Distributed Generation Analysis of a Microgrid System

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Chapter 1: Preliminary Proposal

Section 1.1: Problem Definition

Evertec, a company situated at PR-176 KM 1.3 in San Juan, PR, is evaluating various electrical energy sources. Many residential, commercial, and industrial establishments are operating at excessive speeds on an unreliable and unstable power grid because of the exorbitant electric bill costs. Presently, the utility company of the island is engaged in the reconstruction of its infrastructure and the development of a dependable grid. Consequently, the utility increases the prices by fifty percent of the average price in the United States as a whole. In an effort to reduce the overall cost of electricity and accommodate the current condition of the local grid, businesses and residents are converting to and constructing alternative systems, such as a micro-grid system that provides backup power from the utility, co-generation, and renewable energy. Geographically, Puerto Rico is among the most advantageous locations, receiving over five hours of direct sunlight per day, which is sufficient to power a functional solar system.

As a result, these professional services propose the design and installation of a microgrid system in which one power source is a photovoltaic system. The facility is powered by a cogeneration system and supported by the utility. A solar energy technique referred to as photovoltaic converts solar radiation directly into electricity by utilizing the unique properties of certain semiconductors. A photovoltaic (PV) system comprises an array of PV modules and additional electrical components necessary for the conversion of solar energy into usable electricity for applications. Electrical components, such as inverters, charge controllers, and disconnects, regulate, and condition the direct current (DC) power originating from the array. Consequently, this power must be converted into alternate current (AC) power for utilization by AC loads or directed towards DC loads. Photovoltaic systems offer energy independence, which is a critical and essential characteristic. A micro-grid system utilizes the utility as a backup system; if the photovoltaic system is unable to provide sufficient energy due to extreme conditions or poor weather, the remainder can be supplied at a reasonable cost through co-generation with the local grid. Electrical systems are obligated to conform to the appropriate standards and requirements. These professional services ensure that all pertinent requirements are met by any design-build project developed in adherence to the National Electric Code and local utility authorities.

Section 1.2: System Block Diagram

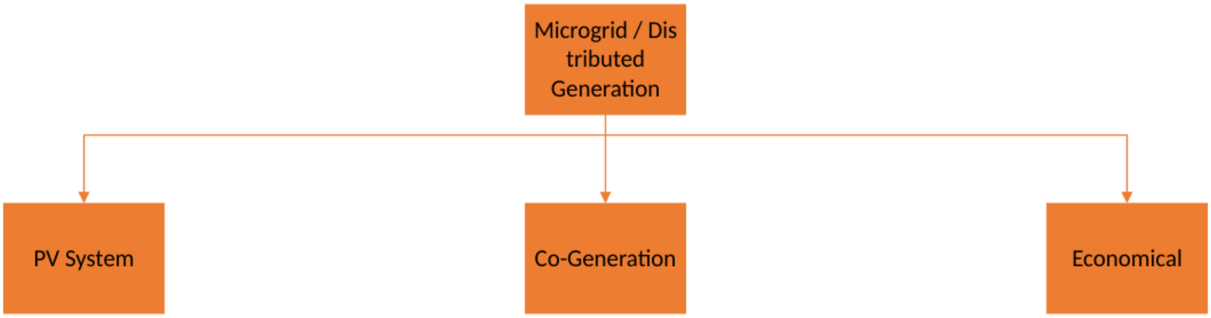


Figure 1.1: System Block Diagram Part 1

Section 1.3: Interface Sub-System Architecture

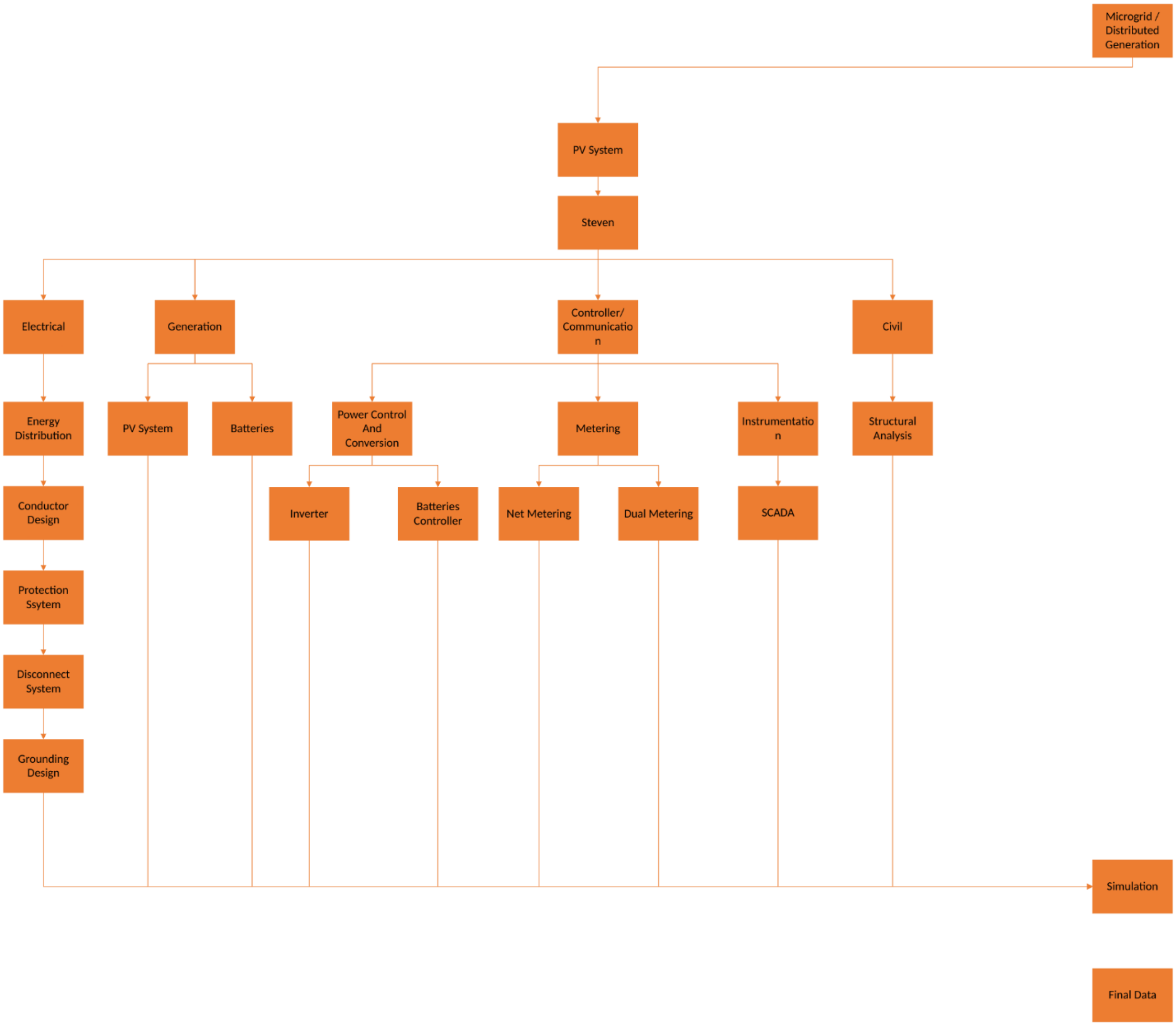


Figure 1.2: System Block Diagram Part 2

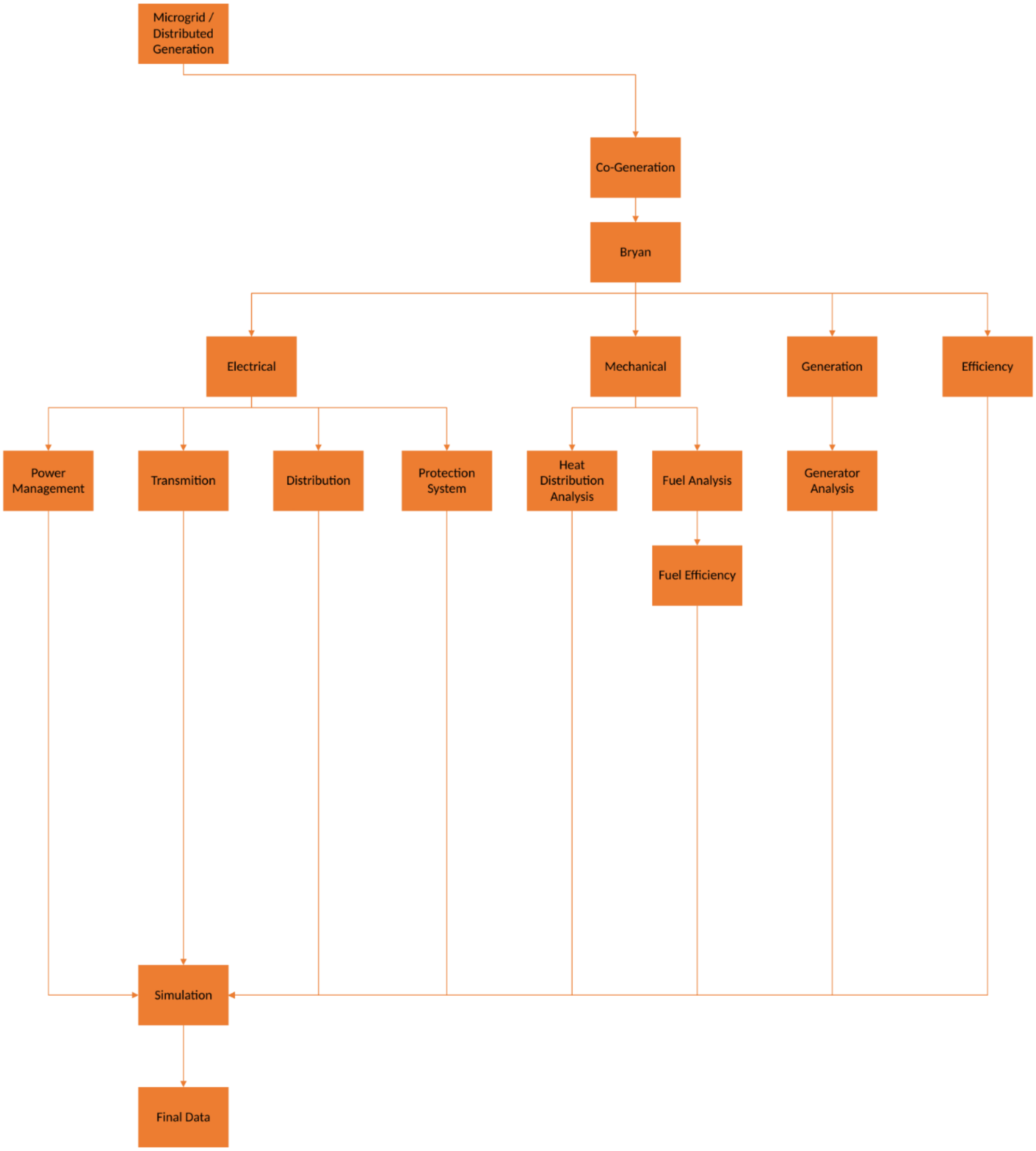


Figure 1.3: System Block Diagram Part 3

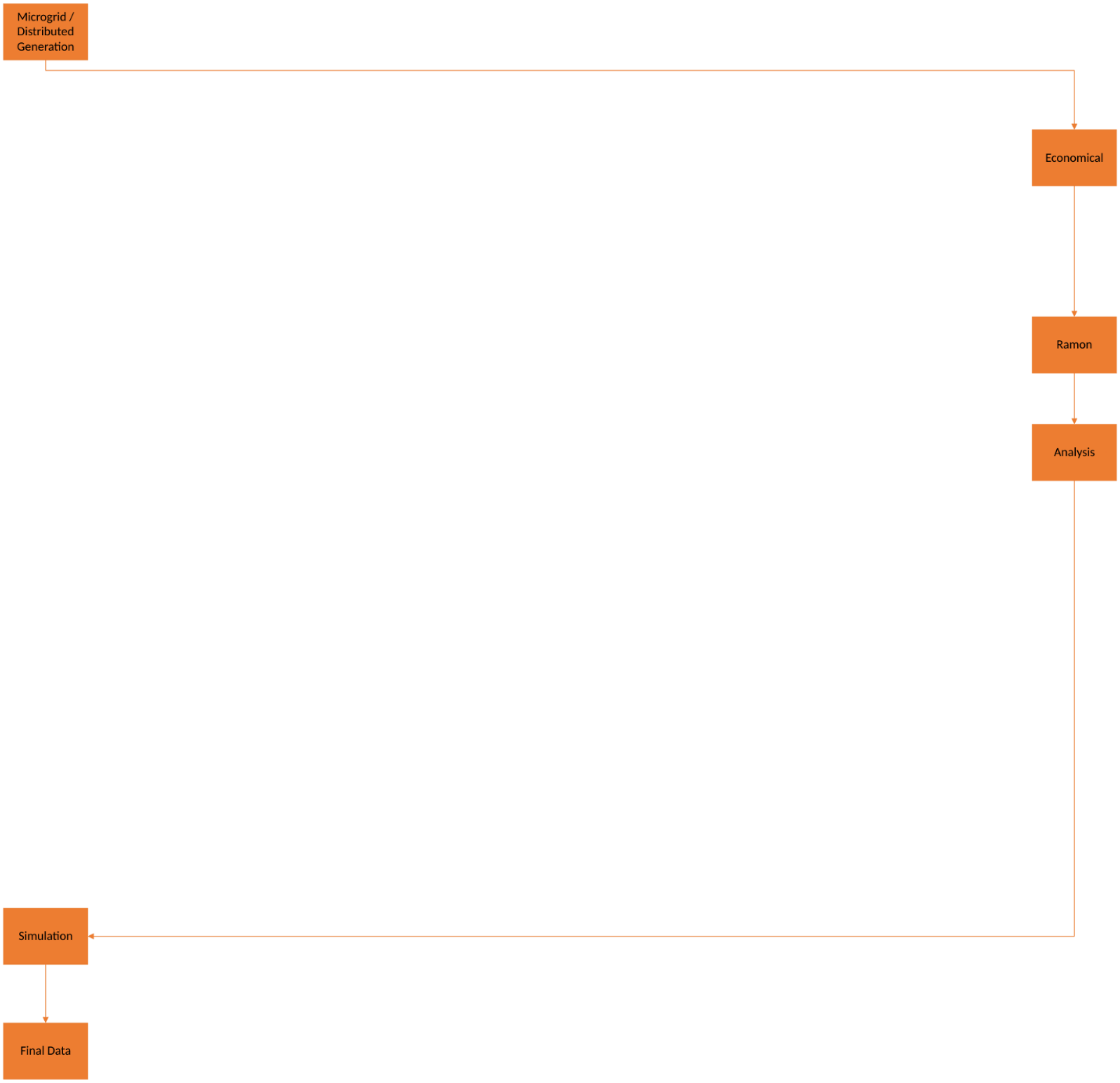


Figure 1.4: System Block Diagram Part 4

Section 1.4 Introduction

Evertec, a frontrunner in the financial technology industry of Puerto Rico, is a leader in transaction processing and payment services. Evertec, which was founded in 2004 and offers a vast array of services including merchant acquiring, payment processing, and business process outsourcing, has experienced substantial expansion. The organization has significantly contributed to the modernization of Puerto Rico's financial infrastructure by providing novel payment alternatives that are specifically designed to cater to the demands of indigenous enterprises and customers. In addition to expanding its presence in Puerto Rico, Evertec now provides services to consumers throughout Latin America and the Caribbean. Throughout its existence, Evertec has exhibited remarkable fortitude in the face of natural calamities and economic adversity, thereby preserving its status as a dominant entity within the financial services sector of the region.

The photovoltaic (PV) sector has undergone significant expansion and evolution in recent times, propelled by cost reductions, technological progress, and heightened environmental consciousness. A substantial increase in photovoltaic (PV) installations has occurred on a global scale since the mid-2010s. This surge has been propelled by governments worldwide establishing ambitious renewable energy targets, supportive policies, and incentives. China has established itself as a chief contender in the manufacturing and implementation of photovoltaics, contributing significantly to the worldwide output and installations of PV systems. Furthermore, significant expansion has been observed in the solar markets of European nations, the United States, and India, where utility-scale solar projects are progressively gaining competitiveness vis-à-vis conventional energy sources. Progress in energy storage technologies, bifacial modules, and floating solar installations have all contributed to the expansion of PV systems' potential applications and overall efficacy. Furthermore, the proliferation of solar power purchase agreements (PPAs) and corporate dedications to sustainability have expedited the installation of PV systems in industrial and commercial sectors. Consequently, solar energy has emerged as a rapidly expanding electricity source on a global scale, assuming a pivotal function in endeavors to alleviate climate change and facilitate the shift towards a more sustainable energy paradigm.

Co-generation systems, alternatively referred to as combined heat and power (CHP) systems, have garnered growing interest in recent times due to their environmental friendliness and efficiency in energy production. Growing concerns regarding energy efficiency, sustainability, and the reduction of greenhouse gas emissions have propelled the implementation of co-generation technology. Co-generation systems have been adopted by institutions, businesses, and industries across the globe to generate electricity and practical thermal energy, such as steam or hot water, concurrently from a single fuel source, which is frequently biomass or natural gas. This methodology facilitates substantial decreases in energy usage and greenhouse gas emissions in comparison to the conventional practice of generating electricity and heat independently. Advancements in co-generation technologies and government policies that encourage energy efficiency and renewable energy have contributed to the extensive implementation of combined heat and power (CHP) systems across multiple sectors. Moreover, the incorporation of sustainable energy sources, including thermal solar and biomass, into cogeneration systems has significantly augmented their ecological advantages and played a role in their expanding adoption across developed and developing nations. With the increasing emphasis on sustainability, it is anticipated that co-generation systems will assume a pivotal function in facilitating the shift towards an energy infrastructure that is both more resilient and low carbon.

The examination of a micro-grid system comprising photovoltaic (PV) systems, cogeneration units, and interaction with the utility system of Puerto Rico necessitates a comprehensive methodology that includes fuel evaluation, economic analysis, and system performance assessment. To begin with, it is critical to perform an economic analysis to ascertain the microgrid system's feasibility and financial viability. This entails evaluating the initial investment requirements for the installation of photovoltaic (PV) systems, cogeneration infrastructure, energy storage solutions, and distribution networks. In addition, it is imperative to consider operational expenditures such as fuel procurement, maintenance, and grid interconnection fees. By employing financial modeling methodologies, including the computation of payback period, internal rate of return (IRR), and net present value (NPV), valuable insights can be obtained regarding the prospective long-term economic advantages and returns on investment. Moreover, the economic analysis can be enhanced by considering revenue streams such as electricity sales to the utility, participation in demand response programs, and incentives like tax credits or feed-in tariffs. This information empowers stakeholders to make well-informed decisions concerning the financing and execution of the project.

Likewise, it is critical to assess various fuel alternatives for the cogeneration system to maximize environmental sustainability, cost-effectiveness, and energy efficiency. Natural gas, diesel, biomass, and biogas are all viable fuel alternatives that warrant consideration, each possessing distinct merits and demerits. An exhaustive evaluation should be conducted of variables including fuel availability, price volatility, emissions profile, and regulatory compliance. Furthermore, an investigation into waste heat recovery technologies and renewable fuel sources has the potential to bolster the cogeneration system's sustainability and resilience. This could entail a diminished dependence on fossil fuels and the mitigation of environmental repercussions. By incorporating fuel flexibility into the design of the system, one can effectively respond to evolving market conditions and regulatory demands, thereby guaranteeing sustained viability and competitiveness.

Furthermore, it is imperative to evaluate the micro-grid system's performance to enhance its functionality, dependability, and robustness. This entails analyzing the PV systems' and cogeneration units' electricity generation capacity, energy output, and efficiency across a range of operational scenarios and conditions. Proficient modeling and simulation tools empower stakeholders to replicate diverse weather patterns, demand profiles, and grid interactions, thereby furnishing valuable insights into the behavior and performance of the system. Furthermore, the assessment of grid integration functionalities, encompassing interconnection prerequisites, voltage regulation, and frequency control, guarantees a smooth and uninterrupted exchange with the utility system of Puerto Rico, all the while preserving the stability and dependability of the grid. In addition, the evaluation of the system's capacity to withstand potential disturbances, including equipment malfunctions and severe weather, assists in the development of contingency plans and mitigation strategies that reduce operational risks and downtime.

It is crucial to conduct a comprehensive evaluation of the micro-grid system, which should include fuel, economic, and performance factors, to ensure that its design, operation, and economic feasibility are optimized. Through the application of data-driven insights and the integration of stakeholder input, policymakers can formulate resilient and sustainable micro-grid deployment strategies that not only fulfill Puerto Rico's energy requirements but foster economic expansion and environmental stewardship.

Section 1.5 Objectives

Research

- Acquire basic knowledge of how microgrid systems work.
- Research Photovoltaic systems and Co-generation plant.
- Explore electrical and mechanical instrumentation to integrate in the microgrid.
- Discover electrical instrumentation to be implemented on the Micro Grid system.
- Learn about safety tests to be performed on site.
- Research protection equipment.
- Determine whether cogeneration and/or PV systems is a feasible option.
- Analyze previous cogeneration Project done in Evertec local.
- Study the communication and control techniques used in PV systems.
- Acknowledge the contribution of civil and mechanical engineering to PV systems.
- Categorize different standards that may apply to different disciplines in PV systems and cogeneration.

Understanding

- Understand Micro Grid systems.
- Explain the type of PV system that will help the client the most.
- Illustrate how to operate each electrical equipment for backup and protection system.
- Recognizing how photovoltaic systems communicate and manage their operations.
- Understanding the jobs performed by civil and mechanical disciplines on PV systems and cogeneration.
- Outline any standard, requirement, and safety regulation for different disciplines.
- Acknowledge the process of design.

- Implement software solutions for integrating and managing different electrical sources such as PV systems and cogeneration.

Calculation

- Compute the potential annual cost savings that cogeneration and PV systems can offer.
- Simulate the Microgrid design to avoid any errors or complications and prove the real situation with security parameters.

- Perform load analysis.
- Determine system sizing and equipment.
- Estimate costs for Project.
- Analyze fuel options for cogeneration.
- Inspect the performance data of cogeneration to ensure it meets efficiency and output targets.

Design

- Develop a procedure and planning for system development.
- Simulate a Microgrid that utilizes PV system and cogeneration.
- Utilize simulation results to prove viability of PV system and cogeneration on the Microgrid.
- Design a plan for connecting the cogeneration plant to the utility grid.

Section 1.6 Realistic Constraints

Economical:

- The design of the system should be cost-effective for the client budget specifications.
- Given the specified financial constraints of the client, the company should meet the goals from the design and being able to implement the system.
- Upon establishing the budget, it is crucial to manage and ensure the equipment selection durability, effectiveness, and high quality.

Design:

- Must not depend only on one system to operate. Multiple systems interconnected with each other to prevent any accident from shutting down the entire system, as if one goes offline, other backs it up.
- In case the independent systems fail, the grid will be connected to the system as the last option to prevent a complete electric disconnection of the structure.
- The instructions and descriptions will be included in the system design and presented clearly and straightforwardly.
- For precision and reliability, the drawings, designs, and models for the project will be handwritten and written on a computer.

Equipment:

- Wiring
- Manufactured specifications
- High quality

Safety:

- All Health and safety regulation standards given by OSHA's to be implemented in the workplace and everything.
- IEEE Standards for all the Electrical equipment and installation.
- NEC (National Electrical Code) regulations for any electrical component.
- Proper grounding.
- Calibration, test, and simulations before any installation.

Environmental:

- Must not obstruct public spaces where people can be exposed to any accident due to the installed system.
- Ecofriendly.
- The place selected to be installed the system should be suitable, monitored, and meet any standards by law, safety for the environment, facility visits and the community surrounding, and for the constant weather around the installation.

Social:

- Only certified personnel will be able to handle the equipment.

Section 1.7 Multidisciplinary Aspects

Microgrid/Distributed Generation:

- Electrical
- Mechanical
- Civil/Structural
- Control & Communication
- Thermal
- Generation
- Project Management

Standards: The standards to follow within the design, which will be written below, are intended to ensure protection regarding the risks that may cause any accident and compromise the life of an individual in the installation. Consequently, to increase the reliability and safety of the design.

Electrical

- Power Generation and Distribution Systems
- Energy Distribution
- Communication System
- Transmission
- Conductor Design
- Disconnect System
- Grounding Design
- Protection System
- Software:

    - LTspice
    - AutoCAD
    - CogenS

Mechanical

- Heat Distribution Analysis
- Fuel Analysis
- Fuel Efficiency

Civil/Structural

- Structural Analysis.

Control & Communication

- Control System
- Metering
- Power Control & Conversion
- Instrumentation
- Inverter
- Batteries Controller
- Software:
    - SCADA
    - AutoCAD

Thermal Engineering

- Heat recovery, utilization, and exchanger efficiency.
- Thermal Storage systems

Generation

- Generator Analysis
- PV System
- Cogeneration System
- Batteries

Project Management

  - Office 365: an office suite with software like Word and PowerPoint to write documents and make presentations.
- Electrical Design and Calculation:
  - CableCalc Pro: For sizing cables according to various international standards.
- HVAC Specific:
  - Carrier HAP (Hourly Analysis Program): A tool for HVAC system design and analysis.
  - Trane TRACE 700: For designing and analyzing HVAC systems and conducting energy and economic analysis.

Software

- CAD Software:
- AutoCAD Electrical: Widely used for creating and editing electrical control systems.
- Simulation and Modeling:
  - MATLAB and Simulink: Highly regarded for system simulation for energy systems modeling.
- Electrical Power Systems Analysis:
  - ETAP: Industry-standard for power system modeling, analysis, simulation, and optimization.
- Renewable Energy and Co-Generation modeling Analysis:

  - HOMER Pro: Specialized in microgrid and distributed generation modeling, optimizing energy choices including cogeneration.

Relevant standards for each discipline:

Electrical Engineering for Cogeneration and PV Systems:

- IEEE 1547: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- IEEE 519: IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
- IEEE 142 - IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems
- IEEE 1100 - IEEE Recommended Practice for Powering and Grounding Electronic Equipment
- NFPA 70 (NEC) - National Electrical Code for electrical safety.
- NEPA 70E – Electrical Safety in the Workplace (Arc Flash Protection).

Mechanical Engineering for Cogeneration and PV Systems:

- ASHRAE 62.1-2016 - Ventilation for Acceptable Indoor Air Quality.
- ANSI/ASHRAE 15-2016 - Safety Standard for Refrigeration Systems.
- API RP 1604-1996 and API RP 1615-2011 - Recommended practices for the closure and installation of underground petroleum storage tanks.
- API 614 - Lubrication, Shaft-Sealing, and Control-Oil Systems and Auxiliaries for Petroleum, Chemical, and Gas Industry Services.
- ISO 14031 - Environmental Performance Evaluation

Civil/Structural Engineering for Cogeneration and PV Systems:

- ACI 318 - Building Code Requirements for Structural Concrete.
- AISC 360 - Specification for Structural Steel Buildings.

- NEC 690 – Solar Photovoltaic System

Control & Communication

- IEC 61131-3: This is the most well-known and widely adopted standard for PLC programming languages. It defines the syntax and semantics for a suite of programming languages including Ladder Diagram (LD), Function Block Diagram (FBD), Structured Text (ST), Instruction List (IL), and Sequential Function Charts (SFC).
- IEC 61800-5-1 is crucial as it outlines the safety requirements for adjustable speed drives.
- IEEE 1547: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.
- IEEE 519: IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.
- IEEE 1547.1, Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.
- IEEE 1547.2, Application Guide for IEEE Standard 1547, Standard for Interconnecting. Distributed Resources with Electric Power Systems.
- NEC 705 – Interconnected Electric Power Production Sources.
- UL 1741, Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources.

Thermal Engineering for Cogeneration and PV Systems

- ASHRAE 55-2010 - Thermal Environmental Conditions for Human Occupancy.
- ASHRAE 188 - Legionellosis: Risk Management for Building Water Systems.
- ISO 16814 - Thermal Performance and Condensation Risk Assessment.

Generation for Cogeneration and PV systems

- IEC 62093:2005: Balance-of-System Components for Photovoltaic Systems - Design Qualification Natural Environments

- IEC 62109-1:2010: Safety of Power Converters for Use in Photovoltaic Power Systems - Part 1: General requirements
- IEC 62109-2:2011: Safety of Power Converters for Use in Photovoltaic Power Systems - Part 2: Requirements for inverters
- IEC 62446-1:2016: Photovoltaic (PV) Systems - Requirements for Testing, Documentation, and Maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection.
- IEC 60269-6 ed1.0: Low-Voltage Fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
- IEC 61727 ed2.0: Photovoltaic (PV) systems - Characteristics of the Utility Interface

Procedure for Project Implementation

Research

- Obtain information on how Micro Grid systems work.
- Investigate Co-Generation and Photo Voltaic systems.
- Define utility generation and understanding how it works.
- Identify possible electrical instruments that may be used on the Micro Grid system.
- Survey software applications to be used in the Micro Grid system.
- Inspect possible electrical protection equipment for the local
- Study about protection system and operation equipment for PV systems and cogeneration.
- Discover what fuel source is best for cogeneration.
- Study electrical system designing fundamental concepts.

Understanding

- Determine the scope, scale, and objectives of the project.
- Understand the purpose of a Micro Grid system and how it works.
- Decide which electrical instrumentation will be used.
- Learn how to manage and use software for project implementation.

- Select electrical protection equipment for the local.
- Examine safety tests that can be performed on Micro Grid systems.
- Revise PV system control and communication.
- Interpret electrical system designing application.
- Secure a reliable and consistent fuel supply, whether it's natural gas, biomass, coal, or other.
- Ensure control equipment is professionally installed and operational.
- Apply electrical system designing fundamentals.

Calculations

- Analize cogeneration and PV system design for the site
- Utilize previous cogeneration results for the Micro Grid system.
- Make use of chosen software applications to corroborate expected results.
- Experiment with safety tests on the Microgrid system.
- Economic analysis.
- Efficiency analysis.
- Determine back-up system magnitude necessary for load demand.

Design

- Provide all and any documentation required and written reports of project process and status.
- Perform simulation of the system created.
- Elaborate system structure and planning for design process.
- Select equipment and components based on calculation results.
- Use performance data to identify opportunities for optimization and cost reduction for the Microgrid.

Budget

Licenses	**License Cost ($)**	**Amount per employee**	**Amount of time (monthly)**	**Total Price ($)**
Helioscope	159.00	3	6	2,862.00
Homer	60	3	6	1,080
Microsoft Office 365	99.99	3	6	299.97
Auto CAD	---	3	6	6,090.00

Table 1.1: Budget Table 1

Micro-Grid System Analysis Design			
Total Employees	Salary per Hour	Minimum Week Hours	Total Weeks
4	30	5	32
Total Salary per employee			
4800			

Table 1.2: Budget Table 2

Chapter 2: Renewable Energy and Sustainable Energy

Section 2.1: Definitions of Renewable and Sustainable Energy

Renewable energy is defined as power generated from self-renewing natural resources that do not deplete over brief periods of time. In contrast to fossil fuels including oil, coal, and natural gas, these resources undergo ongoing restoration. Renewable energy sources are regarded as more ecologically sustainable due to their reduced contaminant emissions and contribution to the mitigation of greenhouse gas emissions, which are prominent contributors to climate change.

Solar energy is generated when sunlight is converted into heat or electricity through solar panels. Another form is with wind turbines that generate electricity using the kinetic energy of the wind. Hydropower, known as waterpower, generates electricity through water in dams, streams, rivers, or other channels. Applied more to agriculture and farming, biomass generates energy through organic materials such as waste, biomass, and agricultural commodities are burnt or converted into biofuels. Finaly, geothermal energy generates electricity and cools and preheats structures by utilizing heat contained beneath the earth's surface. Utilizing the energy generated by the tides in oceans and waters to produce electricity is tidal energy.

The broader notion of sustainable energy encompasses not solely the production of energy from renewable sources, but the judicious and effective utilization of energy. It prioritizes the fulfillment of current requirements while safeguarding the capacity of forthcoming generations to fulfill their own needs. Sustainable energy encompasses not only renewable energy sources, but resource management, long-term availability, and energy efficiency.

While all renewable energy is, at its core, sustainable, not all sustainable energy practices are founded exclusively on renewable sources. The objectives of sustainable energy practices are to mitigate adverse environmental effects, foster energy security, and guarantee social and economic stability.

Chapter 3: PV System

Section 3.1: PV System Electrical

Photovoltaic (PV) systems are a cutting-edge technological advancement utilized for the direct conversion of solar energy into electrical power. The performance is an essential role in the implementation of solar energy, which is regarded as one of the most plentiful and ecologically sustainable types of renewable energy. An exhaustive examination of PV systems is provided below, encompassing their operation, effectiveness, components, and additional aspects.

PV systems consist of various components that facilitate solar energy conversion into electrical energy. These systems are powered by photovoltaic cells, which are semiconductor devices that generate electricity through the photovoltaic effect when exposed to sunlight. Silicon, due to its widespread availability and favorable semiconductor characteristics, is commonly employed in the fabrication of these cells.

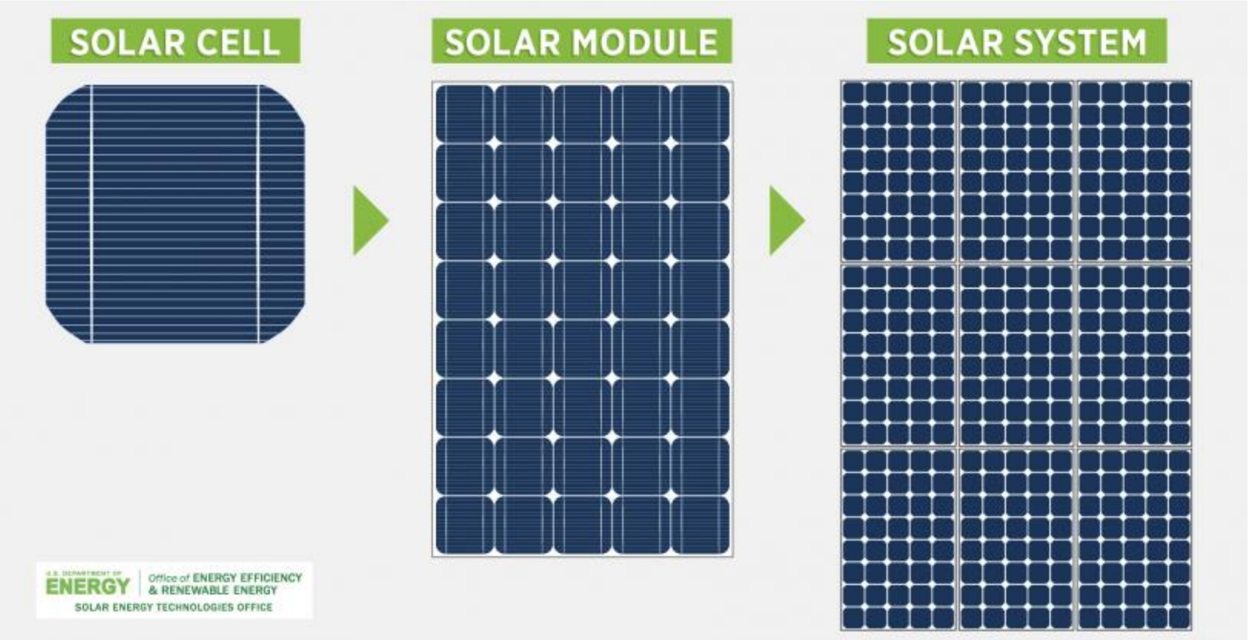


Figure 3.1: Photovoltaic Cells

To enhance the output beyond the modest quantity of electrical energy typically generated by a single PV cell, modules are formed by combining cells in series and parallel. Through the integration of multiple modules (or panels) into an array, it is possible to achieve the desired output for a specific application, such as providing power to an individual device or the nationwide grid.

Section 3.2: PV System Distributed Generation

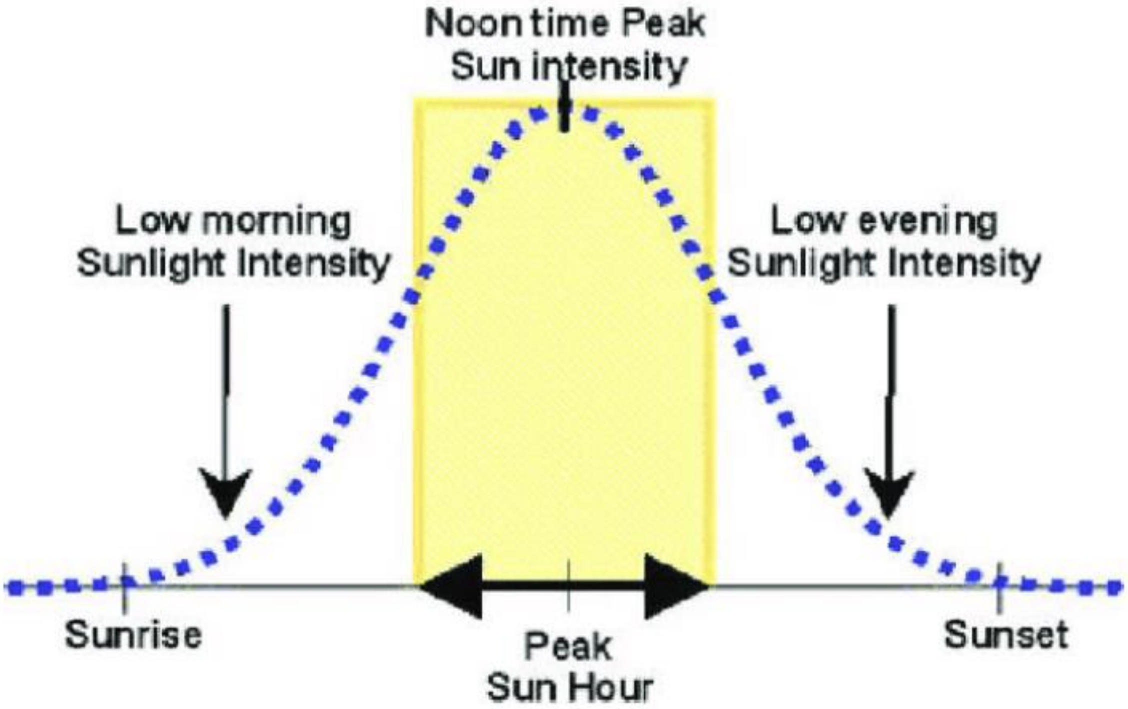


Figure 3.2: Peak Sun Hour

Every photovoltaic (PV) cell is equipped with a layer of semiconductor material designed to absorb solar radiation. This process energizes electrons, resulting in their liberation from their atomic counterparts. The voltage produced by the attraction of free electrons to a particular terminal of the cell is sufficient to drive an electric current through an external circuit. The electric current produced by photovoltaic panels is direct current (DC). An inverter converts direct current (DC) to alternating current (AC), used by the utility and most residences. After undergoing a transformation to alternating current, the generated electricity can be stored for subsequent utilization, supplied to household appliances, or integrated into the electrical grid. Efficiency is defined within the domain of photovoltaic (PV) systems as the proportion of electrical power produced in relation to the input of solar energy. Typically, commercial PV systems exhibit efficiencies ranging from 15% to over 22%, contingent upon the specific type of PV cell employed. System efficiency is influenced by numerous factors, including system configuration, environmental conditions (such as temperature and insolation), cell type (e.g., monocrystalline, polycrystalline, thin film), and losses resulting from inverter conversion, shading, and soiling.

Regarding photovoltaic systems to be included into a microgrid, systems must several components as described in figure 3.3.

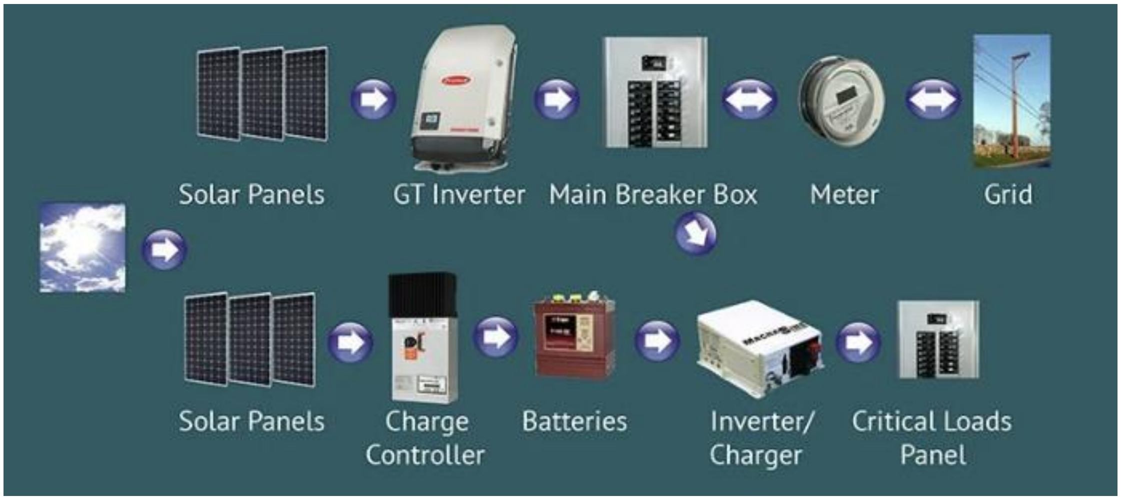


Figure 3.3: PV System Components

1. PV panels for the capture of solar radiation.
2. Inverter converts DC to AC.
3. Batteries preserve excess energy for back up.
4. Charge Controller evaluates and rates battery electric current charge and discharge.
5. Infrastructure Interconnection Equipment enables the prospective connection of the system to the utility infrastructure.
6. Monitoring and Control System develops a framework to oversee operational efficiency and optimize configurations.

Section 3.3: Site Assessment and Selection

For the most important part of the civil aspects in any photovoltaic system project, is the selection of the right location in which the system will be installed. Civil engineers have a vital role for this section, to implement the system correctly in the correct place. The ideal objective is to install the photovoltaic system in a location where the solar exposure is optimal, with minimal shading and sufficient space for the solar panels array.

Factors to be considered:

1. Topography – Scoping out the terrain of the potential project, to decide if it is feasible for solar panel installation. Uneven terrain requires grading, which will increase costs and overruns. In addition, areas in the location selected which cannot be used will reduce the power capacity anticipated and end up altering the economics of the project.
2. Soil Conditions – Mixture of soil and rock evaluation can make an arduous process when hammering the piles of the mounting structures, which is the most cost-effective solution. If the evaluation of this mixture in the place where it will be installed is not made, it can extend the time it takes to complete the project and can increase the cost beyond the budget established.
3. Solar Irradiance – The level of solar irradiance will determine the efficiency of the solar panels installed. Low solar irradiance significantly impacts the power quality of the Photovoltaic system's output.
4. Weather Patterns – When air temperature or cloud cover increases, the amount of electricity generated by the solar panels declines. This system implemented; its efficiency is variable due to weather conditions. Therefore, considering the weather patterns where the system will be installed, it is going to determine the efficiency of the electricity generated. Solar panels work best in cool and sunny weather places.
5. Environmental Impacts – By producing clean renewable energy substitutes the traditional power plants electrical generation by burning fuel such as coal, oil, and natural gas; dramatically reducing greenhouse gas emissions.

Figure 3.4: General structure of PV System being installed in a roof.

To ensure with major efficiency that the site where the Photovoltaic System will be located acts in accordance with local regulations and minimizes ecological disruption, civil engineers must collaborate with environmental experts.

Section 3.4: Access and Security

Site Assessment sunlight exposure, shading, and additional environmental factors are evaluated to optimize orientation and placement. Consideration in physical and cyber security for the protection of the system.

Fuse Protection for PV Arrays

Depending on the desired capacity of the Photovoltaic (PV) system, there may be several PV sub-arrays (each subarray consists of multiple strings) connected in parallel to achieve higher currents and subsequently more power.

A fuse link on each sub-array will protect the conductors from current faults and help minimize any safety hazards. Additionally, it will isolate the faulted sub-array so that the rest of the PV system can continue to generate electricity. If several sub-arrays are combined, a further fuse link should be incorporated. A range of NH size fuse links specifically designed for protecting and isolating photovoltaic array combiners and disconnects. These fuse links are capable of interrupting low over currents associated with faulted PV systems (reverse current, multi-array fault).

It should be remembered that the characteristics of PV modules vary with module temperature as well as irradiance level. In operation, fuse links are influenced by ambient temperature.

Figure 3.5: PV modules

Section 3.5: Mounting System

When it comes to installing solar panels, it is vital that it is specified and installed correctly. An inspection is to discard any leak in the roof or any imperfection that could result in solar modules to be insecurely attached.

Trusted mounted solutions for all different roof types:

1. **On Tiled Roofs**

Figure 3.6: Roof Tilted Mount

The installers must slide up the tiles to reveal the wooden roof joists underneath. A U-shaped hook screws into the joist, then the tiles slide back down over the hook, this way it will make the roof completely waterproof. Rails running across the roof are bolted to the protruding hooks, and the solar panels are bolted on to these rails.

2. **On Slate Roofs**

Figure 3.7: PV Mount

Solar panels are installed on slate roofs using solar limpets. First, the team drills through the slate to the rafters and seals these points to avoid leaks. The limpets are then screwed into place. Rails are attached across these limpets with bolts, and solar panels are mounted onto the rails using adjustable brackets for precise alignment.

3. **Roof Mount (Without Penetration)**

Figure 3.8: Solar Roof Panel with no Penetration of cement

Mounting systems for in-roof solar panels offer an appealing solution by integrating the panels to reach perfect alignment with the existing roof line. These systems are adaptable to various roof pitches, ranging from 12 to 50 degrees, and can accommodate panels in either a landscape or portrait orientation. For new constructions, it's possible to leave out tiling in the section designated for solar panels. A waterproof tray is placed in this tile-free zone to prevent water ingress, and the solar modules are subsequently installed atop the tray.

4. **South Facing on Flat Roof**

Figure 3.9: PV Mounts South Facing

Installing solar panels on a south-facing flat roof, it is set by employing a ballasted system that does not penetrate the roof, preventing water damage and ensuring stability against wind. Pre-assembled triangular frames supported by aluminum are used, with about 500mm (about half the length of a baseball bat) spacing between panels to avoid shading. Weights are added under the panels for firm anchorage before bolting securely to the frames.

5. **East/West Facing on Flat Roof**

Figure 3.10: East/West Facing Solar Panels

An east-west (E/W) solar panel system on flat roofs optimizes space by placing panels back-to-back, allowing for more panels without requiring large gaps between them. This layout yields about 85% efficiency but benefits from economies of scale, often improving investment returns compared to south-facing arrays. Additionally, the compact arrangement reduces ballast needs because the design minimizes wind exposure.

6. **Pole Mount**

Figure 3.11: Pole Mount PV Matrix

It is common in public areas where enough space is available. The advantage of this set of modules, since it is elevated, it is much better when it comes to cooling the plates, since the system can reach extremely elevated temperatures during the day, even overpassing excess heat on the plates. It has easy access for maintenance and troubleshooting but can be vulnerable to theft, vandalism, and potential damage. Flexible positioning, easy to adjust tilt angle (for dual axis tracking is possible) but requires construction.

7. **Ground Mounted**

Figure 3.12: Ground Mounted Solar Panels

If your roof is not suitable for solar PV but you have available land, ground-mounted solar can be an excellent alternative for generating electricity. Metal frames are anchored into the ground using metal screws, which support the solar panels at a predetermined angle. The panels are then affixed to this sturdy frame.

- **Solar Carport**

Figure 3.13: Solar Carport

A parking space canopy with solar panels attached to the top do not require an acquisition of new land or to take up space on a roof; carports can be built in most open parking lots. The main cons are the need to build a new structure, the installation cost may be double that of a non-solar carport installation. For the benefits, effective space utilization, reduce energy expenses, protects cars from the elements, EV charger (if wanted), simple to maintain, and increase the value of your investment (ROI). Typically, the payback period is between 5 to 15 years.

8. **Green Roofs**

Figure 3.14: Green Roof Solar Panels

Before installing a green turf roof, a waterproof single ply membrane is applied. The system's base, consisting of plastic plates, is then positioned, followed by metal upstands. Soil is spread over these plates to serve both as ballast for the solar PV system and as a substrate for plant growth. Finally, rails and panels are mounted onto the metal upstands.

9. **Glass Laminates**

Figure 3.15: Glass Laminated Solar Panels

Solar cells can be sandwiched between two glass sheets rather than being assembled into a module with a plastic back. This spacing allows 10-20% of light to pass through, making it an excellent choice for structures like conservatories, walkways, atria, and upscale office buildings. Additionally, this solar glass helps in passive temperature regulation by blocking a significant amount of the sun's heat during summer.

Section 3.6: Structural Analysis

Structural Analysis is part of the engineering process for a rooftop solar project and is critical due to the outcome of the project which can make or break its feasibility and could have significant effects on the system cost and size of racking. After knowing the capacity and all details about the capacity of the current roof framing elements and if necessary, do the laboratory tests, then it can be concluded that the Array can be accommodated in the desired area.

Three Main Steps to Determine Structural Feasibility

1. **Capacity of the current roof framing elements:**
    a. **Analyze load carrying capacities:**
        i. For incorporating additional PV System. In an existing building it is more complicated to add more solar panels.
        ii. Detailed information for the roof structural elements, for accuracy in the

evaluation of those elements load carrying capacities.

  b. **Laboratory tests (rare occasions):**
    i. Coupon tests to identify steel grade, for more accurate results.

2. **Racking & Attachment System Selection**
    - **a. Ballasted**

Figure 3.16: Ballasted Configuration

  b. Fully attached

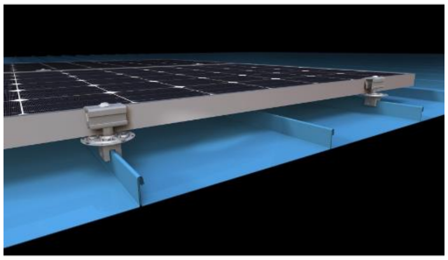


Figure 3.17: Fully Attached Configuration

3. **Roof Structured Feasibility to Accommodate the PV Solar System**

Section 3.7: Structure Loads Analysis

Compliance with municipal regulations, optimization of land utilization, and consideration of ecological impacts are key objectives in zoning and land use.

In structural loads analysis it is considered every detail of any load present. All loads can be named as forces acting on the components of the structure. The success of this analysis will determine the safety and protection of the building with the photovoltaic system installation on it, to avoid any problem in the structure or a failure that could result in an unfortunate tragedy.

Types of Loads:

- **Dead Structural Loads:** Loads that remain still, those that will be always in the place where it was initially built. Such as the floor, the roof, and others.

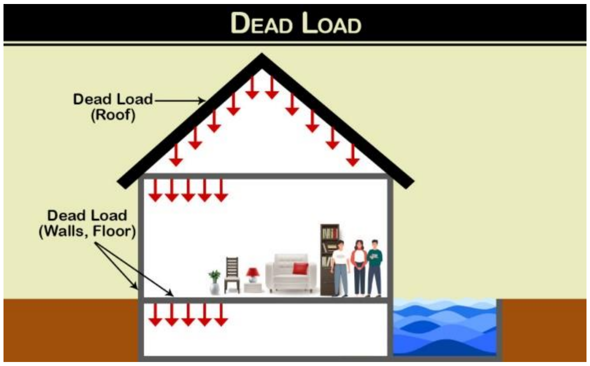


Figure 3.18: Structural Dead Loads. Roof, walls, floor, etc.

