considerations**: Proper cable sizing and layout planning to minimize voltage drops and power losses.

Tilt Angles

Optimal tilt angles are necessary to maximize solar exposure throughout the year. Adjusting the tilt angle based on seasonal changes can significantly improve the system's efficiency. The tilt angle should match the latitude of the installation site. Adjustable panel frames are recommended to accommodate seasonal variations in sun hours, with different optimal angles for winter and summer. For fixed panels, calculating a specific tilt angle to maximize annual radiance is essential. Positioning the panels to face south is generally advised to capture the most sunlight throughout the day, especially during the afternoon. These measurements ensure that the panels are set at the optimal angle for maximum energy production throughout the year. [9]

The solar panel tilt angles are generally either optimized for monthly optimal tilt, seasonal optimal tilt, or based on the annual average optimal tilt, as illustrated in Figure 5. In Gerlach, the optimal tilt for a single year-round configuration is 31.8°, which is also the optimal seasonal tilt angle for spring and fall. Additional adjustments are needed to optimize the tilt angles on either a seasonal or monthly basis. Proper tilt adjustments can improve energy capture by up to 15-20% compared to a fixed tilt system.

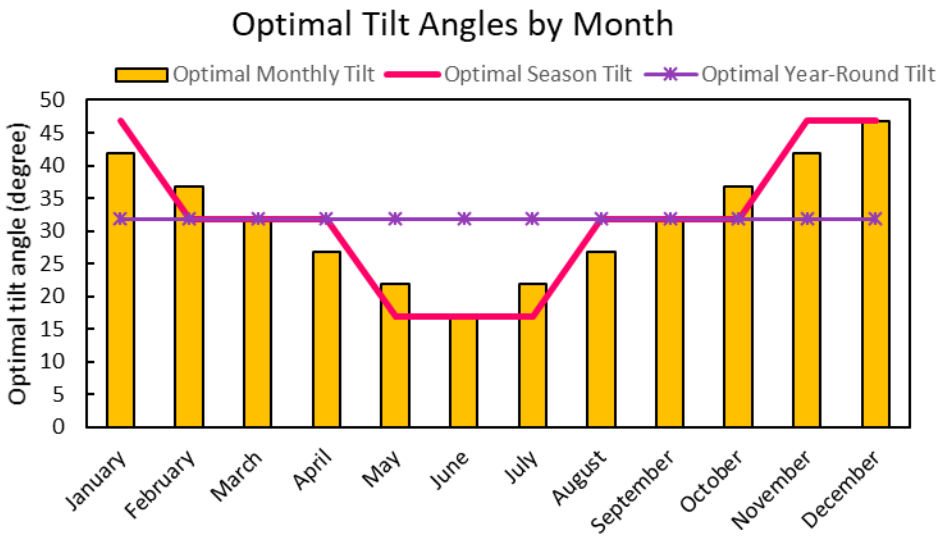

Figure 4. Monthly Average Temperature Gerlach, NV. Source: PVGIS ©European Union, 2001-2024

Land Area Calculation

To ensure the optimal layout and maintenance of the solar PV plant, the effective dimensions of each PV module, including the necessary spacing for maintenance, are calculated based on the dimensions of the solar panels, access requirements, and the location-specific characteristics such as solar angles and optimal tilt angle for solar panels in Gerlach (Table 5).

Land area was determined based on the largest spatial requirement for solar panels (see Figures 5 and 6), which occurs when the largest tilt angle is required. As described in Table 5, the largest land area requirement based on effective solar panel dimensions will coincide with the winter solstice. Table 6 summarizes the land area requirements under each of the future energy demand scenarios, based on the effective solar panel dimensions on the winter solstice and the number of modules required to meet the estimated energy demand.

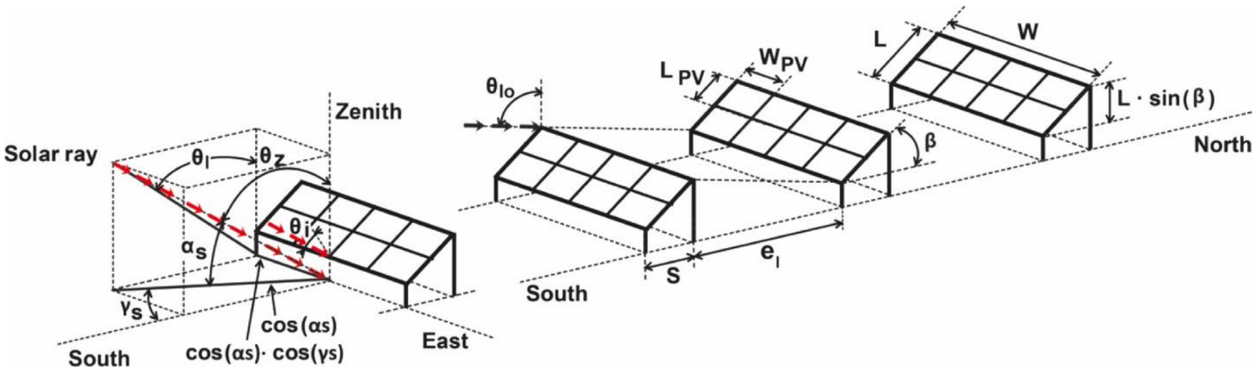

Figure 5. Longitudinal Distance Between Modules. Source [13]

Table 5. System capacity requirements to meet energy demand in 2038 under four scenarios of growth and conservation.