- **Live Structural Loads:** Loads that are in movement or can be easily moved (that is not necessary to destroy the building to remove it, like dead loads). This can be people in the structure, furniture, appliances, and others.

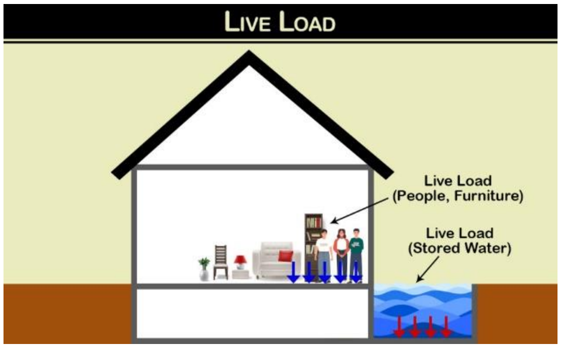


Figure 3.19: Structural Live Loads. People, furniture, appliances, etc.

- **Environmental Loads:** Loads that are not an impact from human hands. Everything that belongs to the environment such as snow, rain, wind, and others.

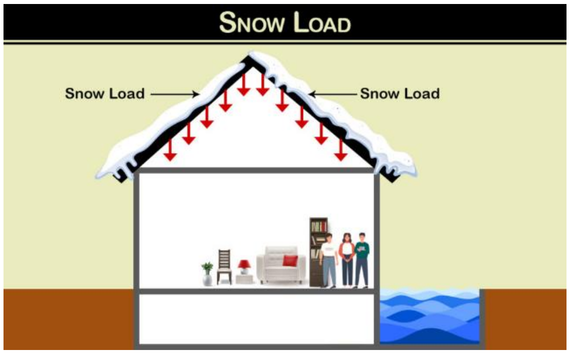


Figure 3.20: Snow Environmental Load.

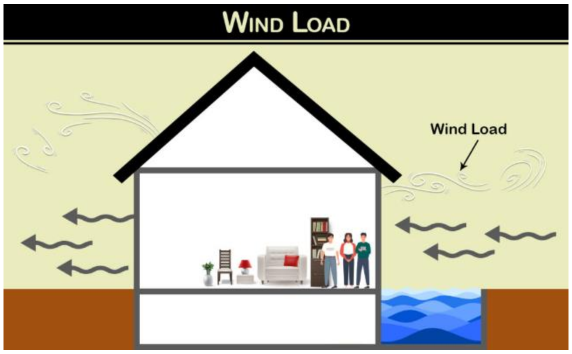


Figure 3.21: Wind Environmental Load.

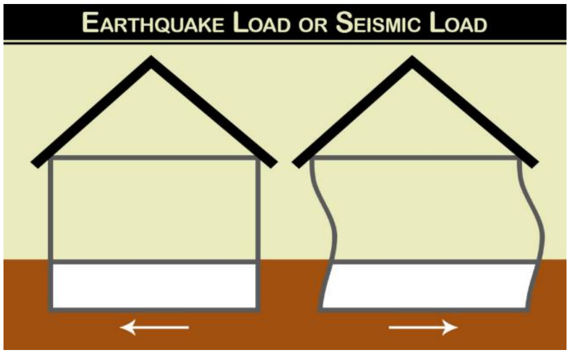


Figure 3.22: Earthquake Environmental Load

- **Concentrated Loads:** Loads that are applied to a specific point or exceedingly small area inside of the whole structure. These loads are called "point load."

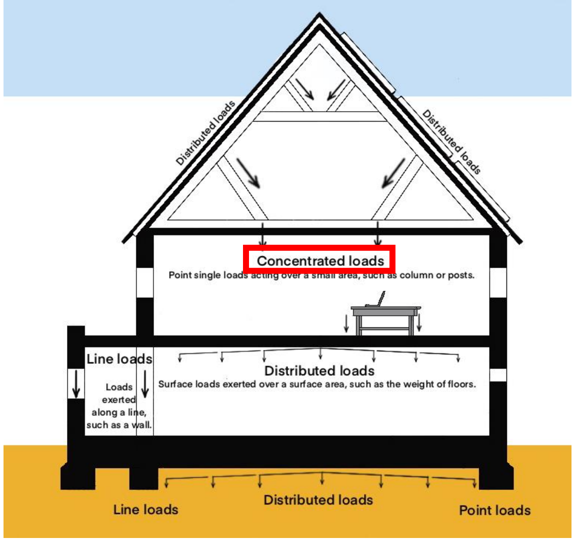


Figure 3.23: Concentrated Load.

- **Line Loads:** Loads that are acting on lines; to apply a line load, a line must already be defined.

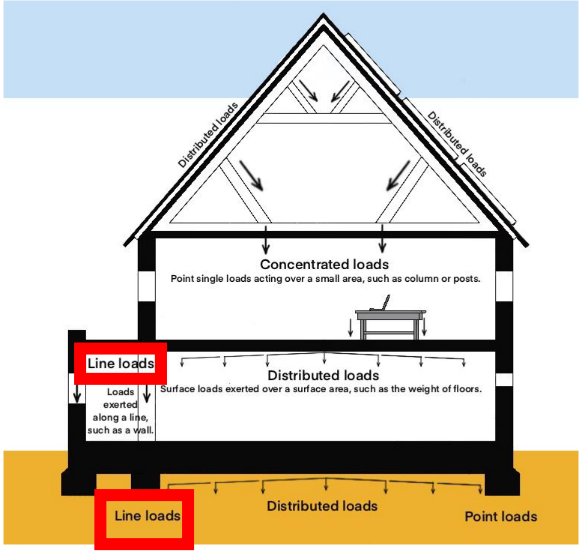


Figure 3.24: Line Load.

- **Distributed Loads:** Loads that are forces which are spread out over a volume, area, or length. Other names for these loads are pressure, weight density, stress and can be the snow in the roof, water, or earth pushing on a surface.

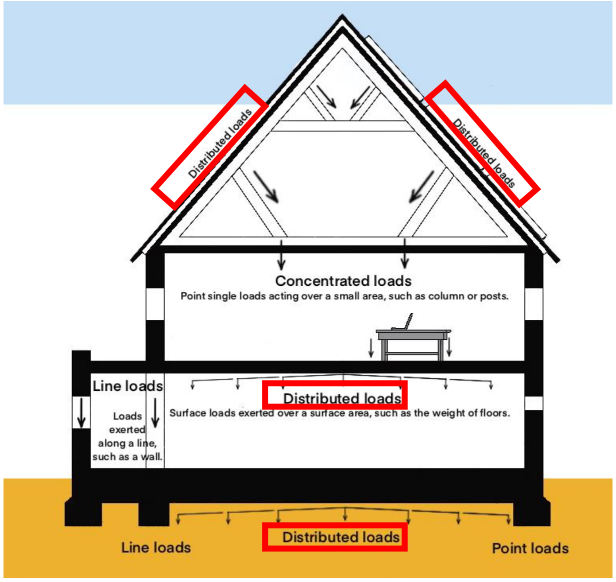


Figure 3.25: Distributed Environmental Load Example

Chapter 4: Co-Generation Electrical

Section 4.1: Power Management

Power management systems (PMS) refer to a set of technologies, processes, and strategies implemented to efficiently manage and control the distribution and consumption of electrical power within various environments. These systems are essential in ensuring that electrical power is utilized optimally, reliably, and safely.

Some key components and functions of power management systems include:

- **Monitoring and Control**: PMS continuously monitor the status of power sources, loads, and distribution networks. Furthermore, PMS facilitate control over various power parameters such as voltage, current, frequency, and power factor.
- **Load Management**: PMS efficiently manage the allocation of electrical power to different loads based on priorities, demand patterns, and available resources. This involves load shedding, load sharing, and load balancing to prevent overloading and ensure stability for the system.
- **Energy Storage and Backup**: PMS often incorporate energy storage systems such as batteries, capacitors, or flywheels to store surplus energy or provide backup power during outages or peak demand periods.
- **Fault Detection and Protection**: PMS employ various mechanisms for detecting faults, abnormalities, and disturbances within the power system. This trigger protective actions such as isolating faulty components, reconfiguring the network, or activating backup sources to prevent damage and ensure continuity of service.
- **Efficiency Optimization**: PMS aim to maximize the efficiency of power generation, transmission, and distribution processes. This involves minimizing losses, improving voltage regulation, reducing idle power consumption, and optimizing the utilization of renewable energy sources.
- **Demand Response**: PMS enable demand response programs where consumers can adjust their electricity usage in response to price signals or grid conditions. This helps to balance supply and demand, alleviate grid congestion, and enhance overall system reliability.
- **Remote Monitoring and Management**: Many modern PMS feature remote monitoring and management capabilities, allowing operators to monitor and control

power systems from a centralized location. This enables real-time decision-making, diagnostics, and troubleshooting, leading to improved operational efficiency and reduced downtime.

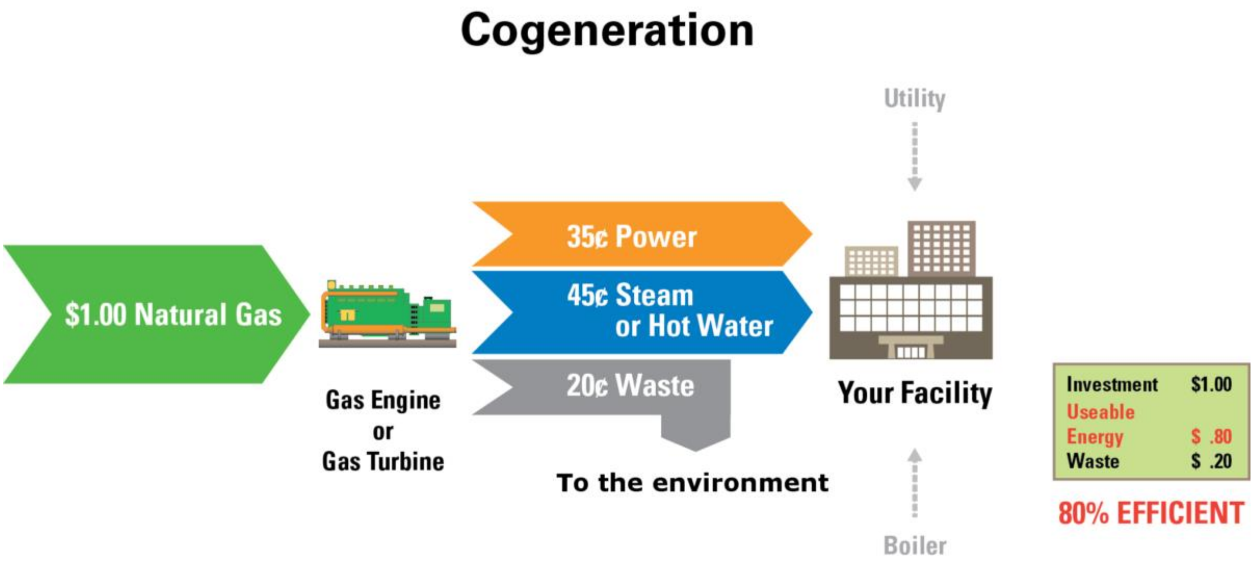


Figure 4.1: Power Management Concept

As shown in figure 8.1, power management systems find applications in various sectors including industrial plants, commercial buildings, data centers, transportation systems, renewable energy installations, and smart grids. The system play a crucial role in ensuring the reliable and sustainable operation of electrical power systems in today's interconnected and dynamic energy landscape, while ensuring better efficiency. The software used for PMS will be SCADA, which is a software used to monitor and manage power systems.

Section 4.2: Transmission

Combined Heat and Power (CHP) transmission is a critical aspect of energy distribution systems, enabling efficient utilization of both electricity and heat generated from a single fuel source. CHP systems typically are comprised of an engine or turbine that drives a generator to produce electricity, with the waste heat captured and repurposed for heating or cooling purposes. Transmission in CHP systems involves transferring electrical power and thermal energy to end-users through electrical grids and district heating networks. This integrated approach enhances overall energy efficiency, reduces greenhouse gas emissions, and optimizes resource utilization. In CHP transmission, advanced control systems ensure seamless coordination between electricity and heat generation, allowing for dynamic adjustments based on demand fluctuations to maximize energy output while minimizing waste.

The materials utilized in CHP transmission infrastructure are selected to withstand the demands of simultaneous electricity and heat transmission while maintaining efficiency and reliability. Electrical transmission components often include high-quality conductors, insulators, and transformers designed to handle the electrical load efficiently and safely. Additionally, heat exchangers, pipes, and insulation materials are employed to transfer thermal energy from the CHP system to end-users with minimal losses. These materials must possess high thermal conductivity, corrosion resistance, and durability to ensure long-term performance and minimize maintenance requirements.

CHP systems use a variety of prime movers to generate power and use excess heat from exhaust or from engines to help in any thermal application needed. A waste heat recovery unit is a heat exchanger that recovers heat from exhaust streams with potential high energy content, such as exhaust gases or from cooling water from a CHP system. A Heat Recovery Steam Generator (HRSG) is a steam boiler that uses hot exhaust gases from gas turbines to heat up water and generate steam. Steam, in turn, drives a steam turbine or is used in commercial applications that require heat. Sometimes a duct burner is used to increase temperatures and improve the quality of the steam from the HRSG.

Figure 4.2: Heat Recovery Steam Generator (HSSG)

Section 4.3: Distribution

CHP (Combined Heat and Power) distribution refers to the process of distributing both heat and electricity generated from a single power source, typically a CHP plant or system. CHP systems, known as cogeneration systems, are designed to simultaneously produce electricity and useful heat from a single fuel source, such as natural gas, biomass, or waste heat from industrial processes.

The distribution of heat and electricity from a CHP system involves several components and considerations which are the following:

- **CHP Plant/System**: This is where the electricity and heat are generated simultaneously. The CHP system could consist of various technologies such as gas turbines, steam turbines, reciprocating engines, or fuel cells.
- **Heat Recovery**: In a CHP system, waste heat generated during electricity production is captured and utilized for heating purposes. This heat can be used for space heating, water heating, industrial processes, or other heating applications.
- **Electricity Distribution**: The electricity generated by the CHP system can be distributed through the electrical grid to end-users, like electricity produced by conventional power plants. Depending on the setup, it may be used on-site or exported to the grid.
- **Heat Distribution**: The heat produced by the CHP system is distributed through a network of pipes to end-users who require heat for various purposes. This could include residential, commercial, or industrial buildings and district heating systems serving multiple customers.
- **Efficiency**: One of the key advantages of CHP systems is their high efficiency compared to separate generation of electricity and heat. By utilizing waste heat that would otherwise be lost, CHP systems can achieve efficiencies of up to 90%, resulting in significant energy savings, reduced greenhouse gas emissions and costs.
- **Economic and Environmental Benefits**: CHP distribution offers various economic and environmental benefits, including reduced energy costs, improved energy security, and lower emissions of greenhouse gases and other pollutants compared to conventional separate heat and power generation.

Overall, CHP distribution plays a crucial role in maximizing the energy efficiency and sustainability of energy systems by capturing and utilizing waste heat for heating purposes while simultaneously generating electricity to other appliances.

Section 4.4: Protection System

Safety is paramount for any type of system, and this section will provide an analysis of the safety aspects of CHP electrical distribution. Some types of protective equipment are the following:

Circuit Breaker:

Circuit breakers are automatic devices which automatically stop the flow of current by opening the circuit. Some key features are:

- Overcurrent Protection: Circuit breakers sense excessive current flow and interrupt the circuit to prevent wiring and equipment and wiring damage.
- Short Circuit Protection: In case of short circuits, circuit breakers quickly cut off power to mitigate potential hazards to equipment and wiring.
- Fault Clearing: Circuit breakers facilitate the isolation and clearing of electrical faults, while helping to troubleshoot electrical problems and minimize downtime.
- Selective Coordination: Coordination among multiple circuit breakers ensures that only the faulty circuit is interrupted, allowing unaffected circuits to remain operational.

Figure 4.3: Circuit Breaker

Surge Arresters

Surge arresters are designed to divert or limit transient voltage spikes or surges that can occur in an electrical system. These surges can result from various sources, including lightning strikes, switching operations, or faults in the power grid. Without surge protection, these voltage spikes can damage or degrade electrical equipment.

Surge arresters operate by providing a low-resistance path for excessive voltage to safely discharge to the ground. When a surge occurs, the surge arrester conducts the excess energy away from the connected equipment and dissipates it harmlessly.

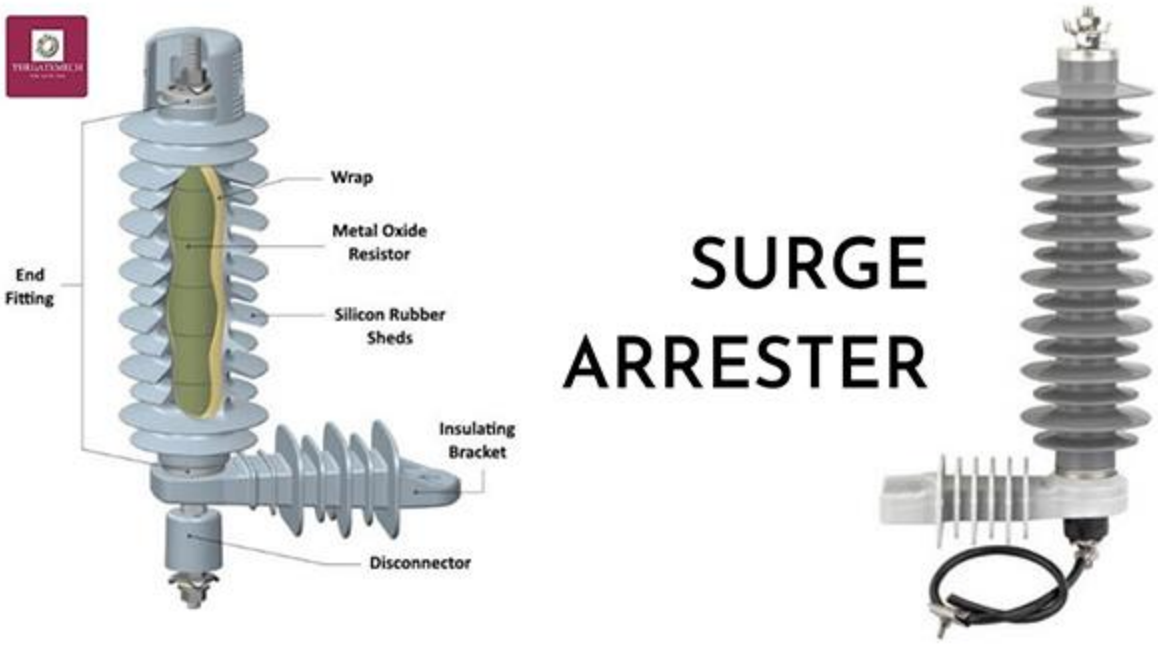


Figure 4.4: Surge Arrester

Fuses

Fuses are protective devices that interrupt electrical circuits by melting a fuse element when exposed to excessive current. Key functions of fuses include:

- Overcurrent Protection: Fuses respond rapidly to overcurrent conditions by melting, thereby opening the circuit and preventing further damage.
- Fault Isolation: Fuses effectively isolate faulty circuits, reducing the risk of electrical fires and equipment damage.

Different types of fuses are shown below, on figure 2.4

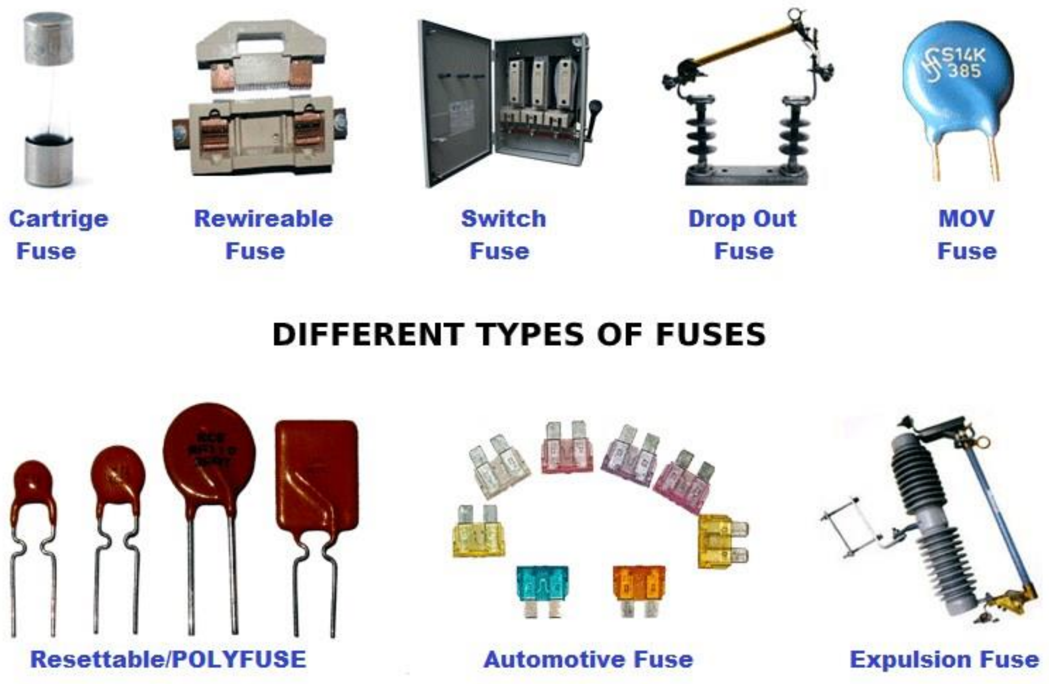


Figure 4.5: Different types of fuses

Grounding

Grounding is a crucial safety measure designed to protect against electrical faults and ensure safety for both people and equipment. Here is how grounding functions:

- **Fault Protection**: Grounding helps to provide a path for fault currents to flow safely away from electrical equipment and into the ground. In the event of a short circuit or other fault, excessive current flows through the grounding system, triggering protective devices such as fuses or circuit breakers to disconnect the power supply and prevent damage or injury.
- **Lightning Protection**: Grounding systems are essential for protecting buildings and equipment from damage caused by lightning strikes. By providing a low-resistance path to the ground, grounding systems help to dissipate the energy from lightning strikes safely into the ground, reducing the risk of fire, electrical damage, or injury.
- **Static Discharge**: Grounding helps to prevent the buildup of static electricity in electrical equipment and conductive materials. By connecting conductive surfaces to

the ground, static charges can be safely discharged, reducing the risk of sparks or electrical hazards.

- **Equipment Safety**: Grounding is essential for ensuring the safety of electrical equipment and appliances. Proper grounding helps to reduce the risk of electric shock by providing a path for fault currents to safely dissipate, preventing the buildup of hazardous voltages on exposed metal surfaces.
- **Noise Reduction**: Grounding can help to reduce electromagnetic interference (EMI) and improve the performance of electrical and electronic equipment. By providing a reference point for electrical signals, grounding helps to minimize unwanted noise and interference, ensuring reliable operation.

An example of grounding of an electrical system is shown in figure 8.6. Grounding works by leveraging the negative electrical properties of the ground. The ground has a negative electrical charge. Therefore, it can neutralize positively charged electricity. Finally, grounding allows excess electricity to safely discharge through the ground.

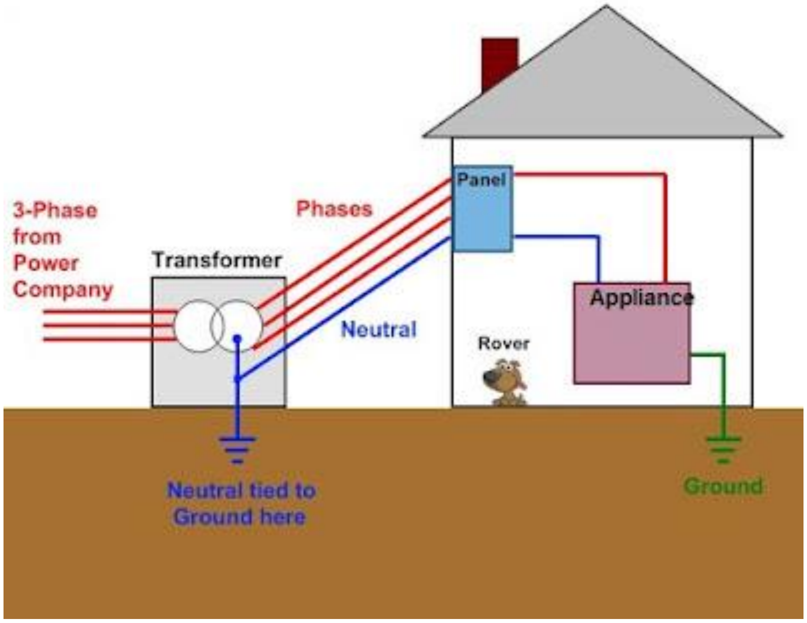


Figure 4.6: Example of grounding an electrical system.

Overall, grounding plays a critical role in electrical equipment protection by providing a safe path for fault currents, dissipating energy from lightning strikes, preventing static buildup, enhancing equipment safety, and reducing electromagnetic interference. Proper grounding practices are essential for maintaining the safety and reliability of all electrical systems.

Chapter 5: Co-Generation Mechanical

Section 5.1: Turbine

The turbine is a crucial component in the cogeneration system's ability to perform efficiently. It acts as the core of the system, primarily transforming thermal energy into mechanical energy, which then gets converted into electrical energy. The effectiveness of this process is essential for the system's overall efficiency and economic feasibility. This section delves into the various turbines used, their essential parts, operational principles, and the maintenance required for optimal performance.

Turbine Types and Their Specific Applications

Different turbines are used based on the cogeneration system’s specific needs. Steam turbines are preferred in high-power applications and are particularly effective in systems designed for waste heat recovery. Gas turbines are chosen for their small size and rapid startup, making them suitable for industries with limited space or where quick changes are necessary. Additionally, combined-cycle turbines, which use both gas and steam turbines in sequence to optimize thermal energy use, are growing in popularity. Choosing the right type of turbine is a critical design decision influenced by the energy source, space limitations, and efficiency goals.

Principal Components and Their Roles

Key parts of a turbine include the blades, rotor, stator, casing, and bearings. Blades are intricately designed to capture and convert thermal energy to mechanical rotation efficiently. The rotor is the central axis that holds the blades and aids in converting thermal to mechanical energy. The stator is a fixed part that directs the steam or gas flow onto the blades. The casing encloses all these parts, providing a controlled environment and acting as a safety feature. Bearings are vital for supporting the rotor and reducing friction, enhancing the efficiency of the motion.

Operational Principles

Turbines work by converting thermal energy into mechanical energy, which a connected generator then converts into electrical energy. For steam turbines, high-pressure steam pushes against the blades, spinning the rotor. In gas turbines, combustion gases have a similar effect. The generated mechanical energy is then transformed into electrical energy by a generator linked to the turbine’s shaft. This conversion is governed by thermodynamics and fluid mechanics principles, and its efficiency depends significantly on the turbine components' design and condition.

Maintenance Protocols for Optimal Performance

Regular maintenance is crucial to maintain optimal turbine performance and prolong its service life. Maintenance involves routine inspections to check blade condition for wear and tear, examining bearings for signs of fatigue or corrosion, and ensuring the casing and stator's integrity. Lubricating the bearings is critical to reduce friction and prevent overheating. Overhaul procedures might include replacing worn or damaged blades, bearings, or other parts. A well-maintained turbine minimizes downtime and maintains peak efficiency.

Section 5.2: Heat Recovery System

In a cogeneration system, known as a combined heat and power (CHP) system, the heat recovery system plays a crucial role by capturing and utilizing waste heat from electricity generation for various heating and cooling uses. The main objective of the heat recovery system is to enhance energy efficiency and minimize waste in power generation processes.

Overview of the Heat Recovery System in Cogeneration:

- Cogeneration (CHP) System: This system produces both electricity and useful thermal energy (heat) simultaneously from a single energy source, such as natural gas, biomass, or industrial waste heat. It is utilized in a range of settings including industrial sites, commercial buildings, and institutions.
- Electricity Generation: Using a prime mover like a gas turbine, steam turbine, or reciprocating engine, the cogeneration system generates electricity and concurrently produces waste heat.
- Heat Recovery: Capturing the waste heat—whether in the form of hot gases, steam, or hot water—from electricity generation, the system transfers this heat to a heat recovery setup.

- Heat Exchangers: Essential to the heat recovery system, heat exchangers allow the transfer of thermal energy from the waste heat to another fluid (typically water or a heat transfer fluid) without direct contact, enabling the heated fluid's use in various applications.

Applications of Recovered Heat:
- Space heating for buildings during colder periods.
- Domestic hot water for showers and other uses.
- Supplying heat to industrial manufacturing processes.
- Absorption chilling to produce chilled water for air conditioning and cooling.

Energy Efficiency: By maximizing the use of the energy source and minimizing waste, the heat recovery system significantly boosts the energy efficiency of the cogeneration plant, presenting an eco-friendly and cost-effective option.

Control Systems: Equipped with advanced control systems, modern heat recovery setups monitor and enhance the performance of both the cogeneration unit and the heat recovery process, ensuring optimal operation and accommodating fluctuations in demand and operational conditions.

Environmental Benefits: By using fuel more efficiently and relying on cleaner energy sources, CHP systems with heat recovery contribute to sustainability goals and help reduce the carbon footprint of facilities.

Maintenance and Monitoring: To maintain its efficiency and reliability, the heat recovery system requires regular maintenance and monitoring. This may include cleaning heat exchangers, inspecting components, and promptly addressing any issues.

Integration: For optimal performance, it is critical that the heat recovery system is seamlessly integrated with the cogeneration unit and the facility's overall heating and cooling infrastructure through precise design and engineering.

Section 5.3: Heat Exchanger

In a combined heat and power (CHP) system, the heat exchanger is an essential component that acts as a critical conduit for capturing and redistributing the excess heat produced during electricity generation. This device plays a key role in ensuring that heat energy, which would otherwise be lost, is effectively utilized. By transferring this thermal energy to various applications efficiently, the heat exchanger not only boosts the overall system efficiency but reduces unnecessary energy expenditure.

Purpose of a Heat Exchanger: The primary function of a heat exchanger is to transfer heat from one fluid to another without the fluids directly mixing. Within a cogeneration context, it captures waste heat from exhaust gases, coolant, or other heated fluids produced during electricity generation.

Types of Heat Exchangers:

- Shell and Tube: Comprising an outer shell and a bundle of tubes, with hot fluid passing through the tubes and cold fluid circulating around them inside the shell.
- Plate: Consists of multiple plates that form channels allowing hot and cold fluids to pass through, enhancing heat transfer through increased surface area.
- Finned-Tube: Typically used for air-to-fluid heat exchange, these exchangers have fins on the tubes to increase surface area and improve heat transfer efficiency.
- Regenerators: Cycle heat storage and release, particularly in specific cogeneration setups.

Heat Transfer Process: Heat exchangers facilitate the movement of heat from a hot fluid (like exhaust gas) to a cold fluid (such as water or a heat transfer fluid) via conduction, with the fluids separated by walls that promote efficient heat transfer.

Fluids Involved: In cogeneration, the hot fluid is usually the waste heat from electricity production, while the cold fluid is the medium to which this heat is transferred for use in heating spaces, supplying domestic hot water, or aiding industrial processes.

Efficiency Improvement: By recovering and reutilizing waste heat, the heat exchanger significantly enhances the cogeneration system's efficiency, which leads to decreased fuel use and reduced operational costs.

Integration: Effective integration of the heat exchanger into the cogeneration system is crucial. It must be optimally positioned to efficiently capture waste heat, with consideration given to the temperature and flow rates of the cold fluid.

Control and Monitoring: Contemporary cogeneration systems include control systems that monitor and adjust the heat exchanger's operation to optimize performance based on varying demands and conditions, ensuring maximal heat recovery.

Maintenance: Regular maintenance is vital for the heat exchanger to maintain effective heat transfer capabilities. This includes cleaning surfaces, inspecting leaks, and promptly addressing any issues.

Environmental Benefits: Using a heat exchanger in a cogeneration system promotes environmental sustainability by reducing greenhouse gas emissions, thereby supporting more efficient use of energy sources, and aligning with sustainability objectives.

Section 5.4: Heat Storage

In cogeneration plants, the role of heat storage is crucial for maintaining energy balance and ensuring continuous service, particularly in high-demand settings such as banks. Here is the comprehensive strategy for integrating heat storage into the system:

Phase Change Materials (PCMs) Integration:

- Primary Storage Medium: PCMs will be utilized as the main method for thermal energy storage.
- Selection Criteria: PCMs that have melting points well-suited to the operational temperatures of the cogeneration system.

- Storage Configuration: PCM modules will be encapsulated and housed in insulated tanks, allowing for a consistent energy supply even during times of low demand.

Tank Design and Placement:

- Redundancy: Multiple tanks will be used to ensure there is always a backup available should any single tank go offline.
- Material and Design: Considering Puerto Rico's humid climate, tanks will be constructed from corrosion-resistant materials and designed for longevity.
- Location Strategy: Tanks will be strategically positioned near areas of high energy use, such as server rooms, to facilitate quick delivery of energy as needed.

Monitoring and Management:

- Thermal Sensors: Real-time monitoring will be conducted using thermal sensors, which will track the energy stored to prevent any unexpected shortages during peak demand periods.
- Automated Controls: The system will include automated controls to manage the heat's flow and discharge, ensuring efficient use of the stored energy and reducing waste.

This approach will not only provide a robust support system to manage energy loads efficiently but ensure that the bank's operations can continue smoothly without disruption, enhancing operational reliability and energy efficiency.

Section 5.5 Heat Distribution

Ensuring efficient heat distribution across all operational areas is critical for an institution as dynamic as a bank. Here is the strategy for achieving optimal heat distribution:

District Heating System:

- Distribution Network: A network of insulated pipelines will be established to transport heat to various sections of the bank.

- Advanced Insulation: Given Puerto Rico's tropical climate, the pipelines will be equipped with advanced insulation materials to minimize heat loss during transmission.
- Targeted Distribution: The network will be designed to prioritize areas with higher energy demands, ensuring a consistent and adequate heat supply where needed most.

Regulation Mechanism:

- Control Devices: State-of-the-art pumps and electronically actuated valves will be used to manage the flow of heat throughout the bank.
- Centralized Control: These components will be integrated into the SCADA (Supervisory Control and Data Acquisition) system, providing centralized control and real-time monitoring of the heat distribution.
- Adaptive Flow Management: Utilizing data from sensors, the system can adjust the flow rate and direction dynamically to maintain even heat distribution and prevent overheating in any part of the bank.

Maintenance and Efficiency:

- Regular Inspections: Routine checks will be conducted to identify any potential blockages or malfunctions within the distribution system, ensuring uninterrupted operations.
- Analytics for Optimization: The SCADA system's advanced analytics capabilities will help identify and address any inefficiencies, allowing continuous optimization of heat distribution to maximize energy conservation.

Through this comprehensive approach, the aim is to maintain a reliable and efficient heating distribution system that supports the bank’s dynamic needs while optimizing energy use and minimizing operational disruptions.

Section 5.6 Fuel Supply System

The fuel gas supply system for the Plant is meticulously engineered to purify natural gas, thereby enhancing its efficiency when utilized by the gas turbine in power plants. This system is crucial as it safeguards the gas turbine from potential damage and elevates the overall system efficiency. VALMAX is notable for its extensive experience in EPC Turnkey projects in Korea, making it a valuable partner in such developments.

Complex Regulatory Compliance and Project Scope:

- Regulatory Navigation: The project involves navigating complex local regulations through an integrated environment permitting system which includes obtaining necessary licenses and permissions.
- Comprehensive Design and Execution: The scope covers basic and detailed design encompassing various disciplines such as process, piping, equipment, electrical, instrumentation and control, civil, architecture, firefighting, HVAC, and electrical corrosion.
- Project Execution: Additional aspects include fabrication design, equipment production, comprehensive start-up, commissioning, erection, and onsite services such as maintenance and supervision.

Fuel Supply System for Natural Gas:

- Pressure and Supply Management: Natural gas is supplied to the Plant under high pressure via pipelines and needs to be decompressed to the pressures required by end-users, which includes the power plant itself and potentially other users like city gas companies.
- System Functions: The land fuel supply system is designed to adjust pressure, measure flow rates for billing purposes, and incorporate safety mechanisms to cut off and dissipate the natural gas supply in emergencies.

Specialization of VALMAX:

- Industry Leadership: VALMAX collaborates with leading domestic and international EPCs and energy-related public institutions, providing comprehensive solutions from design through to commissioning of natural gas supply systems.

Gas Turbine Fuel Supply System:

- Optimizing Thermal Efficiency: The specific design of the gas turbine fuel supply system within cogeneration and combined thermal power plants aims to remove impurities and supply natural gas at a controlled pressure and temperature (over 250 degrees Celsius). This precision ensures the gas turbine operates at high thermal efficiency.

By integrating such advanced systems and leveraging VALMAX's expertise, the Plant aims to maintain a highly efficient and reliable fuel supply system that meets stringent operational and safety standards. This system not only contributes to the operational efficiency of the plant but aligns with environmental and regulatory requirements.

Section 5.7 Fuel Storage

Industrial Fuel Storage Tanks

Industrial fuel storage tanks, commonly known as petroleum tanks, are versatile units capable of storing various fluids. It is typically used for storing non-organic and organic liquids, vapors, and various flammable fluids. Available in diverse designs and sizes, these tanks are specifically engineered to store a broad range of fuels, vapors, and industrial liquids effectively.

Types of Industrial Fuel Storage Tanks

- Aboveground Tanks (ASTs): These tanks are favored for their lower long-term maintenance and upfront costs. Aboveground installation is less costly than underground because it avoids expenses related to deep excavation, backfilling, and extensive piping.
- Underground Tanks (USTs): USTs are used when the visual impact of aboveground tanks is a concern or when space utilization is crucial. These tanks are regulated, especially when used for storing hazardous materials, and require registration with environmental authorities like the EPA.

Advantages of Using Fuel Storage Tanks

1. Cost Efficiency: On-site fuel tanks reduce the need for transport to refueling facilities, saving both time and costs associated with off-site refueling.
2. Variety: The market offers a variety of tanks including aboveground, underground, and self-bunded tanks, each serving unique needs based on durability, capacity, and spill prevention.

3. Versatility: Tanks can be customized to meet specific storage requirements and are available in portable models for easy relocation.

Industrial Gas Storage Tanks

In addition to liquid storage, industrial facilities may use tanks for storing gases under pressure. These include compressed gases in cylinders and cryogenic gases in specially designed tanks.

Liquefied Natural Gas (LNG) Storage Tanks

LNG tanks are designed to store natural gas in liquid form at exceptionally low temperatures, utilizing a double container system to ensure effective insulation. These tanks help maintain the low temperature necessary to keep the gas in liquid form.

Compressed Natural Gas (CNG) versus Liquefied Natural Gas (LNG)

- CNG: Stored at high pressure and ambient temperature, CNG requires tanks capable of handling high pressures.
- LNG: Stored at low temperature and ambient pressure, LNG requires cryogenic storage tanks.

Safety and Maintenance

Proper design, construction, and regular maintenance of fuel storage tanks are critical to ensure safety and operational efficiency. Tanks must adhere to safety standards and regulations to prevent failures and accidents, such as the historical Boston molasses disaster, which underscores the importance of rigorous testing and quality assurance in tank design and construction.

Section 5.8 Fuel Transport

The fuel supply system in a Combined Heat and Power (CHP) system is critical for safely and efficiently delivering gaseous fuel such as natural gas or biogas to the gas combustion unit or engine. This system's design and operation are vital to the overall performance and efficiency of the CHP system.

Components of a Fuel Supply System:

- Gas Supply Line: Consists of pipelines or conduits that transport gaseous fuel from its source to the CHP system. The material selection for these lines (steel, stainless steel, or plastic for low-pressure lines, and carbon steel for high-pressure lines) is influenced by the type of gas, pressure, temperature, and environmental conditions. The line includes essential valves and fittings for maintenance, isolation, and control.

- Gas Regulator: Key for controlling the gas pressure to match the requirements of the CHP system, ensuring consistency within the safe operating range. Safety features like overpressure relief valves are included to prevent equipment damage.

- Gas Shut-Off Valve: Provides a safety function allowing manual or automated shutdown of the gas supply in emergencies or for maintenance. It is linked to safety systems for automatic shutoff in the event of a gas leak or flame failure.

- Gas Meter: Measures the flow rate and volume of the consumed gas, critical for billing and monitoring usage. Accuracy and calibration of these meters are essential for system management.

- Pressure Relief Valve: Acts as a safety device to release excess gas pressure and prevent system over-pressurization, with a set pressure for opening to avoid catastrophic failures.

- Gas Filters: These remove impurities and particulates from the gas, protecting downstream equipment and ensuring clean combustion. These filters require regular maintenance and replacement to maintain effectiveness.

- Gas Pressure Gauges: Offer real-time monitoring of gas pressure throughout the system, crucial for controlling and ensuring that the pressure stays within specified limits.

Additional Components for Enhanced Functionality:

- Fuel Transfer Pumps: Devices like centrifugal pumps (common for diesel) and positive displacement pumps (ideal for natural gas) are used to move fuel from storage tanks to the system, maintaining constant pressure and flow rates.

- Fuel Management and Inventory Systems: Integrated with the plant's control systems for real-time inventory monitoring and employing predictive analytics to optimize fuel consumption and delivery schedules.

Each component of the fuel supply system plays a crucial role in ensuring the safe, efficient, and reliable delivery of fuel to the CHP system. Proper selection, installation, maintenance, and monitoring of these components are paramount to ensure optimal operation and performance. Safety considerations are especially critical to prevent any accidents, leaks, or system failures.

Section 5.9 Fuel Supply Redundancy

Ensuring the reliability and uninterrupted operation of fuel supply systems is crucial in various industries, especially in critical facilities where downtime is not an option. Implementing redundancy in fuel supply systems is essential to mitigate risks of disruptions and maintain continuous operations.

Multiple Fuel Engines:
- Dual-Fuel Engines: Some CHP systems feature dual-fuel engines that can operate on two diverse types of fuel, such as natural gas and diesel. This capability allows for seamless switching between fuels if one becomes unavailable, ensuring continuous operation.
- Bi-Fuel Systems: Bi-fuel systems can use two fuel sources, such as natural gas and diesel, in varying proportions. This flexibility provides additional redundancies and ensures that the system can continue operating even if one fuel supply is compromised.

Multiple Fuel Sources:

- Diesel: Diesel generators are commonly used for backup power due to their high energy density and reliable performance.
- Natural Gas: Natural gas generators are environmentally friendly and often more cost-effective. The generators can be directly connected to natural gas pipelines or utilize compressed natural gas (CNG) storage systems.
- Propane: Propane is another clean-burning fuel option, suitable for both standby and primary power generation. It is stored in tanks and is readily available.

Selecting multiple fuel sources involves considerations of availability, cost, and environmental impact, ensuring a robust and reliable supply strategy.

Multiple Fuel Tanks:

- Tank Location: Fuel tanks should be strategically placed to minimize risks such as fire hazards or potential contamination.
- Capacity Planning: It is important to calculate the required capacity based on usage patterns and estimated runtimes during emergencies, using tanks of varying sizes.
- Fuel Compatibility: Tanks must be compatible with the different fuel types and equipped with appropriate safety features.

Parallel Fuel Systems:

- Pumps: Each fuel type should have its own dedicated pumps to ensure reliable fuel transfer.
- Backup Pumps: Additional backup pumps should be installed to ensure a continuous flow from storage tanks to the CHP system in case of primary pump failure.
- Pipelines: Separate pipelines for each fuel source help prevent cross-contamination and maintain the integrity of the fuel supply.
- Filtration Systems: Using redundant filtration systems helps maintain fuel quality by removing impurities and water, thus protecting engines and generators from damage.

This comprehensive approach to fuel supply redundancy ensures that critical facilities can maintain operations without interruption, safeguarding against potential failures or shortages in the fuel supply chain.

Section 5.10 Emergency Shutdown System (ESD)

In high-stakes industrial environments where potential risks to human lives, the environment, and valuable assets are a concern, the integration of an Emergency Shutdown System (ESD) is essential. This system is strategically designed to swiftly halt operations under anomalous conditions, thereby averting catastrophic outcomes. This section delves into the primary purpose, key components, and operational protocols of the ESD.

Purpose of the Emergency Shutdown System:

The primary function of the ESD is to facilitate rapid and safe termination of operations during malfunctions, external threats, or unforeseen events that could compromise safety. Whether responding to a sudden surge in system pressure, a significant temperature anomaly, or external events such as natural disasters, the ESD serves as a crucial protective mechanism. By suddenly stopping processes and isolating hazardous components or substances, the ESD effectively minimizes risks, thus protecting personnel, the environment, and infrastructure.

Key Components of the ESD:

- Actuators: Central to the ESD are hydraulic or pneumatic actuators that execute shutdown commands swiftly. These actuators are linked to critical components such as shutdown valves, which stop the flow of gases, liquids, or other substances, thereby isolating hazardous sections of the system.
- Sensors: A comprehensive network of sensors is deployed throughout the system to monitor operational parameters continuously. These sensors detect anomalies and provide real-time feedback, enabling the ESD to take timely action based on specific data inputs.

Operational Mechanics of the ESD:

- Activation: The ESD can be triggered manually by operators in response to perceived threats or automatically through its integrated sensors that detect deviations from safety thresholds.
- Response: Upon activation, the ESD executes a series of pre-defined protocols. Actuators are engaged to drive shutdown valves to their closed positions, effectively isolating hazardous substances and securing the plant's operations.
- Controlled Response: While the system's response is designed to be immediate, it is controlled to ensure that abrupt shutdowns do not create secondary problems, such as pressure spikes or system shocks.

The ESD's role is pivotal in maintaining safety and operational integrity in industrial settings. Its design must not only ensure responsiveness and effectiveness but adaptability to various industrial scenarios, ensuring that all potential risks are adequately addressed. The system's maintenance and testing are crucial for its reliability, necessitating regular checks and updates to accommodate new safety standards and technological advancements. This proactive approach in safety management helps safeguard against emergencies and enhances the overall resilience of industrial operations.

Section 5.11 Emissions Control

In the realm of energy production, cogeneration systems are celebrated for their efficiency but scrutinized for their environmental impact, particularly regarding emissions. This section explores the emission controls integrated into cogeneration systems, highlighting their purpose, underlying technologies, and the regulatory framework in the United States that governs their application.

Purpose of Emissions Controls:

The main goal of implementing emissions controls in cogeneration systems is to reduce pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter. These emissions can negatively affect human health, contribute to climate change, and degrade natural ecosystems. Therefore, emission controls are vital not only for ensuring that cogeneration systems are environmentally compliant and for maintaining their operational efficiency and meeting energy production targets.

Technological Vanguard in Emissions Control:

- Selective Catalytic Reduction (SCR): SCR is a leading technology used to reduce NOx levels in exhaust gases. It involves injecting a reagent, usually ammonia or urea, into the exhaust, which then reacts with NOx over a catalyst to form harmless nitrogen and water, thus significantly lowering NOx emissions.

Selective Non-Catalytic Reduction (SNCR): SNCR reduces NOx without a catalyst. Instead, it relies on the optimal temperature and the addition of specific reagents to facilitate the chemical transformation of NOx into less harmful compounds.

- Particulate Filters: These devices are employed to capture and contain fine particulate matter from exhaust gases, ensuring cleaner emissions and compliance with strict particulate matter standards.

Regulatory Mandates and the U.S. Perspective:

In the United States, the Environmental Protection Agency (EPA) plays a crucial role in the regulatory oversight of emission controls in cogeneration systems. The EPA sets strict limits on permissible pollutant levels based on extensive research intended to protect public health and environmental integrity. Compliance with these standards is mandatory, with cogeneration facilities undergoing regular inspections, audits, and required to adhere to stringent reporting measures. As environmental technology advances and the understanding of the impact of pollutants evolves, the EPA periodically updates these regulations, ensuring the remain effective and reflective of the latest scientific understanding.

The integration of advanced emission control technologies and adherence to rigorous regulatory standards are essential for minimizing the environmental impact of cogeneration systems. This ensures that these systems can continue to provide efficient energy solutions while aligning with broader environmental sustainability goals.

Chapter 6: Cogeneration Distributed Generation

Section 6.1: Distributed Energy

Distributed generation in cogeneration involves the simultaneous production of electricity and useful thermal energy at or near the point of use. Here is how it is typically applied:

- **Selection of Cogeneration Technology:** The first step is to select an appropriate cogeneration technology, such as combined heat and power (CHP) system or trigeneration system. These systems utilize various sources of energy, such as natural gas, biomass, or waste heat, to generate electricity and capture the waste heat for heating, cooling, or industrial processes.
- **Site Assessment:** Conduct a thorough assessment of the site where distributed cogeneration will be implemented. Factors such as energy demand, thermal requirements, available space, environmental regulations, and grid connectivity should be considered to determine the optimal configuration and size of the cogeneration system.
- **System Design:** Design the cogeneration system based on the site assessment and specific energy needs. This involves selecting the appropriate size and type of equipment, such as gas turbines, reciprocating engines, or fuel cells, and integrating heat recovery components like heat exchangers and absorption chillers.
- **Installation and Integration:** Install the cogeneration system and integrate it with existing energy infrastructure. This may require modifications to the building or facility layout, as well as the installation of control systems and monitoring equipment to optimize system performance and ensure seamless operation.
- **Operation and Maintenance:** Once the distributed cogeneration system is operational, it requires ongoing monitoring, maintenance, and optimization to ensure reliable performance and maximize energy efficiency. This involves regular inspections, preventive maintenance, and adjustments to system parameters based on changing energy demand and environmental conditions.
- **Grid Interconnection:** Depending on local regulations and grid requirements, the cogeneration system may be interconnected with the LUMA grid to export excess electricity or to maintain grid stability during peak demand periods. Grid

interconnection may require additional equipment such as inverters, transformers, and protective relays to ensure safe and reliable operation.