Characteristic/Operational Parameter	Value
Gerlach Solar Elevation Angle on Winter Solstice	23.5°
Gerlach Zenith Angle (θz) on Winter Solstice	66.5°
Solar Panel Effective Width	1.025 m
Solar Panel Effective Length	3.525 m

Table 6. System capacity requirements to meet energy demand in 2038 under four scenarios of growth and conservation.

Energy Demand Scenario for 2038	Number of Modules	Land Area Occupied (m^2)	Land Area Occupied (acres)
No Conservation, No Growth	3,576	11,345.74	2.80
25% Conservation, No Growth	2,355	8,501.55	2.10
Growth (0.3%), No Conservation	3,150	11,367.89	2.81
Growth (0.3%), 25% Conservation	2,358	8,526.82	2.11

Site Selection Considerations

Gerlach is close to critical habitat for pronghorn, bighorn sheep, and mountain goats (Figure 1). It is surrounded by publicly owned lands under the jurisdiction of the Bureau of Land Management, including the Black Rock Desert High Rock Canyon National Conservation Area, Calico Mountains Wilderness, and numerous proposed wilderness study areas (WSA) including Selenite Mountains WSA, Mt. Limbo WSA, and Fox Range WSA. The local community enjoys expansive desert mountain views. Specific site selection must consider these and other factors. The following provides additional considerations to select land that is suitable for establishing a solar farm.

Gerlach has open lands that can be suitable locations for implementing a solar farm. As illustrated in Figure 8, this includes a large stretch of BLM land adjacent to Gerlach that has been identified as a good candidate for solar energy development in the BLM Utility-Scale Solar Energy Development analysis [14].

Additionally, the community center has land area that may be suitable for a small-scale rooftop and covered parking area (Figure 9). The community center solar structure, depending on suitability and selected configuration, has sufficient land area to address approximately 10% of energy requirements.

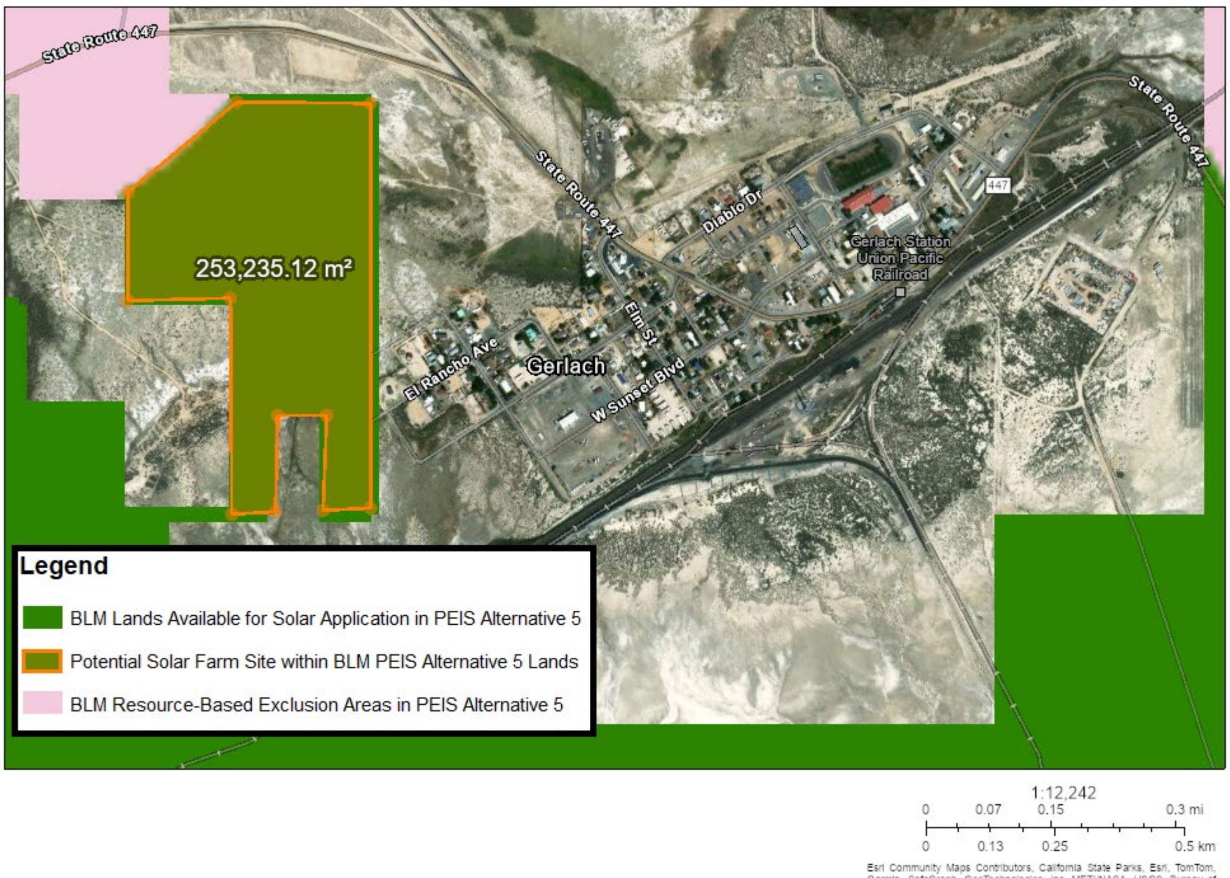

Figure 6. BLM lands identified as suitable for solar development in their most restrictive scenario that includes environmental and land characteristics.