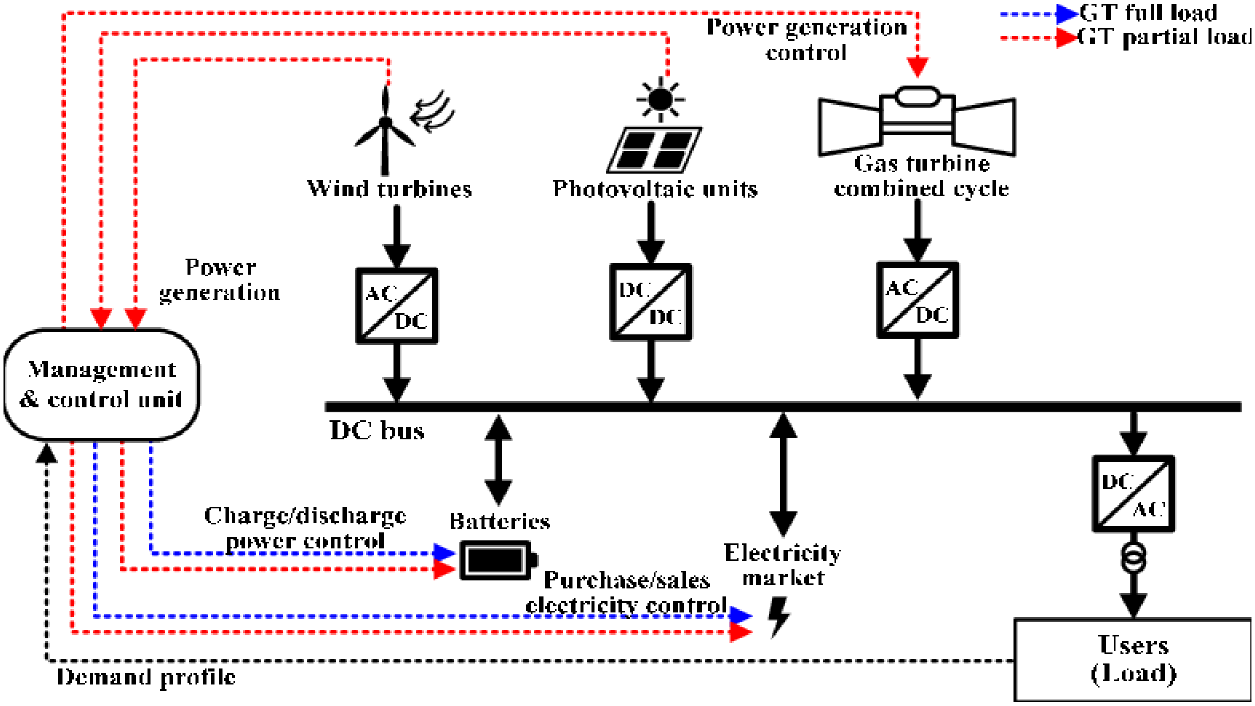


Figure 6.1: Distributed Energy Concept

As it can be shown in figure 10.1, energy distribution is especially useful to help with energy management and costs by controlling the energy distribution of a system that uses multiple energy sources. In the context of linking up with LUMA Energy, a backup power supply needs to be accessible. Furthermore, this connection is facilitated through a primary line operating at 38,000 volts. Nevertheless, the availability of these resources is contingent upon the customer's preference for electrical generation. Moreover, its primary function is to offer an additional alternative that complements the client's existing power sources (Evertec), which is comprised of four electric generators operating concurrently with alternative generator systems (two powered by diesel and two by natural gas). Ultimately, this connection is strategically directed towards catering to the areas of highest demand within the customer's infrastructure, with emphasis placed on supplying power to a computer center as the priority.

Section 6.2: Control

Control systems serve as an indispensable cornerstone in any cogeneration system. These frameworks oversee the systems processes, including thermal management, electrical output, and safety mechanisms. Therefore, the selection, implementation, and management of these systems are critically important. This section offers an exhaustive guide to optimal choices for Programmable Logic Controllers (PLC) detailing the mechanics of their implementation and the legal standards which govern them. Among the myriads of choices available for Programmable Logic Controllers (PLC), the Siemens S7-1500 series, Allen-Bradley's ControlLogix series, and Schneider Electric's Modicon M340 and M580 series stand out as industry frontrunners. These PLCs offer unparalleled reliability, swift processing speed, and robust features that ensure comprehensive management of cogeneration systems. Their compatibility with high-speed Ethernet protocols such as PROFINET and EtherNet/IP ensures seamless data communication. Additionally, these PLCs are modular and scalable, allowing them to adapt easily to future technological advancements or system expansion. Implementation of PLC systems involves a multi-stage process. An exhaustive list of input/output (I/O) modules, which must be drafted to ensure comprehensive coverage of all the sensors and actuators within the cogeneration system. Detailed control logic diagrams must be developed to guide the programming of the PLC. The hardware is customarily housed in an electrically isolated, climate-controlled cabinet located within a centralized control room for operational convenience and safety. Compliance with international standards is vital; most notably, PLCs should adhere to the IEC 61131 standard that provides guidelines for PLC hardware and software.

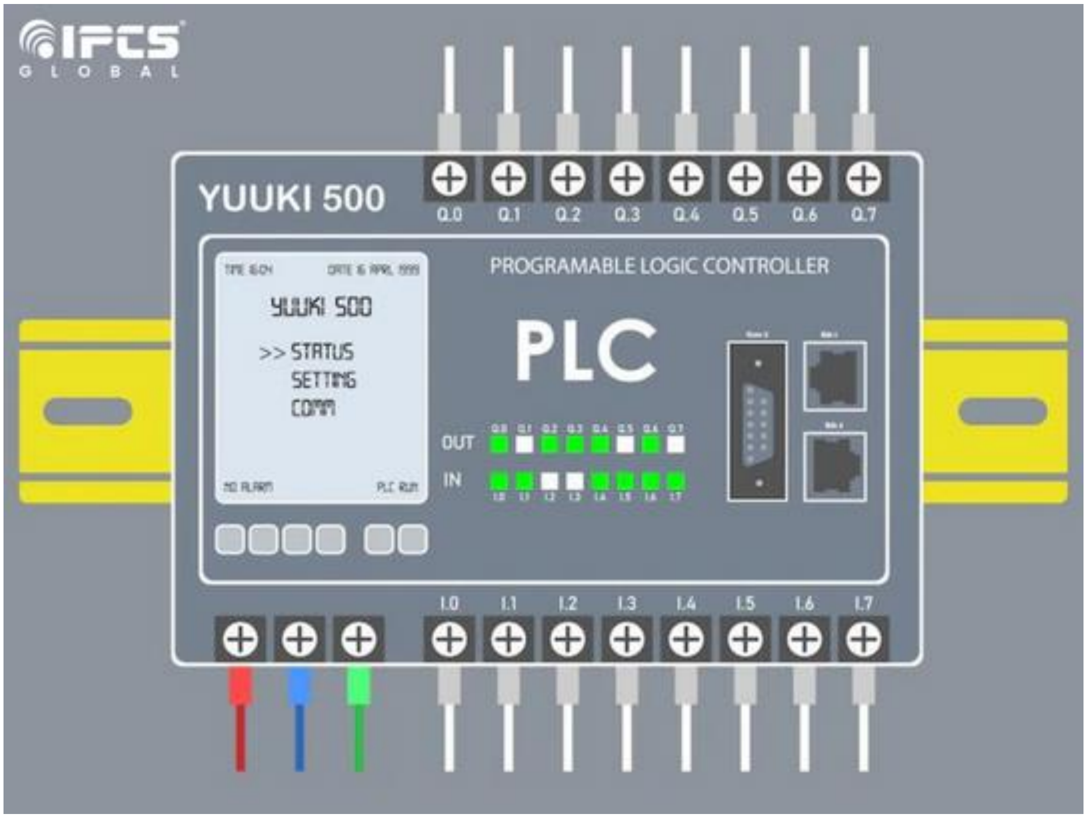


Figure 6.2: PLC example model

Furthermore, in figure 10.2, it shows an example model of a PLC where it has the inputs below and the outputs in the top of the example, where the PLC has a range from 0-7 I/O (an actual PLC can have up to 16 I/O).

Inputs for the PLC to be considered:

Mechanical Parameters

- Turbine Speed (RPM) – Speed sensor
- Vibration Levels – Vibration sensor
- Temperature – Temperature sensor
- Turbine inlet and outlet Temperatures - Temperature sensor

Thermal Parameters

- Steam Pressure – Pressure sensor
- Steam Temperature - Temperature sensor

- Boiler Water Level – Level sensor
- Flue Gas Temperature (Boiler outlet Temperature) - Temperature sensor

Electrical Parameters

- Generator Voltage – Voltage sensor
- Generator Frequency – Frequency sensor
- Generator Current- Current sensor
- Power Factor – Power Factor sensor

Safety Parameters

- Fire Detector – Smoke and Heat sensor
- Gas Leak Detector – Gas Leak sensor
- Pressure Relief Valve Status – Pressure sensor

Miscellaneous

- Cooling Water Temperature - Temperature sensor
- Lubrication Oil Pressure - Pressure sensor
- Ambient Temperature - Temperature sensor
- Ambient Humidity - Humidity sensor

Outputs for the PLC to be considered:

Control Actions

- Turbine Throttle Valve Position
- Boiler Feedwater Pump Speed
- Cooling Fan Speed
- Lubrication System Activation

Electrical Adjustments

- Generator Excitation Control
- Synchronization to Grid Control

Safety Measures

- Emergency Shutdown Command
- Fire Suppression System Activation
- Gas Isolation Valve Command

Alarms and Notifications

- High Temperature Alarm
- Low Pressure Alarm
- Vibrations Alarm
- Emergency Alerts to the Control room

Section 6.3: Instrumentation

Instrumentation plays a crucial role in cogeneration systems by providing operators with real-time data on various parameters related to the generation, distribution, and utilization of energy. A detailed explanation of the importance of instrumentation is shown below:

1. **Measurement of Energy Parameters:**
    - **Electricity Generation:** Instruments such as wattmeter's, power analyzers, and energy meters measure electrical parameters like voltage, current, power, and energy output from generators.
    - **Thermal Energy Output:** Instruments like flow meters, temperature sensors, and heat meters measure parameters such as flow rate, temperature, and thermal energy output from heat recovery systems or boilers.
    - **Fuel Consumption:** Flow meters, pressure sensors, and gas analyzers measure fuel flow rates, pressure, and composition to monitor fuel consumption and combustion efficiency.

2. **Monitoring System Health:**
    - **Vibration Sensors:** These sensors monitor the vibration levels of rotating equipment such as turbines, pumps, and motors, helping detect abnormal conditions or potential failures.
    - **Temperature Sensors:** Thermocouples, RTDs (Resistance Temperature Detectors), and infrared thermometers monitor temperatures at critical points in the system to prevent overheating and ensure optimal performance.
    - **Pressure Sensors:** Pressure transducers and gauges measure pressure levels in steam, water, and gas lines, ensuring safe operating conditions and efficient energy transfer.
3. **Control of System Components:**
    - **Valve Position Sensors:** Sensors monitor the position of control valves, such as turbine throttle valves or steam bypass valves, to regulate flow rates and maintain desired operating conditions.
    - **Pump Speed Controllers:** Variable frequency drives (VFDs) or motor controllers regulate the speed of pumps and fans to match energy demand and optimize efficiency.
    - **Generator Excitation Control:** Control systems adjust the excitation current supplied to generators to control voltage levels and ensure stable operation when connected to the grid.
4. **Safety and Emergency Measures:**
    - **Emergency Shutdown Systems:** Sensors and control logic trigger emergency shutdown procedures in response to critical events such as equipment malfunction, elevated temperatures, or pressure spikes.
    - **Fire and Gas Detection Systems:** Detectors sense the presence of fire or hazardous gases and activate suppression systems or isolate affected areas to prevent accidents and protect personnel and equipment.
5. **Data Acquisition and Communication:**
    - **SCADA (Supervisory Control and Data Acquisition) Systems:** SCADA systems collect, monitor, and analyze data from instrumentation throughout the

cogeneration plant, providing operators with a comprehensive view of system performance and enabling remote control and troubleshooting.

- **Communication Protocols:** Instruments communicate with control systems and each other using standard protocols such as Modbus, Profibus, or Ethernet, facilitating seamless integration and interoperability.

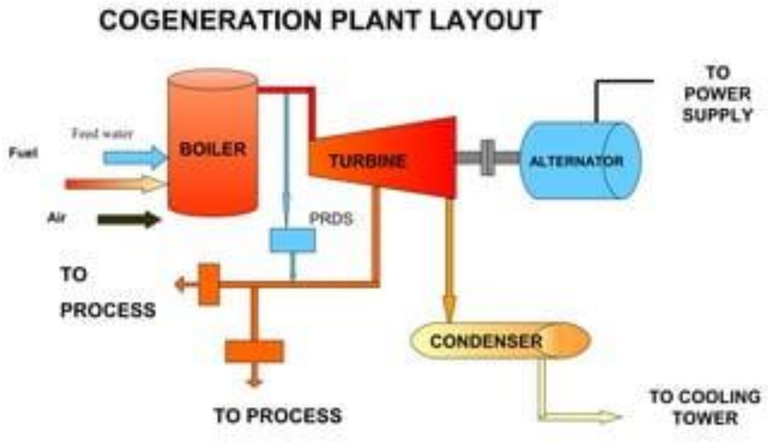


Figure 6.3: Instrumentation needed in a cogeneration plant.

Shown in figure 10.3 is the standard layout for a cogeneration plant, with the components needed for the plant to work efficiently. In the dynamic world of finance, especially within banking institutions in Puerto Rico, a sophisticated cogeneration system demands precise instrumentation. These instruments serve as the lifeline of the system, offering a comprehensive view of the facility's operational health. Given Puerto Rico's tropical climate, with fluctuating temperatures and humidity levels, it is imperative for a bank's cogeneration system to incorporate instruments that can resist this harsh climate. Monitoring these fluctuations with precision is key to preventing potential failures that might disrupt banking services. In the banking sector, where consistent uptime is a primary requirement, timely and accurate data can prevent expensive downtimes and optimize energy usage. By adhering to international standards like the ISA, the institution demonstrates its commitment to efficiency, performance, and most importantly, safety for both its employees and customers.

Sensors are the frontline defense of cogeneration systems, detecting and transmitting anomalies to the control system for immediate action. Their role in safeguarding both personnel and assets

are extremely important. This section elucidates the several types of sensors utilized in cogeneration plants, elaborating on their operational principles, and shedding light on best practices for their deployment. Safety and efficiency are paramount in banking operations, and the sensors within the cogeneration system play a vital role in achieving these benchmarks. Due to the critical nature of banking services, sensors are proactive in detecting anomalies, allowing issues to be addressed before it escalates. Monitoring the ambient conditions in server rooms to ensure balanced energy distribution during high transaction periods, these sensors ensure smooth banking operations. In the context of Puerto Rico's unique climate, these sensors help detect environmental variables that might impact energy consumption, promoting eco-friendly and efficient operations.

Section 6.4: Data Acquisition

Data acquisition (DAQ) is the practice of gathering data about various electrical or physical events, like voltage levels, temperature, pressure, or sound. A DAQ system is comprised of sensors, specialized hardware for taking various measurements, and a computer equipped with programmable software like LabVIEW, for managing and analyzing data.

Some software used for data acquisition are mentioned below:

- LabVIEW - LabVIEW from National Instruments is a versatile platform that can be customized to monitor and control CHP systems. It allows you to create applications for data acquisition, instrumentation control, and real-time monitoring.
- SCADA Systems - Supervisory Control and Data Acquisition (SCADA) systems like Wonderware InTouch, Siemens WinCC, and Ignition are used in CHP applications to provide real-time monitoring, data logging, and control of power generation, heat recovery, and distribution systems.
- PLC Systems - Programmable Logic Controllers (PLC) are commonly used in CHP systems for control and data acquisition. PLC programming software from

manufacturers like Siemens, Allen-Bradley, and Schneider Electric can be employed to program and configure PLCs.

- Distributed Control Systems (DCS) – DCS platforms, such as ABB Ability System 800xA and Emerson DeltaV, are utilized in large-scale CHP installations for integrated control and data acquisition of power generation, heat recovery and distribution processes.
- Energy Management Systems (EMS) - EMS software like Siemens Spectrum Power or ABB Network Manager is used for monitoring and optimizing the electrical grid in CHP systems, especially in utility-scale applications.
- Data Historians- Data historians like OSIsoft PI System and Honeywell Uniformance are used to archive and analyze historical data from CHP systems, enabling performance analysis and predictive maintenance.
- Human Machine Interface (HMI) Software – Human Machine Interface (HMI) software, such as Ignition or FactoryTalk View from Rockwell Automation, can provide operators with user-friendly interfaces to visualize and control CHP operations.
- Remote Monitoring and Control - Cloud-based monitoring and control platforms like AWS IoT, Microsoft Azure IoT, or third-party solutions can be integrated with CHP systems to enable remote monitoring and control.

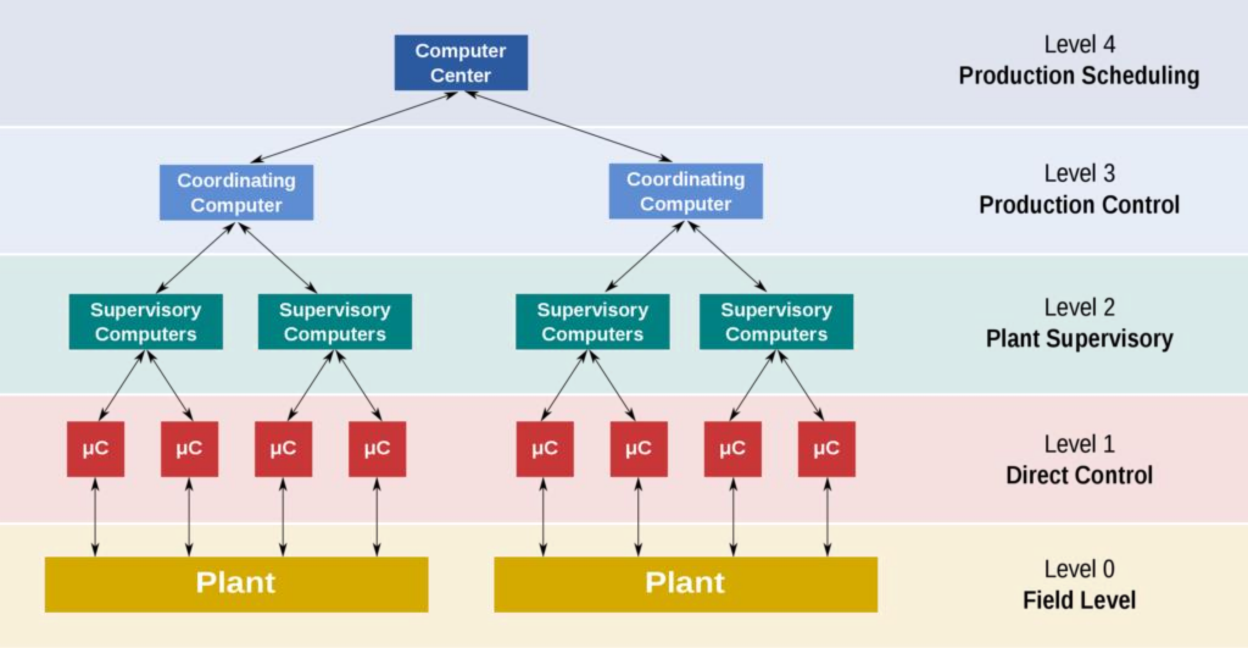


Figure 6.4: Control Triangle.

Similarly, figure 6.4 shows a control triangle, where in level 2 is the DAQ systems like SCADA. The program is tasked with controlling the process with the data received from controllers and plants.

Section 6.5: Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) systems are integral components of cogeneration plants, providing centralized control, monitoring, and management of the entire system. Here is an overview of what SCADA systems provide the following in cogeneration plants:

- **Centralized Monitoring and Control -** SCADA systems serve as the central nervous system of cogeneration plants, allowing operators to monitor and control various processes and equipment from a centralized location. This includes monitoring electrical generation, thermal energy output, fuel consumption, temperatures, pressures, flow rates, and other critical parameters.

- **Real-Time Data Acquisition -** SCADA systems collect real-time data from sensors, meters, and control devices distributed throughout the cogeneration plant. This data is transmitted to the SCADA system via communication protocols such as Modbus, Profibus, DNP3, or OPC, enabling operators to visualize and analyze system performance in real-time.
- **Graphical User Interfaces (GUI) -** SCADA systems provide user-friendly graphical interfaces, dashboards, and HMI (Human-Machine Interface) displays that allow operators to visualize real-time data in the form of charts, graphs, trend lines, and alarms. GUIs provide intuitive navigation and enable operators to quickly identify abnormal conditions, trends, or alarms.
- **Alarm and Event Management -** SCADA systems monitor data for predefined thresholds or conditions and generate alarms, alerts, or notifications when anomalies or critical events occur. Operators can configure alarm settings, priorities, and escalation procedures to ensure timely response to alarms and prevent equipment damage or safety hazards.
- **Historical Data Logging and Analysis -** SCADA systems store historical data in a centralized database or historian, allowing operators to analyze trends, patterns, and performance metrics over time. Historical data analysis enables predictive maintenance, optimization of energy efficiency, and identification of opportunities for process improvement.
- **Remote Monitoring and Access -** Many SCADA systems support remote monitoring and access, allowing operators to monitor system performance, view alarms, and make control adjustments from anywhere with an internet connection. Remote access features improve operational flexibility, efficiency, and responsiveness to events.
- **Integration with Control Systems -** SCADA systems integrate seamlessly with control systems, such as PLCs (Programmable Logic Controllers), and other automation devices. This integration enables bidirectional communication between the SCADA system and control devices, allowing operators to adjust setpoints, control parameters, and initiate actions based on real-time data.
- **Security and Compliance -** SCADA systems implement robust security measures to protect sensitive data, prevent unauthorized access, and ensure compliance with

industry regulations and standards. Security features may include user authentication, role-based access control, encryption, audit trails, and intrusion detection.

SCADA systems play a crucial role in ensuring the efficient and reliable operation of cogeneration plants by providing centralized monitoring, control, and management of critical processes and equipment. This system enables operators to make informed decisions, optimize performance, and respond promptly to events, maximizing energy efficiency, reliability, and safety.

Section 6.6: Safety Systems

The complexity of operations within a cogeneration system, marked by high-pressure boilers, rapidly rotating turbines, and electrical generators, warrant the incorporation of sophisticated safety measures. In this regard, Programmable Logic Controllers (PLC) serve not merely as operational control units but as custodians of safety, orchestrating a complex set of safety related functionalities. These functionalities are indispensable for ensuring the protection of human resources, the integrity of the equipment, and compliance with regulatory standards.

Sensor Integration for Real-time Safety Monitoring

An array of specialized sensors is strategically deployed throughout the cogeneration facility to continually monitor safety parameters. Pressure sensors are pivotal in averting overpressure conditions that could lead to boiler explosions. Similarly, gas leak sensors serve as an early warning system for combustible or hazardous gas leaks. Temperature sensors, on the other hand, monitor a wide range of components including turbines, bearings, and steam lines to ensure operation within their thermal limits. These sensors transmit real-time data to the PLC, enabling immediate control adjustments or initiation of emergency protocols based on programmed safety logic.

Sophisticated Safety Logic and Interlock Mechanisms

Modern cogeneration PLC are equipped with intricate safety logic algorithms and interlock mechanisms designed to preempt and mitigate operational hazards. These logical sequences serve as conditional barriers that prevent the progression to the next operational phase unless specific safety criteria are met. For instance, the PLC could prevent the initiation of the combustion process if gas concentration levels exceed predefined safety thresholds.

Emergency Shutdown Systems (ESD) and Safety Protocols

A cornerstone of PLC managed safety in cogeneration systems is the Emergency Shutdown System (ESD). Upon detecting parameters that deviate significantly from safe operation conditions, the PLC can autonomously initiate an emergency shutdown, thereby averting potential safety hazards. The shutdown sequence encompasses a range of actions including the isolation of hazardous materials by closing off valves, the de-energization of electrical systems, and the activation of mechanical brakes on rotational equipment. Manual override capabilities are provided to operators for extreme contingencies.

Compliance with Regulatory Standards and Laws

Adhering to regulatory standards and laws is of utmost importance, particularly concerning the safety protocols implemented in PLC. It is essential that these safety systems align with established international standards such as ISO 45001 and ANSI/ISA 84, which serve as benchmarks for ensuring occupational safety and functional safety of instrumented systems. Additionally, compliance with national regulations, such as the Occupational Safety and Health Administration (OSHA) guidelines in the United States, is mandatory. These rigorous regulations outline the minimum safety requirements, risk assessment procedures, and emergency response strategies that must be integrated into the safety logic of PLC.

Chapter 7: Software applications

Section 7.1: Helioscope

Helioscope is a software utility that is particularly effective in the solar energy sector. It is specifically engineered for designing, simulating, and analyzing solar photovoltaic solar systems. A 3D model of solar panel configurations is one of the major features of Helioscope, which assists users in visualizing the appearance and functionality of installations. The program simulates the energy production of solar PV systems by considering a variety of factors, including location, shading, and weather conditions. Enables users to evaluate the impact of shadows from adjacent objects on the performance of solar panels throughout the day and year. Additionally, it provides tools for estimating the financial viability, repayment periods, and return on investment (ROI) of solar projects.

Engineers and designers use the helioscope to develop solar panel layouts optimized for locations. This system assists in the assessment of prospective solar installation sites by examining solar insolation and shading. Aids in the optimization and monitoring of the performance of existing solar installations and facilitates the development of detailed project proposals and reports for stakeholders and investors.

Section 7.2: Homer

HOMER, or the Hybrid Optimization of Multiple Energy Resources, is a sophisticated software instrument used in the energy sector to optimize distributed energy resources (DER) and microgrid systems. It is especially beneficial for the development of systems that integrate a variety of energy sources, including solar power, wind energy, diesel generators, and battery storage.

In order to identify the most cost-effective and dependable solutions, Homer evaluates various combinations of energy resources. Assesses the comprehensive lifecycle expenses of energy systems, which encompass capital, operational, and maintenance expenses. Provides an intuitive interface that enables users to readily submit data and visualize results, as well as to evaluate the influence of changes in input parameters (such as petroleum prices or energy demands) on the system's performance and costs.

This program helps engineers develop microgrids that effectively incorporate a variety of energy sources. Assists project developers in conducting feasibility studies to ascertain the viability of proposed energy systems. Encourages the integration of renewable energy sources into existing energy systems and assists policymakers in comprehending the implications of various energy strategies and investments.

Chapter 8: Conceptual Diagrams

Section: 8.1: Conceptual Diagram of a Photovoltaic System

Firstly, figure 8.1 illustrates a conceptual diagram of a photovoltaic system (PV) integrated with an inverter and battery bank, showing how energy is managed in the system. The solar PV panels capture sunlight and convert it into direct current (DC) electricity, which is then processed by the inverter. This inverter converts the DC power into alternating current (AC) to supply household or business AC loads, such as appliances. Additionally, the inverter manages the battery bank, storing excess solar energy for use during periods of low sunlight, such as at night. If the solar energy and battery power are insufficient, the system can draw electricity from the utility grid to meet energy demands. Moreover, when there is excess solar power, the system can export it back to the grid through a meter that tracks electricity flow in both directions, often part of a net metering setup. This design allows for efficient energy use, combining renewable energy with backup from the grid.

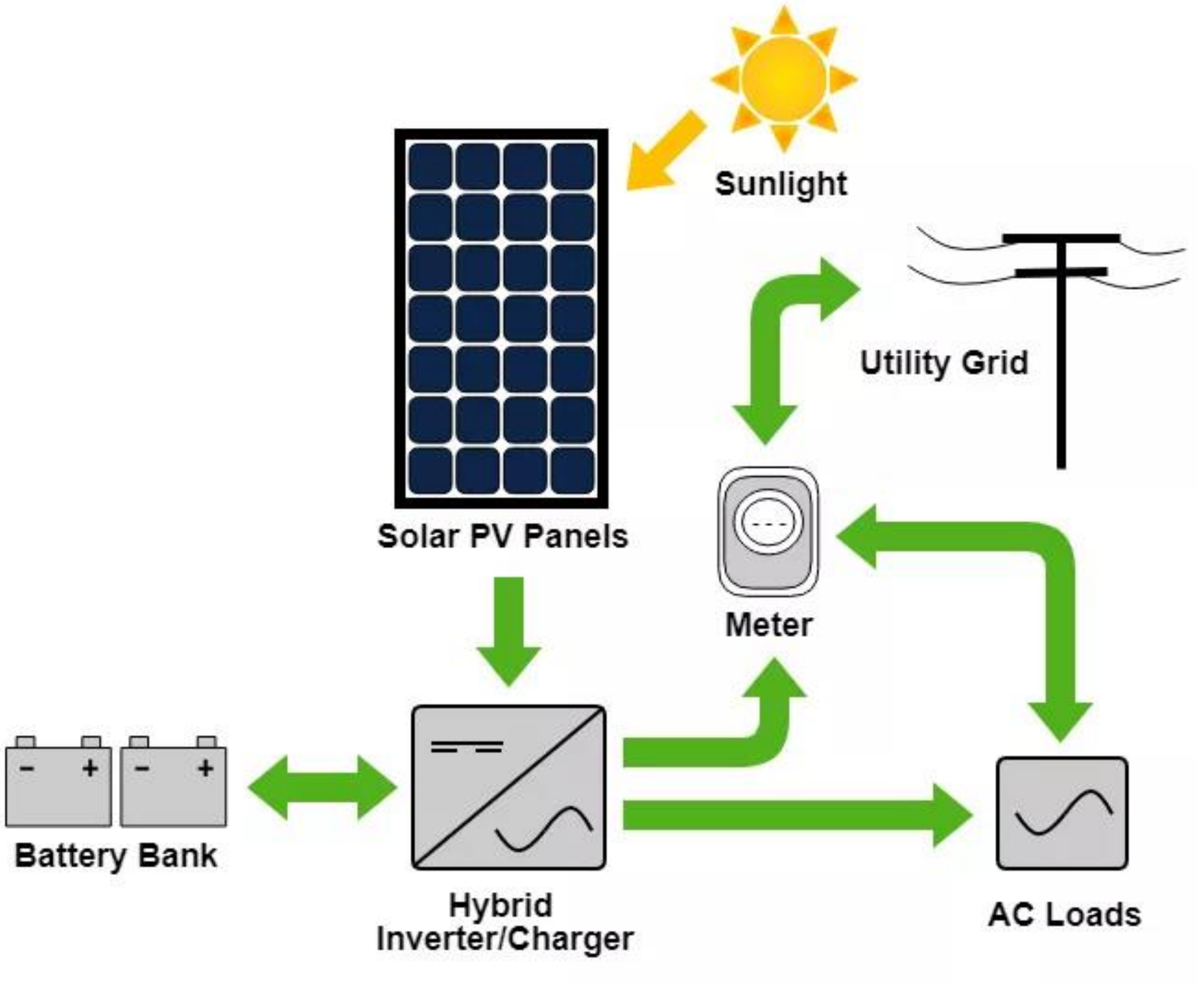


Figure 8.1: PV system Conceptual Diagram

Section 8.2: Conceptual Diagrams of a Cogeneration System

The diagrams on figure 8.2 and figure 8.3 illustrate a cogeneration system that simultaneously generates electricity, heating, and cooling from a single fuel source through a combined heat and power (CHP) unit. The CHP system produces both electricity and heat, with the heat being used for direct heating or sent to an absorption chiller. The absorption chiller converts the waste heat into chilled water, which is distributed for cooling purposes, such as air conditioning through an HVAC system. Additionally, boilers provide supplementary heat if the CHP system does not meet the total heat demand. This highly efficient system maximizes energy use by producing electricity and utilizing the byproduct heat for both heating and cooling, reducing overall energy waste.

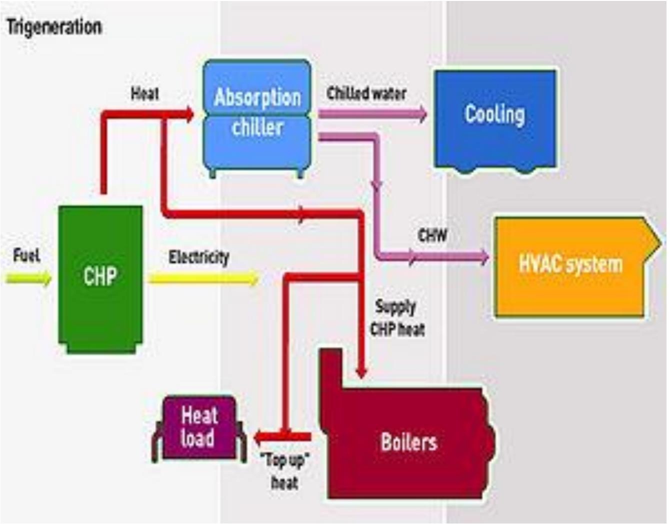


Figure 8.2: Conceptual Diagram for a Cogeneration system.

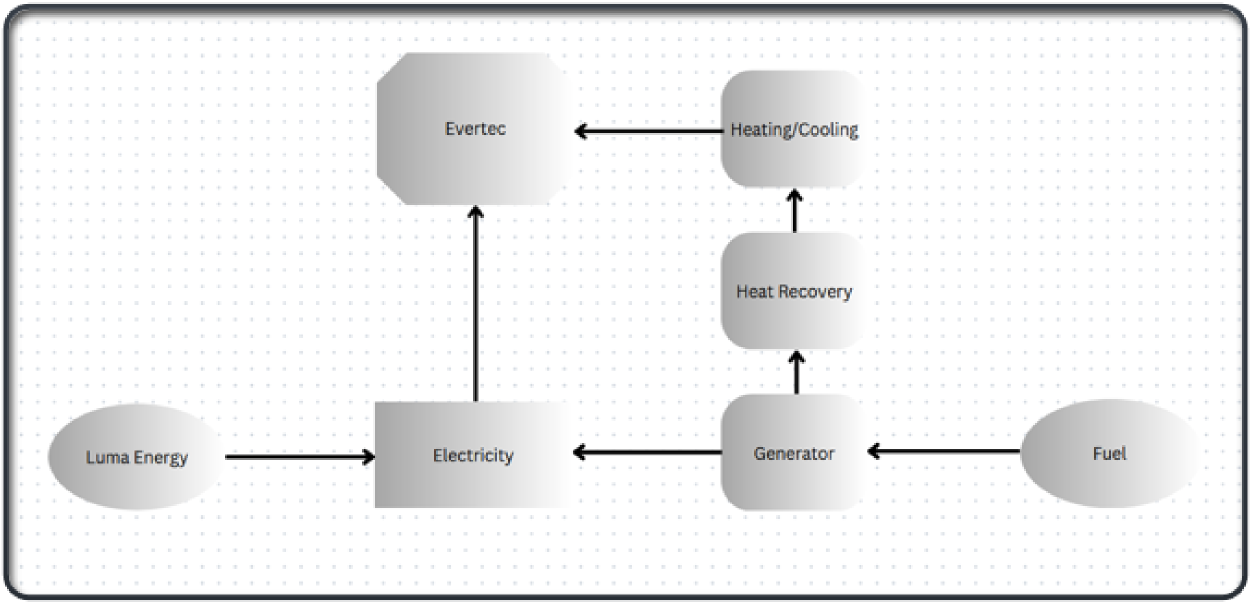


Figure 8.3: Cogen Energy Distribution Concept

Section 8.3: Conceptual Diagrams of a Microgrid System

Lastly, figures 8.4 and 8.5 depict diagrams of a microgrid system where various energy sources, including wind, solar, battery storage, and other combined heat and power (CHP) sources, are integrated and managed by a central controller for optimizing energy distribution. The system can interact with the utility grid for additional power supply when necessary. The controller intelligently allocates energy from these sources to meet the demand of controllable loads, ensuring efficient energy use. The battery storage allows for energy storage during periods of excess production, such as when solar or wind power is abundant, and provides backup during periods of low generation. The system's ability to draw from multiple energy sources and store power enhances its reliability and energy efficiency, making it suitable for balancing renewable and conventional energy inputs.

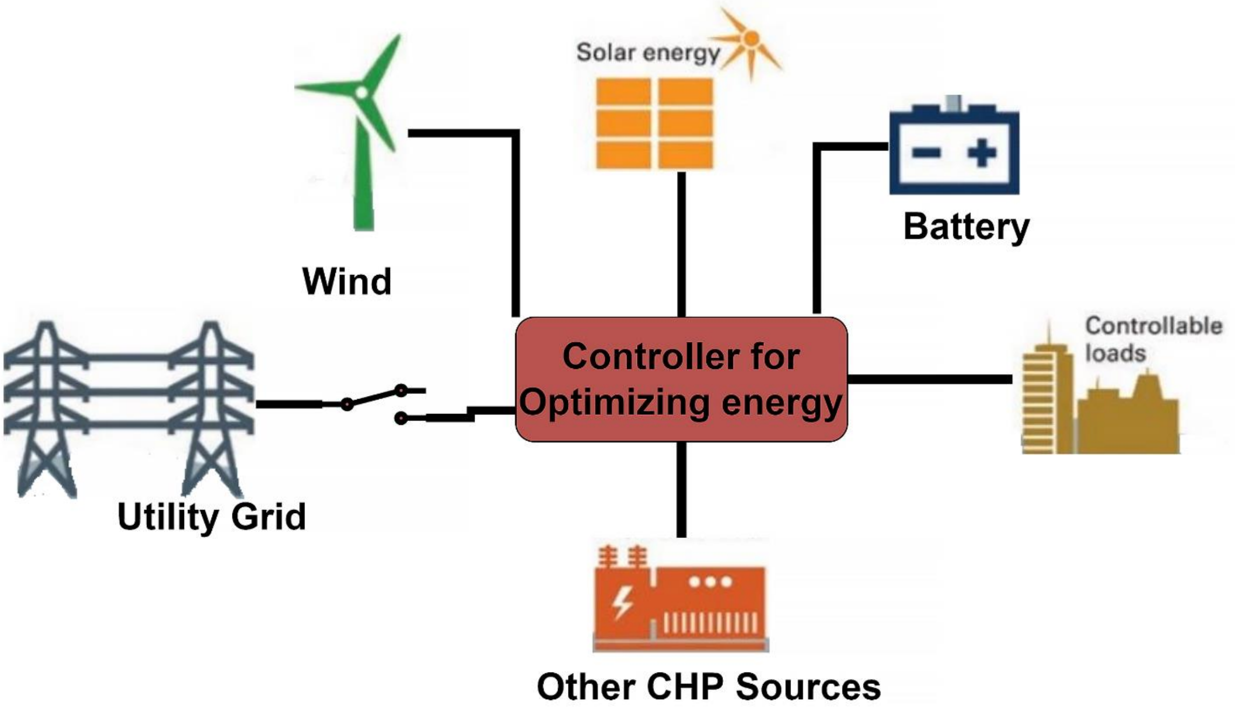


Figure 8.4: Micro Grid Conceptual Diagram 1

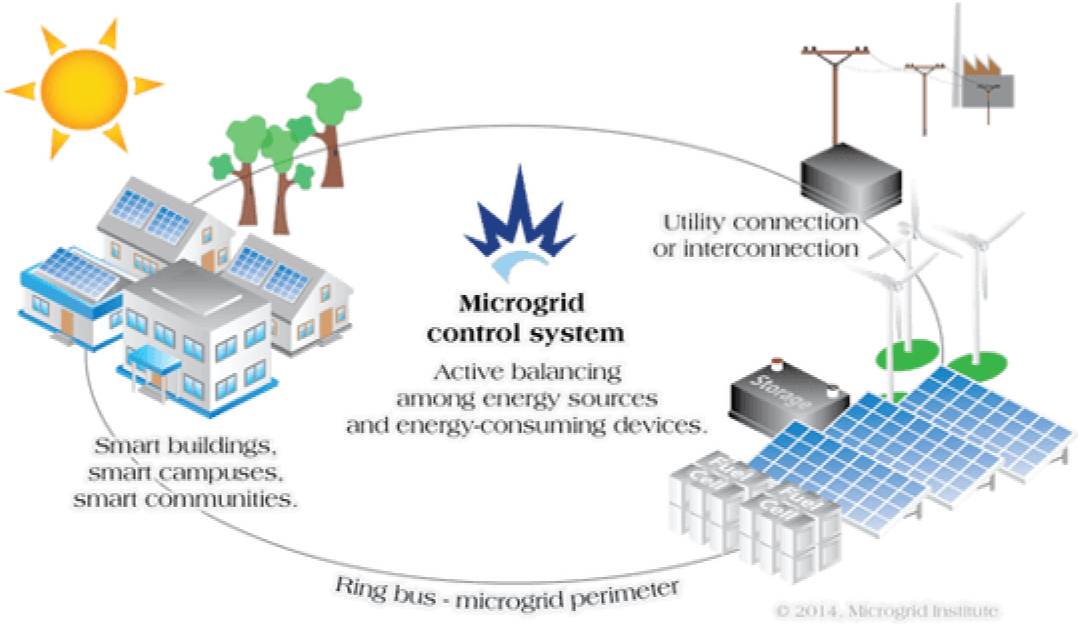


Figure 8.5: Micro Grid Conceptual Diagram 2

Chapter 9: PV Generation System Design

Section 9.1: Building Measurements

Evertec's photovoltaic design in Cupey, PR diverges from traditional commercial designs by prioritizing the number of photovoltaic modules that can be integrated into the multi-level parking facility and regular parking spaces. The areas to be discussed are shown in figure 9.1, and are marked in red.

Figure 9.1: Evertec Workspaces

Multiplying the length (L) and the width (W) determines the total area. In equation 9.1, the formula for measuring the area is as follows.

$A = L*W$: (Equation 9.1)

Figure 9.2: Multi-Level Parking Segments

RED Segment– Multi-Level Parking (Using equation 9.1):

Length: 194.82’ (Taking into consideration the buildings in the middle of the RED segment)

Width: 40’

Area = L * W = (194.82) (40) = **7,792.8 ft^2**

YELLOW Segment– Multi-Level Parking (Using equation 9.1):

Length: 256.58’

Width: 40’

Area = L * W = (256.58) (40) = **10,263.2 ft^2**

PURPLE Middle Segment– Multi-Level Parking (Using equation 9.1):

Length: 177.63’

Width: 45’

Area = L * W = (177.63) (45) = **7,993.35 ft^2**

PURPLE Corner Segments– Multi-Level Parking (Using equation 9.1):

Length: 177.63’

Width: 16’

Area = L * W * 2= (177.63) (16) (2) = **5,684.16 ft^2**

ORANGE Segments– Multi-Level Parking (Using equation 9.1):

Length: 109.81’

Width: 16’

Area = L * W * 2= (109.81) (16) (2) = **3,513.92 ft^2**

Ground Level Parking Area:

1st part: 4324.15 ft^2

2nd part: 8225.78 ft^2

3rd part: 7392.47 ft^2

Area = Sum all parts = (4324.15) + (8225.78) + (7392.47) = **19,942.4 ft^2**

Area Considering the 3ft fire line (Using equation 9.1):

Ground-Level Parking:

1st part: 4324.15 ft^2

2nd part: 8225.78 ft^2

3rd part: 7392.47 ft^2

Area = Sum of all parts = (4324.15 - 3) + (8225.78 - 3) + (7392.47 - 3) = **19,936.4 ft^2**

The previously calculated area values are summarized in table 9.1 below.

Description	Multi-Level Parking	Ground-Level Parking
Original Roof Area	56,270.55 ft^2	19,942.4 ft^2
RED Segment	7,792.8 ft^2	N/A
YELLOW Segment	10,263.2 ft^2	N/A
PURPLE Middle Segment	7,993.35 ft^2	N/A
PURPLE Corner Segments	5,684.16 ft^2	N/A
ORANGE Segments	3,513.92 ft^2	N/A
Area Considering 3ft Fire Line	N/A	19,936.4 ft^2
Total Usable Space	35,247.4 ft^2	19,936.4 ft^2

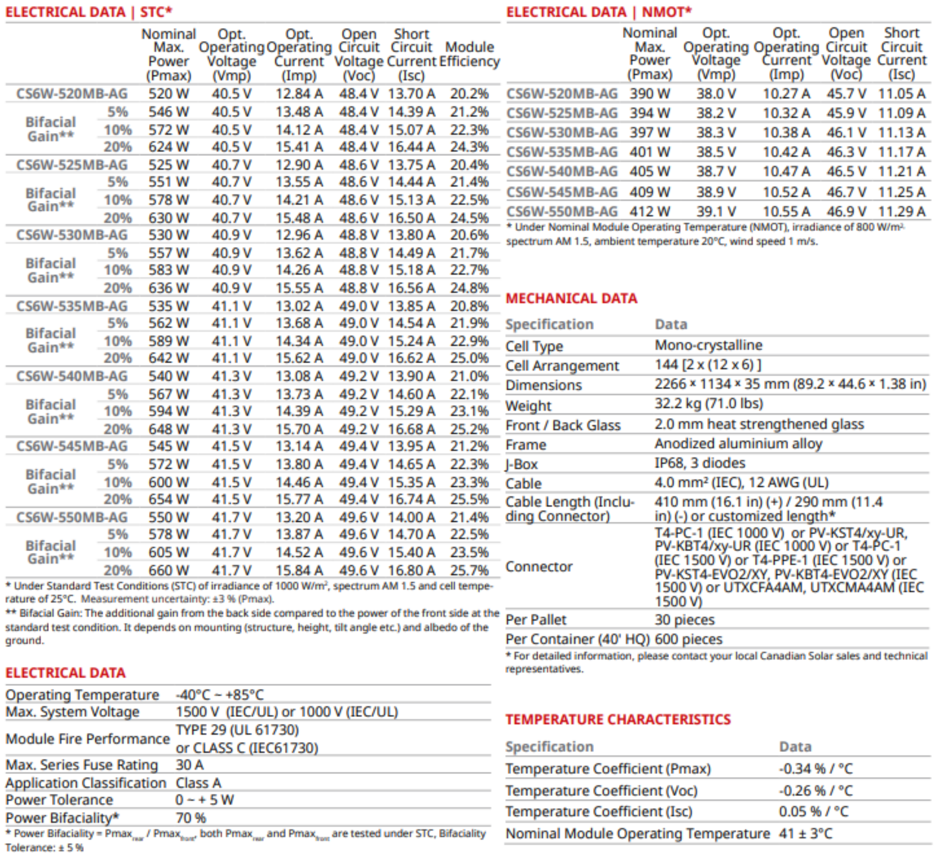
Table 9.1: Area Values Summary

Section 9.2: PV Module Selection and Capacity

Without a doubt, to guarantee the optimal performance and cost-effectiveness of the solar array, it is necessary to evaluate a variety of factors when selecting the PV module to be used, for this reason, the Canadian Solar BiHiKu6 Bifacial Mono 550W was chosen. These factors include both mechanical and electrical characteristics, where the most essential elements are the voltage, current, and power output, in which are critical electrical characteristics. The module's energy production capacity is determined by the parameters.

Furthermore, the selection process is significantly influenced by factors such as price, availability, and warranty. Mechanical considerations are equally significant and the installation for long-term durability is contingent upon the structural integrity, weight, and dimensions of the module. Reliability and safety necessitate the capacity to endure mechanical stresses, including snow and wind. The selection process prioritizes efficacy in power generation, mitigating losses, and competitive pricing, given the diverse range of PV modules available. Moreover, energy production is maximized by modules that provide a high-power output per hour of sunlight. Modules with a high-power output are prioritized due to the absence of energy production constraints in this endeavor. Effectively satisfying the project's requirements, the selected PV module must achieve a proportion between cost-effectiveness, mechanical robustness, and electrical performance.

Lastly, to achieve comprehension of the technical specifications, performance under diverse conditions, conformance with standards, warranty terms, installation guidelines, and system integration of a PV module is crucial to consult the modules datasheet (refer to figures 9.3 and 9.4). It enables users to make informed decisions, ensures proper utilization, and enables comparison with other modules.



ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS6W-520MB-AG		520 W	40.5 V	12.84 A	48.4 V	13.70 A	20.2%
Bifacial Gain**	5%	546 W	40.5 V	13.48 A	48.4 V	14.39 A	21.2%
	10%	572 W	40.5 V	14.12 A	48.4 V	15.07 A	22.3%
	20%	624 W	40.5 V	15.41 A	48.4 V	16.44 A	24.3%
CS6W-525MB-AG		525 W	40.7 V	12.90 A	48.6 V	13.75 A	20.4%
Bifacial Gain**	5%	551 W	40.7 V	13.55 A	48.6 V	14.44 A	21.4%
	10%	578 W	40.7 V	14.21 A	48.6 V	15.13 A	22.5%
	20%	630 W	40.7 V	15.48 A	48.6 V	16.50 A	24.5%
CS6W-530MB-AG		530 W	40.9 V	12.96 A	48.8 V	13.80 A	20.6%
Bifacial Gain**	5%	557 W	40.9 V	13.62 A	48.8 V	14.49 A	21.7%
	10%	583 W	40.9 V	14.26 A	48.8 V	15.18 A	22.7%
	20%	636 W	40.9 V	15.55 A	48.8 V	16.56 A	24.8%
CS6W-535MB-AG		535 W	41.1 V	13.02 A	49.0 V	13.85 A	20.8%
Bifacial Gain**	5%	562 W	41.1 V	13.68 A	49.0 V	14.54 A	21.9%
	10%	589 W	41.1 V	14.34 A	49.0 V	15.24 A	22.9%
	20%	642 W	41.1 V	15.62 A	49.0 V	16.62 A	25.0%
CS6W-540MB-AG		540 W	41.3 V	13.08 A	49.2 V	13.90 A	21.0%
Bifacial Gain**	5%	567 W	41.3 V	13.73 A	49.2 V	14.60 A	22.1%
	10%	594 W	41.3 V	14.39 A	49.2 V	15.29 A	23.1%
	20%	648 W	41.3 V	15.70 A	49.2 V	16.68 A	25.2%
CS6W-545MB-AG		545 W	41.5 V	13.14 A	49.4 V	13.95 A	21.2%
Bifacial Gain**	5%	572 W	41.5 V	13.80 A	49.4 V	14.65 A	22.3%
	10%	600 W	41.5 V	14.46 A	49.4 V	15.35 A	23.3%
	20%	654 W	41.5 V	15.77 A	49.4 V	16.74 A	25.5%
CS6W-550MB-AG		550 W	41.7 V	13.20 A	49.6 V	14.00 A	21.4%
Bifacial Gain**	5%	578 W	41.7 V	13.87 A	49.6 V	14.70 A	22.5%
	10%	605 W	41.7 V	14.52 A	49.6 V	15.40 A	23.5%
	20%	660 W	41.7 V	15.84 A	49.6 V	16.80 A	25.7%

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m^2, spectrum AM 1.5 and cell temperature of 25°C. Measurement uncertainty: ±3 % (Pmax).

** Bifacial Gain: The additional gain from the back side compared to the power of the front side at the standard test condition. It depends on mounting (structure, height, tilt angle etc.) and albedo of the ground.

ELECTRICAL DATA

Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500 V (IEC/UL) or 1000 V (IEC/UL)
Module Fire Performance	TYPE 29 (UL 61730) or CLASS C (IEC61730)
Max. Series Fuse Rating	30 A
Application Classification	Class A
Power Tolerance	0 ~ + 5 W
Power Bifaciality*	70 %

* Power Bifaciality = Pmax_{rear} / Pmax_{front}, both Pmax_{rear} and Pmax_{front} are tested under STC, Bifaciality Tolerance: ± 5 %

ELECTRICAL DATA | NMOT*

	Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)
CS6W-520MB-AG	390 W	38.0 V	10.27 A	45.7 V	11.05 A
CS6W-525MB-AG	394 W	38.2 V	10.32 A	45.9 V	11.09 A
CS6W-530MB-AG	397 W	38.3 V	10.38 A	46.1 V	11.13 A
CS6W-535MB-AG	401 W	38.5 V	10.42 A	46.3 V	11.17 A
CS6W-540MB-AG	405 W	38.7 V	10.47 A	46.5 V	11.21 A
CS6W-545MB-AG	409 W	38.9 V	10.52 A	46.7 V	11.25 A
CS6W-550MB-AG	412 W	39.1 V	10.55 A	46.9 V	11.29 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m^2, spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline
Cell Arrangement	144 [2 x (12 x 6)]
Dimensions	2266 × 1134 × 35 mm (89.2 × 44.6 × 1.38 in)
Weight	32.2 kg (71.0 lbs)
Front / Back Glass	2.0 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 diodes
Cable	4.0 mm^2 (IEC), 12 AWG (UL)
Cable Length (Including Connector)	410 mm (16.1 in) (+) / 290 mm (11.4 in) (-) or customized length*
Connector	T4-PC-1 (IEC 1000 V) or PV-KST4/xy-UR, PV-KBT4/xy-UR (IEC 1000 V) or T4-PC-1 (IEC 1500 V) or T4-PPE-1 (IEC 1500 V) or PV-KST4-EVO2/XY, PV-KBT4-EVO2/XY (IEC 1500 V) or UTXCFA4AM, UTXCMA4AM (IEC 1500 V)
Per Pallet	30 pieces
Per Container (40' HQ)	600 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.34 % / °C
Temperature Coefficient (Voc)	-0.26 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

Figure 9.3: Solar Module Data

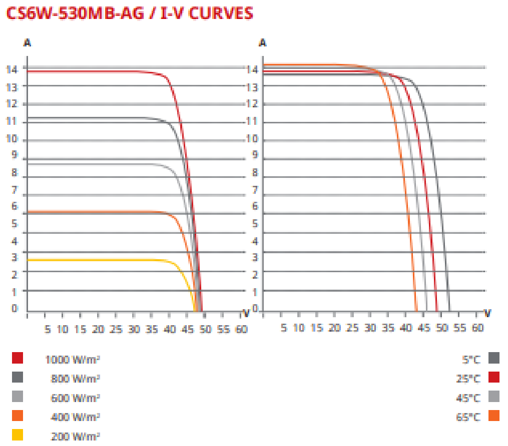


Figure 9.4: Solar Module Data Curves

In addition, the available space for the Evertec company PV system design will be divided into Ground-Level Parking and Multi-level Parking segments, as illustrated in section 9.1. This will result in two distinct surface areas. The purpose of preventing system frequency and voltage stability issues, the power output of the solar array must be restricted to less than 1 MW, as the client has no interest in investing in a battery backup system. Consequently, the PV system will not provide complete coverage of Evertec's energy consumption. The quantity of PV modules necessary will be determined by utilizing a minimum guaranteed solar array DC power output of 750,000Wdc in the calculations. The client specifically needs close to 600,000Wac for the system to run independently from the grid. The capability to verify whether there is sufficient space for the quantity of PV modules necessary to generate 750,000Wdc, it is necessary to first determine the number of PV modules that can be installed in each segment of the roof by utilizing the available surface area.

Modules A $= \frac{\mathrm{A_{FA}}}{\mathrm{A_M}}$: (Equation 9.2)

Where:

$AFA = Final\ Area\ of$ Multi-Level Parking’s $roof$

$AM = Area\ per\ modul$e

$$\text{\# of modules} = \frac{\text{Available Space Area}}{\text{Module Area}}$$

The length and width of each PV module are demonstrated below, in table 9.2, and the usable surface area of the roof for the multi-level parking facility, is illustrated in table 9.3 below. The length and width of each PV module are demonstrated in table 9.2 as well. This information is available in the manufacturer's datasheet document, which was previously displayed in section 9.2. After converting to feet, the final values are seen in their respective tables below.

Description	**PV Module Size (in)**	**PV Module Size (ft)**	**Data Origin**
Length	89.2	7.4	Canadian Solar
Width	44.6	3.7	Canadian Solar

Table 9.2: Module Sizes

Description	**Multi-Level Parking**	**Ground-Level Parking**	**Data Origin**
Total Usable Space	35,247.4 ft^2	19,936.4 ft^2	Evertec

Table 9.3: Available Space

Equation 9.2 is used to determine the total number of PV modules for the roof's multi-level parking.

$$\text{Modules} = \frac{35{,}247.4\ \text{ft}^2}{[(7.4\ \text{ft}) * (3.7)]} = \mathbf{1,287}$$

Consequently, the total number of PV modules for the multi-level parking is 1,287, as determined by the available surface area of the roof previously mentioned. Additionally, equation 9.3 will be utilized to determine the total number of PV modules for the ground-level parking referencing the values in table 9.3.

$\text{Modules B} = \frac{A_{FB}}{A_M}$: (Equation 9.3)

Where:

AFB = Final Area of Ground-Level Parking

$AM = Area\ per\ modul$e

$$\text{Modules} = \frac{19{,}936.4\ \text{ft}^2}{[(7.4\ \text{ft}) * (3.7)]} = \mathbf{728}$$

The total number of PV modules is 728, as determined by equation 9.3, using the available surface area on the ground-level parking.

Currently, equation 9.4 must be utilized to determine the necessary quantity of PV modules to generate the minimum guaranteed solar array power output of 750,000Wdc. These calculations will be conducted using the datasheet for the Canadian Solar BiHiKu6, which is illustrated in section 9.2.

$\text{N} = \frac{P_{arr-g}}{P_{mpp}}$: (Equation 9.4)

Where:

N = Total number of PV modules

$Parr{-}g = Power\ guaranteed\ from\ the\ solar\ array\ without\ losses$

$Pmpp = Power\ produced\ per\ PV\ modul$e

$$\text{N} = \frac{750{,}000\text{W}}{550\text{W}} = \mathbf{1363}$$

Consequently, 1,363 PV modules are necessary to achieve a minimum guaranteed solar array power output of 750,000Wdc. Following simulations conducted on Helioscope, the solar array panels will be split to optimize the limited area available. The solar array will consist of 1,224 PV modules for the multi-level parking and 139 for the ground-level parking, as Evertec's areas are divided into two. There is sufficient surface area to accommodate the specified number of PV modules per parking space.

Section 9.3: Inverter Selection and Capacity

It is imperative to choose the appropriate inverter for a photovoltaic system in order to ensure its efficacy, performance, and longevity. It is crucial to consider the following parameters when selecting this device:

- Nominal Power (kW): The nominal power of the inverter should correspond to the output capacity of the solar panels. Considering the potential future expansions of the system, it is crucial to guarantee that the inverter has the necessary capacity to manage the utmost power generated by the solar panels.
- Energy efficiency: The efficacy of inverters is essential, as it dictates the amount of solar energy that is converted into usable electricity. High-efficiency inverters can optimize energy production and minimize conversion losses.
- Maximum Power Point Tracking (MPPT): Inverters that utilize MPPT technology continuously modify the electrical capacity to optimize energy production, even in the presence of variable solar conditions. Toward guaranteeing maximum system performance, it is essential to use an inverter equipped with a dependable MPPT algorithm.
- Protection toward Overvoltage and Short Circuits: Inverters must be equipped with robust protection features to mitigate the risks of damage from overvoltage, short circuits, or other adverse conditions and ensure the safety of the system.
- Durability and Reliability: It is crucial to choose an inverter from a reputable manufacturer that provides a sufficient warranty and high-quality products. The longevity of the inverter is essential for the uninterrupted operation of the photovoltaic system.
- Monitoring Systems Compatibility: Certain inverters are equipped with integrated monitoring functions that enable the monitoring of system performance in real time.

Effective system administration and maintenance may necessitate the capacity to establish connections to external monitoring systems.

Moreover, table 9.2 provides a comparison of the relevant parameters of various inverters to ascertain the most optimal choice for the project, based on the aforementioned information.

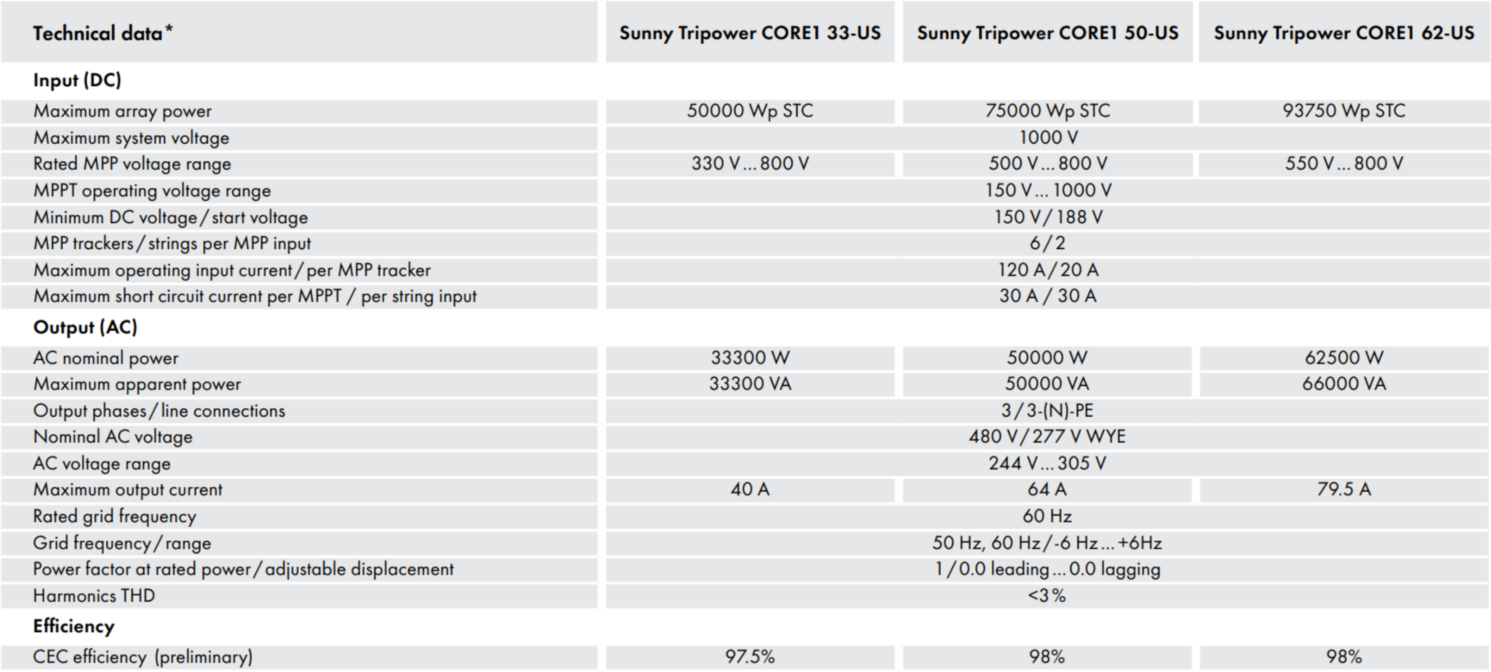
	SMA	**Growatt**	**Ginlong**
Model	TRIPOWER CORE1 62-US	MAC 70KTL3-X MV	Solis-100K-5G-US
Power Ratings	62,500 W	70,000 W	100,000 W
Efficiency	98%	98.80%	98.80%
MPP Trackers	6	3	10
Price	6,700.00	3,700.00	7,000.00

Table 9.4: Inverter Characteristics

Upon analyzing table 9.4, the inverter that most accurately meets the specified requirements is the SMA Sunny Tripower 62-US, as it delivers optimal output power and accommodates a respectable number of strings per input. The disadvantage of this system is their high price, nevertheless, in the event of an inverter failure, a substantial percentage of power production will not be lost.

Additionally, it is crucial to evaluate the inverter's capacity in series, parallel, maximum current, and maximum power, in addition to comparing the parameters. The datasheet of the equipment is illustrated in figures 9.5 and 9.6, which demonstrate that it continues to satisfy the essential specifications for this project.

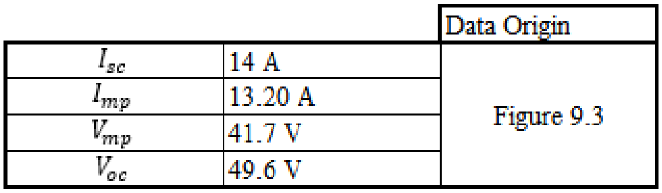
Figure 9.5: String Inverter Model Description



Technical data*	Sunny Tripower CORE1 33-US	Sunny Tripower CORE1 50-US	Sunny Tripower CORE1 62-US
Input (DC)			
Maximum array power	50000 Wp STC	75000 Wp STC	93750 Wp STC
Maximum system voltage		1000 V	
Rated MPP voltage range	330 V ... 800 V	500 V ... 800 V	550 V ... 800 V
MPPT operating voltage range		150 V ... 1000 V	
Minimum DC voltage / start voltage		150 V / 188 V	
MPP trackers / strings per MPP input		6 / 2	
Maximum operating input current / per MPP tracker		120 A / 20 A	
Maximum short circuit current per MPPT / per string input		30 A / 30 A	
Output (AC)			
AC nominal power	33300 W	50000 W	62500 W
Maximum apparent power	33300 VA	50000 VA	66000 VA
Output phases / line connections		3 / 3-(N)-PE	
Nominal AC voltage		480 V / 277 V WYE	
AC voltage range		244 V ... 305 V	
Maximum output current	40 A	64 A	79.5 A
Rated grid frequency		60 Hz	
Grid frequency / range		50 Hz, 60 Hz / -6 Hz ... +6Hz	
Power factor at rated power / adjustable displacement		1 / 0.0 leading ... 0.0 lagging	
Harmonics THD		<3 %	
Efficiency			
CEC efficiency (preliminary)	97.5%	98%	98%

Figure 9.6: String Inverter Datasheet

The quantity of inverters required for the design will be examined in this section. A series connection is the optimal solar panel configuration for this undertaking prior to commencing the calculations. This suggests that the direct current (DC) output of one panel is connected to the next panel, thereby increasing the total system voltage, as all panels are electrically connected in series. The inverter is subsequently connected to this chain. As previously mentioned, this configuration offers several benefits, such as an increase in system voltage, which reduces wiring losses, provides design flexibility, and improves system performance. The subsequent step will involve determining the quantity of inverters necessary for the undertaking. Furthermore, the calculation requires specific values from the technical datasheets of the PV module and the designated inverter, as detailed in the preceding sections. Lastly, table 9.5 and table 9.6 reflect this information.



		Data Origin
I_{sc}	14 A	Figure 9.3
I_{mp}	13.20 A	
V_{mp}	41.7 V	
V_{oc}	49.6 V	

Table 9.5: PV Module Specifications

AC Nominal Power	**Maximum System Voltage**	**Maximum Input Current**	**Maximum Input Current per MPP**	**Maximum Output Current**	**Maximum Array Power**	**Data Origin**
62,500 W	1000 V	120 A	20 A	79.5 A	93,785 W	Figure 9.6

Table 9.6: Inverter Specifications

Initially, the utmost number of solar modules that can be connected in series for a specific inverter is denoted by equation 9.5 below. The process divides the open circuit voltage of the photovoltaic module by the maximal system voltage of the inverter (table 9.5). This guarantees that the inverter's utmost permissible voltage is not exceeded by the string's total voltage.

$\text{Modules per string} = \frac{V_{\text{Inom}}}{V_{\text{OC}}}$: (Equation 9.5)

Where:

V_{Inom} = Inverter nominal system voltage

V_{OC} = PV module open circuit voltage

$$\text{Modules per string} = \frac{850\ \text{V}}{49.6\ \text{V}} = \mathbf{17}$$

The subsequent stage, as illustrated in equation 9.6, determines the total power of a series of solar modules for the photovoltaic system. The energy generation capacity of the string is determined by multiplying the nominal power of a single module (figure 9.3) by the total number of modules per string (equation 9.5).

$Power\ per\ string = Modules\ per\ string * Module\ power$: (Equation 9.6)

$Power\ per\ string = 17 * 550W = \mathbf{9{,}350\ \mathit{W}}$

Equation 9.7 determines the greatest number of solar module strings that can be connected to a single inverter. The maximum power output of the inverter is divided by the total power output of a series of modules in this calculation, which was determined in equation 9.6. This phase is essential for the proper scaling of the system and the prevention of inverter saturation is reached.

$\text{Strings per Inverter} = \frac{\text{Maximum Inverter Power}}{\text{Power per String}}$: (Equation 9.7)

$$\text{Strings per Inverter} = \frac{75{,}000\ \text{W}}{9{,}350\ \text{W}} = \mathbf{8}$$

Consequently, equation 9.8 gives the total number of solar modules that can be connected to a single inverter in a photovoltaic system. This quantity is determined by multiplying the number of modules per string (as determined by equation 9.5) by the number of threads per inverter (as determined in equation 9.7). This is being done to prevent the inverter from being overloaded and to ensure that the system is properly sized

$Modules\ per\ inverter = Modules\ per\ string * String\ per\ inverter$: (Equation 9.8)

$Modules\ per\ inverter = 17 * 8 = \mathbf{136}$

Finally, equation 9.9 calculates the total number of inverters required in the photovoltaic system by examining the total number of solar modules (equation 9.4) and the number of modules that can be connected to a single inverter (equation 9.8). The efficient utilization of the available inverters is contingent upon this calculation.

$\text{Inverter Cuantity} = \frac{\text{Total Modules Needed}}{\text{Modules per Inverter}}$: (Equation 9.9)

$$\text{Inverter Quantity} = \frac{1363}{136} = \mathbf{10}$$

In summary, the PV system necessitates a total of 10 inverters. The inverter values previously derived are briefly summarized in table 9.7 below.

PV System		**Data Origin**
Modules per String	17	Equation 9.5
Power per String	9,350 W	Equation 9.6
Strings per Inverter	8	Equation 9.7
Modules per Inverter	136	Equation 9.8
Total Inverters	10	Equation 9.9

Table 9.7: PV System Inverter Specifications

Section 9.4: Energy Production

The subsequent phase in the solar array calculations is to determine the total quantity of energy that the PV system can generate in a year. Additionally, it is imperative to ascertain the proportion of Evertec's energy consumption that will be produced by the solar array. These calculations will be conducted using the datasheet for the Canadian Solar BiHiKu6, which is illustrated in section 9.3. The solar arrays minimum guaranteed power output is 750,000Wdc, as specified in section 9.4. This is the reason equation 9.10 will be used, to determine the impact of temperature on the power output of the PV modules. Moreover, PV modules operate at 42°C, while the ambience temperature in Puerto Rico is approximately 36°C. Additionally, the PV modules have a temperature coefficient of -0.0034/°C.

$$\mathrm{P_{arr-t}} = \frac{\mathrm{P_{arr-g}}}{1-\lambda*(\mathrm{T_{amb}}-\mathrm{T_{op}})}\text{: (Equation 9.10)}$$

Where:

$Parr{-}t$ = Power output considering temperature effect

$Parr{-}g$ = P$ower\ guaranteed\ from\ the\ solar\ array\ without\ losses$

λ = $Temperature\ coefficien$t

$$\mathrm{P_{arr-t}} = \frac{750{,}000\ \mathrm{W}}{1-\left(-\frac{0.0034}{°\mathrm{C}}\right)*(42°\mathrm{C}-36°\mathrm{C})} = 735{,}006\ \mathrm{W}$$

The remaining calculations for energy production are found in Chapter 15, Section 15.1.

.

Chapter 10: PV Electrical System Design

Section 10.1: Wiring Equipment Selection

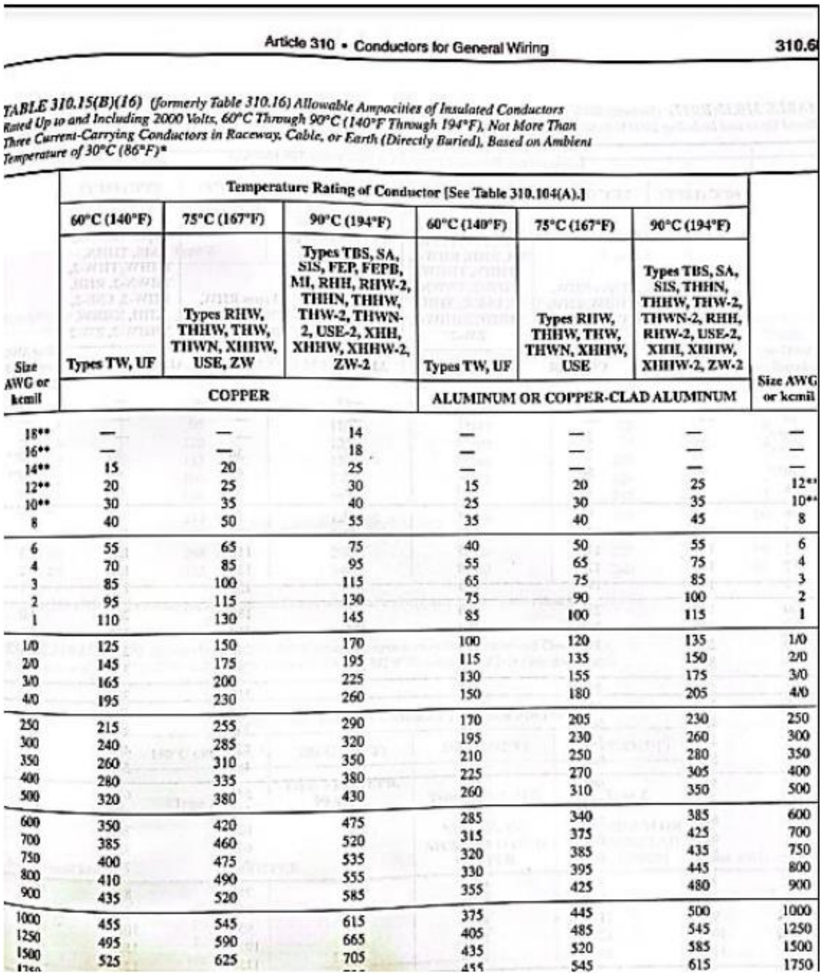
Conductors:

- **PV input to inverter from strings:**

The National Electrical Code (NEC), specifically Article 690 and Section 310, will be used to determine the appropriate wire size. As illustrated in chapter 9, section 9.3, each string produces a short circuit current of 14 amps. The DC photovoltaic brief circuit current must be increased by a factor of 1.25 in accordance with NEC 690.8(A)(1). Consequently, to ascertain the DC conductor's ampacity for the PV system, the short circuit current must be multiplied by Isc*1.25, as illustrated in equation 10.1.

Ampacity = 11.77 A * 1.25 = **14.71 A**: (Equation 10.1)

The geographical position of Puerto Rico produces diverse weather conditions, given that the island is near the equator. Therefore, the insulation for wiring will be THWN, which is specifically engineered for both dry and wet conditions with copper conductors, making the wire perfect for humidity. Additionally, figure 10.1 indicates a #14 AWG (THWN) wire, based on the computed ampacity. Nevertheless, to address safety concerns and avoid voltage loss, a #10 AWG (THWN) wire will be selected in place of a #14 AWG (THWN).



Article 310 • Conductors for General Wiring 310.6

*TABLE 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)**

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
Size AWG or kcmil	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18**	—	—	14	—	—	—	—
16**	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
				455	545	615	1750

Figure 10.1: NEC Table 310.15(B)(16)

- **Inverter to the sub-panel:**

The AC output of each inverter will be connected to an AC load sub-panel. Here, the purpose of these sub-panels is to consolidate the individual AC outputs of all inverters into a single AC output that will be directed to the AC main panel. The minimum conductor dimension must have an allowable ampacity that is not less than the non-continuous load plus 125% of the continuous load to calculate the proper AC conductor ampacity, as stated in NEC Article 210.19(A)(1). The selected inverter has a maximum AC output current of 79.5A as illustrated in table 10.1 below. Lastly, the appropriate conductor ampacity required from the inverter to the sub-panel is illustrated in equation 10.2.

Maximum Output Current	**Data Origin**
79.5 A	Table 9.6

Table 10.1: Maximum Current at the output

Ampacity = 79.5 A * 1.25 = 99.37 A: (Equation 10.2)

Therefore, in accordance with figure 10.1, a #3 AWG (THWN) size wire is necessary for the calculated ampacity. However, a #2 AWG (THWN) size wire will be employed due to safety and voltage drop concerns.

- **From sub-panels to the primary panel of the substation:**

The sub-panels will be divided into three sub-panels. Sub-panels A and B will each contain 5 and 4 inverters respectively, while C will contain only one. The maximum AC output current for sub-panels A, B and C will be illustrated in table 10.2. According to NEC Article 210.19(A)(1), the minimum conductor size must have an allowable ampacity that is not less than the non-continuous load plus 125% of the continuous load for it to calculate the appropriate AC conductor ampacity. Equations 10.3 through 10.5 will be employed to determine the required ampacity for sub-panels A, B, and C.

AC Output Current for Sub-panel A with 5 Inverters	**AC Output Current for Sub-panel B with 4 Inverters**	**AC Output Current for Sub-panel C with 1 Inverter**	**Data Origin**
400 A	320 A	80 A	Table 9.6

Table 10.2: AC Output Current for Inverters

$Ampacity_{sub-panel_A} = 400A * 1.25 = \mathbf{500\ A}$: (Equation 10.3)

$Ampacity_{sub-panel_B} = 320A * 1.25 = \mathbf{400\ A}$: (Equation 10.4)

$Ampacity_{sub-panel_C} = 80A * 1.25 = \mathbf{100\ A}$: (Equation 10.5)

Therefore, in accordance with figure 10.1 above, a #500 Kcmil (THWN) size wire is necessary to achieve the calculated ampacity for sub-panels A and B. Furthermore, a #2/0 AWG (THWN) size wire is necessary for sub-panel C to meet the calculated ampacity. Nevertheless, the highest gauge wire that is recommended is #500 Kcmil (THWN) for the sake of simplicity of installation and voltage loss considerations. As a result, a parallel wire run will be implemented to decrease the ampacity necessary for sub-panels A and B.

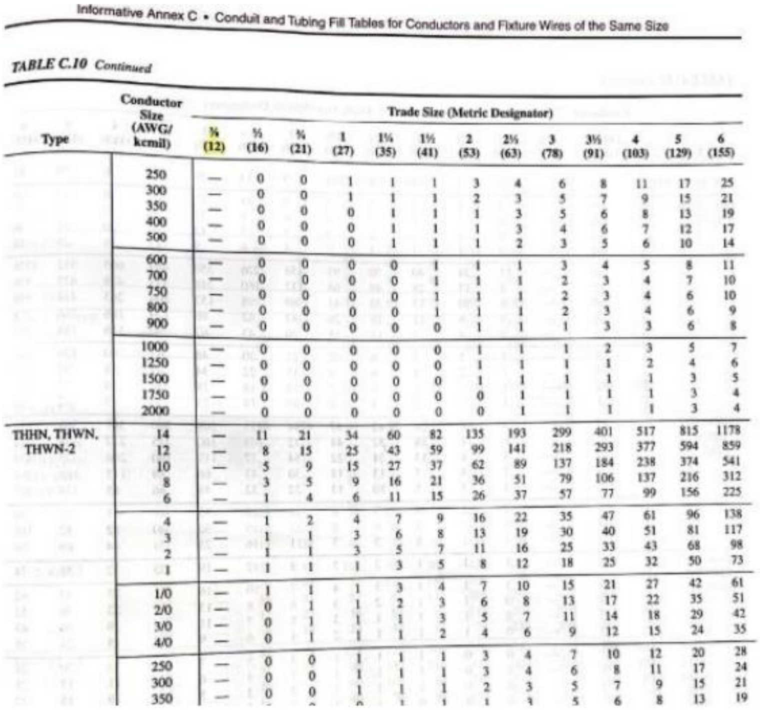
Junction Box:

Junction Boxes, as depicted in figure 10.2 below, are typically constructed from PVC material, and can be installed either grounded or ungrounded. Furthermore, these boxes serve as junctions where electrical wires are merged or introduced to continue their journey through a conduit. Evertec's PV system comprises 10 inverters with 8 strings per each one, where it contains 17 PV modules. As a result, 25 junction boxes measuring 8 by 8 by 4 inches are required, with each box capable of accommodating 17 modules. The cables from the PV modules will be connected to a 20A fuse within these receptacles for overcurrent protection (see section 10.3) prior to being directed to the input of the inverter's Maximum Power Point (MPP) tracking system.

Figure 10.2: Junction Box 8' x 8' x 4"

Section 10.2: Conduits

Referring to figure 10.3, the conductor size calculations from section 10.1 and NEC table C.10 will be employed to determine the appropriate conduit sizes. The appropriate grounding wire size will be determined by referring to NEC Table 250.66 (see figure 10.4). PVC Schedule 40 was chosen as the material for all conduits.



Informative Annex C • Conduit and Tubing Fill Tables for Conductors and Fixture Wires of the Same Size

TABLE C.10 Continued

Type	Conductor Size (AWG/ kcmil)	Trade Size (Metric Designator)												
		⅜ (12)	½ (16)	¾ (21)	1 (27)	1¼ (35)	1½ (41)	2 (53)	2½ (63)	3 (78)	3½ (91)	4 (103)	5 (129)	6 (155)
	250	—	0	0	1	1	1	3	4	6	8	11	17	25
	300	—	0	0	1	1	1	2	3	5	7	9	15	21
	350	—	0	0	0	1	1	1	3	5	6	8	13	19
	400	—	0	0	0	1	1	1	3	4	6	7	12	17
	500	—	0	0	0	1	1	1	2	3	5	6	10	14
	600	—	0	0	0	0	1	1	1	3	4	5	8	11
	700	—	0	0	0	0	1	1	1	2	3	4	7	10
	750	—	0	0	0	0	1	1	1	2	3	4	6	10
	800	—	0	0	0	0	1	1	1	2	3	4	6	9
	900	—	0	0	0	0	0	1	1	1	3	3	6	8
	1000	—	0	0	0	0	0	1	1	1	2	3	5	7
	1250	—	0	0	0	0	0	1	1	1	1	2	4	6
	1500	—	0	0	0	0	0	1	1	1	1	1	3	5
	1750	—	0	0	0	0	0	0	1	1	1	1	3	4
	2000	—	0	0	0	0	0	0	1	1	1	1	3	4
THHN, THWN, THWN-2	14	—	11	21	34	60	82	135	193	299	401	517	815	1178
	12	—	8	15	25	43	59	99	141	218	293	377	594	859
	10	—	5	9	15	27	37	62	89	137	184	238	374	541
	8	—	3	5	9	16	21	36	51	79	106	137	216	312
	6	—	1	4	6	11	15	26	37	57	77	99	156	225
	4	—	1	2	4	7	9	16	22	35	47	61	96	138
	3	—	1	1	3	6	8	13	19	30	40	51	81	117
	2	—	1	1	3	5	7	11	16	25	33	43	68	98
	1	—	1	1	1	3	5	8	12	18	25	32	50	73
	1/0	—	1	1	1	3	4	7	10	15	21	27	42	61
	2/0	—	0	1	1	2	3	6	8	13	17	22	35	51
	3/0	—	0	1	1	1	3	5	7	11	14	18	29	42
	4/0	—	0	1	1	1	2	4	6	9	12	15	24	35
	250	—	0	0	1	1	1	3	4	7	10	12	20	28
	300	—	0	0	1	1	1	3	4	6	8	11	17	24
	350	—	0	0	1	1	1	2	3	5	7	9	15	21

Figure 10.3: NEC Table C.10

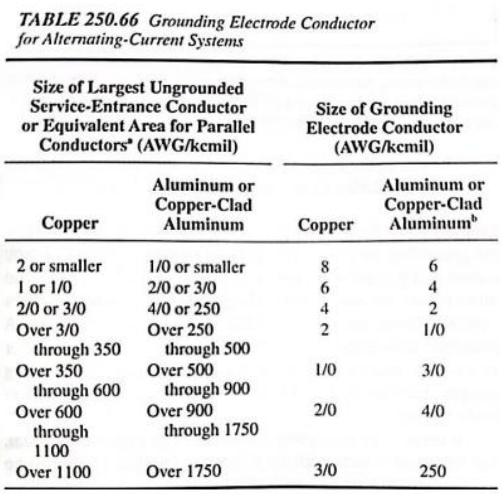


TABLE 250.66 *Grounding Electrode Conductor for Alternating-Current Systems*

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors[a] (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum[b]
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Figure 10.4: NEC Table 250.66

String to Inverter:

- Total number of wires = **3**
    - 1 positive #10 AWG wire
    - 1 negative #10 AWG wire
    - 1 ground #10 AWG wire
- Conduit size = **¾ inch**
- Total number of conduits = **108**

Inverter to Sub-panels:

- Total number of wires = **5**
    - 3 live #2 AWG wire
    - 1 neutral #2 AWG wire
    - 1 ground #8 AWG wire
- Conduit size = **2 inch**
- Total number of conduits = **4 (One set per Inverter)**

Sub-panel A to Substation Main Panel:

- Total number of wires = **5**
    - 3 live #500 Kcmil wire
    - 1 neutral #500 Kcmil wire
    - 1 ground #1/0 AWG wire
- Conduit size = **4 inch**
- Total number of conduits = **2 (Parallel wire run)**

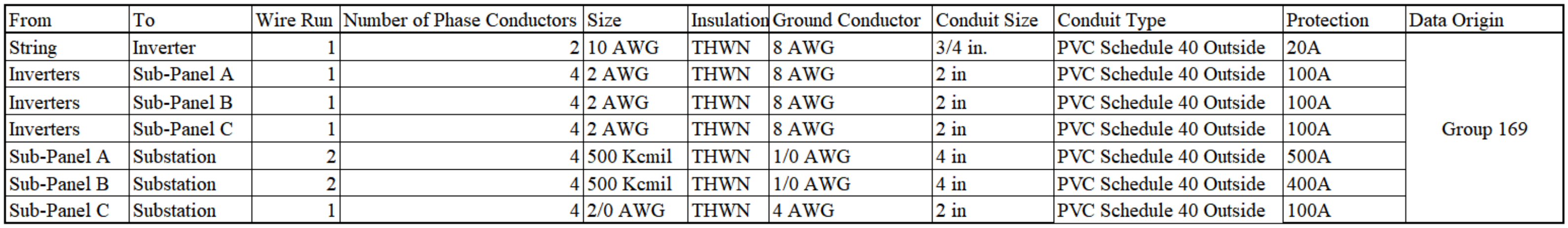
Sub-panel B to Substation Main Panel:

- Total number of wires = **5**
    - 3 live #500 Kcmil wire
    - 1 neutral #500 Kcmil wire
    - 1 ground #1/0 AWG wire
- Conduit size = **4 inch**
- Total number of conduits = **2 (Parallel wire run)**

Sub-panel C to Substation Main Panel:

- Total number of wires = **5**
    - 3 live #2/0 AWG wire
    - 1 neutral #2/0 AWG wire
    - 1 ground #4 AWG wire
- Conduit size = **2 inches**
- Total number of conduits = **1**

Finally, table 10.3 provides a comprehensive summary of the wire and conduct diameters that are necessary for the PV system.



From	To	Wire Run	Number of Phase Conductors	Size	Insulation	Ground Conductor	Conduit Size	Conduit Type	Protection	Data Origin
String	Inverter	1	2	10 AWG	THWN	8 AWG	3/4 in.	PVC Schedule 40 Outside	20A	Group 169
Inverters	Sub-Panel A	1	4	2 AWG	THWN	8 AWG	2 in	PVC Schedule 40 Outside	100A	
Inverters	Sub-Panel B	1	4	2 AWG	THWN	8 AWG	2 in	PVC Schedule 40 Outside	100A	
Inverters	Sub-Panel C	1	4	2 AWG	THWN	8 AWG	2 in	PVC Schedule 40 Outside	100A	
Sub-Panel A	Substation	2	4	500 Kcmil	THWN	1/0 AWG	4 in	PVC Schedule 40 Outside	500A	
Sub-Panel B	Substation	2	4	500 Kcmil	THWN	1/0 AWG	4 in	PVC Schedule 40 Outside	400A	
Sub-Panel C	Substation	1	4	2/0 AWG	THWN	4 AWG	2 in	PVC Schedule 40 Outside	100A	

Table 10.3: PV System Wiring and Conduit Sizes Summary

Section 10.3: Protection Equipment Selection

Rapid Shut Down Protection:

The prevention of electrocution for emergency responders in the event of a conflagration during daylight, the National Electric Code (NEC) mandates that a rapid shutoff device be connected to each PV module (article 690.12(A) through (B). The sole exception to this code is when the voltage of the PV array is less than 80V. The primary objective of a rapid shutoff switch is to rapidly halt the flow of DC power from individual solar modules and deactivate the entire PV system, even when the sun is still beaming. This is essential for the safety of emergency responders during any emergency, especially crucial when employing string inverters, as the DC wiring from the solar panels remains energized even when disconnected from the rest of the system in the absence of rapid shutoff switches, which poses a safety hazard. The JMS-F rapid shutoff switch (figure 10.5) will be installed on the aluminum frame of each PV module for this project. A black cable is utilized to connect the output connector of each module to the input connector of the JMS-F. Red cables are used to connect the output connectors of adjacent JMS-F switches within each string. The 80V limit specified by the NEC is exceeded by the sequences of modules in this proposed system, and for this reason, the JMS-F shut-off devices will be installed on every inverter.

Figure 10.5: SunSpe model JMS-F Rapid Shutdown System

Protection from Overcurrent:

As stipulated in NEC Article 690.8 (A)(1), conductor ampacity calculations must incorporate a factor of 125% of the maximum current of the PV system. Additionally, DC breakers or fuses must be rated for a minimum of 125% of the ampacity determined in NEC Article 690.8(A)(1), and NEC Article 690.9 (B)(1). Therefore, to guarantee that the system is adequately safeguarded, the subsequent total system current calculations were conducted with a total factor of 156%.

PV Module Short Circuit Current	Data Origin
14 A	Table 9.3

Table 10.4: Short Circuit Current

String to Inverter:

$\mathrm{I_{string}} = \mathrm{I_{SC}} * 1.56 = (14) * (1.56) = \mathbf{21.84\ A}$: (Equation 10.6)

Where:

$Istring$ = $PV\ string\ ampacity$

Isc = $PV\ module\ short\ circuit\ current$

AC breakers or fuses must be rated for a minimum allowable ampacity that is not less than the non-continuous load plus 125% of the continuous load, as per NEC Article 210.19(A)(1). Furthermore, the purpose of preventing the occurrence of superfluous breaker trips, the appropriate AC three phase breaker capacity will be determined using the following equations: 10.7, 10.8, 10.9, 10.10 and 10.11.

Inverter Output Current	**Data Origin**
79.5A	Table 9.4

Table 10.5: Inverter Current Data

Inverter to AC sub-panel:

$\mathrm{I}_{\mathrm{Max\ \_Inverter}} = \mathrm{I}_{\mathrm{inv}} * 1.25 = (79.5\mathrm{A})(1.25) = \mathbf{99.37A}$: (Equation 10.7)

Where:

$I_{Max\_Inverter}$ = $Inverter\ ampacity$

I_{inv} = $Inverter\ output\ current$

AC sub-panel A to AC main panel:

$\mathrm{I}_{\mathrm{sub\_panel\_A}} = \mathrm{I}_{\mathrm{inv}} * \mathrm{Q}_{\mathrm{inv}} * 1.25 = (99.37\mathrm{A})(5) = \mathbf{500\ A}$: (Equation 10.8)

Where:

$I_{\mathrm{sub\_panel\_A}}$ = $Subpanel\ A\ ampacity$

$I_{Max\_Inverter}$ = $Inverter\ ampacity$

Q_{inv} = $Total\ number\ of\ inverters\ per\ subpanel$

AC sub-panel B to AC main panel:

$\mathrm{I_{sub\_panel\_B}} = \mathrm{I_{inv}} * \mathrm{Q_{inv}} * 1.25 = (99.37\mathrm{A})(4) = \mathbf{400\ A}$: (Equation 10.9)

Where:

$I_{\mathrm{sub\_panel\_B}} = Subpanel\ \mathrm{B}\ ampacity$

$I_{Max_{-Inverter}} = \text{ Inverter ampacity}$

$Q_{inv} = Total\ number\ of\ inverters\ per\ subpanel$

AC sub-panel C to AC main panel:

$\mathrm{I_{sub\_panel\_C}} = \mathrm{I_{inv}} * \mathrm{Q_{inv}} * 1.25 = (99.37\mathrm{A})(1) = \mathbf{100\ A}$: (Equation 10.10)

Where:

$I_{\mathrm{sub\_panel\_C}} = Subpanel\ \mathrm{C}\ ampacity$

$I_{Max_{-Inverter}} = \text{ Inverter ampacity}$

Q_{inv} = Total number of inverters per subpanel (shown in chapter 9, section 9.5)

Substation AC main panel:

$\mathrm{I_{main\_panel}} = \mathrm{I_{inv}} * \mathrm{Q_T} * 1.25 = (99.37\mathrm{A})(10) = 1000\mathrm{A}$: (Equation 10.11)

Where:

$I_{Max_{-Inverter}} = \text{ Inverter ampacity}$

Q_T = Total number of inverters (shown in chapter 9, section 9.5)

In addition, it is imperative to install a 20A fuse for each PV string and a 100A triple pole breaker to connect the inverter to the AC load sub-panel, as per equations 10.6 and 10.7. A 500A main breaker is necessary to connect 5 inverters to sub-panels A, 4 inverters to sub-panel B with a 400A main breaker, and 1 inverter to sub-panel C with a 100A main breaker, as illustrated in equations 10.8, 10.9 and 10.10. Moreover, the protection of the AC main panel at the substation, a 1000A main breaker, will be installed as illustrated in equation 10.11. In the event of an overcharge or short circuit, these breakers and fuses are designed to protect the system. Lasty, table 10.6 provides a summary of the overcurrent protection devices.

Protection	**Three Phase Breaker**	**Fuse**	**Data Origin**
PV strings to inverter	N/A	20A	Group 169
Inverter to AC sub-panel	100A	N/A	
AC sub-panel A to AC main panel	500A	N/A	
AC sub-panel B to AC main panel	400A	N/A	
AC sub-panel C to AC main panel	100A	N/A	
Substation AC main panel	1000A	N/A	

Table 10.6: Overcurrent protection devices for the PV system

Section 10.4: Voltage Drop

DC Voltage Drop

A tolerable voltage drop of 3% is allowed for the most distant receptacle in a branch circuit, according to the National Electrical Code (NEC). Nonetheless, a maximum voltage variation of 5% is allowed when considering the feeders connected to the branch circuit panel. A maximum voltage variation of 3% is allowable for both DC and AC systems due to the load side connector type. Additionally, NEC’s tables 8 and 9 will be used for calculating DC and AC voltage drop in this project, since the utilization of ohms per kilofoot (ohms/kFT) for voltage drop assessment.

Furthermore, manual calculations will be performed using specific equations that are designed for both AC and DC systems. In accordance with NEC regulations, the precise determination of voltage drop is guaranteed by equations 10.12, 10.13, and 10.14:

$\mathrm{Vdrop}_{\mathrm{DC}} = \frac{\mathrm{M*I*L*R}}{\mathrm{P}}$: (Equation 10.12)

Where:

$Vdrop_{DC}$ = DC voltage drop in volts

M = Multiplier: 2 for DC voltage drop

I = Current in amps

L = Length of conductor

R = Resistance (NEC Chapter 9, table 8) in ohms/kFT

P = Parallel wire runs

$\mathrm{Vdrop}_{\mathrm{AC}} = \frac{\mathrm{M*I*L*R}}{\mathrm{P}}$: (Equation 10.13)

Where:

$Vdrop_{AC}$ = AC voltage drop in volts

M = Multiplier: $\sqrt{3}$ for three phase AC voltage drop

I = Current in amps

L = Length of conductor

R = Resistance (NEC Chapter 9, table 8) in ohms/kFT

P = Parallel wire runs

$$\%\text{Vdrop} = \frac{\text{Vdrop}}{\text{V}_{\text{L-L}}} * 100\%\text{: (Equation 10.14)}$$

Where:

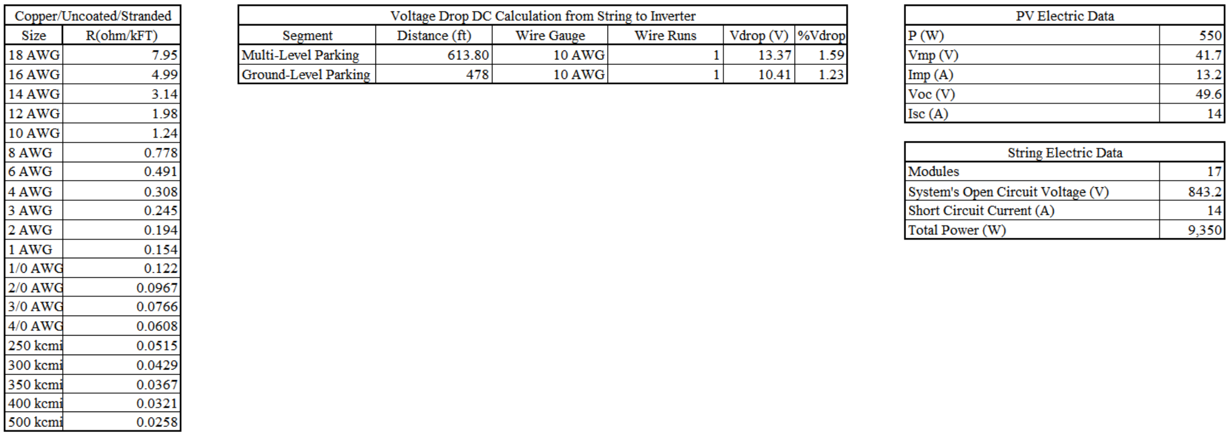
$\%Vdrop$ = Percentage of voltage drop

$Vdrop = Voltage\ drop\ in\ volts$

$\text{V}_{\text{L-L}} = Line\ voltage$

DC Voltage Drop:

An Excel spreadsheet tool was developed using equations 10.12 and 10.14 (see figure 10.6) to compute and recommend the suitable conductor size for the PV system based on DC voltage loss specifically. Consequently, the DC voltage drop for the chosen wire gauge and run length may be shown by entering the specified wire size from section 10.1 for the PV strings into the spreadsheet tool. The distances of the wire lines are detailed in Chapter 9, Section 9.1, and the electrical specifications for the PV string and inverter are detailed in sections 9.2 and 9.3 of chapter 9, respectively. Additionally, table 8 of NEC Chapter 9 delineates the resistance values for various wire gauges.



Copper/Uncoated/Stranded	
Size	R(ohm/kFT)
18 AWG	7.95
16 AWG	4.99
14 AWG	3.14
12 AWG	1.98
10 AWG	1.24
8 AWG	0.778
6 AWG	0.491
4 AWG	0.308
3 AWG	0.245
2 AWG	0.194
1 AWG	0.154
1/0 AWG	0.122
2/0 AWG	0.0967
3/0 AWG	0.0766
4/0 AWG	0.0608
250 kcmi	0.0515
300 kcmi	0.0429
350 kcmi	0.0367
400 kcmi	0.0321
500 kcmi	0.0258

Voltage Drop DC Calculation from String to Inverter					
Segment	Distance (ft)	Wire Gauge	Wire Runs	Vdrop (V)	%Vdrop
Multi-Level Parking	613.80	10 AWG	1	13.37	1.59
Ground-Level Parking	478	10 AWG	1	10.41	1.23

PV Electric Data	
P (W)	550
Vmp (V)	41.7
Imp (A)	13.2
Voc (V)	49.6
Isc (A)	14

String Electric Data	
Modules	17
System's Open Circuit Voltage (V)	843.2
Short Circuit Current (A)	14
Total Power (W)	9,350

Figure 10.6: DC Voltage Drop Calculation

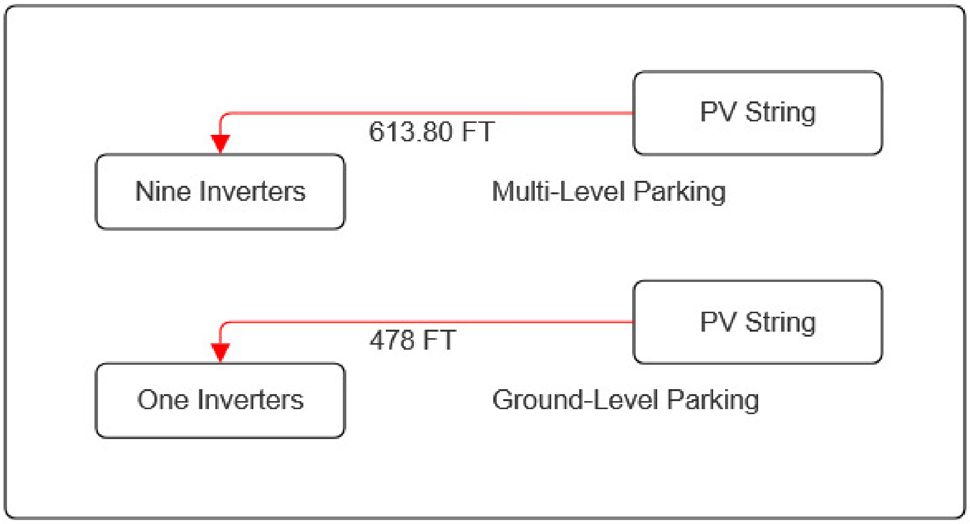


Figure 10.7: Longest Distance measurement of Multi-Level and Ground-Level Parking for DC voltage drop calculation.

AC Voltage Drop:

The Excel spreadsheet tool was developed using equations 10.13 and 10.14 (see figure 10.8) to compute and recommend the suitable conductor size for the PV system based on AC voltage loss. The distance from the inverters to the AC sub-panels A, B, and C may be considered negligible owing to their closeness. Consequently, the AC voltage loss will be exclusively assessed for the wire route from the AC sub-panels A, B, and C to the main panel of the AC substation. The Excel spreadsheet tool can demonstrate the AC voltage drop for the chosen wire size and run distance by entering the wire size specified in section 10.1 for subpanels A, B, and C. The inverter's electrical data is presented in chapter 9, section 9.3, while the lengths of the wire lines are measured in chapter 9, section 9.1. Furthermore, the aggregate current of AC sub-panels A, B, and C is detailed in chapter 10, section 10.3, while the resistance values for the wire gauges are specified in NEC Chapter 9 Table 8.