Figure 7. Rooftop and a combined rooftop with extended solar shading over a parking area at the Gerlach community center.

Site suitability considers land features such as:

- **Altitude**: Gerlach is located at an altitude of 1198 meters (3930 feet) above sea level. The high altitude is beneficial for solar energy production as it typically results in higher solar irradiance and less atmospheric interference.
- **Shape and Size**: The shape of the land should ideally be as regular as possible, such as square or rectangular, to facilitate the efficient layout of the PV modules according to the land area required for the project. Irregularly shaped plots may require additional design considerations to optimize module placement.
- **Slope**: The terrain slope is a crucial factor for the installation and maintenance of the solar PV plant. A slope of ≤ 5° is preferred to ensure:
  - **Efficient Construction**: Gentle slopes facilitate easier and less costly construction processes.
  - **Maintenance**: Slope affects the ease of access for maintenance activities and the overall stability of the mounting structures.
- **Rural Environment:** The low population density and abundance of undeveloped land are good conditions for finding a site that reduces the project's environmental footprint.
- **Proximity to Grid**: The selected site should be reasonably close to the existing power grid to minimize the costs and complexities of grid connection.
- **Environmental and Regulatory Compliance**: The site should comply with local zoning regulations and environmental guidelines.

Material Requirements

To ensure the successful implementation of the Gerlach Solar PV microgrid, it is essential to specify and procure the necessary materials. Each component plays a critical role in the overall efficiency, durability, and reliability of the solar power system. This section details the key material requirements for the project. Table 7 provides a summary of materials and other specifications for the major equipment.

Table 7. Specifications for Components in Gerlach PV, ESS microgrid

System Components	Features
PV Modules	• **Total Modules**: 3,140 • **Module Rating**: 400W each • **Type**: Monocrystalline or polycrystalline modules, chosen for their high efficiency and longevity. Monocrystalline modules typically offer higher efficiency rates and better space efficiency, which is crucial for maximizing energy production within the available land area. • **Dimensions:** Each module measures approximately 1 meter by 2 meters. • **Efficiency**: Around 20%, which ensures a high conversion rate of sunlight to electricity. • **Lifespan**: Approximately 25-30 years, with a degradation rate of about 0.5% per year.
Mounting Systems	• **Fixed Tilt Angle**: The mounting systems will have a fixed tilt angle optimized for year-round performance, with seasonal adjustments if necessary. • **Material**: Galvanized steel structures • **Durability**: Galvanized steel offers excellent resistance to corrosion and harsh weather conditions, ensuring the structural integrity of the PV plant over its lifespan. • **Adjustability**: The design allows for seasonal tilt adjustments to maximize solar exposure throughout the year.
Inverters	• **Function**: converting the direct current (DC) generated by the photovoltaic (PV) modules into alternating current (AC) that cycles consistently at a frequency of 60 Hz and is suitable for use • **High-Efficiency Inverters**: Suitable for a 1.256 MW system • **Efficiency**: Greater than 98%, ensuring minimal energy loss during DC to AC conversion. • **Features**: Includes maximum power point tracking (MPPT) to optimize the power output from the PV modules, grid-tied capabilities, and remote monitoring and control. • **Capacity**: Adequate to handle the total generated power (MW) of the solar farm.

System Components	Features
Transformers	• **Function**: increase the voltage output from the inverters to match the grid requirements. • **Capacity**: Adequate to handle the total generated power (MW) of the solar farm.
Cabling and Connectors	• **Function**: increase the voltage output from the inverters to match the grid requirements. • **Features**: weather-proof connectors, and cables with double insulation and UV resistance are essential, while AC cabling should be rated for the expected voltage and current levels without significant losses or degradation over time. • **Capacity**: Adequate to handle the total generated power (MW) of the solar farm.
Batteries	• **Function**: provide back-up power to ensure a period of autonomy if other power systems fail. The desired period of autonomy and expected energy demand over that period drive battery size and costs. For this project, the period of autonomy is one day. • **Features**: Lithium-ion batteries are preferred due to their high energy density, long cycle life, and low maintenance requirements (example system in Figure 10) • **Capacity**: Adequate to handle the total generated power (MW) of the solar farm. • **Maintenance**: typically estimated at 1.5% of the system's initial cost per year [15] • **Lifespan**: generally limited to 5,000 cycles or about 20 years
Charge Controllers	There are two primary types of charge controllers available in the market: 1) Pulse Width Modulation (PWM) Controllers and 2) Maximum Power Point Tracking (MPPT) Controllers. For the Gerlach Solar PV project, considering the balance between cost and efficiency, PWM charge controllers will be used to manage the system. This decision considers the project's budget constraints while still ensuring reliable performance. **Pulse Width Modulation (PWM) Controllers** o **Functionality**: PWM charge controllers match the input power of the battery regardless of the power generated by the PV panels. This type of controller can result in inherent power losses. o **Suitability**: PWM controllers are cost-effective and suitable for smaller systems with lower efficiency requirements. o **Capacity:** the controllers should be able to handle the peak current output from the PV array while maintaining the correct voltage levels; sized according to the PV power.

Figure 8. BESS System. Source: DEPCOM POWER

Capital Cost Estimation

A detailed cost estimation is crucial for the financial planning and feasibility analysis of the Gerlach Solar PV Plant. This section outlines the costs associated with the major components and installation of the solar power system. Overall cost estimates are summarized in Tables 8 and 9.