Copper/Uncoated/Stranded	
Size	R(ohm/kFT)
18 AWG	7.95
16 AWG	4.99
14 AWG	3.14
12 AWG	1.98
10 AWG	1.24
8 AWG	0.778
6 AWG	0.491
4 AWG	0.308
3 AWG	0.245
2 AWG	0.194
1 AWG	0.154
1/0 AWG	0.122
2/0 AWG	0.0967
3/0 AWG	0.0766
4/0 AWG	0.0608
250 kcmil	0.0515
300 kcmil	0.0429
350 kcmil	0.0367
400 kcmil	0.0321
500 kcmil	0.0258

Voltage Drop AC Calculation from Inverter to Substation					
Segment	Distance (ft)	Wire Gauge	Wire Runs	Vdrop (V)	%Vdrop
Multi-Level Parking	868.90	500 kcmil	4	3.86	0.80
Ground-Level Parking	468.2	2/0 AWG	1	6.23	1.30

Inverter AC Output	
Power per Inverter (W)	62,500
Voltage	480
Current per Inverter	79.5
Quantity	10
Total Power (W)	750,000
Max Current per Run GL Parking (A)	79.5
Max Current per Run ML Parking (A)	397.5
Total Current (A)	795
Total Current with 125% Protection (A)	1,000

Figure 10.8: AC Voltage Drop Calculation

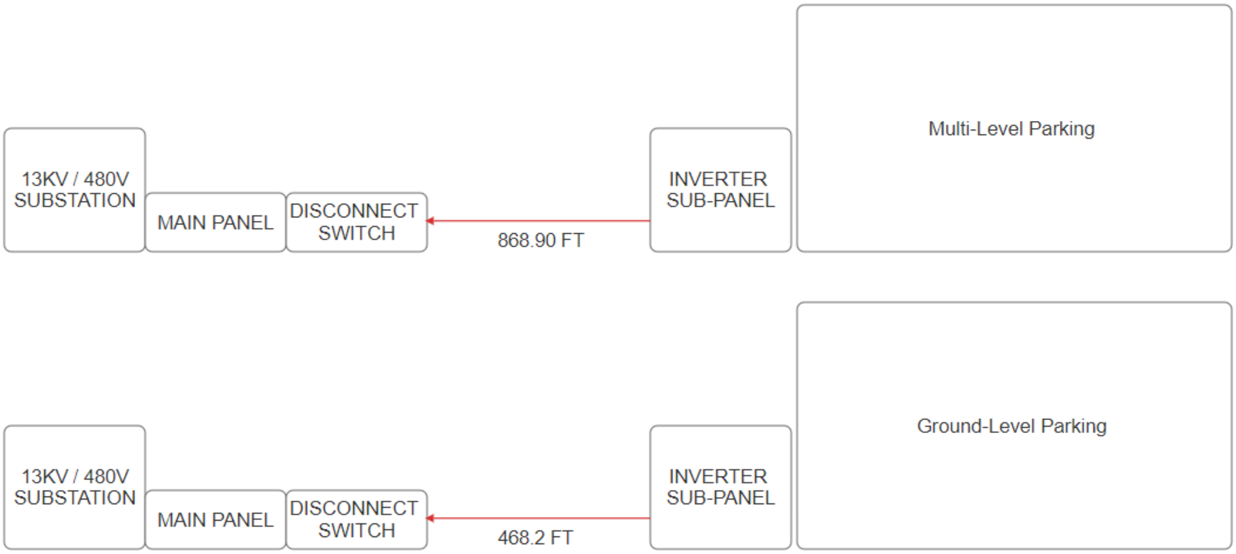


Figure 10.9: Longest Distance measurements of Multi-Level and Ground-Level Parking for AC voltage drop calculation.

Chapter 11: PV Civil System Design

Section 11.1: Mounting Structure Evaluation

Carport are a covered structure that is employed to provide limited protection to vehicles, predominantly automobiles, from the elements such as the sun, rain, and snow. Carports, in contrast to garages, are typically open on one or more sides and may be either freestanding or affixed to a wall. Additionally, carports are available in a variety of materials and designs, including metal, wood, and composite materials, and can be either temporary or permanent structures.

Benefits of Carports:

1. Cost-effective: In general, it is less expensive to construct and maintain compared to a fully enclosed garage.

2. Installation simplicity: The installation of a carport is generally less complex and more efficient than the construction of a garage.

3. Weather protection: Although carports are not entirely enclosed, the encloser still offer protection from the sun, rain, and precipitation, which can help prolong the lifespan of a vehicle's interior and paint.

4. Ventilation: Carports are open-air structures, which facilitate superior ventilation in comparison to garages. This can mitigate the risk of mildew or pollutants.

5. Versatility: Equally important, carports function as shaded outdoor spaces for activities other than parking vehicles, such as a covered area for barbecues, gatherings, or outdoor storage.

Specifications in accordance with the Puerto Rico Electric Code:

The local building and electrical codes in Puerto Rico require specific considerations when constructing a carport. These codes are in accordance with the National Electrical Code (NEC) but may include specific amendments.

1. Electrical Wiring and Outlets: The wiring must adhere to the NEC and local amendments if the carport has illumination, outlets, or other electrical installations. This encompasses the utilization of components that are both outdoor-rated and weather-resistant in order to endure the humid and coastal climate. Improving the system’s safety, it is necessary to install Ground Fault Circuit Interrupter (GFCI) protection on all outdoor receptacles and electric systems.

2. Lightning Protection: In view of Puerto Rico's frequent thunderstorms, it may be prudent to evaluate lightning protection for carports with metal structural elements, since this can lead to the attraction of lightning strikes. Carports can be protected by implementing lightning rods or grounding.

3. Adherence to Zoning Regulations and Setbacks: The carport must comply with zoning regulations that define the maximum height, coverage limits for impermeable surfaces, and setbacks from property lines to provide safety and comfort for working in future repairs.

4. Wind Load Requirements and Structural Integrity: Carports must be constructed to withstand high wind loads, which can typically reach 165 mph or higher, depending on the location, due to Puerto Rico's hurricane-prone status. This may entail the utilization of reinforced anchoring systems or heavier materials to ensure securely fastened to the earth.

Finally, this is the most advantageous location for the PV system in this project. Chapter 16, Section 16.3 provides details on materials and pricing.

Chapter 12: Cogen. Load Analysis

Section 12.1: Cogen. load analysis

1. Fuel input: The cogeneration plant begins with the input of a primary fuel source, such as natural gas, biomass, coal, propane gas or waste heat from an industrial process. The type of fuel determines whether it requires pre-processing steps such as cleaning, pulverizing (for coal), or other treatments to prepare it for combustion.
2. Combustion: The fuel is burned in a combustion chamber or boiler, generating high-temperature, high-pressure gases. This combustion process releases energy as heat.
3. Generation of electricity: The high-temperature, high-pressure gases from combustion are used to drive a turbine, which is connected to an electrical generator. The generator converts the mechanical energy into electricity, which can be used to power equipment within the plant or sent to the grid for distribution to consumers.

Calculations for the energy produced will be made using data provided by the manufacturer of the cogeneration plant and Evertec. Firstly, to define energy produced, which refers to the total amount of usable energy generated by the system, typically measured in kilowatt-hours (kWh). This includes the electrical energy output and, where applicable, the thermal energy recovered and used in the system. In a cogeneration system, energy production reflects the generator's ability to efficiently convert fuel into electricity and heat.

The generator's maximum wattage is known, and how many loads it has. Additionally, knowing that 7.43 ft^3 of natural gas is required to generate 1 kWh of electricity under standard conditions. This value is based on the energy content of natural gas, which is typically 1,030 BTU/scf, and the conversion ratio of 1 kWh = 3,412 BTU.

The energy generated is directly related to the output of the generator, as outlined in equation 12.1 below. Next, the conversion of natural gas flow rate, from ft^3/h to m^3/h is computed, then the energy content of natural gas is used to compute the equivalent in kWh for energy generation. In the absence of precise fuel data, using conventional values for the composition and energy content of natural gas is used typically. The conversions and energy content data facilitate the calculation of the generator's energy output, as seen in equation 12.2.

$$\text{Energy Consumed} = (\text{Max Wattage of generator}) \cdot (\text{Loads}) \cdot (7.43\ \text{ft}^3)$$ (Equation 12.1)

$$\text{Energy Consumed} = (1{,}200\text{kWh})(1)(7.43\text{ft}^3) = \mathbf{8,916\ ft^3/h}$$ (Equation 12.2)

$$\left(\frac{8{,}916\text{ft}^3}{\text{h}}\right)\left(\frac{1\text{m}^3}{35.315\text{ft}^3}\right) = \mathbf{252.471m^3/h}$$

$$\left(\frac{252.471\text{m}^3}{\text{h}}\right)\left(\frac{35.31\text{scf}}{1\text{m}^3}\right) = \mathbf{8,914.75\ scf/h}$$

$$\frac{\left(\frac{8{,}914.75\text{scf}}{\text{h}}\right)(\text{Energy Content})}{3{,}412\ \text{BTU}} = \frac{\left(\frac{8{,}914.75\text{scf}}{\text{h}}\right)\left(\frac{1{,}030\text{BTU}}{\text{scf}}\right)}{3{,}412\text{BTU}} = \mathbf{2691.15kWh}$$

Power kW	**Energy Produced (scf/h)**	**Energy Produced (kWh)**	**Data Origin**
1,200	8,914.75	2,691.15	Eq. 12.1 and Eq.12.2

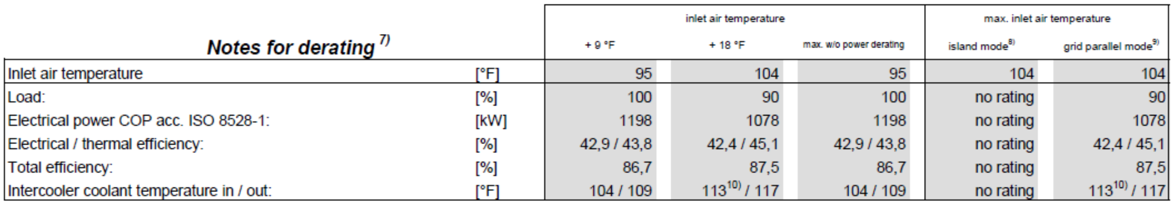
Table 12.1: Calculations results for energy produced and peak wattage.

Now, the calculation for the electrical energy consumed (EC).

- Heat Recovery - As the gases move through the turbine, it releases part of their energy, but still retains a substantial amount of heat. This excess heat is collected using heat exchangers or other recovery systems. The recovered heat can be utilized for different applications like heating buildings, supplying hot water, or powering absorption chillers for cooling.
- Distribution of thermal energy - The captured thermal energy can be delivered through a system of pipes to nearby buildings or industrial operations. In certain situations, the thermal energy may be converted into forms like steam or hot water before being distributed.
- Thermal Utilization - The distributed thermal energy can be utilized for space heating, water heating, industrial processes, or other applications, depending on the specific needs of the end-users.

- Generation of Electricity - The high-temperature, high-pressure steam generated in the cogeneration plant is used to drive a turbine. The turbine is linked to an electrical generator that transforms mechanical energy into electricity. This electricity can then be used to power different electrical systems within the plant or sent to the grid for distribution to consumers.

Notably, able 12.3 shows the data sheet for heat exhaust, from the manufacturer, where the calculations are referenced from.



Notes for derating [7)		inlet air temperature			max. inlet air temperature	
		+ 9 °F	+ 18 °F	max. w/o power derating	island mode[8)	grid parallel mode[9)
Inlet air temperature	[°F]	95	104	95	104	104
Load:	[%]	100	90	100	no rating	90
Electrical power COP acc. ISO 8528-1:	[kW]	1198	1078	1198	no rating	1078
Electrical / thermal efficiency:	[%]	42,9 / 43,8	42,4 / 45,1	42,9 / 43,8	no rating	42,4 / 45,1
Total efficiency:	[%]	86,7	87,5	86,7	no rating	87,5
Intercooler coolant temperature in / out:	[°F]	104 / 109	113[10) / 117	104 / 109	no rating	113[10) / 117

Figure 12.1: Generator plant datasheet.

The following values are taken from the generators data sheet (figure 12.1), and with some simple calculations, the values needed for the load analysis can be achieved. The conversion from BTU to kWh can be seen in equation 12.2 above, which will be used again. Additionally, some values like the enthalpy of feed water and steam enthalpy at 8 BARS were taken from another analysis done in Evertec, by Group 162, and were taken as reference for the analysis.

- Exhaust heat with temp. after heat exchanger (Q) = 33,184 BTU/min= **583.63 kW**
- Exhaust heat with 10% losses = 583.63*90%=**525.267 kW**
- Available heat = **525.267 kW or 525.267 kJ/s**
- Enthalpy of feed water at 91.84℃ = **385 kJ/kg**
- Steam Enthalpy at 8 BAR = **2768 kJ/kg**
- Net enthalpy = (2768 kJ/kg) – (385 kJ/kg) = **2383 kJ/kg**

The values obtained from the generator's data sheet, the next step is to calculate the steam generated to move the turbine and express it in kg/h. This is done in equation 12.3, and in equation 12.4, the conversion to kW was made.

$$Steam\ generated\ (m) = \frac{\frac{kJ}{s}}{\frac{kJ}{kg}} = \frac{\frac{525.267kJ}{s}}{\frac{2383kJ}{kg}} = \frac{0.22kg}{s} = \mathbf{792\ kg/h}$$: (Equation 12.3)

$$m = \frac{steam * net\ entahlpy}{3{,}600sec} = \frac{\left(\frac{792kg}{h}\right)\left(2383\frac{kJ}{kg}\right)}{3{,}600s} = \mathbf{524\ kW}$$: (Equation 12.4)

Below, in table 12.3, are the results for the steam generated. The weekly average peak wattage was provided by Evertec where an average of 9 months was considered, since the data was collected from January to September of 2024 (actual).

Average Peak Production (kW)	**Available heat (kW)**	**Inlet water temperature (°C)**	**Generated steam (kg/h)**	**Steam (kW)**	**Data Origin**
839.388	525.267	93	792	524	Appendix A.20, Eq. 12.3, Eq. 12.4

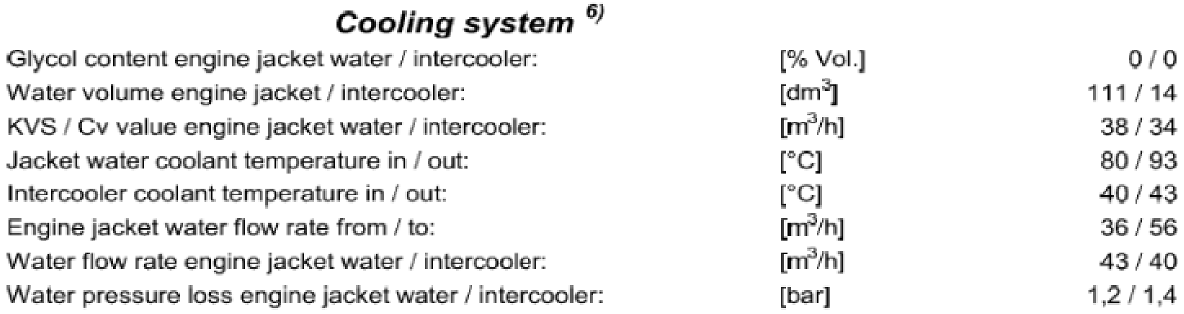
Table 12.2: Results for the generated steam.

Now, the calculations of hot water and steam used for chillers.

- Cooling Water System - In many cogeneration systems, water acts as a coolant to dissipate excess heat produced during combustion or from other heat sources. The cooling system usually involves a cooling tower or heat exchanger, where the hot water from the cogeneration plant is cooled by ambient air or through a separate water loop. The cooled water is then recirculated back to the plant to absorb more heat, completing the cooling cycle.
- Steam Generation - Water is commonly used to produce steam in a cogeneration plant, which can be utilized to drive turbines for electricity production or support industrial processes. During steam generation, water is heated to its boiling point using heat from

combustion or other sources. The resulting steam is then routed to steam turbines or industrial machinery for power generation or process heating.

- Heat Exchange - Water flow plays a key role in heat exchange processes within a cogeneration system. Heat exchangers transfer heat between different fluid streams, such as between hot exhaust gases and incoming water, or between steam and water. Water moves through one side of the heat exchanger while another fluid flows through the opposite side, enabling heat transfer without the fluids mixing.
- Condensation - In steam-based cogeneration systems, after passing through the steam turbines, the steam is condensed back into liquid form. This liquid, called condensate, is collected, and returned to the steam generation system to be reheated and reused, completing the steam cycle.
- Water Treatment and Conditioning - Towards maintaining efficiency and reliable operation for the cogeneration plants water flow system, water treatment and conditioning may be required. This can include processes like filtration, chemical treatments to prevent corrosion and scaling, as well as pH adjustments to ensure proper water quality.
- Distribution and Recirculation - Water is circulated throughout the cogeneration system via a network of pipes, pumps, valves, and other equipment. Additionally, pumps ensure the water flows at the necessary rates, while control valves manage the flow and pressure within the system.



Cooling system 6)

Glycol content engine jacket water / intercooler:	[% Vol.]	0 / 0
Water volume engine jacket / intercooler:	[dm^3]	111 / 14
KVS / Cv value engine jacket water / intercooler:	[m^3/h]	38 / 34
Jacket water coolant temperature in / out:	[°C]	80 / 93
Intercooler coolant temperature in / out:	[°C]	40 / 43
Engine jacket water flow rate from / to:	[m^3/h]	36 / 56
Water flow rate engine jacket water / intercooler:	[m^3/h]	43 / 40
Water pressure loss engine jacket water / intercooler:	[bar]	1,2 / 1,4

Figure 12.2: Cooling system data sheet.

The following data is taken from the cooling system data sheet (figure 12.2). As a result of steam being in units of m^3/h, the necessary conversion was made to change the units to m^3/h. After this, an additional conversion must be made to change the units into kg/h, and this is done by multiplying the water flow rate by the density of water which is 1,000 kg/m^3. Computation gives the mass flow rate of water, and this is done below in equation 12.5. Finally, in equation 12.6, the calculation of the change in temperature of water in optimal conditions is done, and as mentioned before, these values were taken as reference from Group 162, who already made a similar analysis on Evertec's CHP system.

- Hot water flow rate = **38 m^3/h**
- Specific Heat of Water = **4.2 kJ/kg**

$$\text{Steam (m)} = \left(38\,\frac{\mathrm{m}^3}{\mathrm{h}}\right)\left(\frac{1{,}000\mathrm{kg}}{\mathrm{m}^3}\right) = \mathbf{38{,}000kg/h} \quad \text{(Equation 12.5)}$$

$$\text{Delta T} = \text{Inlet Temp} - \text{Outlet Temp} = 93℃ - 80℃ = \mathbf{13}℃ \quad \text{(Equation 12.6)}$$

The formula that expresses the quantitative relationship between heat transfer and temperature change includes three key factors: Q = mcΔT, where Q represents the heat transfer, m is the specific energy needed to increase 1kg of the substance by 1°C, c is the specific heat of water, and ΔT is the change in temperature. This calculation is done in equation 12.7 and gives the hot water generated in kJ/s, which is kWh too. Lastly, the calculation for the hot water consumption by using a specific heat for water at 4,186 J/kg °C, and the process is shown in equation 12.8.

$$Q = \frac{mc*Delta\ T}{3{,}600s} = \frac{\left(\frac{38{,}000kJ}{h}\right)\left(\frac{4.2kJ}{kg}\right)(13℃)}{3{,}600\mathrm{s}} = \mathbf{576.33\ kJ/s} \quad \text{(Equation 12.7)}$$

$$Q = \frac{576.33kJ}{s} = \boldsymbol{576.33kWh}$$

$$m = \frac{Q}{c*Delta\ T} = \frac{576.33kW}{4{,}186\frac{\mathrm{J}}{\mathrm{kg}}℃*13℃} = \mathbf{10.59\ kg/s} \quad \text{(Equation 12.8)}$$

A summary of all data collected and calculated for the load analysis can be observed on table 12.3.

Metric	Value	Data Origin
Power (kW)	1,200	Generator Data Sheet
Energy Production (scf/h)	8,916	Eq. 12.1
Energy Production (kWh)	2,691.147	Eq. 12.2
Average Peak Production (kW)	839.388	Appendix A.20
Available heat (kJ/s)	524.7	Eq. 12.6
Inlet Max temperature (℃)	93	Generator Data Sheet
Generated Steam (kg/h)	792	Eq. 12.3
Steam (kW)	524	Eq. 12.4
Hot Water Flow Rate (kg/h)	38,000	Eq. 12.5
Change in temperature (℃)	13	Eq. 12.6
Specific Heat of Water (kJ/kg)	4.2	Internet
Hot Water Generated (kWh)	576.33	Eq.12.7
Hot Water Consumption (kg/s)	10.59	Eq. 12.8

Table 12.3: Summary of all calculations.

In summary, the collected data highlights the system's high efficiency in utilizing energy to generate heat and steam. With a substantial power output of 1,200 kW, the energy produced is approximately 2,691.15 kWh, reflecting effective energy conversion from the supplied fuel. A consistent weekly average power output of approximately 839.39 kW further demonstrates stable and reliable performance over time.

The system effectively harnesses available heat, producing a heat output of 524.7 kJ/s, which contributes to a steam generation rate of 792 kg/h and a corresponding steam power output of 524 kW. Additionally, the hot water flow rate of 38,000 kg/h with an inlet temperature of 93°C and a temperature differential of 13°C highlights the system's capacity to deliver hot water at a significant rate. By leveraging the specific heat of water (4.2 kJ/kg·°C) and a hot water consumption rate of 10.59 kg/s, the system demonstrates exceptional efficiency in thermal energy delivery. The energy produced is indicative of the system's overall performance in converting fuel into both electrical and thermal outputs. Overall, the data confirms that the system performs with a high degree of efficiency in energy production and heat utilization, making it a robust solution for cogeneration applications.

Chapter 13: Cogen. Performance Analysis

Section 13.1: Electrical, Mechanical and Hot Water Efficiencies

In the power plant industry, combined cycle technology stands out for its high thermodynamic efficiency. Cogeneration plants, designed to challenge traditional methods, focus on maximizing both power output and overall efficiency of the systems where it is installed. Unlike conventional power plants, cogeneration plants generate electricity and capture useful thermal energy from a single fuel source simultaneously. A cogeneration plant's main goal is to enhance efficiency by producing electricity and effectively utilize the heat waste generated by the fuel source. In a combined heat and power (CHP) system, the focus is on delivering multiple benefits, including electricity generation, and supplying useful heat tailored to meet the needs of end users. This client-focused approach offers a more efficient, sustainable, and adaptable power generation solution. By capturing waste heat, cogeneration systems can reach an efficiency of 60 to 80 percent, significantly higher than traditional methods. This improvement is especially noticeable when using natural gas, as it requires less fuel and leads to lower costs compared to buying electricity separately. In summary, the combined heat and power (CHP) approach maximizes energy output, offering both economic and environmental benefits over conventional energy generation techniques.

Evaluation of the theoretical efficiency for the cogeneration plant when it is running at 100 %

1. Electrical Efficiency – NELEC is described as the "Net Electrical Efficiency," and it is the ratio between the output electrical useful energy (EC) and the input fuel power (FC). In table 13.1, having the values for peak energy and energy consumed.

Data	Value	Data Origin
Peak Energy (Output)	1,200 kW	Appendix B.1
Energy Produced (Input)	2,691.147 kWh	Eq. 12.2

Table 13.1: Data Values from Load Analysis for Electrical Efficiency

$$\text{Net Electrical Efficiency} = \frac{\text{Energy Consumed}}{\text{Energy Produced}} * 100\% \text{ : (Equation 13.1)}$$

$$\text{Net Electrical Efficiency} = \frac{1{,}200\text{kW}}{2691.147\text{kWh}} * 100\% = \mathbf{44.59}\%$$

The NELEC system is a measure of how effectively it converts fuel energy into useful electrical energy. The typical efficiency formula was used, the system's output divided by the input of said system. In this case, the output is the electrical energy consumed by the load and the input is the fuel energy injected into the plant. The power generation efficiency was 44.59%, which is what the generator produces. This means that the system can convert approximately 44.59% of the total energy injected into useful electrical energy. A higher NELEC efficiency rating indicates a more efficient system, as it can produce more electricity with the same amount of fuel injected into the system.

2. Mechanical Efficiency - Mechanical efficiency in a cogeneration plant refers to the effectiveness with which the plant converts the input energy from fuel into useful mechanical work, typically to drive turbines or generators. In cogeneration, the goal is to maximize this efficiency by utilizing both the mechanical power for electricity generation and the waste heat for heating or other processes. This dual-use approach improves the overall energy efficiency of the cogeneration plant compared to traditional power plants. Mechanical efficiency in a cogeneration system is influenced by factors like the quality of fuel, turbine performance, and the integration of heat recovery systems. Finally, by optimizing mechanical efficiency, cogeneration plants achieve higher energy output with reduced fuel consumption, resulting in economic savings and a lower environmental impact. This calculation is done in equation 13.2.

Data	**Value**	**Data Origin**
Steam Generated (Output)	524 kWh	Eq. 12.4
Energy Produced (Input)	2,691.147 kWh	Eq. 12.2

Table 13.2: Data Values from Load Analysis for Mechanical Efficiency

$$\text{Mechanical efficiency} = \frac{\text{Steam Generated}}{\text{Energy Produced}} * 100\% \text{ : (Equation 13.2)}$$

$$\text{Mechanical Efficiency} = \frac{524\text{kWh}}{2{,}691.147\text{ kWh}} * 100\% = \mathbf{19.47}\%$$

As can be seen in equation 13.2, the mechanical efficiency for the system is approximately 19.47%. This means that the cogeneration plant utilizes 19.47% of the fuel injected as steam, effectively. This is used to drive the steam turbine and move the generator.

3. Hot Water Efficiency - Hot water efficiency in a cogeneration plant refers to the effective utilization of waste heat to produce hot water for heating or industrial processes, maximizing overall system efficiency. In a cogeneration setup, the plant generates electricity, and the excess heat that would otherwise be lost is captured and used to heat water. This hot water can then be distributed for building heating, domestic hot water, or other industrial uses. By effectively using this thermal energy, cogeneration plants reduce the need for additional energy sources to heat water, increasing the plant's overall energy efficiency. This not only lowers fuel consumption, but reduces operating costs and the environmental impact, making the plant more sustainable and economical in the long term. Lastly, considering a typical 3% loss of water in the heat exchanger, the true values of the hot water efficiency are calculated. The computation for the hot water efficiency, considering losses is done below, in equation 13.3.

Data	**Value**	**Data Origin**
Hot Water Generated (Output)	576.33 kWh	Eq. 12.7
Energy Produced (Input)	2,691.147 kWh	Eq. 12.2

Table 13.3: Data Values from Load Analysis for Hot Water Efficiency

$$\text{Hot Water Efficiency} = \frac{\text{Hot Water Generated}}{\text{Energy Produced}} * 100\% \quad \text{(Equation 13.3)}$$

$$\text{Hot Water Efficiency} = \frac{576.33\text{ kWh}}{2{,}691.147\text{ kWh}} * 100\% = 21.41\ \%$$

$$\text{Hot Water Efficiency} = 21.41\% - 3\% = \mathbf{18.41}\%$$

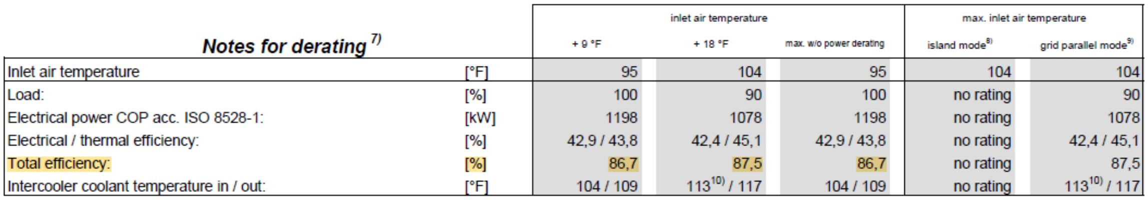
The hot water efficiency of a system measures how effectively it converts fuel energy into hot water. The system can convert approximately 18.41% of the input fuel energy into hot water. Higher hot water efficiency indicates a more efficient system in terms of producing hot water for industrial processes or facilities.

Finally, the overall efficiency of the cogeneration plant system is the sum of all efficiencies, which is done below, in equation 13.4.

$$\text{Overall Efficiency} = \text{Electrical} + \text{Mechanical} + \text{Hot Water Efficiencies} : \text{(Equation 13.4)}$$

$$\text{Overall Efficiency} = 44.59\% + 19.47\% + 18.41\ \% = \mathbf{82.47}\%$$

In summary, the efficiencies provided for the performance of the cogeneration plant details its ability to convert input fuel into effective energy usage. Based on the calculations done, the maximum overall efficiency of the system is 82.47%, meaning that the system is effectively utilizing most of the available energy to produce power, and can be compared to the efficiency of the manufacturer's data sheet. Additionally, these values are close to each other, meaning that there is proof that the value calculated is correct, and this can be observed below, in figure13.1. Finally, table 13.4 highlights every efficiency calculated.



Notes for derating [7]		inlet air temperature			max. inlet air temperature	
		+ 9 °F	+ 18 °F	max. w/o power derating	island mode[8]	grid parallel mode[9]
Inlet air temperature	[°F]	95	104	95	104	104
Load:	[%]	100	90	100	no rating	90
Electrical power COP acc. ISO 8528-1:	[kW]	1198	1078	1198	no rating	1078
Electrical / thermal efficiency:	[%]	42,9 / 43,8	42,4 / 45,1	42,9 / 43,8	no rating	42,4 / 45,1
Total efficiency:	[%]	86,7	87,5	86,7	no rating	87,5
Intercooler coolant temperature in / out:	[°F]	104 / 109	113[10] / 117	104 / 109	no rating	113[10] / 117

Figure 13.1: Generator Data Sheet.

Electrical Efficiency (%)	**Mechanical Efficiency (%)**	**Hot Water Efficiency (%)**	**Overall Efficiency (%)**	**Data Origin**
44.59	19.47	18.41 %	82.47	Eq. 13.1 to Eq. 13.4

Table 13.4: Efficiency Results.

Chapter 14: Economic Billing Assessment

Section 14.1: Pre-Cogeneration Economic Consumption and Cost Analysis

Starting the Cost analysis and economic consumption of the pre-cogeneration, a careful observation at table 14.1 below it must be made, because it will be the standard for this analysis. This table shows the data taken from the electric bill sheet given by Evertec and the calculated average values. In addition, it provides a detailed comparison of the energy consumption and cost for 2019 and 2020, before the installation of the cogeneration system at the Cupey Center buildings. In context, the calculated values were the average ones, which were made by taking the data given from Evertec and dividing it each year by all the months (12), for energy consumption and cost.

Year	Total Energy (kWh)	Average Energy (kWh)	Total Cost ($)	Average Cost ($)	Data Origin
2019	11,515,898.00	959,658.17	2,329,939.38	194,161.62	Appendix A: Figure A.1
2020	11,079,377.80	923,281.48	2,116,091.69	176,340.97	

Table 14.1: Energy Consumption and Cost Comparison Before COGEN Installation

In 2019, the buildings recorded an average monthly energy consumption of 959,658.17 kWh and an average monthly cost of $194,161.62. The high energy usage and associated costs highlight the building’s significant operational demands during this period. In 2020, the building's average monthly energy consumption decreased to 923,281.48 kWh, and the average monthly cost dropped to $176,340.97. While there was a reduction in both energy usage and costs, the building continued to face substantial energy expenditures, indicating that efficiency measures had yet to be implemented.

In summary, 2020 reflects improved energy management compared to 2019, with stable energy consumption and reduced costs. This serves as a baseline for comparing the financial and operational impacts after the installation of the cogeneration system.

Section 14.2: Post-Cogeneration Energy and Cost Evaluation

Now, for the post-cogeneration energy consumption and cost evaluation, the standard for this analysis is in table 14.2, which has calculated average values and other data given by Evertec. Therefore, this table presents energy consumption from the electric utility and cost data for the years 2021 to 2024, following the installation of the COGEN system at the Cupey Center buildings. The significant reduction in energy consumption from the electric utility is directly attributable to the COGEN system, which allowed the building to meet much of its energy needs internally.

Year	**Total Energy (kWh)**	**Average Energy (kWh)**	**Total Cost ($)**	**Average Cost ($)**	**Data Origin**
2021	3,554,410.00	296,200.83	797,229.16	66,435.76	Appendix A: Figure A.1
2022	2,789,160.00	232,430.00	925,275.77	77,106.31	
2023	1,081,080.00	90,090.00	407,919.12	33,993.26	
2024	856,680.00	95,186.67	309,732.38	34,414.71	

Table 14.2: Energy Consumption and Cost Analysis After COGEN Installation

In 2021, following the COGEN system's implementation, there was a sharp decrease in average monthly energy consumption from the electric utility to 296,200.83 kWh. Along with this reduction, the average monthly cost fell to $66,435.76. This decrease in reliance on external electricity is due to the COGEN system generating a substantial portion of the buildings' power needs internally. The significant drop in both utility-supplied energy consumption and costs highlights the immediate impact of the COGEN system's integration.

Furthermore, in 2022, total energy consumption from the electric utility decreased further to 2,789,160 kWh, with an average monthly usage of 232,430 kWh. However, the total cost increased to $925,275.77, with an average monthly cost of $77,106.31. This rise in costs, despite reduced energy consumption, is likely to reflect the transition to full operational use of the COGEN system, as well as possible changes in energy rates. The building's reliance on external power continued to decrease, but fluctuations in energy pricing led to an increase in expenses. Subsequently in 2023, the downward trend in utility energy consumption continued, reaching 1,081,080 kWh, with an average monthly usage of 90,090 kWh. The total cost of energy dropped significantly to $407,919.12, resulting in an average monthly cost of $33,993.26. This reduction in both energy consumption and costs reflects improved efficiency of the COGEN system, which enabled the building to further reduce its dependence on external electricity. The system's increasing efficiency helped lower costs, possibly aided by better operational practices and more efficient energy management.

Now, on 2024 the buildings' average monthly energy consumption from the electric utility raised a little at 95,186.67.14 kWh, with an average monthly cost of $34,414.71, keeping in mind this average may lower as the year passes. This continued reduction in energy consumption and costs indicates the ongoing optimization of the COGEN system, allowing the building to minimize its use of external power. The data shows the system's long-term benefits in reducing utility energy consumption.

The data from 2021 to 2024 reflects the building's transition to a more self-sustained energy model, with the COGEN system dramatically reducing the need for external electricity. While energy consumption from the electric utility has steadily decreased, costs have fluctuated, likely influenced by changes in energy rates and external market factors. Overall, the COGEN system has led to a more cost-effective and efficient energy consumption model, as the buildings' reliance on the electric utility diminished significantly.

Section 14.3: Water Consumption and Cost Evaluation

The implementation of the cogeneration (COGEN) system at the Cupey Center Buildings, along with the integration of chillers within the combined heat and power (CHP) system, resulted in a notable increase in water consumption and related costs. Additionally, table 14.3 illustrates the water consumption and cost data before and after the COGEN system was put into operation.

Metric	Before COGEN	After COGEN	Change	Change (%)	Data Origin
Average Monthly Volume (m^3)	2,218.58	2,738.73	520.15	123.45	Appendix A.11
Average Yearly Volume (m^3)	26,623.00	32,864.80	6,241.80	123.45	
Average Monthly Cost ($)	15,067.10	19,715.86	4,648.76	130.85	
Average Yearly Cost ($)	180,805.21	236,590.28	55,785.08	130.85	

Table 14.3: Water Consumption and Cost Breakdown for 2020 and 2021

Before the COGEN system, the building consumed an average of 2,218.58 m³ of water per month. However, after the installation of the system and the use of chillers, the consumption increased to 2,738.73 m³ per month, representing an increase of 520.15 m³. Annually, this increase in water usage rose from 26,623.00 m³ to 32,864.80 m³, with an additional consumption of 6,241.80 m³ each year.

This rise in water consumption was accompanied by an increase in costs. Before the COGEN system was implemented, the average monthly water cost was $15,067.10. After the system became operational, the average monthly cost increased to $19,715.86, reflecting an additional cost of $4,648.76 per month. On a yearly basis, the water costs rose from $180,805.21 to $236,590.28, a total increase of $55,785.08.

The increase in water consumption and costs can be directly attributed to the operational demands of the chillers, which require additional water as part of the cooling process. While the COGEN system effectively reduced the building’s reliance on external electricity and helped lower electricity costs, the use of chillers has introduced new operational expenses. This increased demand for water is expected in CHP systems that use absorption chillers to enhance efficiency, but it reflects the trade-offs in resource use associated with such systems.

While the COGEN system has successfully reduced electricity consumption and operational costs, the integration of chillers within the CHP system has led to a significant rise in water consumption and costs. This increase highlights the complex balance between improved energy generation efficiency and the additional resources required for system cooling. As the system continues to optimize energy use, the ongoing management of water resources will play a key role in maintaining overall operational efficiency.

Section 14.4: Pre-Cogeneration and Post-Cogeneration Comparison

Building upon previous research, table 14.4 shows the calculated and given data. This table compares the energy consumption and costs, before and after the installation of the COGEN system. The installation of the COGEN system at the Cupey Center Buildings resulted in a significant reduction in the energy consumption sourced from the electric utility. From 2019 to 2020, the building relied entirely on external power provided by the utility company. During this period, the average monthly energy consumption from the electric utility was 941,469.83 kWh, with an average monthly cost of $185,251.29. These figures highlight the substantial energy demand of the building, and the associated excessive costs reflect the reliance on external energy supply, which can be subject to fluctuating market prices.

Metric	**Before COGEN**	**After COGEN**	**Change**	**Savings (%)**	**Data Origin**
Average Monthly Energy (kWh)	902,022.00	184,029.56	-717,992.44	79.60	Appendix A: Figure A.10
Average Yearly Energy (kWh)	10,824,264.00	2,208,354.67	-8,615,909.33	79.60	

Average Monthly Cost ($)	175,685.59	54,225.70	-121,459.90	69.13	
Average Yearly Cost ($)	2,108,227.13	650,708.38	-1,457,518.74	69.13	

Table 14.4: Comparative Analysis of Pre and Post COGEN Energy and Costs

Furthermore, with the installation of the COGEN system, the energy profile of the building shifted significantly. From 2021 to 2024, the average monthly energy consumption from the electric utility decreased dramatically to 180,582.60 kWh, reflecting a reduction of 760,887.23 kWh compared to the pre-COGEN period. This decrease represents an 80.82% reduction in the building’s dependency on the external power grid. Along with this reduction in energy consumption, there was a substantial decrease in costs, with the average monthly cost falling to $53,368.21, saving the building $131,883.08 per month on utility bills, which equates to a 71.19% reduction in costs.

The dramatic reduction in energy consumption from the electric utility after the COGEN system was implemented underscores the system's ability to meet a substantial portion of the building’s energy needs internally. The system allowed the building to reduce its reliance on external power, thereby lowering operational costs. The sharp decline in average monthly utility costs signifies the economic efficiency of the COGEN system, contributing to considerable long-term savings.

Comparing energy consumption and costs before and after the installation of the COGEN system, the system has had a transformative impact on the building’s energy management. The substantial decrease in utility-sourced energy, along with the significant reduction in associated costs, reflects the effectiveness of the COGEN system in optimizing the building’s energy efficiency. This transition to internal energy generation has not only reduced the buildings’ dependency on the electric utility but demonstrated the financial viability of cogeneration technology for long-term operational savings.

Chapter 15: Micro-Grid System Simulations

Section 15.1: Helioscope Simulation

Helioscope is a photovoltaic system simulator created by Folsom Labs in San Francisco, available by subscription, specifically intended for creating PV system pictures at the client's designated site. Helioscope's advanced modelling capabilities evaluate the system's performance under various conditions, ensuring maximum efficiency. The cloud-based platform utilizes a systematic process that begins with the input of project details, such as location, roof characteristics, and specific system requirements, enabling the assembly of the solar array.

Data including the system's location, chosen solar panels, and inverters will be entered. Utilizing this information, the specified area will be filled with solar panels until the necessary number of modules and the appropriate inverter capacity are attained. This procedure involves carefully positioning solar panels until the determined amount corresponds with the total power consumption needs. Subsequently, Helioscope will provide the site and relevant information of the solar system, delivering a comprehensive visual report along with a detailed cost-benefit analysis.

Additionally, to start a project in Helioscope, users must adhere to the following procedures. The user must first visit Helioscope.com and choose "New Project." The project's name, address, and site classification (commercial, ground-mounted, or residential) must thereafter be recorded. Subsequently, selecting "New Design" followed by "Create New Design" will direct people to the specified URL. Lastly, figure 15.1 shows the location of the project in Evertec, located in San Juan, Puerto Rico.

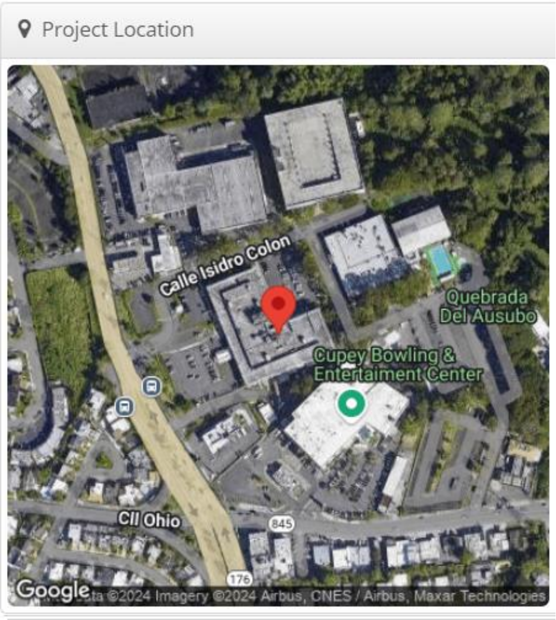


Figure 15.1: Selected Project Location Evertec

The selected locations for the carport were identified in figure 15.2. This design consists of eight primary carport photovoltaic array sections positioned inside the multi-level parking facility of Evertec, in addition to one smaller part situated in the ground-level parking area.

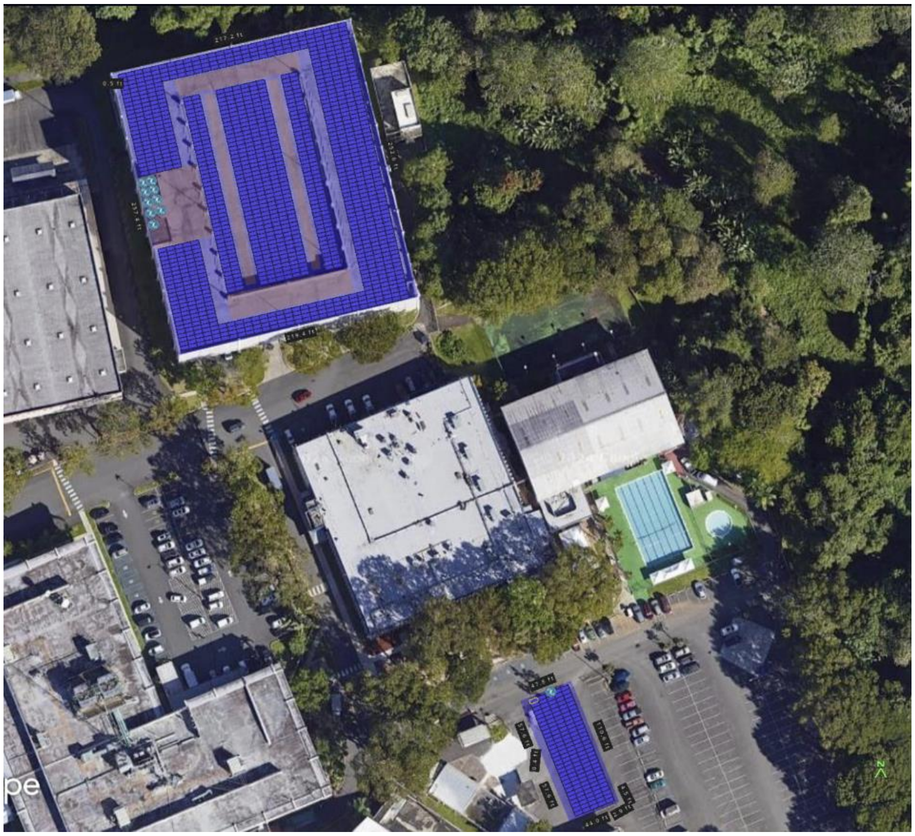
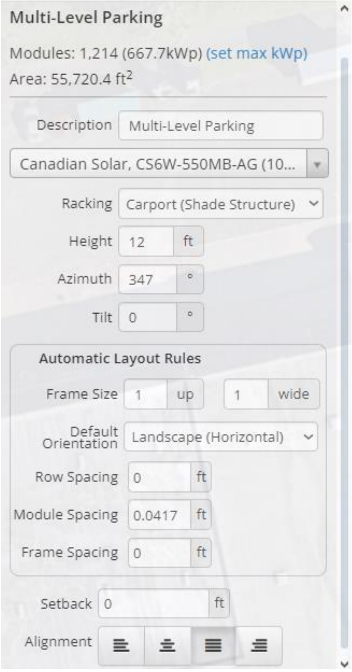


Figure 15.2: Photovoltaic Module Areas Evertec

Upon selecting the PV module locations, the necessary input data pertaining to the system was entered, as seen in figure 15.3. For this photovoltaic system design, the chosen module will be identical to that of the photovoltaic design.



Multi-Level Parking

Modules: 1,214 (667.7kWp) (set max kWp)
Area: 55,720.4 ft^2

Description: Multi-Level Parking
Canadian Solar, CS6W-550MB-AG (10...
Racking: Carport (Shade Structure)
Height: 12 ft
Azimuth: 347 °
Tilt: 0 °

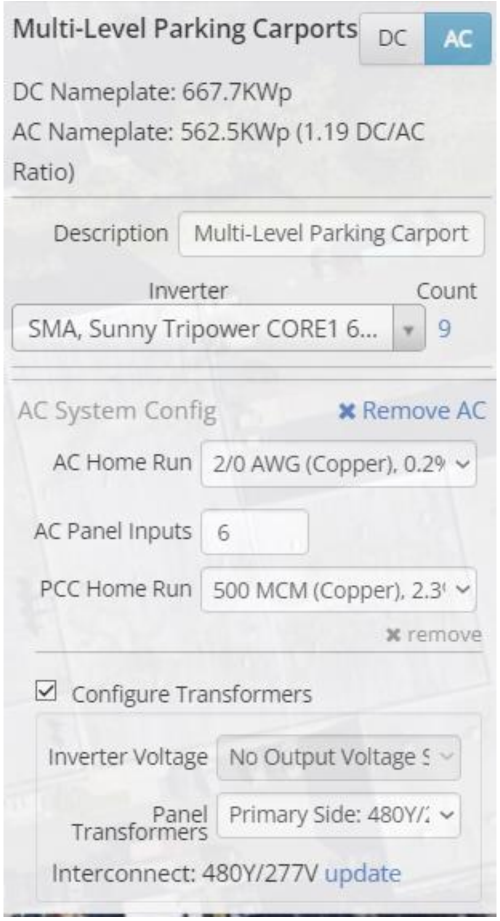
Automatic Layout Rules

Frame Size: 1 up 1 wide
Default Orientation: Landscape (Horizontal)
Row Spacing: 0 ft
Module Spacing: 0.0417 ft
Frame Spacing: 0 ft

Setback: 0 ft
Alignment

Figure 15.3: Input Data for Multi-Level Parking

Moreover, figure 15.4 below illustrates the input data for the AC wiring zone of Parque Central. The PV design for Parque Central will use the same inverter as the CDT design, namely the SMA Sunny Tripower CORE1 62-US.



Multi-Level Parking Carports

DC Nameplate: 667.7KWp

AC Nameplate: 562.5KWp (1.19 DC/AC Ratio)

Description: Multi-Level Parking Carport

Inverter: SMA, Sunny Tripower CORE1 6... Count: 9

AC System Config

AC Home Run: 2/0 AWG (Copper), 0.29

AC Panel Inputs: 6

PCC Home Run: 500 MCM (Copper), 2.3

☑ Configure Transformers

Inverter Voltage: No Output Voltage S

Panel Transformers: Primary Side: 480Y/

Interconnect: 480Y/277V

Figure 15.4: Wiring Zone AC Input Data for Multi-Level Parking

The configuration of the modules for Evertec’s design will be situated in the natatorium's parking lot. As seen in figure 15.1, the carport installation consists of eight primary portions inside the multi-level parking and one supplementary section located in the ground-level parking. Eight tiers of the multi-level parking include 1,224 modules, whilst the ground-level parking area will consist of 139 modules. A total of 1,363 modules will be present.

Furthermore, as seen in figure 15.5, and table 15.1, the Helioscope presents a production graph indicating output exceeding 80 KWh each month throughout the production period. Moreover, producing over 110 kWh in a minimum of three months annually.

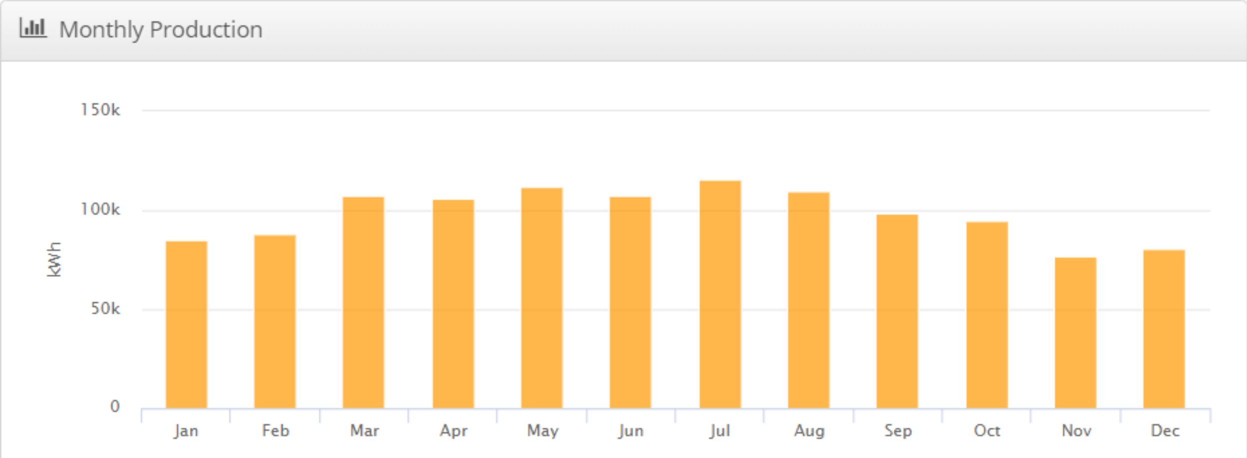
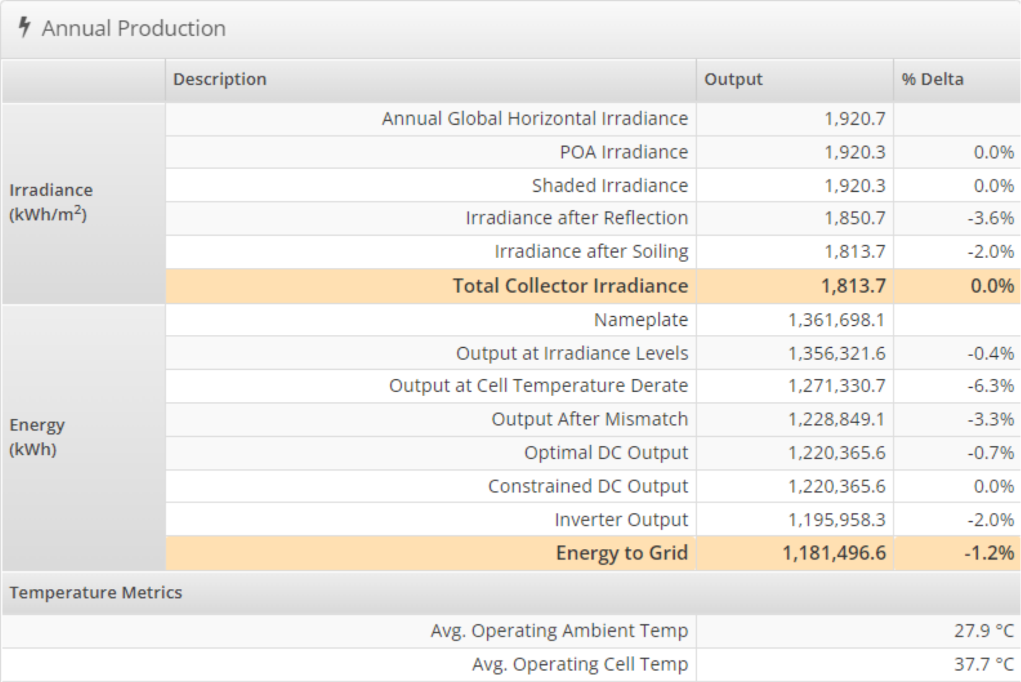


Figure 15.5: Evertec's Helioscope Monthly Production Simulation

The total collector irradiance accessible to the modules in the Evertec array was estimated to be 1,813.7 kWh/m². The yearly energy output to the grid was determined to be 1,181,496.6 kWh, as seen in figure 15.6. Furthermore, table 15.1 presents a comprehensive analysis of the monthly AC solar output at Evertec.