To calculate the total cost for the Gerlach Solar PV project using the provided data from the charts, we considered each category of expenses and sum them up for both the Minimum Sustainable Price (MSP) and Modeled Market Price (MMP). The MSP is included in the analysis because these costs can be used for setting subsidies, tax incentives, and assessing the financial viability of suppliers, since MSP indicates the minimum price that a supplier may charge while remaining solvent. The analysis will focus on MMP, because this is the price that is likely to be paid for the materials and equipment, as this cost incorporates current market conditions.

Costs are estimated for each component using the features and specifications described in Table 7, and are driven by assumptions under each scenario as described below:

- The energy storage system (ESS), which includes the battery, battery management system, and other components are expected to be the largest cost under all scenarios (Figure 11). Thus, the ESS cost for each scenario is driven by the annual energy demand scenario.
- The second largest expense under each scenario is the fieldwork required to install the PV system, such as labor and installation activities that occur on-site. This cost is driven by the land area required for the scenario.
- The site balance of system (SBOS) is the third largest expense under all scenarios and comprises the on-site PV system infrastructure like mounting racks and other hardware; this cost is driven by the land area estimates for each scenario (Table 6).
- The PV modules are high-efficiency 400 W modules selected for reliability and durability to maximize energy production and longevity. The PV module and inverter costs are estimated according to the size of the system (KW) in each demand scenario.
- The EBOS includes all electrical components required to connect the solar PV system to the grid or to other electrical systems. It covers items such as transformers, circuit breakers, conductors, grounding equipment, and any other electrical infrastructure needed to ensure safe and efficient operation. This cost is driven by the capacity of the system under each scenario.
- Office encompasses costs related to planning, engineering, logistics, permits, interconnection applications, and other administrative tasks required to develop and execute the solar PV project. This cost is proportional to the capacity of the system.

Overall, the scenario of conservation with no future growth in demand resulted in the lowest overall costs particularly through savings in PV module and ESS size requirements. The scenario with conservation and 0.3% future growth in demand only resulted in marginal increases in the overall cost. Without conservation, the system is estimated to cost approximately $1 million more than the conservation scenarios – this potential cost savings can be used as a benchmark to evaluate the cost efficacy of investing in conservation measures.

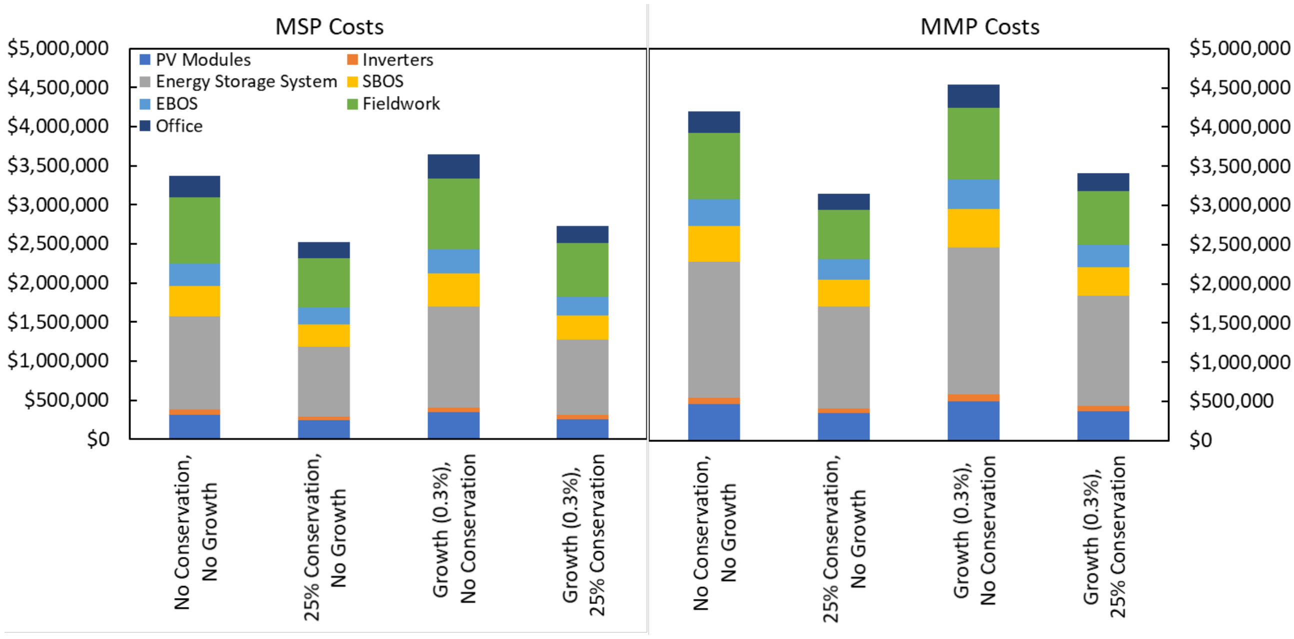

Figure 9. Breakdown of costs under Minimum Sustainable Price (MMP) and Modeled Market Price (MSP) estimates.