Annual Production

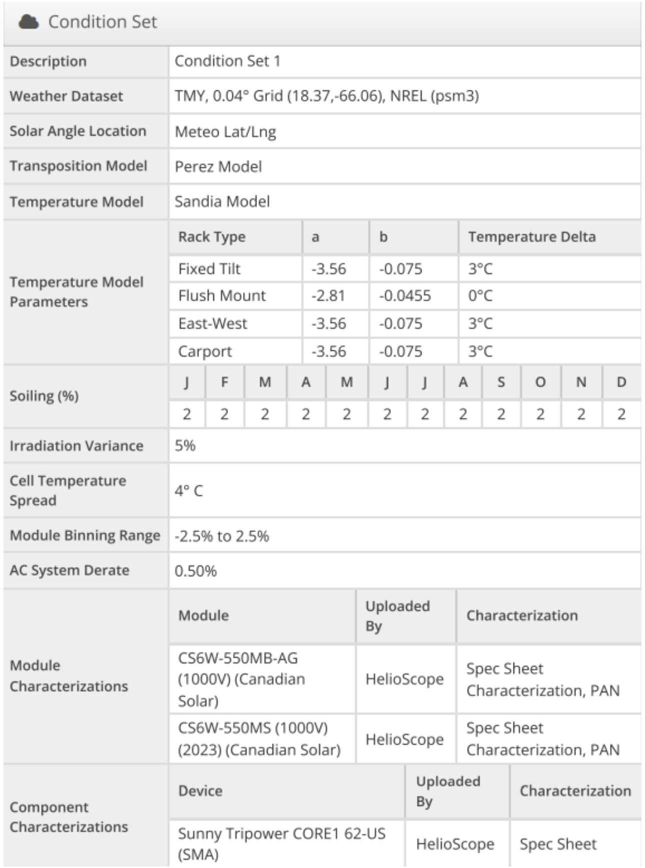
	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,920.7	
	POA Irradiance	1,920.3	0.0%
	Shaded Irradiance	1,920.3	0.0%
	Irradiance after Reflection	1,850.7	-3.6%
	Irradiance after Soiling	1,813.7	-2.0%
	Total Collector Irradiance	**1,813.7**	**0.0%**
Energy (kWh)	Nameplate	1,361,698.1	
	Output at Irradiance Levels	1,356,321.6	-0.4%
	Output at Cell Temperature Derate	1,271,330.7	-6.3%
	Output After Mismatch	1,228,849.1	-3.3%
	Optimal DC Output	1,220,365.6	-0.7%
	Constrained DC Output	1,220,365.6	0.0%
	Inverter Output	1,195,958.3	-2.0%
	Energy to Grid	**1,181,496.6**	**-1.2%**
Temperature Metrics			
	Avg. Operating Ambient Temp		27.9 °C
	Avg. Operating Cell Temp		37.7 °C

Figure 15.6: Evertec's Helioscope Annual Production Simulation

Month	Energy to Grid (KWh)	Data Origin
January	84,737.6	Figure 15.5
February	88,028.0	
March	107,301.0	
April	106,253.5	
May	111,839.1	
June	107,277.1	
July	115,399.8	
August	110,002.1	
September	98,493.7	
October	94,679.6	
November	76,546.4	
December	80,937.2	

Table 15.1: Evertec's Monthly AC Solar Production

The condition set report for Evertec was furnished, as shown in figure 15.7. This report delineates all environmental factors that could potentially impact the system's performance.



Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 0.04° Grid (18.37,-66.06), NREL (psm3)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C
East-West	-3.56	-0.075	3°C
Carport	-3.56	-0.075	3°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	2	2	2	2	2	2	2	2	2

Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Module Characterizations

Module	Uploaded By	Characterization
CS6W-550MB-AG (1000V) (Canadian Solar)	HelioScope	Spec Sheet Characterization, PAN
CS6W-550MS (1000V) (2023) (Canadian Solar)	HelioScope	Spec Sheet Characterization, PAN

Component Characterizations

Device	Uploaded By	Characterization
Sunny Tripower CORE1 62-US (SMA)	HelioScope	Spec Sheet

Figure 15.7: Evertec's Condition Set

Furthermore, figure 15.8 depicts the generating losses, with the predominant energy loss due to temperature, being 6.3% of the total generation. Mismatch losses are 3.3%, reflection loss is 3.6%, and all other losses are at or below 2%, as seen in the graph.

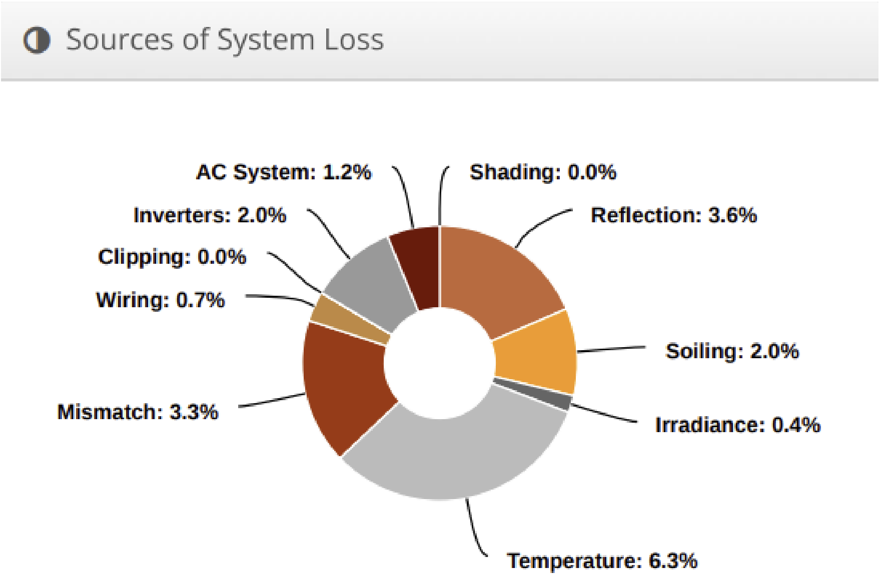


Figure 15.8: Evertec's System Loss Simulation

Finally, Helioscope assesses the impact of surrounding shadows on the modules and delivers irradiation percentages accordingly. The design indicates that the irradiation level is minimal, as seen in figure 15.8, owing to the height of the multi-level parking and the absence of vegetation in the ground-level parking. Furthermore, Helioscope provides the system metrics for Evertec's comprehensive project, which will be shown in figure 15.9.

The next step is to incorporate the percentage of losses generated by the electric system, which encompasses wiring, shading, connections, light-induced degradation, nameplate rating, availability, soiling, and incompatibilities. The Helioscope simulation was employed to determine these percentages of losses, as illustrated in table 9.8. The electric system's calculated loss is in percentage. Consequently, the solar array's total output power can be calculated by employing equation 9.11 and the power output considering temperature effects is displayed in table 9.8 below.

%Ploss	**Data Origin**
19.5%	Figure 15.8
Power output considering temperature effect	Equation 9.10
735,006 W	

Table 15.2: %Ploss of the Electric System and Power Output Considering Temperature Effect Input

$\mathrm{P} = \mathrm{P}_{\mathrm{arr-t}} - (\mathrm{P}_{\mathrm{arr-t}} * \%\mathrm{P}_{\mathrm{Loss}})$: (Equation 15.1)

Where:

P = Total output power of the solar array

P_{arr-t} = Power output considering temperature effect

$\%P_{Loss}$ = Percentage of power loss

$\mathrm{P} = 735{,}006\ \mathrm{W} - (735{,}006\ \mathrm{W} * 0.195) = \mathbf{591{,}679.83\ W}$

Furthermore, the power loss calculation of the solar array yielded a resultant of 591,679.83 W. The following phase in the calculation of solar array energy production is to ascertain the daily DC power output that the PV modules will generate, utilizing the resultant total power described in equation 15.1. The average number of peak sun hours in Puerto Rico is approximately 5.5 per day. The solar array will generate the following DC power in a day, as indicated by equation 15.2:

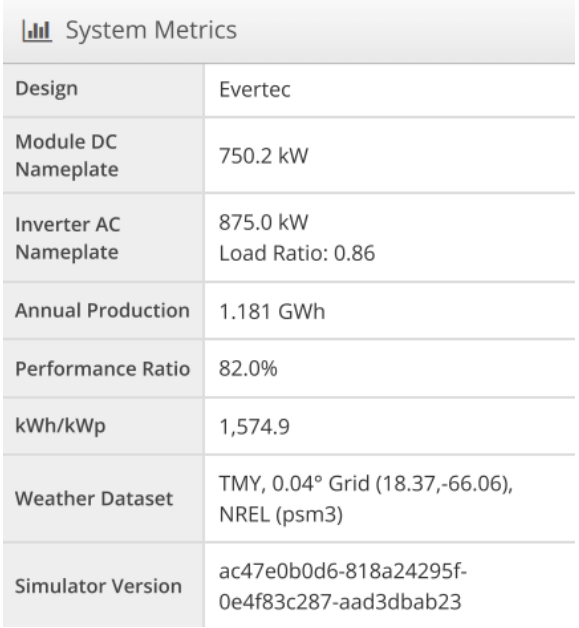
$\mathrm{E}_{\mathrm{daily}} = 591{,}679.83\ \ \mathrm{W} * \frac{1\mathrm{kw}}{1000\mathrm{w}} * \frac{5.5\mathrm{hr}}{1\mathrm{day}} = 3{,}254.24\ \frac{\mathrm{KWh}}{\mathrm{day}}$: (Equation 15.2)

Equations 15.3 and 15.4 can be employed to determine the total AC power generation of the solar array over the course of the month and the year.

$\mathrm{E}_{\mathrm{month}} = 3{,}254.24\ \frac{\mathrm{KWh}}{\mathrm{day}} * \frac{30\ \mathrm{days}}{1\ \mathrm{month}} = 97{,}627.17\ \frac{\mathrm{KWh}}{\mathrm{month}}$: (Equation 15.3)

$\mathrm{E_{year}} = 97{,}627.17\ \frac{\mathrm{KWh}}{\mathrm{month}} * \frac{\mathrm{12\ months}}{\mathrm{1\ year}} = 1{,}171{,}526.1\ \frac{\mathrm{KWh}}{\mathrm{year}}$: (Equation 15.4)

Consequently, the solar array's annual AC energy production is estimated to be 1,171,526.1 kWh



System Metrics

Design	Evertec
Module DC Nameplate	750.2 kW
Inverter AC Nameplate	875.0 kW Load Ratio: 0.86
Annual Production	1.181 GWh
Performance Ratio	82.0%
kWh/kWp	1,574.9
Weather Dataset	TMY, 0.04° Grid (18.37,-66.06), NREL (psm3)
Simulator Version	ac47e0b0d6-818a24295f-0e4f83c287-aad3dbab23

Figure 15.9: Evertec's System Metrics

Analysis of results for Evertec

Upon acquiring the theoretical outcomes for the photovoltaic system regarding system size and yearly output rates, these figures may be similar to those produced by the Helioscope software. The engineering report in Helioscope provides accurate numbers derived from the provided data. Analysis of the findings reveals a minimal percentage error, as seen in equation 15.5 and table 15.3.

$\mathrm{Percentage\ Error\ \%} = \frac{|\mathrm{Simulation} - \mathrm{Theorical}|}{\mathrm{Theorical}} \mathrm{x100\%}$: (Equation 15.5)

Evertec	**Theorical Values**	**Helioscope Values**	**%Error**
System Sizing	750,000 W (Refer to Section 9, Equation 9.4)	750,200 W (Refer to Section 15, Figure 15.9)	0.026%
Yearly Energy Production	1,171,526.1 KWh (Refer to Section 9, Equation 9.18)	1,181,496.6 KWh (Refer to Section 15, Figure 15.6)	0.85%

Table 15.3: Summary of the Comparison of the Theoretical results and Helioscope Results

Section 15.2: Homer Simulations

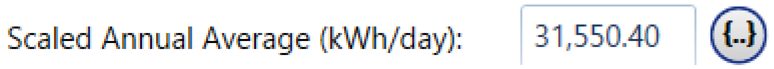
The Homer simulations provide a comprehensive evaluation of monthly energy generation, energy use, operational expenses, and specific energy output for each contributing system. These systems consist of Luma Energy, cogeneration, and a photovoltaic system. First is to analyze Evertec's electricity use with Luma as the only supplier. Subsequently, model the utility in Evertec alongside CHP. A micro-grid system will be developed to integrate all diverse energy sources. The figures below illustrate the energy distribution from several sources to Evertec, the energy output of these sources, and the potential cost implications associated with each energy source. Three scenarios were analyzed: using just the local utility, employing both the local utility and CHP as energy sources, and finally, integrating CHP, local utility, and a PV system (as per Helioscope findings). The Homer simulation requires the inclusion of a boiler in the system, although under ideal specs, since Evertec lacks a boiler in its electrical system. This component exists only for simulation reasons and will not influence the simulation's result. The electric load and thermal load in the system will remain constant throughout the run. The conclusive simulation included all systems, directly linking the photovoltaic specs and system inputs to the Homer simulations from Helioscope. This is the essential element to note. Chapter 15, Section 15.1 delineates the particulars of the PV system simulations.

Section 15.3: Homer Simulations (Utility Only)

Initially, in the simulation of Evertec's electric system prior to the construction of the CHP units, Evertec only relies on electricity from the utility. Utilizing the electric consumption data from 2019, together with the price per kilowatt-hour and the sellback rate for the energy produced by Evertec that is not used internally. Evertec does not generate its own energy; hence, the sellback price is irrelevant. All required data for executing this simulation is detailed in table 15.4 and the data is in their separate tabs as seen in figures 15.4 and 15.5.

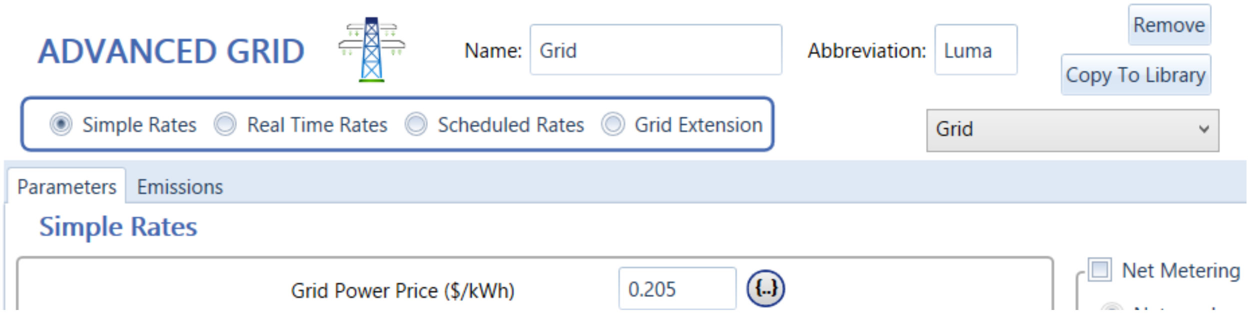
Energy Consumed in 2019 (KWh)	Daily Energy Consumed in 2019 (KWh)	Average Grid Power Price in 2019 ($/KWh)	Data Origin
11,515,898	31,550.4	0.205	Appendix A.18

Table 15.4: Input Data for Utility Only Homer Simulation



Scaled Annual Average (kWh/day): 31,550.40

Figure 15.10: Homer Electric Load Input



Name: Grid

Abbreviation: Luma

● Simple Rates ○ Real Time Rates ○ Scheduled Rates ○ Grid Extension

Grid

Grid Power Price ($/kWh) 0.205

☐ Net Metering

Figure 15.11: Homer Grid Power Price Input for 2019

Consequently, figure 15.12 presents a monoline design illustrating the system's functionality and the interconnection of all components in 2019.

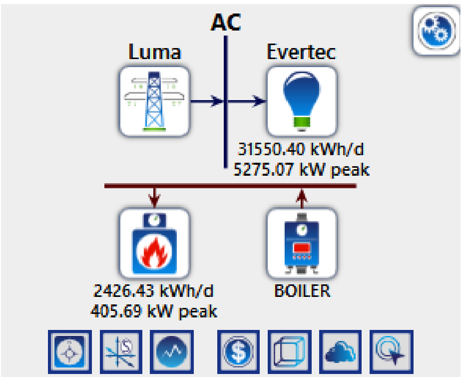
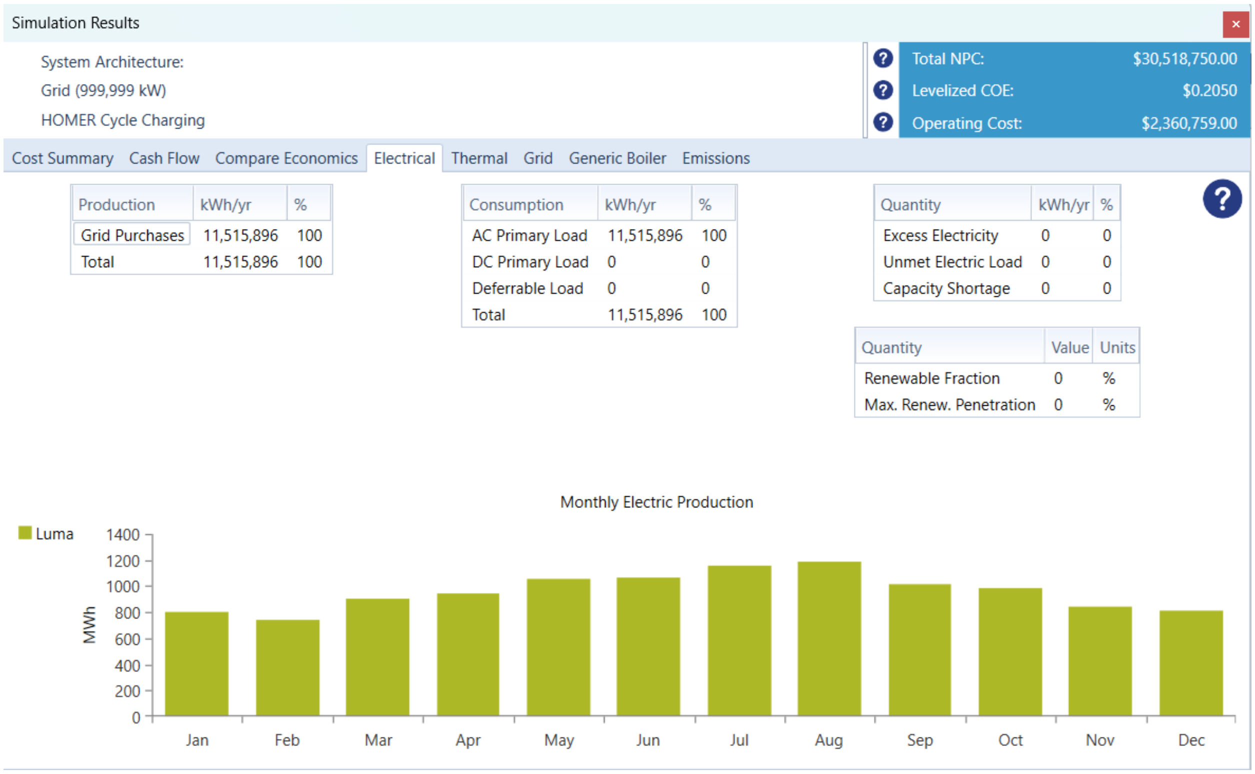


Figure 15.12: Homer LUMA Breakdown of Energy Transmission.

Upon running all parameters required for the first simulation, figure 15.13 presents an electric load profile for Evertec's consumption in 2019, while figure 15.14 provides a comprehensive cost summary outlining the operational and maintenance expenses of the systems.



System Architecture:
Grid (999,999 kW)
HOMER Cycle Charging

Total NPC: $30,518,750.00
Levelized COE: $0.2050
Operating Cost: $2,360,759.00

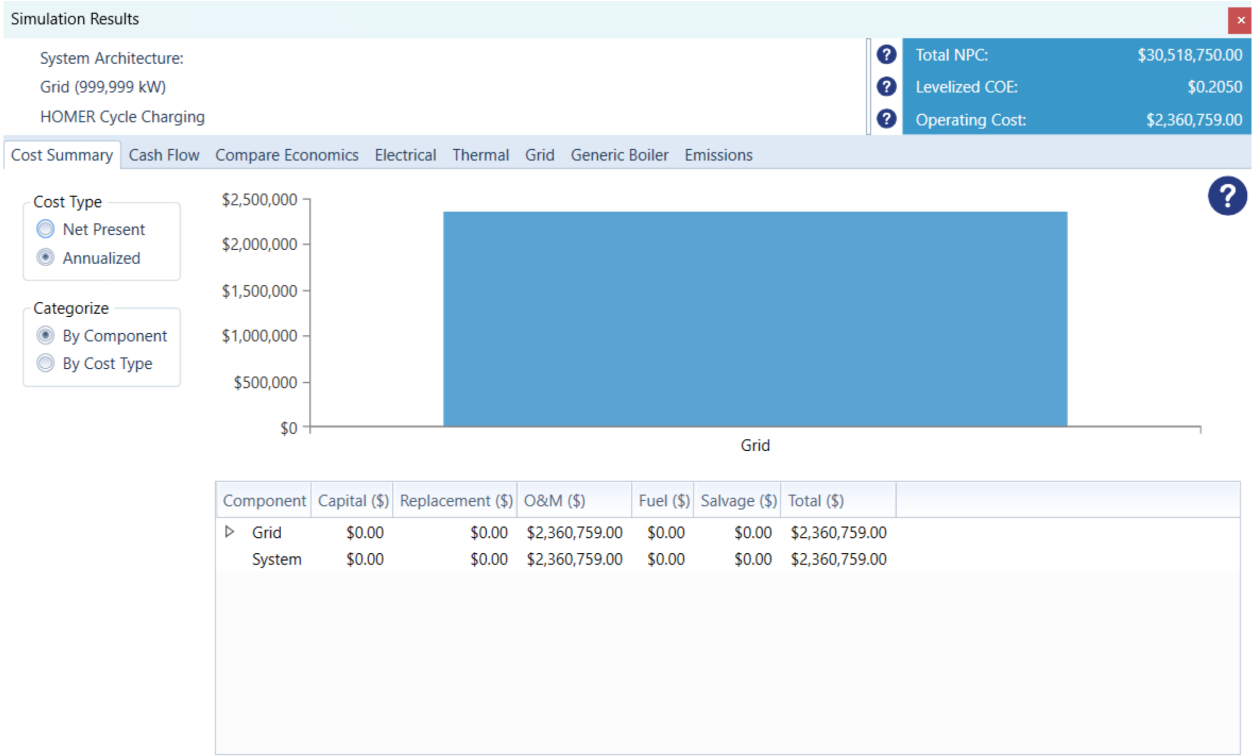
Production	kWh/yr	%
Grid Purchases	11,515,896	100
Total	11,515,896	100

Consumption	kWh/yr	%
AC Primary Load	11,515,896	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	11,515,896	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	0	%

Figure 15.13: Homer Simulation Results only LUMA (Before Cogeneration Plant).



System Architecture:
Grid (999,999 kW)
HOMER Cycle Charging

Total NPC: $30,518,750.00
Levelized COE: $0.2050
Operating Cost: $2,360,759.00

Cost Type
○ Net Present
● Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
▷ Grid	$0.00	$0.00	$2,360,759.00	$0.00	$0.00	$2,360,759.00
System	$0.00	$0.00	$2,360,759.00	$0.00	$0.00	$2,360,759.00

Figure 15.14: LUMA Only Costs Results.

Upon simulating the system for the year 2019, the findings align closely with the actual outcomes for Evertec throughout that year. Homer delivers precise and comprehensive figures drawn from the data provided. However, it’s important to note that Homer does not account for fluctuations in grid power prices, maintenance, and shutdowns of the CHP system resulting from various component failures and mismatches. This component influences the error rate between the real numbers and the simulation results. The analysis indicates a minimal error percentage, as seen in equation 15.6 and table 15.5.

$$\text{Percentage Error }\% = \frac{|\text{Simulation} - \text{Real}|}{\text{Real}} \text{x}100\%\text{: (Equation 15.6)}$$

Evertec	**Real Values**	**Homer Values**	**%Error**
Yearly Energy Consumption	11,515,898 KWh (Refer to Section 15.3, Table 15.3)	11,515,896 KWh (Refer to Section 15.3, Figure 15.13)	0.000017%
Grid Cost	$2,235,390.47 (Refer to Refer to Appendix A: Figure A.1	$2,360,759 (Refer to Section 15.3, Figure 15.14)	5.60%

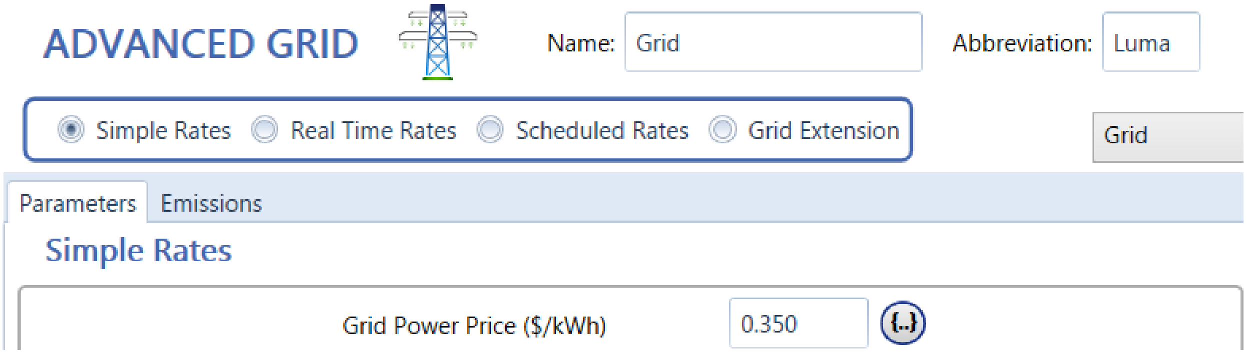
Table 15.5: Summary of the Comparison of the Theoretical results and Homer Results in 2019

Section 15.4: Homer Simulations (Utility & CHP)

Following the simulation of the system with just the utility, the subsequent simulation occurs post-installation of the CHP system. This system offers a comprehensive overview of Evertec's energy use. Evertec's energy production and the sellback price, together with energy demand, are shown in Table 15.6.

Energy Consumed in 2019 (KWh)	**Daily Energy Consumed in 2019 (KWh)**	**Average Grid Power Price in 2022 ($/KWh)**	**Data Origin**
11,515,898	31,550.4	0.35	Appendix A.18

Table 15.6: Input Data for Utility and CHP System Homer Simulation



Name: Grid

Abbreviation: Luma

Grid Power Price ($/kWh) 0.350

Figure 15.15: Homer Grid Power Price Input for 2022

Lastly, figure 15.16 delineates all necessary parameters for Homer to replicate the CHP system. In the Generator tab, the capital represents the total cost per kilowatt of the CHP system, totaling $11,000,000. All parameters are specified in table 15.6. Furthermore, in figure 15.16, one of the factors required by the Homer simulation software is the fuel price for natural gas in $/m3.

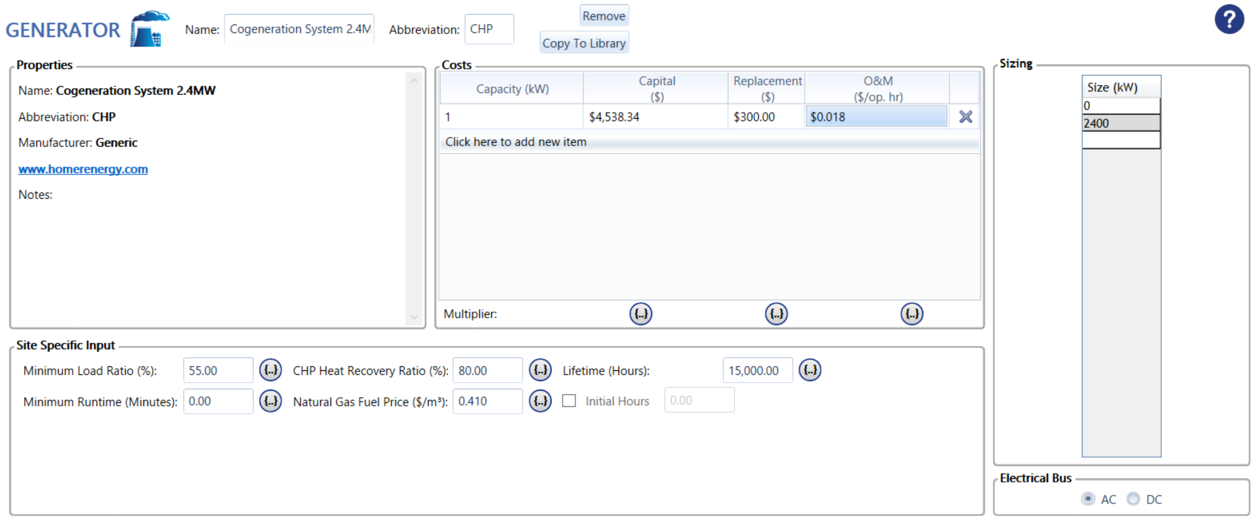
Likewise, to obtain this data, the $11/mmbtu must be converted to the specified units of $/m³, as previously indicated. This conversion is performed in equation 15.7 below. Finalizing this conversion requires using the estimate of 1 mmbtu = 26.81 m³

$$\frac{\$}{m^3} = \frac{\frac{\$11}{1mmbtu}}{\frac{1mmbtu}{26.81m^3}} = \boldsymbol{\$0.41/m^3} \quad \text{(Equation 15.7)}$$

The value obtained from equation 15.7 is used in the natural gas fuel price option on figure 15.16.

Parameters	**Values**	**Data Origin**
Capital ($)	4,538.34	Table 16.1
O&M ($/op.hr)	0.018	Evertec
Minimum Load Ratio (%)	55	Appendix B.1
CHP Heat Recovery Ratio (%)	80	Appendix B.1
Natural Gas Fuel Price ($/m^3)	0.41	Equation 15.3

Table 15.7: CHP Model Parameters for Homer Simulation



Name: Cogeneration System 2.4M

Abbreviation: CHP

Name: **Cogeneration System 2.4MW**

Abbreviation: **CHP**

Manufacturer: **Generic**

www.homerenergy.com

Notes:

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/op. hr)
1	$4,538.34	$300.00	$0.018

Size (kW)
0
2400

Minimum Load Ratio (%): 55.00

CHP Heat Recovery Ratio (%): 80.00

Lifetime (Hours): 15,000.00

Minimum Runtime (Minutes): 0.00

Natural Gas Fuel Price ($/m³): 0.410

☐ Initial Hours 0.00

● AC ○ DC

Figure 15.16: Homer CHP Specification Input

Subsequently, figure 15.17 presents a monoline design illustrating the system's functionality and the interconnection of all components in 2022 when the CHP system was installed.

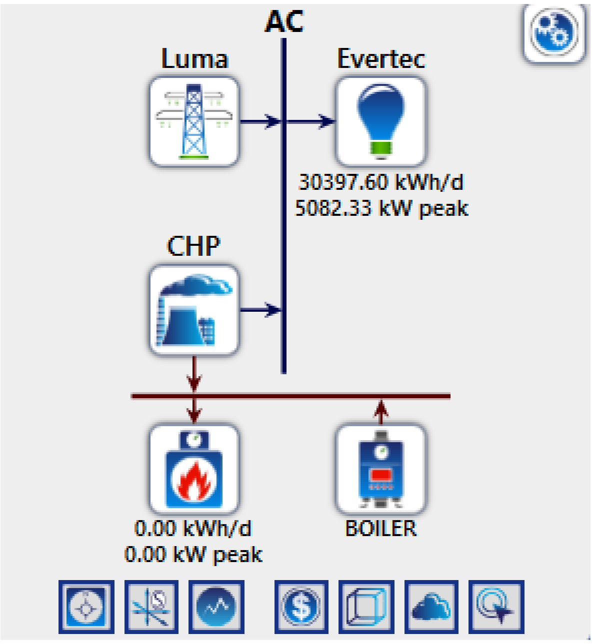
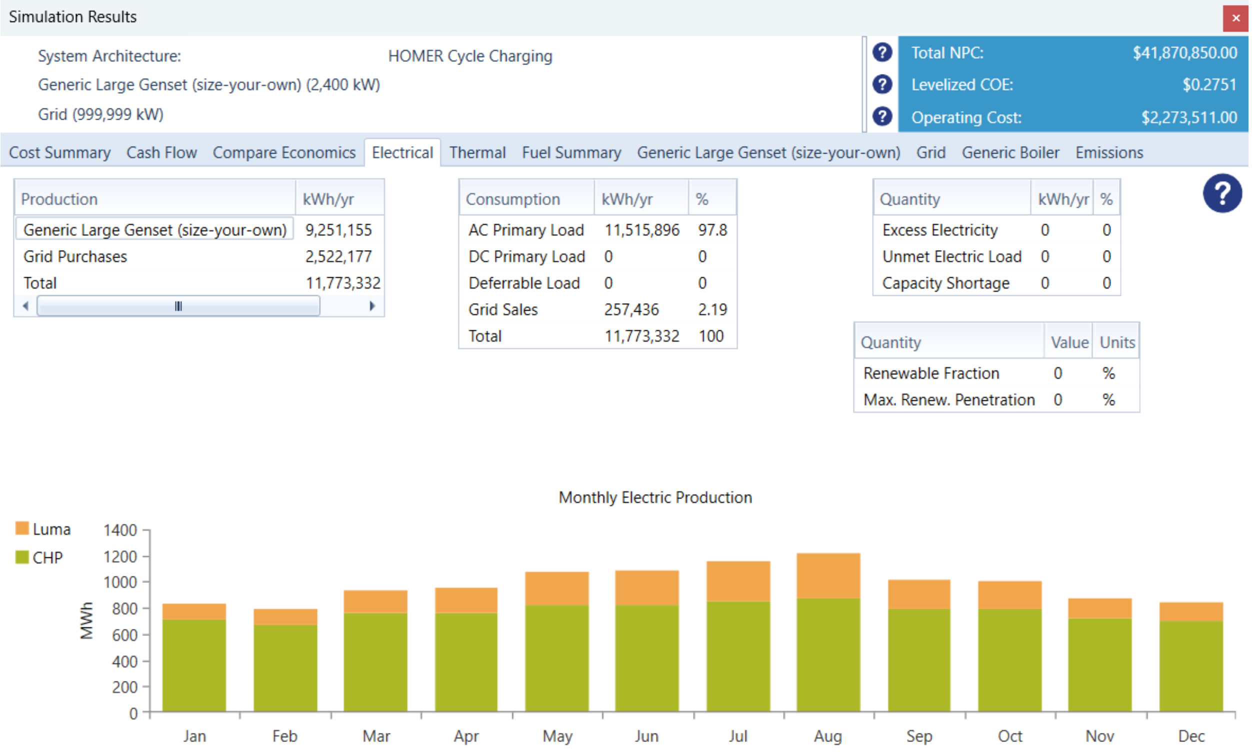


Figure 15.17: Homer LUMA and CHP Breakdown of Energy Transmission.

Subsequently, executing all parameters necessary for the first simulation, figure 15.18 illustrates an electric load profile for Evertec's consumption in 2022, while figure 15.19 offers a detailed cost breakdown delineating the operating and maintenance expenditures of the systems.



Simulation Results

System Architecture: HOMER Cycle Charging
Generic Large Genset (size-your-own) (2,400 kW)
Grid (999,999 kW)

Total NPC: $41,870,850.00
Levelized COE: $0.2751
Operating Cost: $2,273,511.00

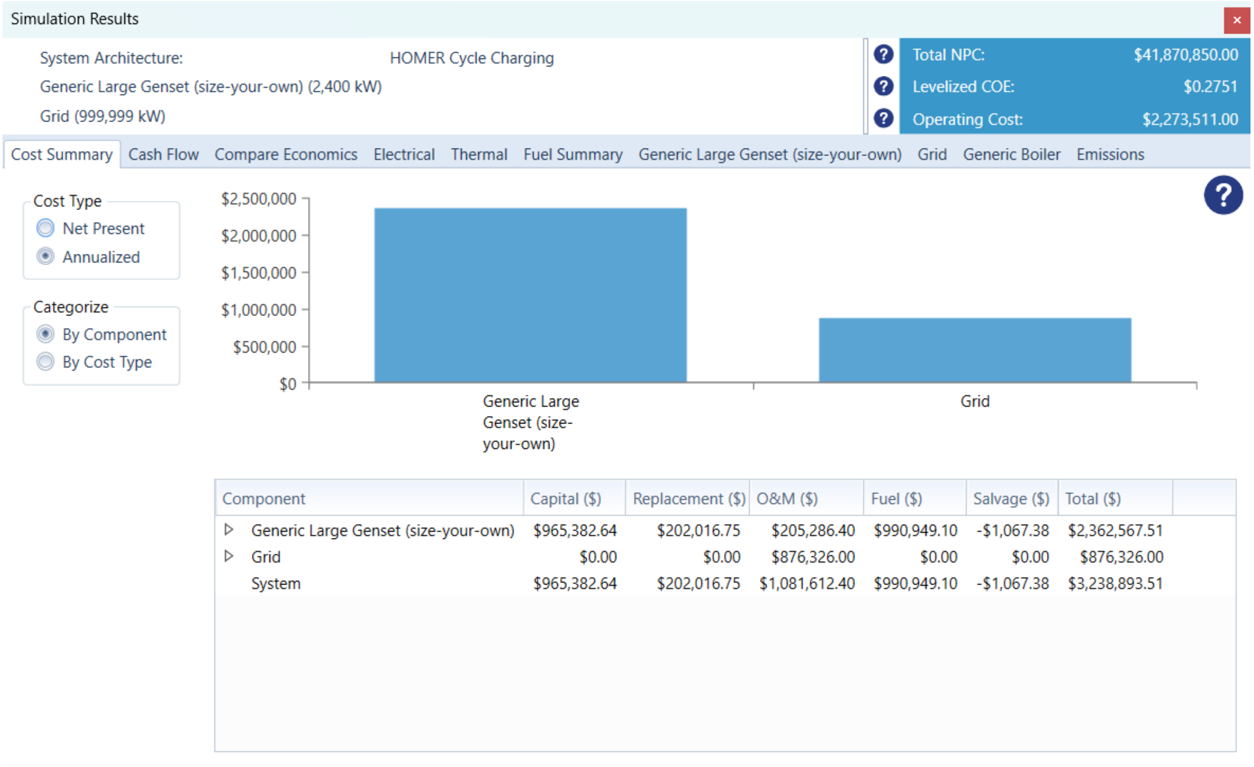
Production	kWh/yr
Generic Large Genset (size-your-own)	9,251,155
Grid Purchases	2,522,177
Total	11,773,332

Consumption	kWh/yr	%
AC Primary Load	11,515,896	97.8
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	257,436	2.19
Total	11,773,332	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	0	%

Figure 15.18: Homer Simulation Results LUMA and CHP (After Cogeneration Plant).



Simulation Results

System Architecture: HOMER Cycle Charging
Generic Large Genset (size-your-own) (2,400 kW)
Grid (999,999 kW)

Total NPC: $41,870,850.00
Levelized COE: $0.2751
Operating Cost: $2,273,511.00

Cost Type
○ Net Present
● Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
▷ Generic Large Genset (size-your-own)	$965,382.64	$202,016.75	$205,286.40	$990,949.10	-$1,067.38	$2,362,567.51
▷ Grid	$0.00	$0.00	$876,326.00	$0.00	$0.00	$876,326.00
System	$965,382.64	$202,016.75	$1,081,612.40	$990,949.10	-$1,067.38	$3,238,893.51

Figure 15.19: LUMA and CHP Costs Results.

The simulation of the system for 2022 yielded results that closely correspond with Evertec's real performance during that year. Homer presents accurate and thorough statistics derived from the supplied data. Nonetheless, it is crucial to acknowledge that Homer does not include variations in grid power costs, maintenance, and the shutdowns of the CHP system due to diverse component failures and discrepancies. This component affects the discrepancy rate between the actual values and the simulated outcomes. The study reveals a negligible error percentage, as seen in equation 15.8 and table 15.8.

$$\text{Percentage Error \%} = \frac{|\text{Simulation} - \text{Real}|}{\text{Real}} \text{x}100\%\text{: (Equation 15.8)}$$

Evertec	Real Values	Homer Values	%Error
Yearly Energy Consumption (Grid)	2,789,160 KWh (Refer to Appendix A: Figure A.1)	2,522,177 KWh (Refer to Section 15.4, Figure 15.18)	9.57%
Grid Cost	$925,275.77 (Refer to Appendix A: Figure A.1)	$876,326 (Refer to Section 15.4, Figure 15.19)	5.29%
Yearly Energy Production (CHP)	8,877,820 KWh (Refer to Appendix A: Figure A.1)	9,251,155 KWh (Refer to Section 15.4, Figure 15.18)	4.20%

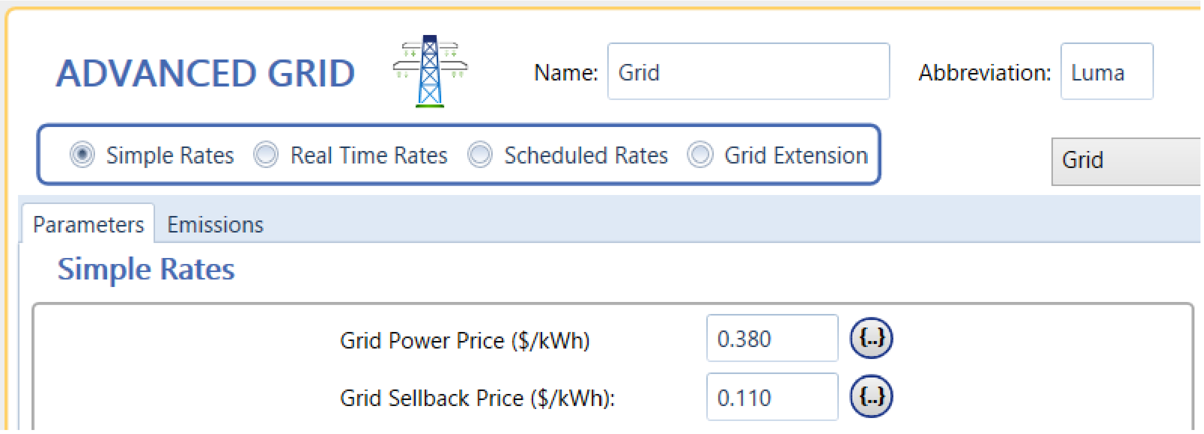
Table 15.8: Summary of the Comparison of the Theoretical results and Homer Results in 2022

Section 15.5: Homer Simulations (Utility + PV System + CHP)

Completing the simulation of the system including the utility, the CHP system, and a newly designed PV system. This system provides a thorough analysis of Evertec's energy use. The energy output of Evertec, the sellback price, the yearly energy production of the PV system, and the energy consumption are shown in table 15.9.

Energy Consumed in 2019 (KWh)	Daily Energy Consumed in 2019 (KWh)	Average Grid Power Price in 2024 ($/KWh)	Grid Sellback price ($/KWh)	Data Origin
11,515,898	31,550.4	0.38	0.11	Appendix A.18

Table 15.9: Input Data for Utility, CHP System and PV System Homer Simulation



Name: Grid

Abbreviation: Luma

● Simple Rates ○ Real Time Rates ○ Scheduled Rates ○ Grid Extension

Grid

Grid Power Price ($/kWh) 0.380

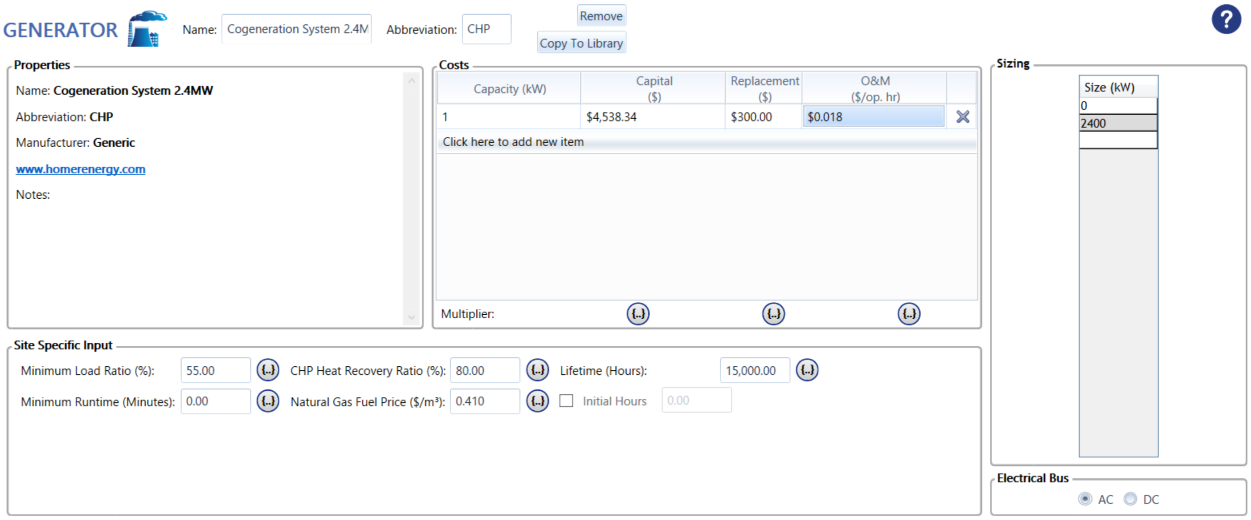
Grid Sellback Price ($/kWh): 0.110

Figure 15.20: Homer Grid Power Price Input for 2024

The specifications for the CHP inputs are shown in figure 15.21 below, which enables the duplication of the essential characteristics of the Cogeneration system. Moreover, all parameters are delineated in table 15.10. Additionally, in figure 15.21, a necessary component for the Homer simulation program is the fuel price for natural gas expressed in $/m3. For this data to be obtained, a conversion must be made from $11/mmbtu to the designated units of $/m3. The contracted price with the LNG provider is $11 per mmbtu. This conversion is performed, and the price is 0.41 ($/m3) as listed below.

Parameters	**Values**	**Data Origin**
Capital ($)	4,538.34	Table 16.1
O&M ($/op.hr)	0.018	Evertec
Minimum Load Ratio (%)	55	Appendix B.1
CHP Heat Recovery Ratio (%)	80	Appendix B,1
Natural Gas Fuel Price ($/m^3)	0.41	Equation 15.3

Table 15.10: CHP Model Parameters for Homer Simulation



Name: Cogeneration System 2.4M

Abbreviation: CHP

Properties

Name: **Cogeneration System 2.4MW**

Abbreviation: **CHP**

Manufacturer: **Generic**

www.homerenergy.com

Notes:

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/op. hr)
1	$4,538.34	$300.00	$0.018
Click here to add new item			

Multiplier:

Sizing

Size (kW)
0
2400

Site Specific Input

Minimum Load Ratio (%): 55.00

CHP Heat Recovery Ratio (%): 80.00

Lifetime (Hours): 15,000.00

Minimum Runtime (Minutes): 0.00

Natural Gas Fuel Price ($/m³): 0.410

☐ Initial Hours 0.00

Electrical Bus

● AC ○ DC

Figure 15.21: Homer CHP Specification Input

For a better visual comprehension, Figure 15.22 depicts a monoline architecture that illustrates the system's operation and the connectivity of all components in 2024.

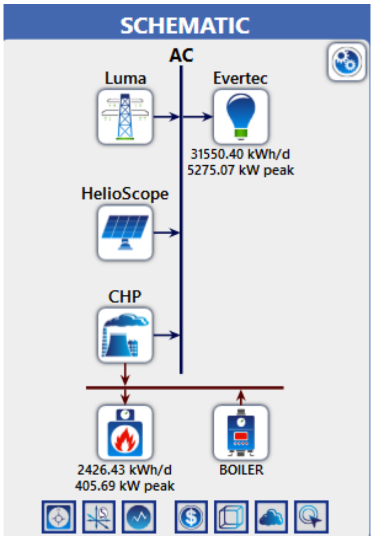


Figure 15.22: Homer LUMA, PV System and CHP Breakdown of Energy Transmission.

Following the execution of all necessary parameters for the first simulation, figure 15.23 presents an electric load profile for Evertec's consumption forecast in 2024, while figure 15.24 provides a comprehensive cost analysis outlining the operational and maintenance expenses of the systems.

System Architecture: Grid (999,999 kW)
HelioScope (1.00) HOMER Cycle Charging
Cogeneration System 2.4MW (2,400 kW)

Total NPC: $36,769,430.00
Levelized COE: $0.2140
Operating Cost: $2,001,731.00

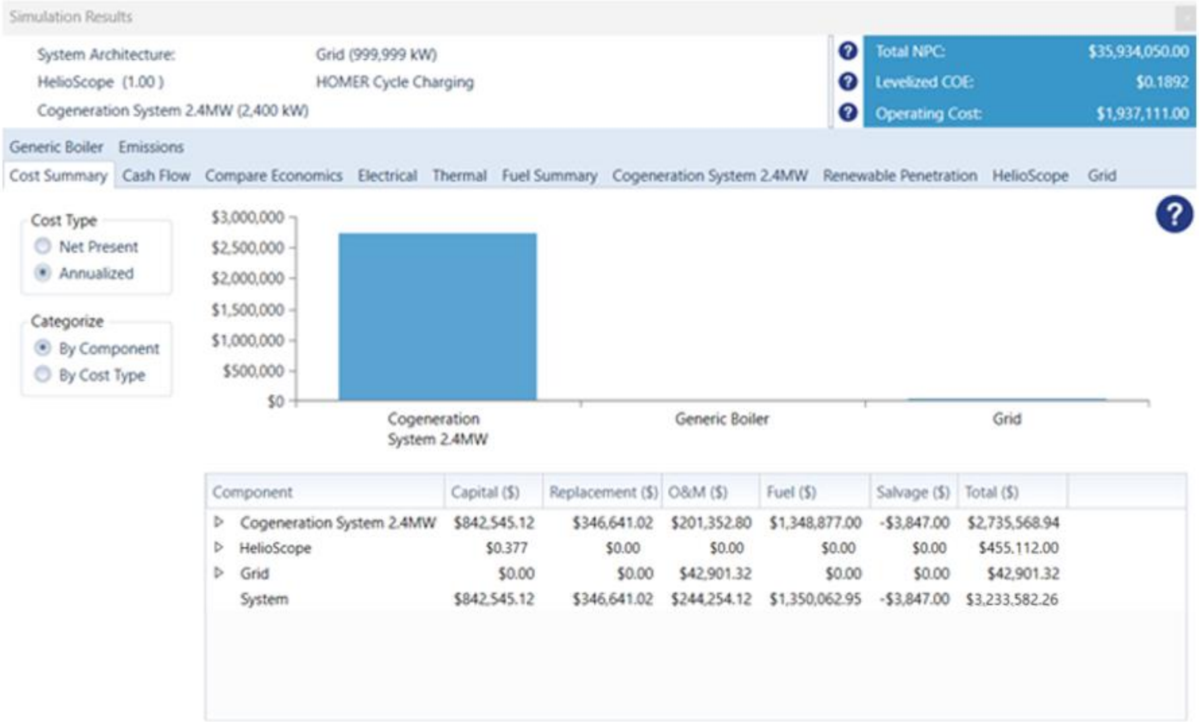
Production	kWh/yr	%
Cogeneration System 2.4MW	10,511,177	80.3
Grid Purchases	1,395,290	10.7
HelioScope	1,181,497	9.03
Total	13,087,964	100

Consumption	kWh/yr	%
AC Primary Load	11,515,896	88.0
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,572,068	12.0
Total	13,087,964	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	67.1	%

Figure 15.23: Homer Simulation Results LUMA, PV System and CHP (After Cogeneration Plant with PV System).