Table 8. MSP breakdown of costs for system components

Cost Component	**No Conservation, No Growth**	**25% Conservation, No Growth**	**Growth (0.3%), No Conservation**	**Growth (0.3%), 25% Conservation**
PV Modules	$502,400	$376,800	$504,000	$377,200
Inverters	$60,189	$45,142	$65,064	$48,798
ESS	$1,192,504	$894,378	$1,289,093	$966,820
SBOS	$387,634	$290,725	$419,031	$314,273
EBOS	$292,167	$219,126	$315,832	$236,874
Fieldwork	$839,873	$629,905	$907,900	$680,925
Office	$275,866	$206,900	$298,210	$223,658
Total Cost	**$3,550,633**	**$2,662,976**	**$3,799,130**	**$2,848,548**

Table 9. MMP breakdown of costs for system components

Cost Component	**No Conservation, No Growth**	**25% Conservation, No Growth**	**Growth (0.3%), No Conservation**	**Growth (0.3%), 25% Conservation**
PV Modules	$466,465	$349,849	$504,247	$378,185
Inverters	$82,760	$62,070	$89,463	$67,097
ESS	$1,731,581	$1,298,686	$1,871,833	$1,403,875
SBOS	$452,239	$339,179	$488,869	$366,652
EBOS	$348,595	$261,446	$376,830	$282,622
Fieldwork	$839,873	$629,905	$907,900	$680,925
Office	$279,628	$209,721	$302,277	$226,708
Total Cost	**$4,201,141**	**$3,150,856**	**$4,541,419**	**$3,406,064**

Monitoring and Maintenance

The longevity and efficiency of the Gerlach Solar PV Plant depend heavily on a robust monitoring and maintenance plan. Besides a cost estimation, this section provides background on the maintenance activities involved to ensure optimal performance and reliability of the PV system.

A regular maintenance schedule is crucial to identify and rectify any issues promptly, ensuring that the system operates at peak efficiency. The maintenance activities are categorized into monthly and annual checks. Monthly checks include visual inspections of PV modules, structures, cabling, obstructions, electrical connection integrity, and reviews of performance data. Annual checks include a comprehensive inspection of all system components, including PV modules, inverters, transformers, and mounting structures. For annual inspections advanced inspection equipment such as thermal imaging may be used in addition to testing of electronics, wiring, and grounding systems. Mechanical inspections during the annual check are conducted to ensure the structural integrity and optimal alignments of the PV modules.

Other maintenance costs originate from administrative activities to monitor system performance. A real-time performance monitoring system provides continuous data on energy production and system health. Performance monitoring data tracks information such as the performance of individual PV modules, strings, the entire array, and environmental conditions (e.g., solar irradiance, temperature). The real-time monitoring system should be configured with automated alerts for any anomalies or deviations from expected performance parameters. Data from this system should also be utilized in the monthly and annual inspections for the system.

Maintenance Cost

To calculate the operation and maintenance (O&M) costs for the Gerlach Solar PV project, we will use the provided benchmark data for community PV systems. The relevant O&M costs are calculated in dollars per kilowatt (kW) per year, thus proportional to the size of the system.

We will consider both the scenario with only the PV system and the scenario with the PV system plus Energy Storage System (ESS). As illustrated in Figure 12, the ESS is anticipated to generate the largest share of O&M costs. Other major costs will be administrative activities to manage customers, land, and insurance. Field activities such as inspection and cleaning will comprise approximately 22% of O&M costs associated with the PV system.

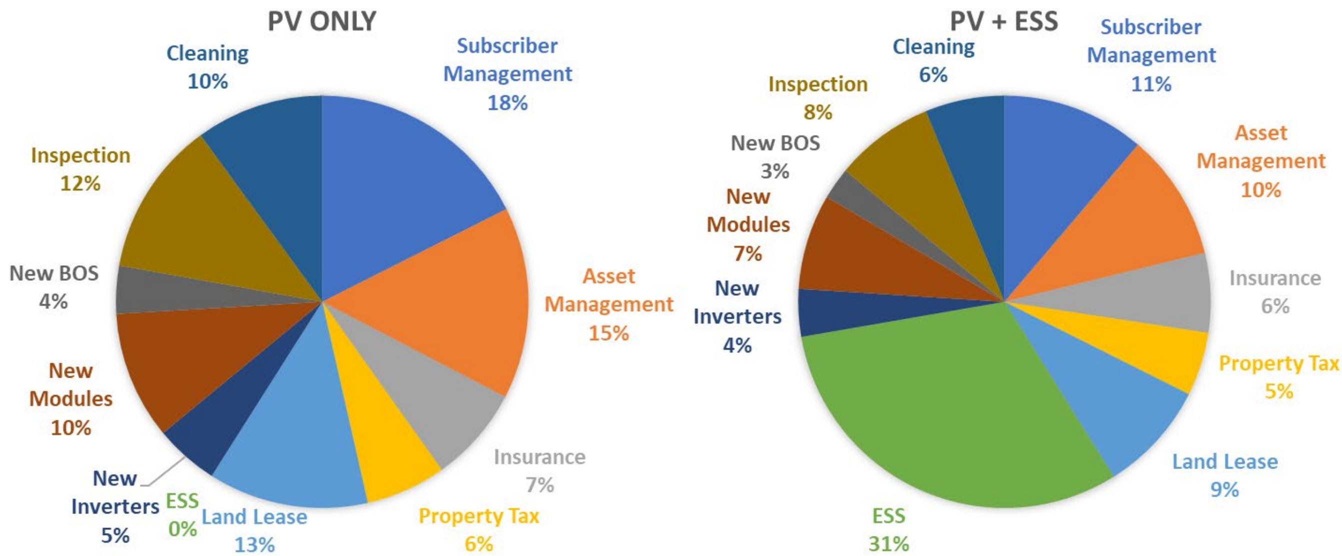

Figure 10. MSP and MMP O&M benchmarks for all modeled systems. Source: NREL

Table 10 summarizes the total estimated O&M costs of the PV and PV + ESS systems. These costs vary under each growth and conservation scenario, proportional to the respective power requirement. Examining the MMP costs, which are representative of expected current market prices, the overall O&M costs can be reduced by $24,000 to $26,000 per year. In the conservation scenarios, the O&M costs are approximately $13,000 lower for the PV system, and $12,000 lower for the ESS system.