System Architecture:
HelioScope (1.00)
Cogeneration System 2.4MW (2,400 kW)
Grid (999,999 kW)
HOMER Cycle Charging

Total NPC: $35,934,050.00
Levelized COE: $0.1892
Operating Cost: $1,937,111.00

Cost Type
○ Net Present
● Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
▷ Cogeneration System 2.4MW	$842,545.12	$346,641.02	$201,352.80	$1,348,877.00	-$3,847.00	$2,735,568.94
▷ HelioScope	$0.377	$0.00	$0.00	$0.00	$0.00	$455,112.00
▷ Grid	$0.00	$0.00	$42,901.32	$0.00	$0.00	$42,901.32
System	$842,545.12	$346,641.02	$244,254.12	$1,350,062.95	-$3,847.00	$3,233,582.26

Figure 15.24: LUMA, PV System and CHP Costs Results.

The system simulation for the 2024 prediction yields findings that closely align with Evertec's actual projections. Additionally, Homer provides precise and comprehensive statistics based on the given data and the projection for 2024 is detailed in table 15.11 below. It is essential to recognize that Homer omits changes in grid power prices, maintenance, and shutdowns of the CHP system resulting from various component failures and inconsistencies. This component influences the variance between the real values and the simulated results. The research indicates a minimal error percentage, as seen in equation 15.9 and table 15.12. Correspondingly, equation 15.10 is used to determine the annual KWh consumption of Evertec due to peak load and other discrepancies.

Projection 2024		**Data Origin**
AEE y AAA 2019-2020 Cost	2,422,804.23	Excel Data Sheet: *Simple Payback Period*
Operation Cost CHP 2024	157680	
Maintenance Cost CHP 2024	182,912.40	
Water Billing Cost 2024	214,641.04	
Utility Cost 2024	412,976.51	
Maintenance Cost Chillers 2024	20,000	
LNG Cost 2024	993284.47	
Total Cost 2024	1981494.42	
Annual Savings 2024	441,309.81	

Table 15.11: 2024 Yearly Cost and Savings Projections

$$\text{Percentage Error } \% = \frac{|\text{Simulation}-\text{Real}|}{\text{Real}} \text{x}100\%\text{: (Equation 15.9)}$$

$$\text{Grid Estimate Cost} = \frac{\text{Total Annual Grid Cost}}{\text{Average Grid Power Price in 2024}} \text{x}100\%\text{: (Equation 15.10)}$$

Evertec	**Homer Projection**
Yearly Energy Consumption (Grid)	112,897 KWh (Refer to Equation 15.5)
Grid Estimate Cost per Year	$42,901.32 (Refer to Figure 15.24)
Yearly Energy Production (CHP)	10,511,177 KWh (Refer to Figure 15.23)
Energy Cost Produced by PV System	$455,112 (Refer to Figure 15.24

Table 15.12: Summary of Homer Projections for 2024.

Chapter 16: Economic Analysis

Section 16.1: Cogen Cost Analysis with LNG

Starting with the cost analysis of the Cogen, the next table 16.1 provides a comprehensive summary of all the components necessary to operate the system and generate the energy necessary for the operations of Evertec's facilities. Furthermore, to commence the economic analysis of the CHP system, it is necessary to examine the initial investment of the undertaking.

Elements	Price ($)	Data Origin
Equipment	5,315,602.01	Appendix A: Figure A.12
Two Co-Generators of 1.2MW each	1,735,084.96	
Two Absorption Chillers of 350 tons each	1,148,000	
Energy Storage System 1.5MW, with 750kW in batteries	1,019,279.00	
Step-Up Transformer; 480V to 13.2kV	151,974.50	
Incoming/Outgoing Switch setup	172,825.00	
Three Cooling Towers, 600 tons each and a sweeper (filter)	763,316.00	
Various pumps for chilled water, condensed water, and heat exchanger	146,276.55	
Motor Control Center (MCC)	178,846.00	
Building for the Combined Heat and Power (CHP) unit	2,535,148.04	
Structural Station for LNG	676,076.39	
Electrical and Control Systems	675,528.83	
Mechanical and Control Installation materials	3,078,291.06	
Total Initial Investment	**11,000,000**	

Table 16.1: Project Initial Investment

Evertec of Cupey made a strategic initial investment of approximately 11 million dollars in a cogeneration plant system in 2021, which consists of 2 cogeneration plants of 1.2MW each. The approach towards the data provided by the corporation is to navigate through the company's energy expenditure before and after this significant investment to obtain a simple payback period which will tell the viability of this project.

The previous comprehensible data about the initial investment made by the company for the cogeneration plant was made strategically to ensure effectiveness and efficiency in its implementation, which cost them as mentioned before, $11 million and reduce more than 50% of the energy consumption from the utility as it is described in Table 14.2 vs the energy consumption before this installation which is recorded in Table 14.1. The investment reflects the corporation's commitment to economic savings and environmental stewardship. This cogeneration system was designed to address the bank's unique energy requirements while maintaining ambitious standards of environmental sustainability, reducing costs and consumption from the utility and reach a certain quantity of savings under a period which can accomplish the objective to recover the initial investment in the best time possible.

The objective is to compare the data recorded before and after the Cogeneration System was implemented in the facilities of Evertec. Furthermore, the base time before cogeneration installation is the year 2019 and 2020; to start calculating the electric utility energy consumption in kWh by Evertec buildings and their expenses for the same.

Subsequently, table 16.2 shows the total electric utility energy consumption in kWh and the total cost of the energy consumed in 2019 and 2020. Evertec consumed 11,095,128.00 in 2019 and 10,553,400.00 in 2020, the first one being the peak; paying a total of $2,235,390.4 and $1,981,063.7, respectively. These values are specially important to compare this data with the consumed energy after the cogeneration was installed because it tells in proportion to the total consumption, how much less is now required from the grid. In addition to this, how much fuel is being paid for the cogenerators. Therefore, by obtaining how much money the company is saving monthly and yearly, it gives the opportunity to calculate a simple payback period.

Total Energy (kWh)	**Total Cost ($)**	**Data Origin**
11,095,128.00	2,235,390.4	*Table 14.1*
10,553,400.00	1,981,063.7	*Table 14.1*

Table 16.2: Electric Utility Energy Consumption and Costs BEFORE cogeneration, data by Evertec.

Now, the same will be happening on the other hand for the time after cogeneration installation, in 2021, 2022, 2023 and 2024. This data is going to help for the comparison of energy consumption and its cost before vs after the Cogeneration System was implemented. This approach provides a clearer view of the annual average savings Evertec receives and the reduced reliance on electrical utility. As in Table 14.2, the total electric utility energy consumption in kWh with its monthly average and the total cost of the energy consumed with its monthly average, for years 2021 to 2024.

Achieving better precision at the results, in 2024, which has not ended yet, the total cost was divided between 9 months which are the total months of given data, to obtain an average monthly cost and the same for the average energy consumed. In this data it is noticeable that the reduction from using the electric utility was more than 50% in comparison to table 14.1 and over a million dollars of savings from it; even almost two million dollars of saving as shown in 2023, $407,919.12 and 2024, $309,732.38. While in 2019 it was $2,235,390.4 and in 2020 $1,981,063.7. Furthermore, the electric utility there is a huge amount of savings from energy consumption and the cost of it. It will be seen down in the last tables of this section (Table 16.3). It must be indicated that these savings include the fuel cost by year.

Total Cost ($)	**Data Origin**
2,235,390.4	*Table 14.1*
1,981,063.7	*Table 14.1*
407,919.12	*Table 14.2*
309,732.38	*Table 14.2*

Table 16.3: Electric Utility Energy Consumption and Costs AFTER cogeneration, data by Evertec.

Another crucial piece of data for the analysis is shown in Table 16.4, which is the energy production and costs of LNG fuel by year. This table will show the total energy produced in mmBtu with its monthly average energy production and the total cost for that energy produced with its monthly average cost, for years 2021 to 2024. This value of monthly average cost and energy was computed manually using as reference the 4 excel data sheets which are indicated in the table below; just by dividing the total of both categories each year by 12, which is the total months in a year. The total cost was divided by 9 months, which are the total months of given data, to obtain an average monthly cost and the same was done for the average energy consumed.

Year	**Total Energy (mmBtu)**	**Average Energy (mmBtu)**	**Total Cost ($)**	**Average Cost ($)**	**Data Origin**
2021	66,920.01	5,576.67	736,150.14	61,345.85	*Appendix A: Figure A.6*
2022	80,666.30	6,722.19	885,983.51	73,831.96	*Appendix A: Figure A.7*
2023	93,953.38	7,829.45	1,026,094.23	85,507.85	*Appendix A: Figure A.8*
2024	68,035.76	7,559.53	744,963.35	82,773.71	*Appendix A: Figure A.9*

Table 16.4: Energy Production and Costs of LNG fuel, data by Evertec.

Upon the establishment of the cogeneration facility that was recently installed in 2021, the cost that the client, Evertec was paying for electricity services to the utility. A total of $797,229.16 in the entire year, and to see the average cost paid to LUMA per month, giving $66,435.76. The total paid in 2021 was more than 1 million dollars less than before the cogeneration.

Total Cost ($)	**Data Origin**
797,229.16	*Table 14.2*
66,435.76 per month	*Table 14.2*

Table 16.5: Values obtained from billing tables in Chapter 14.

The following table 16.6 shows the total annual and monthly average for electric utility energy consumption and the total cost, before and after cogeneration; in addition, the difference value to visualize better how much less the building is consuming and paying for the utility services.

Metric (Avg)	Before Cogen (kWh)	Before Cogen ($)	After Cogen (kWh)	After Cogen ($)	Data Origin
Annually	10,824,264	2,108,227.13	2,208,354.67	650,708.38	*Table 14.4*
Monthly	902,022	175,685.59	184,029.56	54,225.7	*Table 14.4*

Table 16.6: Annual and monthly average Energy Consumption from utility and its costs, Before and After Cogeneration System installation.

Another observation from table 16.6 is that the energy consumption after the Cogeneration System was implemented, from the electric utility, was 80% less than before the installation. This reduction in consumption of energy from the grid reduces the cost, which was about 1.6 million dollars approximately. Furthermore, this does not consider the LNG fuel and water consumption cost.

A summary of the values as averages is seen in table 16.7; is going to present fuel consumption in mmBtu by CHP plants, and their cost. This is calculated using the data given by Evertec for the years 2021 to 2024. Since 2024 is not finished, a projection was necessary to calculate the monthly averages of the pertinent values to then obtain the annual average). The average monthly rate indicated below in table 16.7 uses the months of all 4 years (with the adjustment of 2024 which is incomplete) and its costs.

Description	Average Monthly	Average Annually	Data Origin
Energy (mmBtu)	6,682.3032	80,187.64	*Table 16.4*
Cost ($)	73,247.06	878,964.75	*Table 16.4*

Table 16.7: Annual and monthly average fuel Consumed by the CHP plant and its cost.

The savings calculations conducted after the cogeneration plant implementation, which utilizes natural gas as its primary fuel, necessitate an assessment of Evertec’s expenditures on water services prior to and following the installation of the cogeneration system. Incorporating these figures into the final calculations is essential for the reliability of the simple payback period.

Moreover, table 16.3 illustrates the yearly average payment made to the utility. Prior to the establishment of the CHP system, the customer paid \$2,108,227.13 to LUMA. Following the cogeneration plant, Evertec paid \$650,708.38 monthly. The subtraction from these two quantities yields an average yearly saving of \$1,457,518.75. However, this figure does not represent a genuine saving, as it must be adjusted by deducting the annual average expenditures associated with LNG fuel and other charges that will be elaborated upon later. This figure pertains only to the electric utility savings and does not reflect the company's savings after the implementation of the cogeneration system as illustrated in table 16.8 below.

Avg Annual Saving ($)	**Data Origin**
1,457,518.75	*Table 14.1* *Table 14.4*

Table 16.8: Average Annual Savings calculated using the information from the bill tables in Chapter 14.

Using table 14.3, which includes the water billings before and after cogeneration system, this is an additional cost that must be included for the savings and simple payback period, due to the rise in water usage from the chillers implemented with the CHP system. The annual average water billing cost difference between before and after cogeneration system is the value to consider for this additional water cost, which will be included in table 16.9.

The data shows no significant difference in terms of the water volume used. Before the cogeneration, the annual average was 26,623m^3 and after, 32,864.8m^3. However, there was a substantial difference in price, prior to the cogeneration installation, the annual average of 2019 to 2020 was \$180,805.21 and the average for 2021 to 2024 was \$236,590.28, meaning that the cogenerators water consumption difference in cost on average is \$55,785.08 to the bill annually.

Avg. Water Volume Before	Avg. Water Volume After	Avg. Yearly Cost Before	Avg. Yearly Cost After	Avg. Difference Cost Before vs After	Data Origin
26,623m^3	32,864.8m^3	180,805.21	236,590.28,	55,785.08	*Table 14.3*

Table 16.9: Annual average water consumption and its cost Before and After Cogeneration System installation.

Concluding the planning costs and obtaining the annual savings for the payback period, the expenses for maintenance and operations of the cogeneration system are to be considered acquiring a correct payback period.

The CHP plant has 4 operators with a total salary of $157,680 paid annually. Given maintenance, there is a variation in costs due to the need for the cogeneration plant in each particular year. These costs, regardless of annual variability, have a contract which established a number indicating the monthly cost that it would be paid for the entire year (which does not change). Evertec supplied data for CHP's maintenance, which is illustrated in appendix A.14 to A.17, and $20,000 in chiller maintenance.

Annual Savings 2021		Data Origin
AEE y AAA 2019-2020 Cost	2,422,804.23	*Appendix A: Figure A.14*
Operation Cost CHP 2021	157680	
Maintenance Cost CHP 2021	148,945.80	
Water Billing Cost 2021	240,326.73	
Utility Cost 2021	797,229.16	
Maintenance Cost Chillers 2021	20,000	
LNG Cost 2021	736,150.14	
Total Cost 2021	2,100,331.83	
Annual Savings 2021	322,472.40	

Table 16.10: Annual Savings 2021

Annual Savings 2022		**Data Origin**
AEE y AAA 2019-2020 Cost	2,422,804.23	*Appendix A: Figure A.15*
Operation Cost CHP 2022	157680	
Maintenance Cost CHP 2022	148,945.80	
Water Billing Cost 2022	245,646.73	
Utility Cost 2022	925,275.77	
Maintenance Cost Chillers 2022	20,000	
LNG Cost 2022	885,983.51	
Total Cost 2022	2383531.81	
Annual Savings 2021	39,272.42	

Table 16.11: Annual Savings 2022

Annual Savings 2023		**Data Origin**
AEE y AAA 2019-2020 Cost	2,422,804.23	*Appendix A: Figure A.16*
Operation Cost CHP 2023	157680	
Maintenance Cost CHP 2023	182,912.40	
Water Billing Cost 2023	260,506.74	
Utility Cost 2023	407,919.12	
Maintenance Cost Chillers 2023	20,000	
LNG Cost 2023	1,026,094.23	
Total Cost 2023	2055112.49	
Annual Savings 2023	367,691.74	

Table 16.12: Annual Savings 2023

Annual Savings 2024		**Data Origin**
AEE y AAA 2019-2020 Cost	2,422,804.23	*Appendix A: Figure A.17*
Operation Cost CHP 2024	157680	
Maintenance Cost CHP 2024	182,912.40	
Water Billing Cost 2024	214,641.04	
Utility Cost 2024	412,976.51	
Maintenance Cost Chillers 2024	20,000	
LNG Cost 2024	993284.47	
Total Cost 2024	1981494.42	
Annual Savings 2024	441,309.81	

Table 16.13: Annual Savings 2024

The first step towards the simple payback period for the cogeneration plant includes LNG fuel and all additional costs. This shows how long the investment will be repaid in terms of years. Firstly, the project's first investment payment and the average annual savings from 2021 to 2024 are required to perform equation 16.1. Additionally, the average annual savings were calculated by using the total cost that the client paid before and after the cogeneration plant installation, including electricity, water, and other services. This simple payback period calculation is demonstrated below.

$$\text{Ave. Annual Savings} = \frac{\mathit{Annual\ Savings}\ (2023+2024)}{\text{Total Years}} = \frac{(\$367{,}691.74+\$441{,}309.81)}{2} = \$404{,}500.77$$

$$\text{Simple payback period(years)} = \frac{\text{Pr oject First Investment Payment}}{\text{Average Annual Savings}} \text{:(Equation 16.1)}$$

$$\text{Simple payback period (years)} = \frac{\$11{,}000{,}000}{\$404{,}500.77} = \mathbf{27.19\ Years}$$

Section 16.2: Planning Cost Analysis for Propane Gas

The cogeneration plant has the option to use propane gas as fuel, but it does not last long since it operates at 70% efficiency, meaning that you can only refill propane gas up to 33,600 gallons. Unlike LNG fuel, which operates at 90% efficiency, and it can fill storage tanks up to 43,200 gallons. Propane gas is more volatile, and because of this, the loss of energy on heat is more, and can't be filled up all the way to max capacity, which is 48,000 gallons. Additionally, propane gas lasts way less than LNG, with 10,000 gallons of propane, the cogeneration plant only lasts 24 hours a day for 4 days, while with LNG fuel it lasts 24 hours a day for 20 days. However, if it is assumed that both fuel sources are used simultaneously, with 40,000 gallons each, propane gas would last approximately 12 days, whereas LNG would last the same amount of time as mentioned before. Even though propane is less ideal, the cogeneration plant can still use it and can be considered for emergency situations. Furthermore, in this section, the prices per units of LNG and propane will be compared by converting propane gas units of \$/gallons to \$/mmbtu (since LNG is already in units of \$/mmbtu). Consequently, gas companies were contacted to find prices of propane, and the average of all the prices found is

$4/gallon, whereas the LNG is at $11/mmbtu because the client, Evertec, has a contract with New Fortress Energy which buys the fuel at the price mentioned. After researching on the internet, it was found that 1 gallon of propane is approximately 0.0915 mmbtu, and with this, the conversion of propane units can be started. This process is shown below on equation 16.2.

$$\frac{\$4}{\text{gallon}} * \frac{1\text{ gallon}}{0.091500\text{ mmbtu}} = \$\mathbf{43.715/mmbtu}\text{: (Equation 16.2)}$$

LNG ($/mmbtu)	Propane ($/mmbtu)	Data Origin
11	43.715	Group 169

Table 16.14: Comparison of propane and LNG fuel sources.

As observed above, in table 16.12, propane gas is valued approximately at $43.715/mmbtu, and LNG is valued at $11/mmbtu. As can be seen by this comparison, LNG is way more cost efficient than propane, and as explained before, it is more energy efficient too. Besides, it is not possible to compare with historical records the usage of propane gas in the cogeneration plant at Evertec since it has only been used twice because of how expensive and inefficient it is.

Section 16.3: Planning Cost Analysis for PV System

The initial expenditure for the Photovoltaic System will be detailed in the subsequent section, including construction, solar panels, and further components to consider. Regarding the projected value of each component for the initial investment, the total final cost to execute this system as an integration into the Evertec Cupey micro-grid includes extra expenses such as solar panel maintenance and any other applicable charges. Furthermore, a projected evaluation of the savings generated by Evertec Cupey via the integration of the PV system into their micro-grid, juxtaposed with the savings realized after the establishment of the cogeneration plant in 2022. In 2023, the integration of the cogeneration plant resulted in total savings of

$526,632.84; However, this figure is subject to variability due to the unpredictability of future utility costs. Consequently, this amount will serve as the foundational basis for the economic analysis. This comparison will determine the viability of implementing the PV system into their micro-grid, necessitating a final estimate of the payback period required to repay the investment.

The entire payout for the electric bill in 2024 amounts to $412,976.50, as provided by Evertec Cupey. This base value will facilitate the comparison with the savings generated by the implementation of the PV system and its investment payback term to assess its viability. Determining the energy price established by LUMA, a foundational price of $/kWh is required for the planning costs of the PV system and the anticipated savings for Evertec, including the predicted payback time; Equation 16.3 will facilitate this analysis.

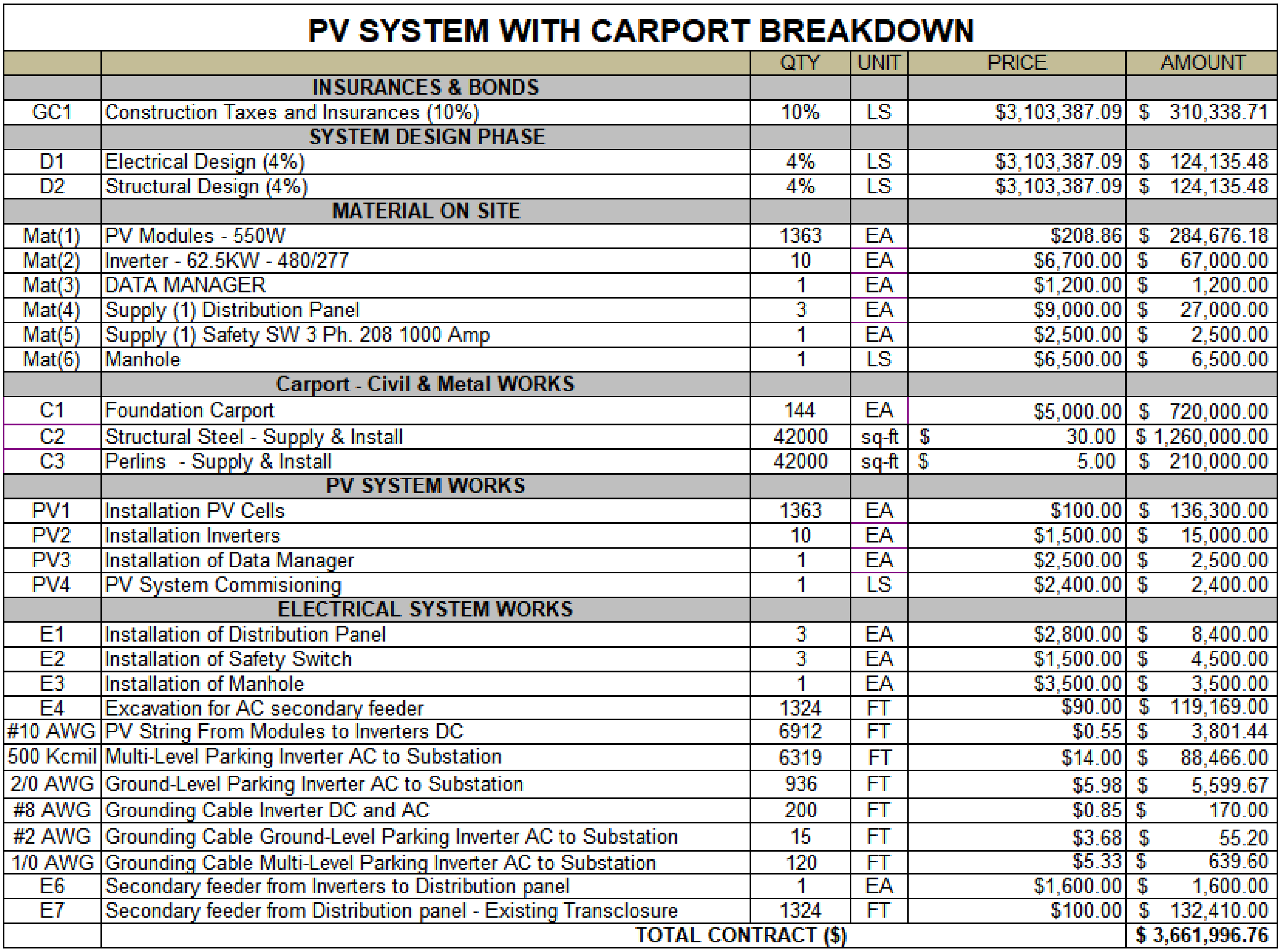
$\text{LUMA (kWh)} = \frac{\text{Monthly bill price}}{\text{Monthly consumption (kWh)}}$: (Equation 16.3)

Additionally, table 16.15 will be utilized in conjunction with Equation 16.3, which delineates the billing for the last seven months of 2024; thus, an estimated price per kWh for the year 2024 can be derived, establishing a standard basis for the analysis of subsequent years and calculating the annual savings alongside the payback period of the photovoltaic system investment. Accompanying the 2024 power bill figures used for the computation, $412,976.50 paid by Evertec to LUMA in the previous year (2024) will be included. The savings presented at the conclusion of this chapter will be more precise and authentic; this is due to the significant fluctuations in electric bill costs over short intervals, rendering it impossible to ascertain an exact figure for the actual savings. However, by utilizing the 2024 bills up to September, the most recent one, it is feasible to derive a highly accurate annual savings estimate.

2024 Monthly Utility Bills	Energy Consumed (kWh)	Cost ($)	Data Origin
January	64,680	25,940.54	Appendix A: Figure A.1
February	47,520	23,269.11	
March	124,800	39,570.79	
April	52,800	23,896.92	
May	97,020	33,938.53	
June	163,020	49,391.05	
July	70,356	31,159.58	
August	142,824	46,680.96	
September	93,060	35,884.90	
October	-	-	
November	-	-	
December	-	-	

Table 16.15: 2024 Electric bills costs AFTER Cogeneration, data from Evertec Cupey

A comparison will be conducted using the entire amount Evertec paid LUMA in 2024, factoring in the cogenerator's operation. This analysis will simulate yearly usage as if the photovoltaic system were in place, given that the cogeneration plant supplies 2.4MW and the photovoltaic system produces 600kW after DC to AC conversion. Additionally, Table 16.16 provides a comprehensive summary of all expenditures associated with the PV system, including design expenses, electrical components, mechanical and civil materials, wiring, feeders, and installation. The total cost for the PV system is listed below.



PV SYSTEM WITH CARPORT BREAKDOWN					
		QTY	UNIT	PRICE	AMOUNT
	INSURANCES & BONDS				
GC1	Construction Taxes and Insurances (10%)	10%	LS	$3,103,387.09	$ 310,338.71
	SYSTEM DESIGN PHASE				
D1	Electrical Design (4%)	4%	LS	$3,103,387.09	$ 124,135.48
D2	Structural Design (4%)	4%	LS	$3,103,387.09	$ 124,135.48
	MATERIAL ON SITE				
Mat(1)	PV Modules - 550W	1363	EA	$208.86	$ 284,676.18
Mat(2)	Inverter - 62.5KW - 480/277	10	EA	$6,700.00	$ 67,000.00
Mat(3)	DATA MANAGER	1	EA	$1,200.00	$ 1,200.00
Mat(4)	Supply (1) Distribution Panel	3	EA	$9,000.00	$ 27,000.00
Mat(5)	Supply (1) Safety SW 3 Ph. 208 1000 Amp	1	EA	$2,500.00	$ 2,500.00
Mat(6)	Manhole	1	LS	$6,500.00	$ 6,500.00
	Carport - Civil & Metal WORKS				
C1	Foundation Carport	144	EA	$5,000.00	$ 720,000.00
C2	Structural Steel - Supply & Install	42000	sq-ft	$ 30.00	$ 1,260,000.00
C3	Perlins - Supply & Install	42000	sq-ft	$ 5.00	$ 210,000.00
	PV SYSTEM WORKS				
PV1	Installation PV Cells	1363	EA	$100.00	$ 136,300.00
PV2	Installation Inverters	10	EA	$1,500.00	$ 15,000.00
PV3	Installation of Data Manager	1	EA	$2,500.00	$ 2,500.00
PV4	PV System Commisioning	1	LS	$2,400.00	$ 2,400.00
	ELECTRICAL SYSTEM WORKS				
E1	Installation of Distribution Panel	3	EA	$2,800.00	$ 8,400.00
E2	Installation of Safety Switch	3	EA	$1,500.00	$ 4,500.00
E3	Installation of Manhole	1	EA	$3,500.00	$ 3,500.00
E4	Excavation for AC secondary feeder	1324	FT	$90.00	$ 119,169.00
#10 AWG	PV String From Modules to Inverters DC	6912	FT	$0.55	$ 3,801.44
500 Kcmil	Multi-Level Parking Inverter AC to Substation	6319	FT	$14.00	$ 88,466.00
2/0 AWG	Ground-Level Parking Inverter AC to Substation	936	FT	$5.98	$ 5,599.67
#8 AWG	Grounding Cable Inverter DC and AC	200	FT	$0.85	$ 170.00
#2 AWG	Grounding Cable Ground-Level Parking Inverter AC to Substation	15	FT	$3.68	$ 55.20
1/0 AWG	Grounding Cable Multi-Level Parking Inverter AC to Substation	120	FT	$5.33	$ 639.60
E6	Secondary feeder from Inverters to Distribution panel	1	EA	$1,600.00	$ 1,600.00
E7	Secondary feeder from Distribution panel - Existing Transclosure	1324	FT	$100.00	$ 132,410.00
	TOTAL CONTRACT ($)				**$ 3,661,996.76**

Table 16.16: PV System with Carport Breakdown

Section 16.4: PV system Economic Analysis

The PV system economic analysis focuses on the year 2024 which is the year where it is going to be implemented since it does not exist physically yet in Evertec. Moreover, the year has not ended, this is why taking an average cost of the current utility price, and the calculation yielded \$0.3852/kWh. Furthermore, the PV system generates 1,181,496.6 kWh annually, and a rough estimate can be made on how much the customer would pay for the utility, and this is the savings used for the calculations below. This is done by multiplying the kWh generated by the

PV system with the average cost of energy provided by LUMA. This is done below on equation 16.4, where it is obtained how much Evertec is supposed to pay for energy to the utility grid. Additionally, to calculate the savings that the PV system will produce, a difference must be made between the current price of electricity that the client pays and the price if the PV system was installed. This calculation is done below, in equation 16.5. Finally, table 16.17 indicates a breakdown of how much Evertec pays with and without the PV system. It also shows the approximate payback period which uses equation 16.1, and this calculation is shown below as well, in equation 16.6.

$\text{Annual Energy Savings with PV system} = \left(\frac{\$0.3852}{\text{kwh}}\right) * 1{,}181{,}496.6\ \text{kWh} = \$\mathbf{455{,}112:}$

(Equation 16.4)

$\text{Energy Costs Savings} = |(\text{Cost without PV}) - (\text{Cost with PV})|$: (Equation 16.5)

$\text{Energy Costs Savings} = |(\$412{,}976.50) - (\$455{,}112)| = \$\mathbf{42{,}135.5}$

$\text{Simple payback period (years)} = \frac{\text{Initial Investment}}{\text{Annual Savings}} = \frac{\$3{,}661{,}996.76}{\$455{,}112} = \mathbf{8.04\ yrs:}$

(Equation 16.6)

The simple payback period of 8.04 years represents the investment value, without the consideration of a loan, which is the procedure our customer will follow. Nevertheless, the computation pertaining to the loan is explained in equation 16.7.

Description	**Amount**	**Data Origin**
Initial Investment	$3,661,996.76	Table 16.16, Figure 15.6, Equation 16.4, Equation 16.5, Equation 16.7
Annual Operational and Maintenance Costs	$0.00	
Energy produced by PV System (kWh annually)	1,181,496.6	
Annual Energy Cost without PV System (2024)	$412,976.50	
Annual Cost of Energy (Average 2024)	$0.3852/kWh	
Annual Energy Savings with PV System (2024)	$455,112	
Energy Costs Residual (2024)	$42,135.5	
Payback Period (Years)	12.3 years	

Table 16.17: PV System costs breakdown with simple payback period.

Next, table 16.17 indicates a breakdown of how much Evertec pays with and without the PV system and it also shows the approximate payback period. The PV system has the potential to produce more energy than demanded by Evertec from the utility. Therefore, at the same rate, this system would cover the annual electric bill for Evertec and produce an additional $42,235.5. This indicates that Evertec can consume more electricity and still pay zero dollars to LUMA.

The annual energy savings from the PV system, amounting to $455,112, represents the overall savings generated by Evertec. Additionally, supposing the customer would proceed with the investment, calculations were conducted for a loan of 3,661,996.76 at an interest rate of 7% and a duration of 12.3 years. Finally, equations 16.7 and 16.8 show the calculations for the true annual payment made towards the loan.

$\mathrm{A} = \mathrm{P} * (\frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{n}}}{(1+\mathrm{i})^{\mathrm{n}}-1})$: (Equation 16.7)

Where:

A = Annual Payment

P = Initial Investment

i = Interest Percentage

n = Total Years

$$\mathrm{A} = 3{,}661{,}996.76 * (\frac{0.07(1+0.07)^{12.3}}{(1+0.07)^{12.3}-1})$$

$$\mathrm{A} = 3{,}661{,}996.76 * 0.12395 = \$\mathbf{453{,}759.86}$$

Now, we will calculate the total interest paid over a span of 12.3 years, utilizing equation 16.8 below. The number displayed will let us know how much the client is going to pay in interest on the loan.

$\mathrm{I} = (\mathrm{A} * \mathrm{n}) - \mathrm{P}$: (Equation 16.8)

Where:

I = Total Interest to Pay

A = Annual Payment

n = Total Years

P = Initial Investment

$I = (\$453{,}759.86 * 12.3\ \text{Years}) - \$3{,}661{,}996.76$ = **$1,915,739.48**

Ultimately, after consolidating all outcomes from prior calculations, the system's output is very feasible. After **12.3 years**, Evertec will realize the whole yearly energy savings from the PV system, so contributing to the payback time of the CHP system and greatly reducing costs annually.

Section 16.5: Costs Comparisons and Repayment, for Cupey

Finalizing the economic analysis, table 16.18 has the comparison between the PV and CHP systems. It summarizes all the calculations done up to this point, and the data given to us by Evertec. The table has the initial investment, annual cost for electricity, and annual cost for operational and maintenance. Additionally, all these comparisons happen in the current year, 2024.

Description	Amount	Data Origin
PV system Initial Investment	$3,661,996.76	Table 16.17, Equation 16.7, Appendix A12-A16
Annual PV System Operational and Maintenance Costs	$0.00	
Annual Energy Cost without PV System (2024)	$412,976.50	
Annual Energy Cost with PV System	$0.00	
Annual cost to utility (2024)	$455,112	
Payback Period PV System (Years)	12.3 years	
CHP Project First Investment Payment	$11,000,000	
Annual Savings (2021-2024)	$404,500.77	
Payback Period CHP System (Years)	27.19 years	

Table 16.18: Payback Period Comparison

Section 16.6: Economic Analysis Summary

The design and implementation of a microgrid system incorporating Photovoltaic (PV) technology and cogeneration offers a sustainable and cost-effective solution to address the energy challenges in areas with unstable grids and high electricity costs. By leveraging Puerto Rico's abundant sunlight, the PV system design provides a renewable source of energy, while the cogeneration system offers backup power and increased efficiency to the system.

The economic analysis compares the initial investment, payback period, and long-term benefits of the cogeneration system and the photovoltaic (PV) system. The following table summarizes the key metrics:

Parameter	Cogeneration System	PV System	Data Origin
Initial Investment	$11 million	$3.6 million	Table 16.18, Table 15.2,
Annual Savings	$404,500.77	$455,112	
Payback Period	27.19 yrs.	12.3 yrs.	
Simulation Error	N/A	0.85%	

Table 16.19: Comparison of PV and Cogeneration System

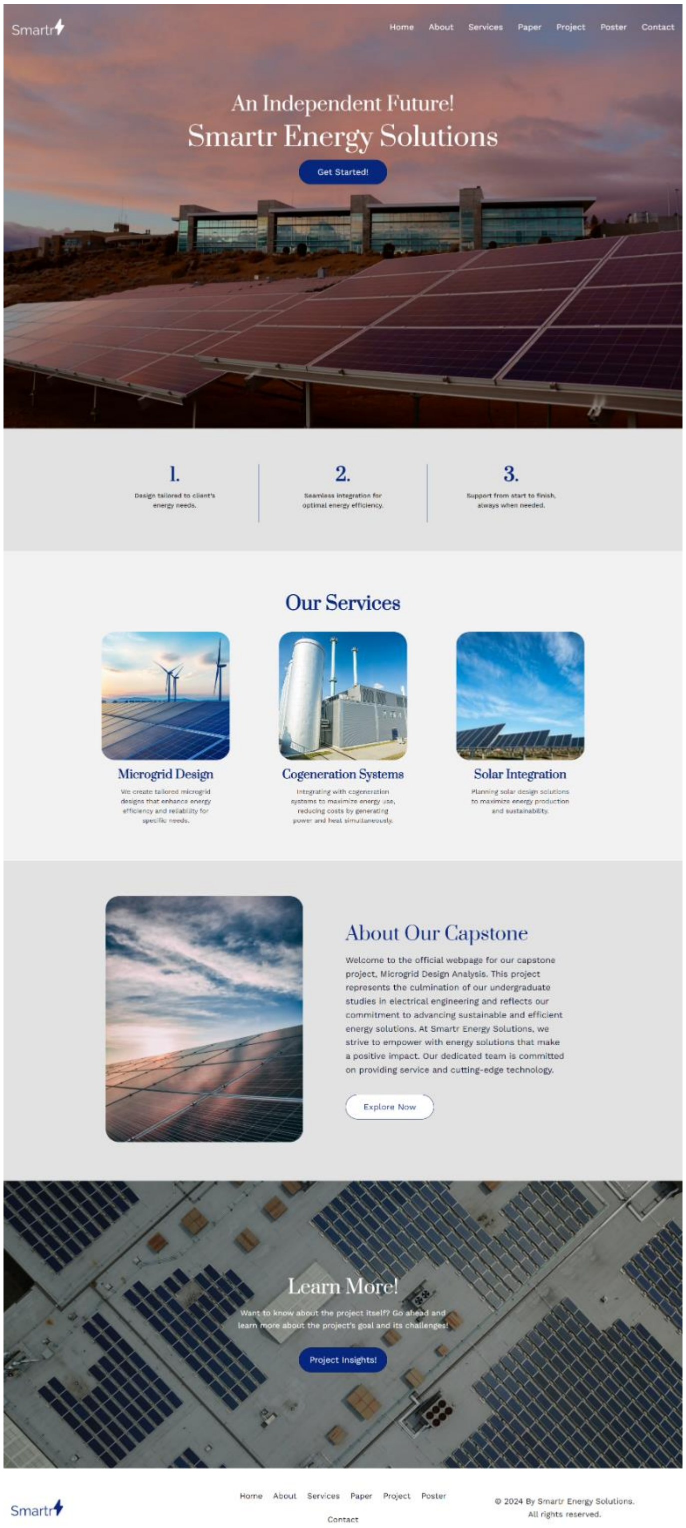
The cogeneration system requires significantly larger initial investment compared to the PV system. However, this higher upfront expense is offset by the system's ability to generate substantial annual savings, dramatically reducing utility costs over time. Furthermore, the longer payback period of the cogeneration system reflects the scale of its initial cost, yet its substantial annual savings make it a financially viable solution for achieving sustained reductions in operating expenses.

In contrast, the PV system demands a smaller initial investment and provides a much faster payback period, enabling quicker returns on investment. While it may lead to a slight increase in energy costs during its first year due to installation and operational expenses, it offers meaningful annual savings as energy prices continue to rise, making it an effective option for long-term financial planning. Additionally, simulations for the PV system validated its design with an exceptionally low error margin of just 0.85% when compared to manual calculations, underscoring its reliability. Taking together these systems offer complementary benefits: the cogeneration system excels in delivering significant long-term savings, while the PV system provides faster returns and adaptability to future energy demands. Both systems represent robust strategies for enhancing energy efficiency and reducing costs over time for the client, Evertec.

The integration of these systems not only reduces dependence on the local utility but enhances energy resilience and sustainability by reducing greenhouse gas emissions and energy costs over time. The careful consideration of economic factors, fuel alternatives, and system performance ensures that this solution is financially viable, environmentally responsible, and aligned with local and national energy regulations. Ultimately, this project contributes to advancing energy independence and offers a scalable model for addressing similar energy challenges in other regions.

Chapter 17: Administrative Documents

Section 17.1: Webpage



An Independent Future!

Smartr Energy Solutions

1. Design tailored to client's energy needs.

2. Seamless integration for optimal energy efficiency.

3. Support from start to finish, always when needed.

Our Services

Microgrid Design

We create tailored microgrid designs that enhance energy efficiency and reliability for specific needs.

Cogeneration Systems

Integrating with cogeneration systems to maximize energy use, reducing costs by generating power and heat simultaneously.

Solar Integration

Planning solar design solutions to maximize energy production and sustainability.

About Our Capstone

Welcome to the official webpage for our capstone project, Microgrid Design Analysis. This project represents the culmination of our undergraduate studies in electrical engineering and reflects our commitment to advancing sustainable and efficient energy solutions. At Smartr Energy Solutions, we strive to empower with energy solutions that make a positive impact. Our dedicated team is committed on providing service and cutting-edge technology.

Learn More!

Want to know about the project itself? Go ahead and learn more about the project's goal and its challenges!

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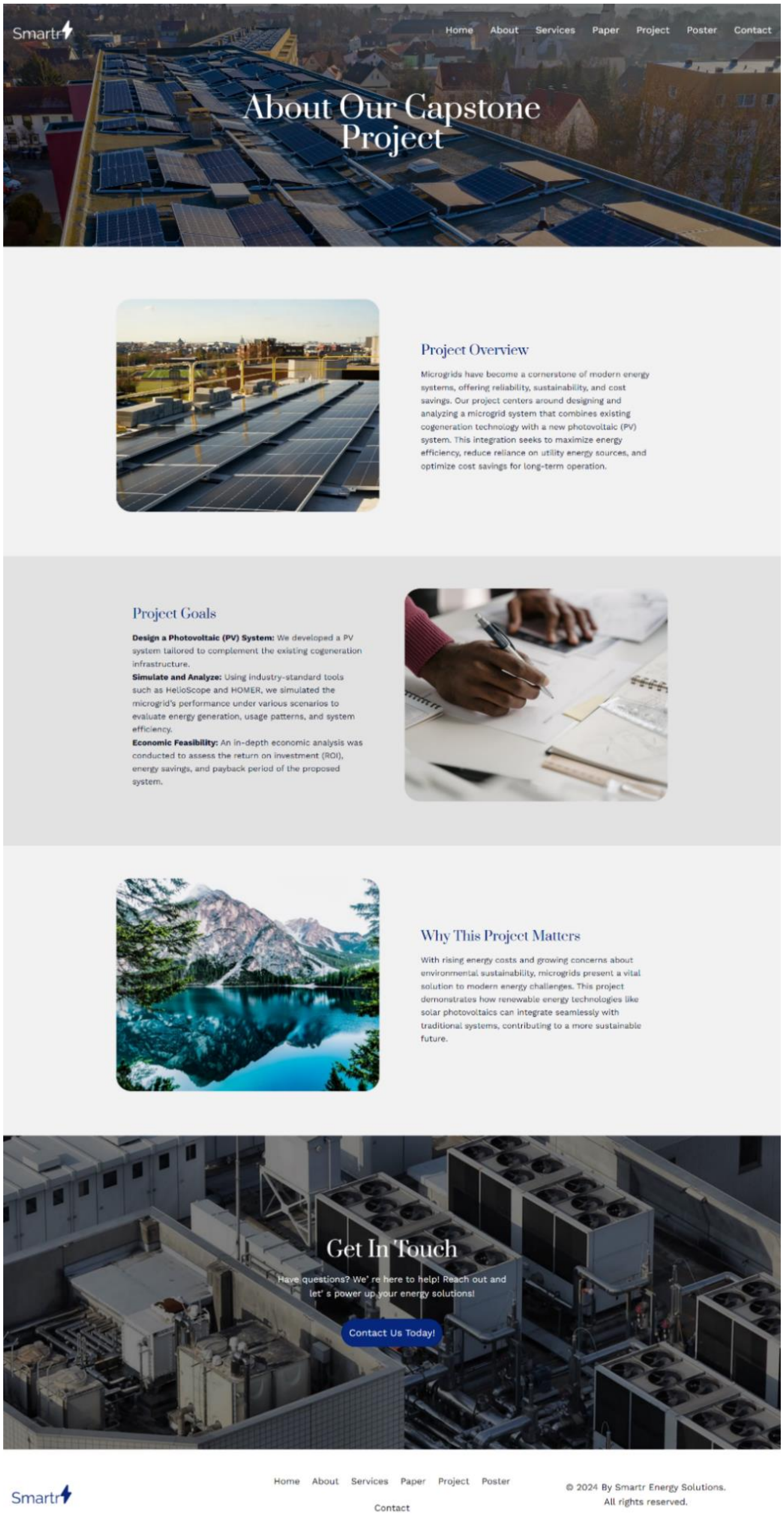
Figure 17.1: Website's Home Page



About Our Capstone Project

Project Overview

Microgrids have become a cornerstone of modern energy systems, offering reliability, sustainability, and cost savings. Our project centers around designing and analyzing a microgrid system that combines existing cogeneration technology with a new photovoltaic (PV) system. This integration seeks to maximize energy efficiency, reduce reliance on utility energy sources, and optimize cost savings for long-term operation.

Project Goals

Design a Photovoltaic (PV) System: We developed a PV system tailored to complement the existing cogeneration infrastructure.
Simulate and Analyze: Using industry-standard tools such as HelioScope and HOMER, we simulated the microgrid's performance under various scenarios to evaluate energy generation, usage patterns, and system efficiency.
Economic Feasibility: An in-depth economic analysis was conducted to assess the return on investment (ROI), energy savings, and payback period of the proposed system.

Why This Project Matters

With rising energy costs and growing concerns about environmental sustainability, microgrids present a vital solution to modern energy challenges. This project demonstrates how renewable energy technologies like solar photovoltaics can integrate seamlessly with traditional systems, contributing to a more sustainable future.

Get In Touch

Have questions? We' re here to help! Reach out and let' s power up your energy solutions!

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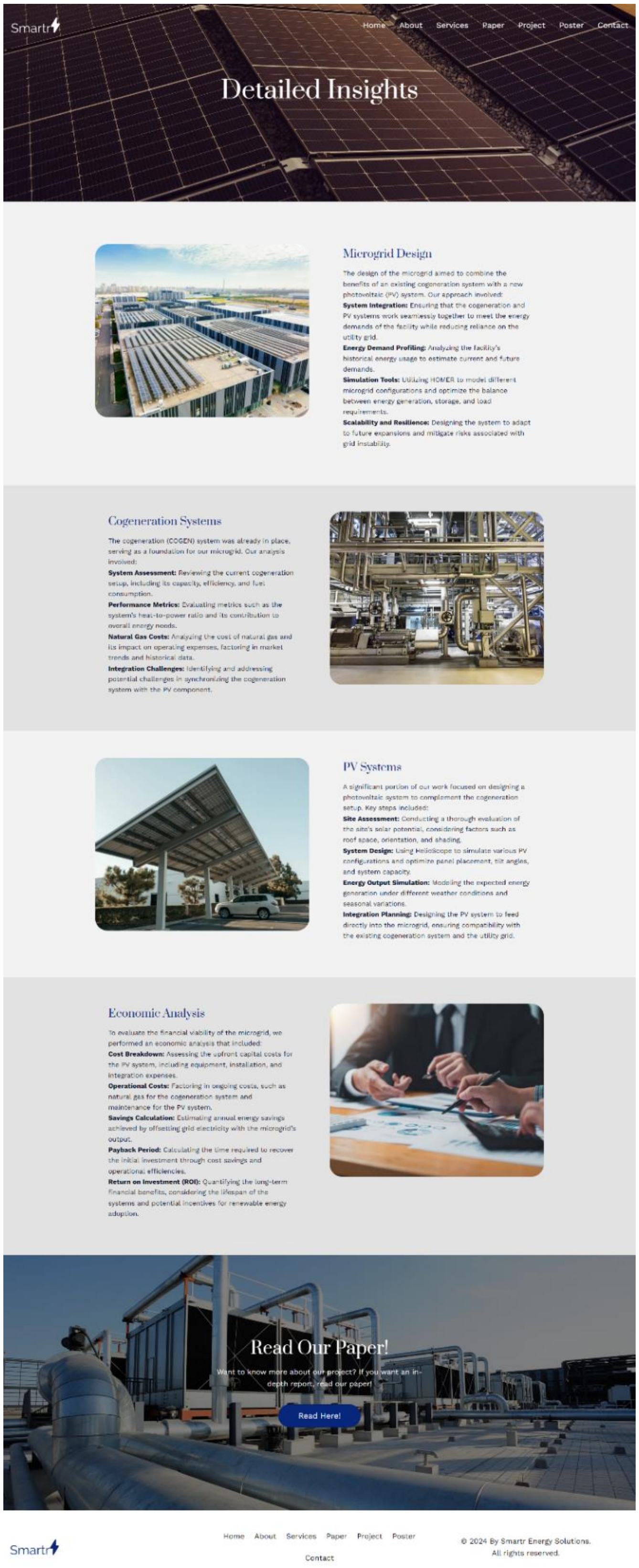

Detailed Insights

Microgrid Design

The design of the microgrid aimed to combine the benefits of an existing cogeneration system with a new photovoltaic (PV) system. Our approach involved:
System Integration: Ensuring that the cogeneration and PV systems work seamlessly together to meet the energy demands of the facility while reducing reliance on the utility grid.
Energy Demand Profiling: Analyzing the facility's historical energy usage to estimate current and future demands.
Simulation Tools: Utilizing HOMER to model different microgrid configurations and optimize the balance between energy generation, storage, and load requirements.
Scalability and Resilience: Designing the system to adapt to future expansions and mitigate risks associated with grid instability.

Cogeneration Systems

The cogeneration (COGEN) system was already in place, serving as a foundation for our microgrid. Our analysis involved:
System Assessment: Reviewing the current cogeneration setup, including its capacity, efficiency, and fuel consumption.
Performance Metrics: Evaluating metrics such as the system's heat-to-power ratio and its contribution to overall energy needs.
Natural Gas Costs: Analyzing the cost of natural gas and its impact on operating expenses, factoring in market trends and historical data.
Integration Challenges: Identifying and addressing potential challenges in synchronizing the cogeneration system with the PV component.

PV Systems

A significant portion of our work focused on designing a photovoltaic system to complement the cogeneration setup. Key steps included:
Site Assessment: Conducting a thorough evaluation of the site's solar potential, considering factors such as roof space, orientation, and shading.
System Design: Using HelioScope to simulate various PV configurations and optimize panel placement, tilt angles, and system capacity.
Energy Output Simulation: Modeling the expected energy generation under different weather conditions and seasonal variations.
Integration Planning: Designing the PV system to feed directly into the microgrid, ensuring compatibility with the existing cogeneration system and the utility grid.