Table 10. Annual Maintenance Cost Breakdown (cost per year)

Growth and Conservation Scenario	PV Only		PV + ESS	
	MSP	MMP	MSP	MMP
No Conservation, No Growth	$49,944	$50,797	$94,359	$96,290
25% Conservation, No Growth	$37,458	$38,098	$70,769	$72,217
Growth (0.3%), No Conservation	$53,990	$54,911	$102,002	$104,089
Growth (0.3%), 25% Conservation	$40,492	$41,184	$76,501	$78,067

Additional Considerations

Risk Assessment and Mitigation

The successful implementation and operation of the Gerlach Solar PV Plant are contingent upon identifying and mitigating various potential risks. Some of the key factors that pose risks to the project include shading, weather conditions, and equipment failure. Each of these risks can significantly impact the efficiency and reliability of the solar PV system if not properly managed. Major risks include shading, weather conditions, and equipment failure.

During the site selection process, shading assessment should be a driving criteria. This analysis will ensure that panel placement and angles maximize sun exposure and that there is minimal risk of adverse weather conditions that can impact performance (e.g., floods, extreme temperatures, high winds).

Another critical strategy to mitigate risks is to utilize high quality materials in the system build. This includes

- Durable PV modules that meet IEC standards (e.g., IEC 61215 and IEC 61730),
- Robust mounting structures designed to withstand high winds and heavy snow loads (e.g., corrosion-resistant galvanized steel or aluminum),
- Reliable inverters and transformers constructed from high-quality components and reputable manufacturers that have adequate cooling systems and protection against weather extremes, and
- Weather-resistant cabling and connector materials (UV-resistant and waterproof).

Complementary Equipment

The integration of smart-grid technologies with the Gerlach Solar PV Plant is essential to optimize energy production, distribution, and consumption. Smart-grid elements enhance the system's efficiency, reliability, and sustainability by enabling real-time monitoring and advanced energy management. Table 11 provides a summary of some key equipment that is complementary to developing an efficient smart grid.

Table 11. Supplemental smart and functional micro-grid elements

Supplemental Elements	Function	Features
Smart Meters	Provide real-time monitoring of energy usage throughout the grid for accurate demand forecasting and management.	• Real-Time Data: Provides consumers and utility operators with immediate insights into energy usage patterns. • Energy Optimization: Helps identify energy waste and areas where efficiency improvements can be made. • Billing Accuracy: Ensures accurate billing based on actual consumption rather than estimates.

Supplemental Elements	Function	Features
Demand Response Systems	Manage and shift electricity load during peak hours.	• Peak Load Management: Reduces the strain on the grid during high-demand periods, enhancing system stability. • Cost Savings: Offers financial incentives to consumers who reduce or shift their energy consumption during peak times. • Grid Reliability: Improves the overall reliability and efficiency of the power system by balancing supply and demand.
Energy Management Systems	Software-based solutions that monitor, control, and optimize the performance of the generation, distribution, and consumption of electrical energy	o Efficient Distribution: Ensures optimal distribution of electricity from the solar PV plant to the grid and end-users. o Energy Storage Integration: Manages the storage and discharge of energy from battery systems, ensuring a stable supply. o Sustainability: Reduces energy waste and enhances the use of renewable energy sources.
3-Phase Power Supply	If required by businesses, provide 3-phase power supply to operate heavy machinery and equipment efficiently.	• **3-Phase Inverters**: Install 3-phase inverters to convert the DC output from the PV modules into 3-phase AC power suitable for industrial applications. • **Step-Up Transformers**: Use step-up transformers to increase the voltage to appropriate levels for 3-phase power distribution. • **Infrastructure**: Develop the necessary electrical infrastructure, including cabling and switchgear, to distribute 3-phase power to businesses requiring it.
Advanced Inverters	Facilitate grid stability through voltage management.	• Utilizing smart inverters with grid-support functionalities can help manage voltage and frequency fluctuations.
Demand Response Programs	Facilitate grid stability with demand management incentives.	• Implementing demand response programs can help balance supply and demand. By encouraging consumers to reduce or shift their energy use during peak times, these programs can alleviate stress on the grid and enhance stability.

Implementation Plan

The implementation plan (Table 12) for the Gerlach Solar PV Plant ensures a systematic process from site preparation to final commissioning and ongoing maintenance. Each phase has specific tasks and objectives crucial for the successful deployment of the solar power system. [16] [17]

Table 12. Implementation Plan

Phase	Tasks	Objectives	Activities
1. Initial Engagement and Analysis	Understand Key Customer Goals	Identify project motivations	Initial discussions to clarify goals and constraints
	Energy Analysis	Determine electricity consumption	Collect and analyze the 12 months of historical electrical usage data
	Power Demand Analysis	Align production and load curves	Obtain interval data from the utility for facility's power load
	Available Area Analysis	Assess potential system locations	Use satellite and aerial photography to analyze roof area or adjacent land
	Utility Analysis	Understand utility policies	Review net metering policies, potential solar taxes, and other regulations
	Financial Incentive Analysis	Identify available financial incentives	Investigate federal, state, and local incentives
2. Preliminary Proposal Development	Preliminary Design & Layout	Create initial system layout	Superimpose a preliminary solar layout onto the specified area
	Budgetary System Price Quotation	Estimate project cost	Develop budgetary price based on system size, interconnection costs, and mounting
	Energy Production Estimates	Forecast energy output	Use simulation software to estimate monthly energy production
	Return on Investment Metrics	Calculate financial viability	Develop a pro forma over the system's lifespan, including IRR, NPV, and LCOE
	Environmental Offset Metrics	Measure environmental impact	Calculate CO2 offset using EPA coefficients
	Operations & Maintenance Options	Plan for ongoing maintenance	Include a maintenance budget in ROI calculations
	Discussion of Preliminary Proposal	Review proposal with customer	Present the proposal, discuss details, and decide on next steps
3. Preliminary Engineering	Detailed Site Inspection	Gather comprehensive site information	Inspect electrical infrastructure and installation area
	Review of All Relevant Standards	Ensure compliance with all codes and standards	Review NEC, UL, and additional local engineering requirements
	Electrical Feasibility Analysis	Determine best interconnection method	Evaluate back feeding, behind-the-meter connections, or utility-side connections
	Glare Analysis	Ensure compliance with FAA requirements	Conduct glare analysis if the project is near an airport
	Major System Specification	Finalize system components	Specifications for modules, inverters, and racking, develop conceptual diagram
	Eng. Procurement and Construction Agreemen	Formalize project agreement	Capture all details in an EPC Agreement and secure initial project deposit

Phase	Tasks	Objectives	Activities
4. Final Detailed System Engineering	Incorporation of All Relevant Standards	Ensure design meets all requirements	Integrate reviewed standards into the final design
	Single-Line Diagrams and Electrical Schematics	Create detailed electrical drawings	Develop drawings for communication with inspectors and the utility
	Dimensioned Mechanical Layout Drawings	Finalize system layout	Generate mechanical drawings detailing project boundaries, obstacles, and system dimensions
	Structural Drawings and Report	Confirm structural feasibility	Produce stamped structural drawings and reports for building permit submission
	Utility Interconnection Application	Secure utility approval	Submit electrical specifications and schematics to the utility
	Permitting	Obtain necessary permits	Submit project drawings to local government for building and electrical permits
5. Procurement	Modules	Secure solar panels	Order polycrystalline or monocrystalline modules based on project requirements
	Inverters	Obtain inverters	Order string inverters or central inverters based on project scale and voltage requirements
	Racking	Acquire mounting systems	Order aluminum or galvanized steel racking systems for ground installations
	Monitoring	Set up performance monitoring	Install independent solar energy production monitoring equipment
	Balance of System (BoS)	Source remaining components	Obtain combiner boxes, wire, grounding clips, conduit, disconnects, and connectors
6. Preconstruction Assessment and Planning	Material Delivery Plan	Plan material logistics	Schedule material deliveries and establish procedures for temporary storage
	Material Staging Plan	Manage material movement	Plan how materials will be moved from storage to construction activities
	Material Handling Plan	Ensure efficient material handling	Determine equipment needed for material handling, such as cranes or forklifts
	Electrical Outage Plan	Minimize operational disruption	Schedule brief electrical outages for system integration, with contingency plans if needed
	Final Construction Schedule	Establish construction timeline	Allocate labor, schedule project phases, and obtain approvals
	On-Site Preconstruction Customer Meeting	Ensure customer readiness	Meet with facility management to coordinate site access and project details
	Materials Delivered	Prepare for construction	Receive materials and commence construction activities

Phase	Tasks	Objectives	Activities
7. Construction	DC Mechanical Scope	Install racking and modules	Set up racking system and connect pre-wired modules
	DC Electrical Scope	Complete DC wiring	Connect module strings to combiner boxes or directly to inverters
	AC Electrical Scope	Connect to the facility	Perform interconnection work by a master electrician
	Monitoring Scope	Install monitoring equipment	Set up internet-connected monitoring systems
	System Testing	Ensure system functionality	Perform detailed system performance checks
8. Commissioning	System Inspection	Verify installation	Schedule inspections with local authorities
	Utility Interconnection	Ensure grid compatibility	Coordinate with the utility for interconnection approval
	Final Punchlist	Address remaining issues	Complete outstanding tasks before system handover
	Quality Assurance	Confirm quality standards	Conduct a final quality check
	Customer Orientation	Educate facility personnel	Provide training on system operations and maintenance
	System Documentation	Finalize project documentation	Generate and handover as-built documentation and owner's manual
9. Operation	Operation and Maintenance Plan	Plan periodic maintenance	Provide various service levels for ongoing operations and maintenance
	Ongoing Performance Monitoring	Monitor system performance	Continue to monitor system performance with installed monitoring equipment
	Annual System Inspection	Ensure long-term performance	Conduct annual system inspection and routine maintenance

Conclusion

The Gerlach Solar PV Project is a forward-thinking initiative designed to address the growing electricity needs of the Gerlach community through sustainable means. The project leverages cutting-edge solar technology and comprehensive planning to ensure not only the current but also future energy demands are met efficiently and reliably. The primary goal of the Gerlach Solar PV Project is to provide a sustainable energy solution that significantly reduces the community's reliance on fossil fuels. By harnessing solar power, the project aims to deliver clean, renewable energy, thereby lowering greenhouse gas emissions and contributing to a healthier environment. The use of high-efficiency PV modules, advanced inverters, and robust mounting systems ensures that the solar plant operates at optimal performance, maximizing energy output and minimizing environmental impact.

Gerlach is located in a region with high potential to capitalize on solar energy. The size of the system required to provide energy for the community depends on the anticipated future energy demands. Energy conservation, weatherization, and energy use measures may provide substantial energy savings that reduce the size and costs of the photovoltaic (PV) and energy storage system (ESS) required to meet community needs. Capital costs anticipated in the 0.3% growth in energy demand with no conservation were $4,541,419, whereas the capital costs when system size is reduced through 25% conservation in energy demand were estimated at $3,406,064.

Similarly, O&M costs in the scenario with 0.3% growth were estimated to be nearly $55,000 per year for the PV system, and slightly over an additional $49,000 for the ESS system. With energy conservation of 25% these costs were estimated to reduce to just over $41,000 per year for the PV system, and just under $37,000 for the ESS system.

Moving forward, the project should pursue planning and optimization measures during site selection, land assessment, and site-specific design of the solar array with the integration of smart-grid technologies. The detailed site analysis ensures that the location is ideal for solar energy production, with minimal environmental disruption. Additionally, long-term performance requires that the system design incorporates high-quality materials and state-of-the-art technologies to ensure durability and long-term reliability. The integration of advanced technologies, such as smart meters, demand response systems, and energy management systems, can further enhance the efficiency and reliability of the solar power system.

References

[1] V. Ramasamy, "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023," NREL, 2023.

[2] "Geo Gerlach - Nevada," 2024. [Online]. Available: https://www.usclimatedata.com/map/USNV0033.

[3] S. R. P. a. S. E. a. E. W. Chitturi, "Efficiency of photovoltaic systems in mountainous areas," in *2018 IEEE International Energy Conference (ENERGYCON)*, 2018, pp. 1-6.

[4] M. Muratori, "RURAL ENERGY USE AND THE CHALLENGES FOR," The National Agricultural & Rural Development Policy Center , Ohio State University, 2013.

[5] L. Martin, "Annual Energy Outlook 2022 Presentation to Electricity Advisory Committee," U.S. Energy Information Administration, 2022.

[6] "PVWatts Calculator," 2024. [Online]. Available: https://pvwatts.nrel.gov/.

[7] P. G. I. SYSTEM, European Comission, 2022.

[8] Nasa, "Nasa Power," 2024. [Online]. Available: https://power.larc.nasa.gov/data-access-viewer/.

[9] E. Franklin, "Solar Photovoltaic (PV) Site Assessment," August 2017. [Online]. Available: https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1697-2017.pdf.

[10] C. McDevitt, "How big are solar panels? Solar panel size and weight," July 2024. [Online]. Available: https://www.energysage.com/solar/average-solar-panel-size-weight/.

[11] E. Glover, "How Long Do Solar Panels Last?," June 2024. [Online]. Available: https://www.forbes.com/home-improvement/solar/how-long-do-solar-panels-last/.

[12] I. Ost, "Does Solar Panel Temperature Coefficient Matter?," April 2020. [Online]. Available: https://www.solar.com/learn/does-solar-panel-temperature-coefficient-matter/.

[13] A. Barbon, C. Bayon-Cueli, L. Bayon and V. Carreira-Fontao, "A methodology for an optimal design of ground-mounted photovoltaic power plants," *Applied Energy,* vol. 314, 2022.

[14] A. N. L. E. S. Division, "Draft Programmatic Environmental Impact Statement for Utility-Scale Solar Energy Development," 2023. [Online]. Available: https://eplanning.blm.gov/public_projects/2022371/200538533/20102762/251002762/2023%20Draft%20Solar%20PEIS%20Volume%201%201-10-2024_508compliant.pdf.

[15] A. A. Khamisani, "Design Methodology of Off-Grid PV Solar Powered System".

[16] SunPeakPower, "Roadmap for Implementing Solar," 2024. [Online]. Available: https://www.sunpeakpower.com/hubfs/01_Roadmap_for_Implementing_Solar_12_17_18.pdf.

[17] "Barlow Solar Energy Centre Construction Plan Report," Stantec Consulting Ltd., 2017.

[18] "Tilt Angle Calculator," 2024. [Online]. Available: https://sunsolartilt.com/pages/calculator.

[19] SOLAIRWORLD, "How Much Does a Solar Inverter Cost?," 2024. [Online]. Available: https://solairworld.com/how-much-does-a-solar-inverter-cost/#:~:text=The%20price%20varied%20from%20as,watt%20aligns%20with%20this%20percentage..

[20] U. o. O. Solar Radiation Monitoring Laboratory, "Solar Radiation Monitoring Laboratory," 2024. [Online]. Available: https://solardata.uoregon.edu/cgi-bin/SunPathChart_test.py.

[21] *PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM (PVGIS),* European Comission, 2022.

[22] E. Franklin, "Calculations for a Grid-Connected Solar Energy System," The University of Arizona Cooperative Extension, 2019.

[23] V. Ajjarapu, "115kV/ 34.5kV Solar Power Plant & Substation Design Project," Iowa State University, 2020.

[24] PWC, "Utility scale solar PV projects," [Online]. Available: https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/Utility%20Scale%20Solar%20PV%20Projects.pdf.

[25] B. Clevenger and E. Romich, "Estimating the Size of Your Solar Electric System," *Farm Energy Fact Sheet Series,* 2014.