Economic Analysis

To evaluate the financial viability of the microgrid, we performed an economic analysis that included:
Cost Breakdown: Assessing the upfront capital costs for the PV system, including equipment, installation, and integration expenses.
Operational Costs: Factoring in ongoing costs, such as natural gas for the cogeneration system and maintenance for the PV system.
Savings Calculation: Estimating annual energy savings achieved by offsetting grid electricity with the microgrid's output.
Payback Period: Calculating the time required to recover the initial investment through cost savings and operational efficiencies.
Return on Investment (ROI): Quantifying the long-term financial benefits, considering the lifespan of the systems and potential incentives for renewable energy adoption.

Read Our Paper!

Want to know more about our project? If you want an in-depth report, read our paper!

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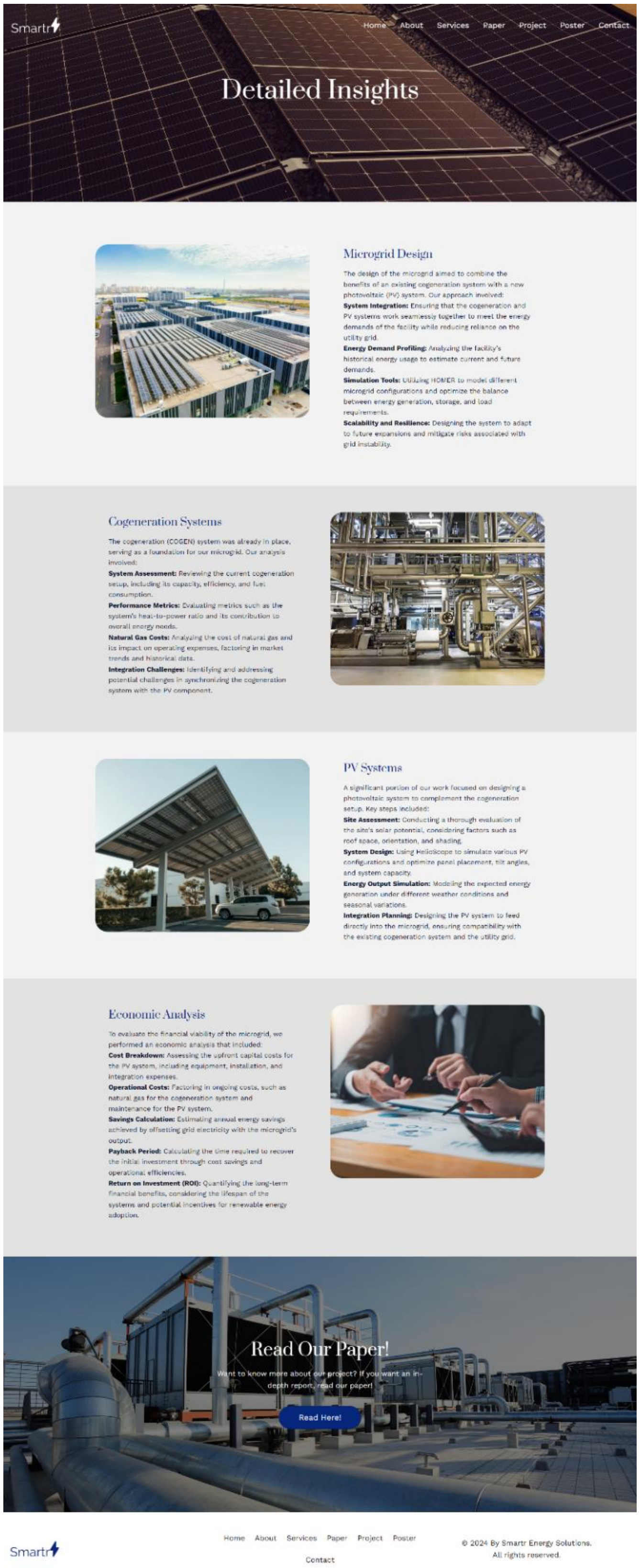
Figure 17.2: Website's About Page



Detailed Insights

Microgrid Design

The design of the microgrid aimed to combine the benefits of an existing cogeneration system with a new photovoltaic (PV) system. Our approach involved:
System Integration: Ensuring that the cogeneration and PV systems work seamlessly together to meet the energy demands of the facility while reducing reliance on the utility grid.
Energy Demand Profiling: Analyzing the facility's historical energy usage to estimate current and future demands.
Simulation Tools: Utilizing HOMER to model different microgrid configurations and optimize the balance between energy generation, storage, and load requirements.
Scalability and Resilience: Designing the system to adapt to future expansions and mitigate risks associated with grid instability.

Cogeneration Systems

The cogeneration (COGEN) system was already in place, serving as a foundation for our microgrid. Our analysis involved:
System Assessment: Reviewing the current cogeneration setup, including its capacity, efficiency, and fuel consumption.
Performance Metrics: Evaluating metrics such as the system's heat-to-power ratio and its contribution to overall energy needs.
Natural Gas Costs: Analyzing the cost of natural gas and its impact on operating expenses, factoring in market trends and historical data.
Integration Challenges: Identifying and addressing potential challenges in synchronizing the cogeneration system with the PV component.

PV Systems

A significant portion of our work focused on designing a photovoltaic system to complement the cogeneration setup. Key steps included:
Site Assessment: Conducting a thorough evaluation of the site's solar potential, considering factors such as roof space, orientation, and shading.
System Design: Using HelioScope to simulate various PV configurations and optimize panel placement, tilt angles, and system capacity.
Energy Output Simulation: Modeling the expected energy generation under different weather conditions and seasonal variations.
Integration Planning: Designing the PV system to feed directly into the microgrid, ensuring compatibility with the existing cogeneration system and the utility grid.

Economic Analysis

To evaluate the financial viability of the microgrid, we performed an economic analysis that included:
Cost Breakdown: Assessing the upfront capital costs for the PV system, including equipment, installation, and integration expenses.
Operational Costs: Factoring in ongoing costs, such as natural gas for the cogeneration system and maintenance for the PV system.
Savings Calculation: Estimating annual energy savings achieved by offsetting grid electricity with the microgrid's output.
Payback Period: Calculating the time required to recover the initial investment through cost savings and operational efficiencies.
Return on Investment (ROI): Quantifying the long-term financial benefits, considering the lifespan of the systems and potential incentives for renewable energy adoption.

Read Our Paper!

Want to know more about our project? If you want an in-depth report, read our paper!

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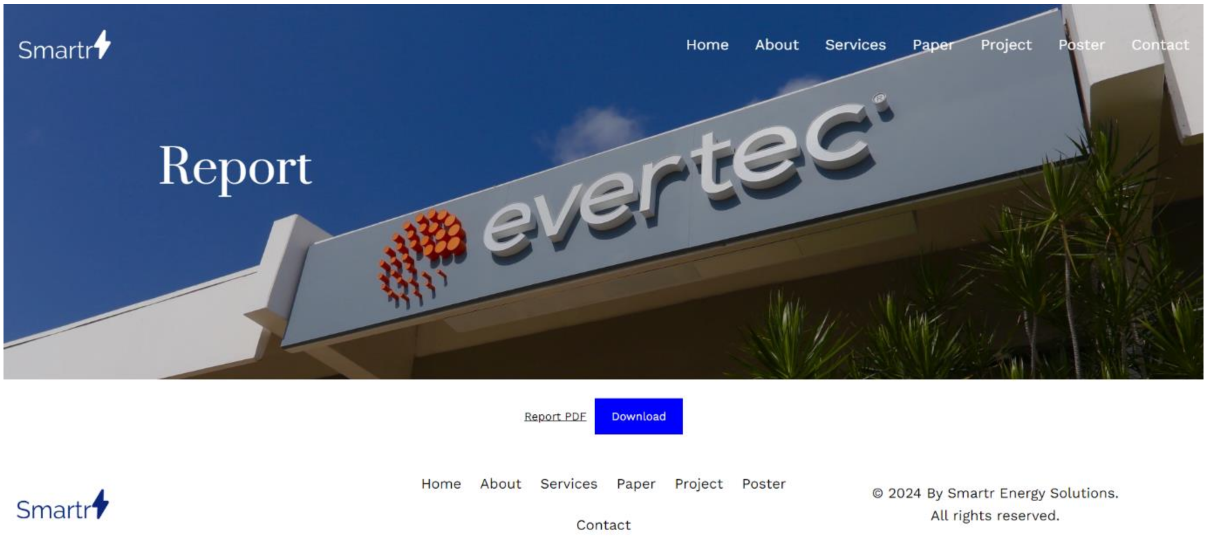
Figure 17.3: Website's Services Page

Paper

Distributed Generation Analysis of a Microgrid System

Figure 17.4: Website's Paper Page



Report

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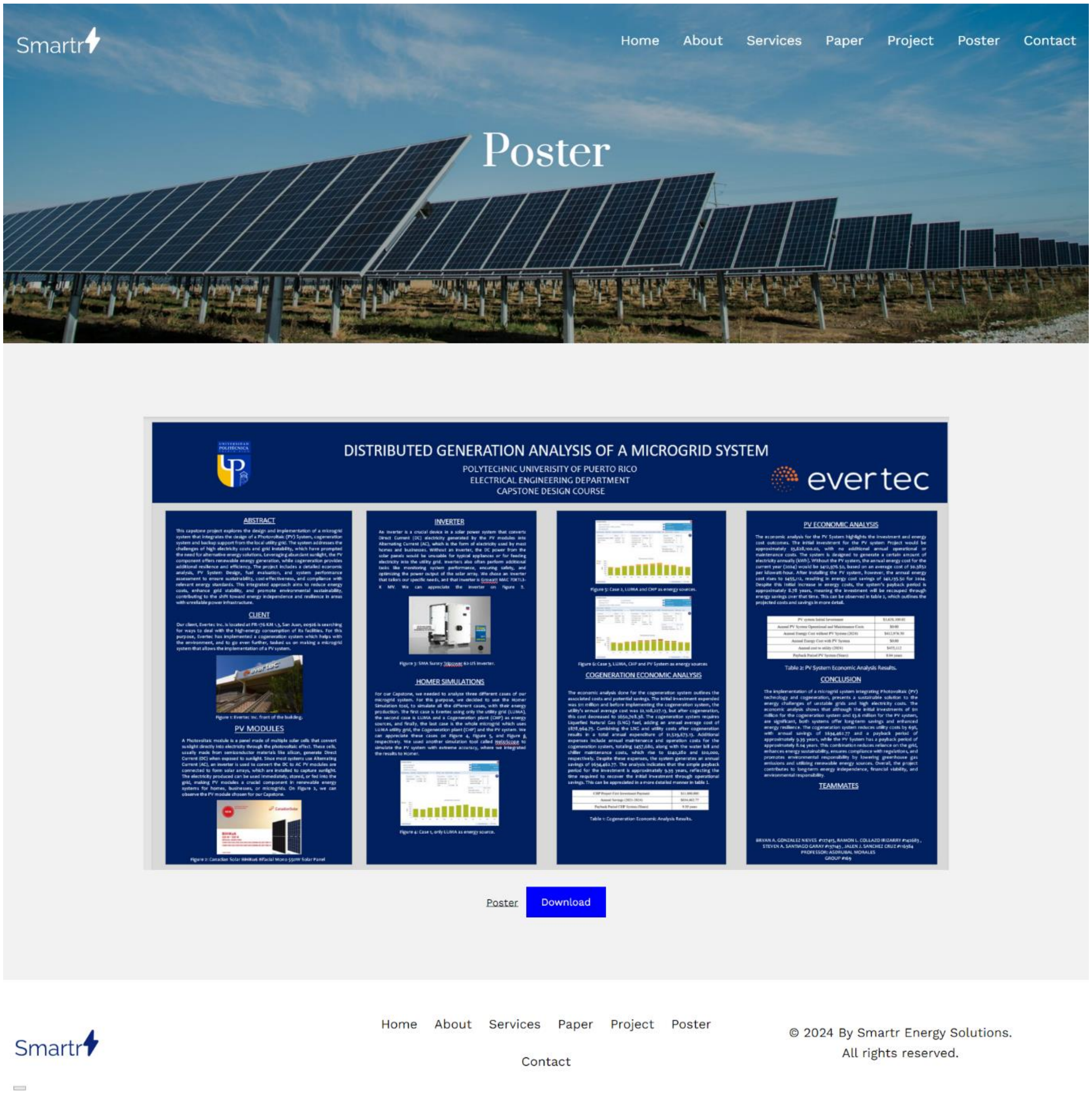
Figure 17.5: Website's Report Page



DISTRIBUTED GENERATION ANALYSIS OF A MICROGRID SYSTEM
POLYTECHNIC UNIVERISITY OF PUERTO RICO
ELECTRICAL ENGINEERING DEPARTMENT
CAPSTONE DESIGN COURSE

ABSTRACT

This capstone project explores the design and implementation of a microgrid system that integrates the design of a Photovoltaic (PV) System, cogeneration system and backup support from the local utility grid. The system addresses the challenges of high electricity costs and grid instability, which have prompted the need for alternative energy solutions. Leveraging abundant sunlight, the PV component offers renewable energy generation, while cogeneration provides additional resilience and efficiency. The project includes a detailed economic analysis, PV System Design, fuel evaluation, and system performance assessment to ensure sustainability, cost-effectiveness, and compliance with relevant energy standards. This integrated approach aims to reduce energy costs, enhance grid stability, and promote environmental sustainability, contributing to the shift toward energy independence and resilience in areas with unreliable power infrastructure.

CLIENT

Our client, Evertec Inc. is located at PR-176 KM 1.3, San Juan, 00926 is searching for ways to deal with the high-energy consumption of its facilities. For this purpose, Evertec has implemented a cogeneration system which helps with the environment, and to go even further, tasked us on making a microgrid system that allows the implementation of a PV system.

Figure 1: Evertec Inc. front of the building.

PV MODULES

A Photovoltaic module is a panel made of multiple solar cells that convert sunlight directly into electricity through the photovoltaic effect. These cells, usually made from semiconductor materials like silicon, generate Direct Current (DC) when exposed to sunlight. Since most systems use Alternating Current (AC), an inverter is used to convert the DC to AC PV modules are connected to form solar arrays, which are installed to capture sunlight. The electricity produced can be used immediately, stored, or fed into the grid, making PV modules a crucial component in renewable energy systems for homes, businesses, or microgrids. On Figure 2, we can observe the PV module chosen for our Capstone.

Figure 2: Canadian Solar HiKu6 Bifacial Mono 550W Solar Panel

INVERTER

An inverter is a crucial device in a solar power system that converts Direct Current (DC) electricity generated by the PV modules into Alternating Current (AC), which is the form of electricity used by most homes and businesses. Without an inverter, the DC power from the solar panels would be unusable for typical appliances or for feeding electricity into the utility grid. Inverters also often perform additional tasks like monitoring system performance, ensuring safety, and optimizing the power output of the solar array. We chose an inverter that tailors our specific needs, and that inverter is Growatt MAC 70KTL3-X MV. We can appreciate the inverter on figure 3.

Figure 3: SMA Sunny Tripower 62-US inverter.

HOMER SIMULATIONS

For our Capstone, we needed to analyze three different cases of our microgrid system. For this purpose, we decided to use the Homer Simulation tool, to simulate all the different cases, with their energy production. The first case is Evertec using only the utility grid (LUMA), the second case is LUMA and a Cogeneration plant (CHP) as energy sources, and finally, the last case is the whole microgrid which uses LUMA utility grid, the Cogeneration plant (CHP) and the PV system. We can appreciate these cases on Figure 4, Figure 5, and Figure 6 respectively. We used another simulation tool called HelioScope to simulate the PV system with extreme accuracy, where we integrated the results to Homer.

Figure 4: Case 1, only LUMA as energy source.

Figure 5: Case 2, LUMA and CHP as energy sources.

Figure 6: Case 3, LUMA, CHP and PV System as energy sources

COGENERATION ECONOMIC ANALYSIS

The economic analysis done for the cogeneration system outlines the associated costs and potential savings. The initial investment expended was $11 million and before implementing the cogeneration system, the utility's annual average cost was $1,108,227.13, but after cogeneration, this cost decreased to $650,768.38. The cogeneration system requires Liquefied Natural Gas (LNG) fuel, adding an annual average cost of $878,964.75. Combining the LNG and utility costs after cogeneration results in a total annual expenditure of $1,529,673.13. Additional expenses include annual maintenance and operation costs for the cogeneration system, totaling $457,680, along with the water bill and chiller maintenance costs, which rise to $240,280 and $20,000, respectively. Despite these expenses, the system generates an annual savings of $634,462.77. The analysis indicates that the simple payback period for the investment is approximately 9.39 years, reflecting the time required to recover the initial investment through operational savings. This can be appreciated in a more detailed manner in table 1.

Table 1: Cogeneration Economic Analysis Results.

PV ECONOMIC ANALYSIS

The economic analysis for the PV System highlights the investment and energy cost outcomes. The initial investment for the PV system Project would be approximately $3,628,100.02, with no additional annual operational or maintenance costs. The system is designed to generate a certain amount of electricity annually (kWh). Without the PV system, the annual energy cost for the current year (2024) would be $412,976.50, based on an average cost of $0.3852 per kilowatt-hour. After installing the PV system, however, the annual energy cost rises to $455,112, resulting in energy cost savings of $42,135.50 for 2024. Despite this initial increase in energy costs, the system's payback period is approximately 8.78 years, meaning the investment will be recouped through energy savings over that time. This can be observed in table 2, which outlines the projected costs and savings in more detail.

Table 2: PV System Economic Analysis Results.

CONCLUSION

The implementation of a microgrid system integrating Photovoltaic (PV) technology and cogeneration, presents a sustainable solution to the energy challenges of unstable grids and high electricity costs. The economic analysis shows that although the initial investments of $11 million for the cogeneration system and $3.6 million for the PV system, are significant, both systems offer long-term savings and enhanced energy resilience. The cogeneration system reduces utility costs by 69%, with annual savings of $634,462.77 and a payback period of approximately 9.39 years, while the PV System has a payback period of approximately 8.04 years. This combination reduces reliance on the grid, enhances energy sustainability, ensures compliance with regulations, and promotes environmental responsibility by lowering greenhouse gas emissions and utilizing renewable energy sources. Overall, the project contributes to long-term energy independence, financial viability, and environmental responsibility.

TEAMMATES

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PROFESSOR: ASDRUBAL MORALES
GROUP #169

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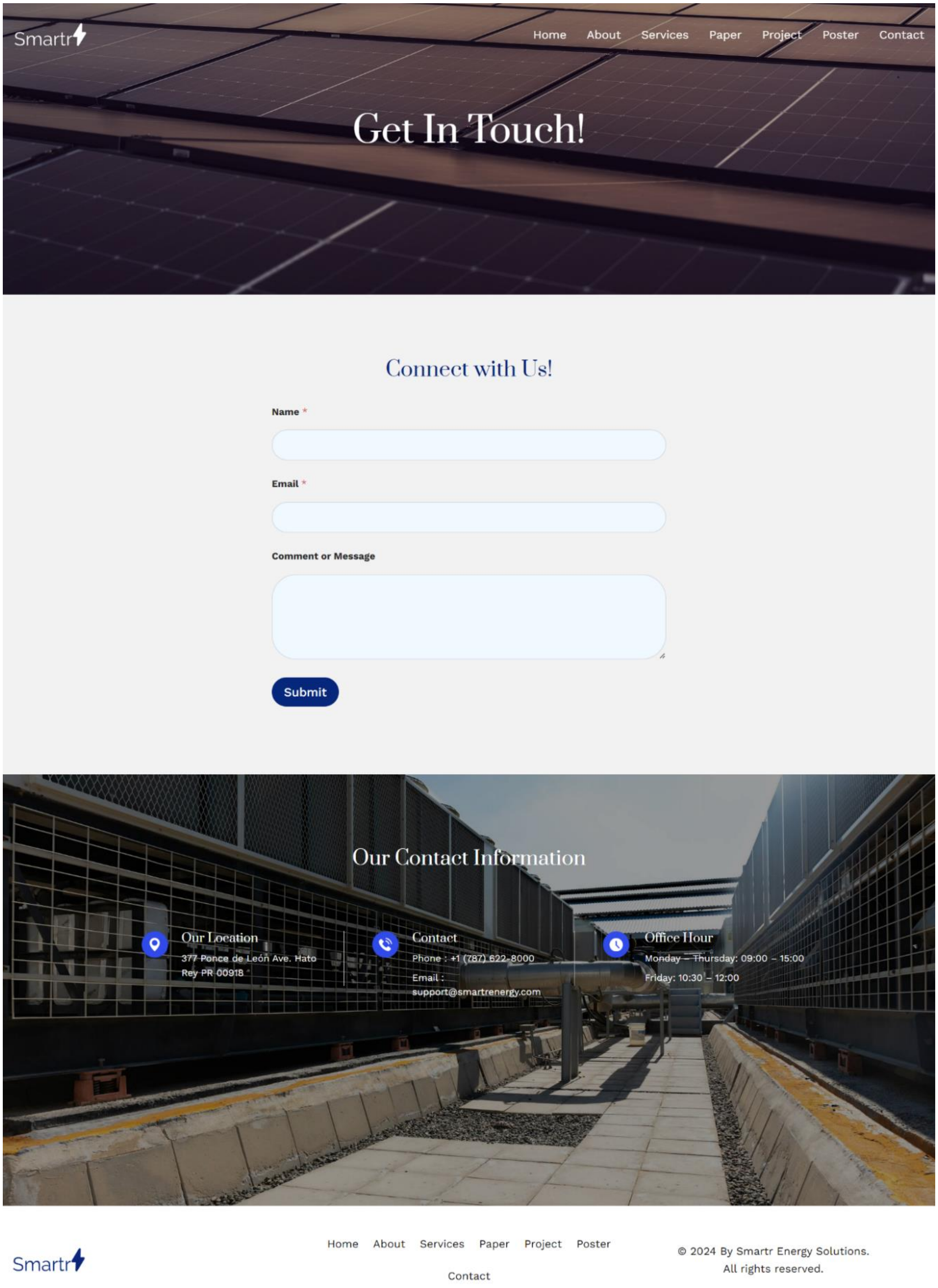
Figure 17.6: Website's Poster Page



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Phone : +1 (787) 622-8000

Email : support@smartrenergy.com

Office Hour

Monday – Thursday: 09:00 – 15:00

Friday: 10:30 – 12:00

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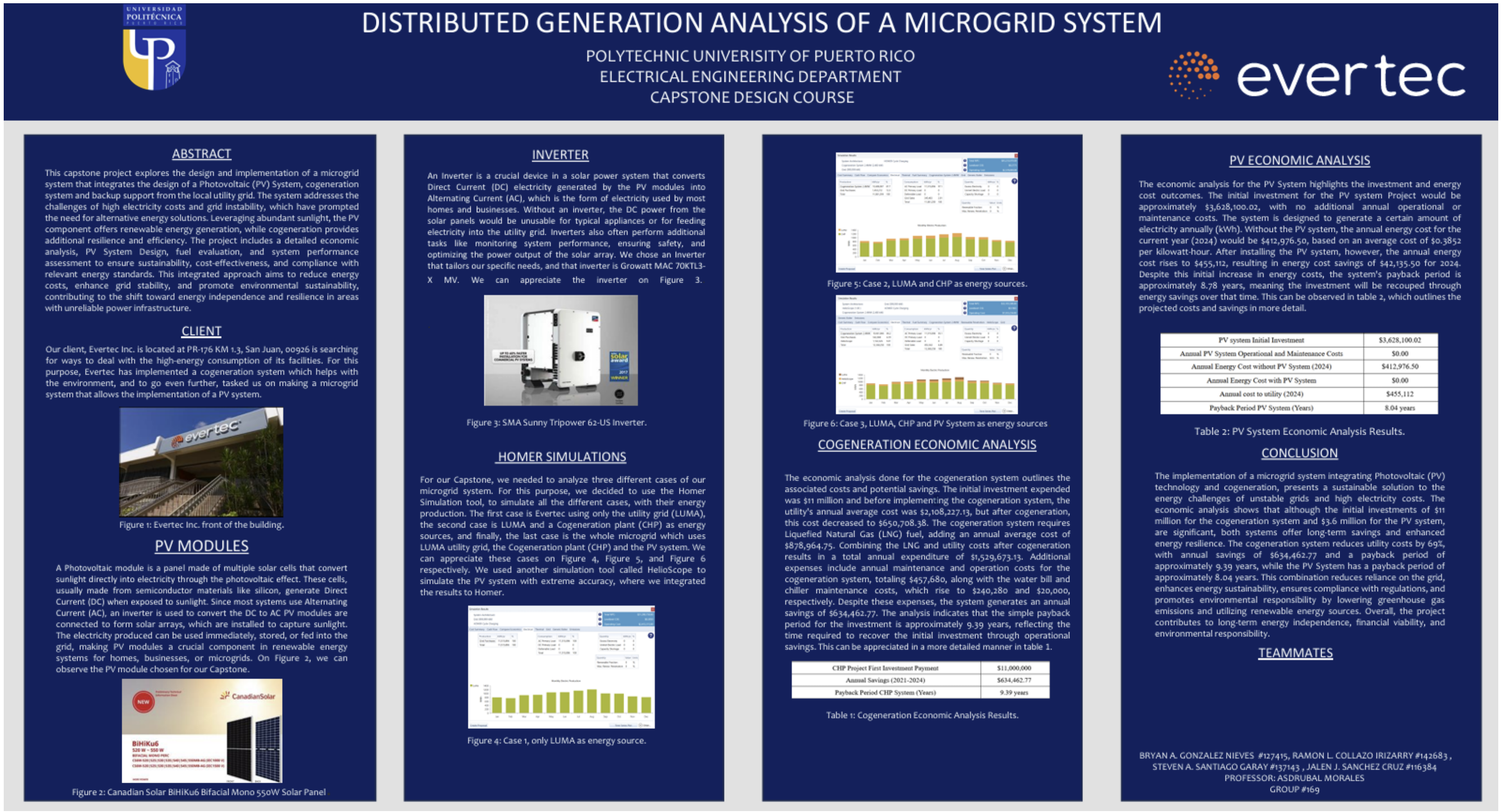
Figure 17.7: Website's Contact Page

Section 17.2: Poster



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CHP Project First Investment Payment	$11,000,000
Annual Savings (2021-2024)	$634,462.77
Payback Period CHP System (Years)	9.39 years

Table 1: Cogeneration Economic Analysis Results.

PV ECONOMIC ANALYSIS

The economic analysis for the PV System highlights the investment and energy cost outcomes. The initial investment for the PV system Project would be approximately $3,628,100.02, with no additional annual operational or maintenance costs. The system is designed to generate a certain amount of electricity annually (kWh). Without the PV system, the annual energy cost for the current year (2024) would be $412,976.50, based on an average cost of $0.3852 per kilowatt-hour. After installing the PV system, however, the annual energy cost rises to $455,112, resulting in energy cost savings of $42,135.50 for 2024. Despite this initial increase in energy costs, the system's payback period is approximately 8.78 years, meaning the investment will be recouped through energy savings over that time. This can be observed in table 2, which outlines the projected costs and savings in more detail.

PV system Initial Investment	$3,628,100.02
Annual PV System Operational and Maintenance Costs	$0.00
Annual Energy Cost without PV System (2024)	$412,976.50
Annual Energy Cost with PV System	$0.00
Annual cost to utility (2024)	$455,112
Payback Period PV System (Years)	8.04 years

Table 2: PV System Economic Analysis Results.

CONCLUSION

The implementation of a microgrid system integrating Photovoltaic (PV) technology and cogeneration, presents a sustainable solution to the energy challenges of unstable grids and high electricity costs. The economic analysis shows that although the initial investments of $11 million for the cogeneration system and $3.6 million for the PV system, are significant, both systems offer long-term savings and enhanced energy resilience. The cogeneration system reduces utility costs by 69%, with annual savings of $634,462.77 and a payback period of approximately 9.39 years, while the PV System has a payback period of approximately 8.04 years. This combination reduces reliance on the grid, enhances energy sustainability, ensures compliance with regulations, and promotes environmental responsibility by lowering greenhouse gas emissions and utilizing renewable energy sources. Overall, the project contributes to long-term energy independence, financial viability, and environmental responsibility.

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GROUP #169

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Section 17.4: Reference Citation

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3.7	Figure 3.19	https://cloudfrontgharpediabucket.gharpedia.com/uploads/2022/06/Imposed-Load-or-Live-Load-03-0202130021-1024x628.jpg
3.7	Figure 3.20	https://cloudfrontgharpediabucket.gharpedia.com/uploads/2022/06/Snow-Load-04-0202130021-1024x628.jpg
3.7	Figure 3.21	https://cloudfrontgharpediabucket.gharpedia.com/uploads/2022/06/Wind-Load-05-0202130021-1024x628.jpg
3.7	Figure 3.22	https://cloudfrontgharpediabucket.gharpedia.com/uploads/2022/06/Wind-Load-05-0202130021-1024x628.jpg
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9.1	Table 9.1	Group 169
9.2	Figure 9.3	https://static.csisolar.com/wp-content/uploads/2020/06/21135442/CS-Datasheet-BiHiKu6_CS6W-MB-AG_v2.1_EN.pdf
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Section 17.5: IEEE Paper

Distributed Generation Analysis of a Microgrid

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Sanchez Cruz

Abstract

This paper examines the design and implementation of a microgrid system at Evertec, a financial technology company in Puerto Rico. The study focuses on integrating photovoltaic (PV) and combining heat and power (CHP) systems to address the challenges of high electricity costs and grid instability. A comprehensive analysis, supported by simulations, evaluates the energy output, economic feasibility, and sustainability of the system. Key findings demonstrate the PV system's efficiency in utilizing Puerto Rico's abundant sunlight and the CHP system's ability to provide stable, cost-effective energy. These results underscore the potential of hybrid microgrids in enhancing energy resilience and reducing costs.

Introduction

Evertec, a prominent leader in financial technology services in Puerto Rico, faces persistent energy challenges, including prohibitively high electricity costs and an unreliable power grid. In response to these pressing issues, the company has explored innovative alternatives, such as microgrid systems that integrate renewable and conventional energy sources. This paper focuses on the design and implementation of a hybrid microgrid that combines photovoltaic (PV) systems and combined heat and power (CHP) technologies. By capitalizing on Puerto Rico’s abundant solar resources and incorporating advanced cogeneration methods, the proposed system seeks to deliver cost-effective, reliable energy while significantly reducing greenhouse gas emissions.

CHP systems, often referred to as cogeneration systems, represent a highly efficient approach to energy production. These systems generate electricity while simultaneously capturing and utilizing waste heat for practical applications such as space heating, water heating, and industrial processes. This dual-purpose capability greatly enhances overall energy efficiency compared to producing electricity and heat independently. Typically fueled by natural gas or biomass, CHP systems include components such as turbines, heat exchangers, and steam generators. The increasing adoption of CHP technologies reflects growing concerns about energy efficiency, sustainability, and the need to mitigate environmental impacts.

In parallel, PV systems harness sunlight to generate electricity through semiconductor materials embedded in solar panels. These systems are complemented by components such as inverters, which convert direct current (DC) into alternating current (AC), and batteries that provide energy storage to enhance system reliability. Particularly effective in regions with high solar irradiance, such as Puerto Rico, PV systems reduce reliance on traditional energy sources while minimizing environmental footprints. Recent advancements in solar technology have further improved the efficiency, scalability, and economic viability of PV systems, making them an essential component of modern energy solutions.

Moreover, by integrating PV and CHP systems into a cohesive microgrid, Evertec aims to reduce dependency on the utility grid, achieve significant long-term cost savings, and enhance overall energy reliability. This paper presents a comprehensive technical and economic analysis of the proposed system, highlighting its capacity to address Evertec’s energy challenges while ensuring financial sustainability. Ultimately, the findings contribute to broader discussions about adopting resilient and sustainable energy solutions, particularly in regions facing similar economic and infrastructural constraints.

PV Generation System Design

Evertec's photovoltaic design in Cupey, PR diverges from traditional commercial designs by prioritizing the number of photovoltaic modules that can be integrated into the multi-level parking facility and regular parking spaces. The areas to be discussed are shown in Figure 1.

Figure 1: Evertec Workspaces

Multiply the length (L) and the width (W) to determine the area. In equation 1, the formula for measuring an area is as follows.

A = LW: (Equation 1)

Figure 2: Multi-Level Parking Segments

The previously calculated area values are summarized in table 1 below.

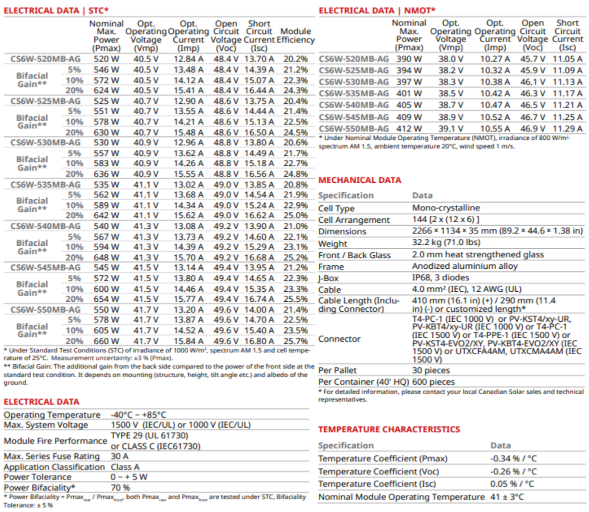
Description	Multi-Level Parking	Ground-Level Parking
Original Roof Area	56,270.55 ft^2	19,942.4 ft^2
RED Segment	7,792.8 ft^2	N/A
YELLOW Segment	10,263.2 ft^2	N/A
PURPLE Middle Segment	7,993.35 ft^2	N/A
PURPLE Corner Segments	5,684.16 ft^2	N/A
ORANGE Segments	3,513.92 ft^2	N/A
Area Considering 3ft Fire Line	N/A	19,936.4 ft^2
Total Usable Space	35,247.4 ft^2	19,936.4 ft^2

Table 1: Area Values Summary

Without a doubt, to guarantee the optimal performance and cost-effectiveness of the solar array, it is necessary to evaluate a variety of factors when selecting the PV module to be used, for this reason, the Canadian Solar BiHiKu6 Bifacial Mono 550W was chosen. These factors include both mechanical and electrical characteristics, where the most essential elements are the voltage, current, and power output, in which are critical electrical characteristics. The module's energy production capacity is determined by the parameters.

Furthermore, the selection process is significantly influenced by factors such as price, availability, and warranty. Mechanical considerations are equally significant and the installation for long-term durability is contingent upon the structural integrity, weight, and dimensions of the module. Reliability and safety necessitate the capacity to endure mechanical stresses, including snow and wind. The selection process prioritizes efficacy in power generation, mitigating losses, and competitive pricing, given the diverse range of PV modules available. Moreover, energy production is maximized by modules that provide a high-power output per hour of sunlight. Modules with a high-power output are prioritized due to the absence of energy production constraints in this endeavor. Effectively satisfying the project's requirements, the selected PV module must achieve a proportion between cost-effectiveness, mechanical robustness, and electrical performance.

Lastly, to achieve comprehension of the technical specifications, performance under diverse conditions, conformance with standards, warranty terms, installation guidelines, and system integration of a PV module, it is crucial to consult its datasheet (refer to figures 3 and 4). It enables users to make informed decisions, ensures proper utilization, and enables comparison with other modules.



ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS6W-520MB-AG		520 W	40.5 V	12.84 A	48.4 V	13.70 A	20.2%
Bifacial Gain**	5%	546 W	40.5 V	13.48 A	48.4 V	14.39 A	21.2%
	10%	572 W	40.5 V	14.12 A	48.4 V	15.07 A	22.3%
	20%	624 W	40.5 V	15.41 A	48.4 V	16.44 A	24.3%
CS6W-525MB-AG		525 W	40.7 V	12.90 A	48.6 V	13.75 A	20.4%
Bifacial Gain**	5%	551 W	40.7 V	13.55 A	48.6 V	14.44 A	21.4%
	10%	578 W	40.7 V	14.21 A	48.6 V	15.13 A	22.5%
	20%	630 W	40.7 V	15.48 A	48.6 V	16.50 A	24.5%
CS6W-530MB-AG		530 W	40.9 V	12.96 A	48.8 V	13.80 A	20.6%
Bifacial Gain**	5%	557 W	40.9 V	13.62 A	48.8 V	14.49 A	21.7%
	10%	583 W	40.9 V	14.26 A	48.8 V	15.18 A	22.7%
	20%	636 W	40.9 V	15.55 A	48.8 V	16.56 A	24.8%
CS6W-535MB-AG		535 W	41.1 V	13.02 A	49.0 V	13.85 A	20.8%
Bifacial Gain**	5%	562 W	41.1 V	13.68 A	49.0 V	14.54 A	21.9%
	10%	589 W	41.1 V	14.34 A	49.0 V	15.24 A	22.9%
	20%	642 W	41.1 V	15.62 A	49.0 V	16.62 A	25.0%
CS6W-540MB-AG		540 W	41.3 V	13.08 A	49.2 V	13.90 A	21.0%
Bifacial Gain**	5%	567 W	41.3 V	13.73 A	49.2 V	14.60 A	22.1%
	10%	594 W	41.3 V	14.39 A	49.2 V	15.29 A	23.1%
	20%	648 W	41.3 V	15.70 A	49.2 V	16.68 A	25.2%
CS6W-545MB-AG		545 W	41.5 V	13.14 A	49.4 V	13.95 A	21.2%
Bifacial Gain**	5%	572 W	41.5 V	13.80 A	49.4 V	14.65 A	22.3%
	10%	600 W	41.5 V	14.46 A	49.4 V	15.35 A	23.3%
	20%	654 W	41.5 V	15.77 A	49.4 V	16.74 A	25.5%
CS6W-550MB-AG		550 W	41.7 V	13.20 A	49.6 V	14.00 A	21.4%
Bifacial Gain**	5%	578 W	41.7 V	13.87 A	49.6 V	14.70 A	22.5%
	10%	605 W	41.7 V	14.52 A	49.6 V	15.40 A	23.5%
	20%	660 W	41.7 V	15.84 A	49.6 V	16.80 A	25.7%

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C. Measurement uncertainty: ±3 % (Pmax).

** Bifacial Gain: The additional gain from the back side compared to the power of the front side at the standard test condition. It depends on mounting (structure, height, tilt angle etc.) and albedo of the ground.

ELECTRICAL DATA

Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500 V (IEC/UL) or 1000 V (IEC/UL)
Module Fire Performance	TYPE 29 (UL 61730) or CLASS C (IEC61730)
Max. Series Fuse Rating	30 A
Application Classification	Class A
Power Tolerance	0 ~ + 5 W
Power Bifaciality*	70 %

* Power Bifaciality = $Pmax_{rear}$ / $Pmax_{front}$, both $Pmax_{rear}$ and $Pmax_{front}$ are tested under STC, Bifaciality Tolerance: ± 5 %

ELECTRICAL DATA | NMOT*

	Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)
CS6W-520MB-AG	390 W	38.0 V	10.27 A	45.7 V	11.05 A
CS6W-525MB-AG	394 W	38.2 V	10.32 A	45.9 V	11.09 A
CS6W-530MB-AG	397 W	38.3 V	10.38 A	46.1 V	11.13 A
CS6W-535MB-AG	401 W	38.5 V	10.42 A	46.3 V	11.17 A
CS6W-540MB-AG	405 W	38.7 V	10.47 A	46.5 V	11.21 A
CS6W-545MB-AG	409 W	38.9 V	10.52 A	46.7 V	11.25 A
CS6W-550MB-AG	412 W	39.1 V	10.55 A	46.9 V	11.29 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m² spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline
Cell Arrangement	144 [2 x (12 x 6)]
Dimensions	2266 × 1134 × 35 mm (89.2 × 44.6 × 1.38 in)
Weight	32.2 kg (71.0 lbs)
Front / Back Glass	2.0 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 diodes
Cable	4.0 mm² (IEC), 12 AWG (UL)
Cable Length (Including Connector)	410 mm (16.1 in) (+) / 290 mm (11.4 in) (-) or customized length*
Connector	T4-PC-1 (IEC 1000 V) or PV-KST4/xy-UR, PV-KBT4/xy-UR (IEC 1000 V) or T4-PC-1 (IEC 1500 V) or T4-PPE-1 (IEC 1500 V) or PV-KST4-EVO2/XY, PV-KBT4-EVO2/XY (IEC 1500 V) or UTXCFA4AM, UTXCMA4AM (IEC 1500 V)
Per Pallet	30 pieces
Per Container (40' HQ)	600 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.34 % / °C
Temperature Coefficient (Voc)	-0.26 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

Figure 3: Solar Module Data

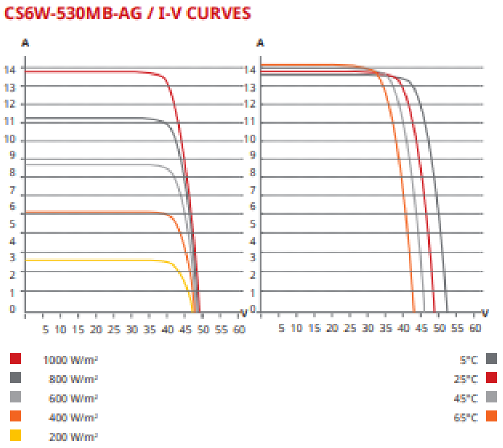


Figure 4: Solar Module Data Curves

In addition, the available space for the Evertec company PV system design will be divided into Ground-Level Parking and Multi-level Parking segments, as illustrated below. This will result in two distinct surface areas. The purpose of preventing system frequency and voltage stability issues, the power output of the solar array must be restricted to less than 1 MW, as the client has no interest in investing in a battery backup system. Consequently, the PV system will not provide complete coverage of Evertec's energy consumption. The quantity of PV modules necessary will be determined by utilizing a minimum guaranteed solar array DC power output of 750,000Wdc in the calculations. The client specifically needs close to 600,000Wac for the system to run independently from the grid. The capability to verify whether there is sufficient space for the quantity of PV modules necessary to generate 750,000Wdc, it is necessary to first determine the number of PV modules that can be installed in each segment of the roof by utilizing the available surface area.

$$\text{Modules A} = \frac{A_{FA}}{A_M}: \text{(Equation 2)}$$

Where:

$AFA = Final\ Area\ of$ Multi-Level Parking’s $roof$

$AM = Area\ per\ module$

The usable surface area of the roof of the multi-level parking facility, as illustrated in table 3. The length and width of each PV module are demonstrated in table 2. The information was available in the manufacturer's data document, which was previously displayed. After converting to feet, these are the final values.

Description	PV Module Size (in)	PV Module Size (ft)
Length	89.2	7.4
Width	44.6	3.7

Table 2: Module Sizes

Description	Multi-Level Parking	Ground-Level Parking
Total Usable Space	35,247.4 ft^2	19,936.4 ft^2

Table 3: Available Space

Equation 2 can be used to determine the total number of PV modules for the roof's multi-level parking.

$$\text{Modules} = \frac{35{,}247.4\ \text{ft}^2}{[(7.4\ \text{ft}) * (3.7)]} = 1{,}287$$

Consequently, the total number of PV modules for the multi-level parking is 1,287, as determined by the available surface area of the roof.

$$\text{Modules B} = \frac{A_{FB}}{A_M}: \text{(Equation 3)}$$

Where:

$AF\text{b} = Final\ Area\ of$ Ground-Level Parking

$AM = Area\ per\ modul$e

Equation 3 can be used to determine the total number of PV modules for ground-level parking referencing the values in table 3.

$$\text{Modules} = \frac{19{,}936.4\ \text{ft}^2}{[(7.4\ \text{ft}) * (3.7)]} = 728$$

Consequently, the total number of PV modules is 728, as determined by the available surface area on the ground-level parking.

Currently, utilizing equation 4 to determine the necessary quantity of PV modules to generate the minimum guaranteed solar array power output of 750,000Wdc. These calculations will be conducted using the datasheet for the Canadian Solar BiHiKu6.

$\text{N} = \frac{\text{P}_{\text{arr-g}}}{\text{P}_{\text{mpp}}}$: (Equation 4)

Where:

N = Total number of PV modules

$Parr{-}g = Power\ guaranteed\ from\ the\ solar\ array\ without\ losses$

$Pmpp = Power\ produced\ per\ PV\ modul$e

$$\text{N} = \frac{750{,}000\text{W}}{550\text{W}} = 1363$$

Consequently, 1,363 PV modules are necessary to achieve a minimum guaranteed solar array power output of 750,000Wdc. Following simulations conducted on Helioscope, the solar array panels will be split to optimize the limited area available. The solar array will consist of 1,224 PV modules for the multi-level parking and 139 for the ground-level parking, as Evertec's areas are divided into two. There is sufficient surface area to accommodate the specified number of PV modules per parking space.

It is imperative to choose the appropriate inverter for a photovoltaic system in order to ensure its efficacy, performance, and longevity. It is crucial to consider the following parameters when selecting this device:

- Nominal Power (kW): The nominal power of the inverter should correspond to the output capacity of the solar panels. Considering the potential future expansions of the system, it is crucial to guarantee that the inverter has the necessary capacity to manage the utmost power generated by the solar panels.
- Energy efficiency: The efficacy of inverters is essential, as it dictates the amount of solar energy that is converted into usable electricity. High-efficiency inverters can optimize energy production and minimize conversion losses.
- Maximum Power Point Tracking (MPPT): Inverters that utilize MPPT technology continuously modify the electrical capacity to optimize energy production, even in the presence of variable solar conditions. In order to guarantee maximum system performance, it is essential to use an inverter equipped with a dependable MPPT algorithm.
- Protection toward Overvoltage and Short Circuits: Inverters must be equipped with robust protection features to mitigate the risks of damage from overvoltage, short circuits, or other adverse conditions and ensure the safety of the system.
- Durability and Reliability: It is crucial to choose an inverter from a reputable manufacturer that provides a sufficient warranty and high-quality products. The longevity of the inverter is essential for the uninterrupted operation of the photovoltaic system.
- Monitoring Systems Compatibility: Certain inverters are equipped with integrated monitoring functions that enable the monitoring of system performance in real time. Effective system administration and maintenance may necessitate the capacity to establish connections to external monitoring systems.

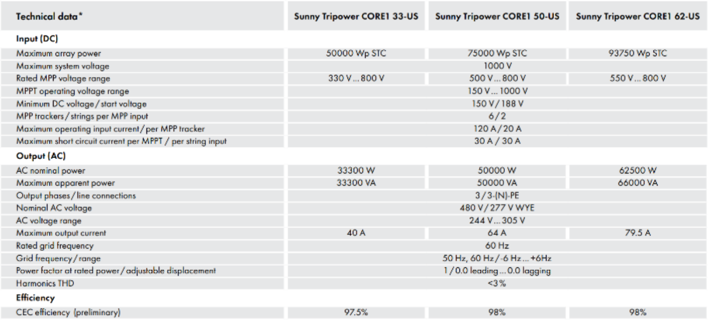
	SMA	**Growatt**	**Ginlong**
Model	TRIPOWER CORE1 62-US	MAC 70KTL3-X MV	Solis-100K-5G-US
Power Ratings	62,500 W	70,000 W	100,000 W
Efficiency	98%	98.8%	98.80%
MPP Trackers	6	3	10
Price	6,700.00	3,700.00	7,000.00

Table 4: Inverter Characteristics

Upon analyzing the aforementioned table, the inverter that most accurately meets the specified requirements is the SMA Sunny Tripower 62-US, as it delivers optimal output power and accommodates a respectable number of strings per input. The disadvantage of these systems is their high price, necessitating more inverters; nevertheless, in the event of an inverter failure, a substantial percentage of power production will not be lost.

Additionally, it is crucial to evaluate the inverter's capacity in series, parallel, maximum current, and maximum power, in addition to comparing the parameters. To accomplish this, the Datasheet of the equipment is illustrated in figures 5 and 6, which demonstrate that it continues to satisfy the essential specifications for t project.

Figure 5: String Inverter Model Description



Technical data*	Sunny Tripower CORE1 33-US	Sunny Tripower CORE1 50-US	Sunny Tripower CORE1 62-US
Input (DC)			
Maximum array power	50000 Wp STC	75000 Wp STC	93750 Wp STC
Maximum system voltage	1000 V		
Rated MPP voltage range	330 V ... 800 V	500 V ... 800 V	550 V ... 800 V
MPPT operating voltage range	150 V ... 1000 V		
Minimum DC voltage / start voltage	150 V / 188 V		
MPP trackers / strings per MPP input	6 / 2		
Maximum operating input current / per MPP tracker	120 A / 20 A		
Maximum short circuit current per MPPT / per string input	30 A / 30 A		
Output (AC)			
AC nominal power	33300 W	50000 W	62500 W
Maximum apparent power	33300 VA	50000 VA	66000 VA
Output phases / line connections	3 / 3-(N)-PE		
Nominal AC voltage	480 V / 277 V WYE		
AC voltage range	244 V ... 305 V		
Maximum output current	40 A	64 A	79.5 A
Rated grid frequency	60 Hz		
Grid frequency / range	50 Hz, 60 Hz / -6 Hz ... +6Hz		
Power factor at rated power / adjustable displacement	1 / 0.0 leading ... 0.0 lagging		
Harmonics THD	<3%		
Efficiency			
CEC efficiency (preliminary)	97.5%	98%	98%

Figure 6: String Inverter Datasheet

The quantity of inverters required for the design will be examined in this section. A series connection is the optimal solar panel configuration for this undertaking prior to commencing the calculations. This suggests that the direct current (DC) output of one panel is connected to the next panel, thereby increasing the total system voltage, as all panels are electrically connected in series. The inverter is subsequently connected to this chain. As previously mentioned, this configuration offers several benefits, such as an increase in system voltage, which reduces wiring losses, provides design flexibility, and improves system performance. The subsequent step will involve determining the quantity of inverters necessary for the undertaking. Accomplishing this requires a specific value from the technical datasheets of the PV module and the designated inverter, as detailed in the preceding sections. Table 5 and Table 6 respectively reflect this information.

		Data Origin
I_{sc}	14 A	Figure 9.3
I_{mp}	13.20 A	
V_{mp}	41.7 V	
V_{oc}	49.6 V	

Table 5: PV Module Specifications

Initially, the utmost number of solar modules that can be connected in series for a specific inverter is denoted by equation 5. The process divides the open circuit voltage of the photovoltaic module by the maximal system voltage of the inverter in Table 5. This guarantees that the inverter's utmost permissible voltage is not exceeded by the string's total voltage.

$$\text{Modules per string} = \frac{\mathrm{V_{Inom}}}{\mathrm{V_{OC}}} : \text{(Equation 5)}$$

Where:

V_{Inom} = Inverter nominal system voltage

V_{OC} = PV module open circuit voltage

$$\text{Modules per string} = \frac{800\ \text{V}}{49.6\ \text{V}} = 17$$

The subsequent stage, as illustrated in Equation 6, is to determine the total power of a series of solar modules for the photovoltaic system. The energy generation capacity of the string is determined by multiplying the nominal power of a single module in figure 3 by the total number of modules in per string Equation 5.

$Power\ per\ string = Modules\ per\ string * Module\ power$: (Equation 6)

$Power\ per\ string = 16 * 550W = 9{,}350\ W$

Equation 7 subsequently determines the greatest number of solar module strings that can be connected to a single inverter. The maximal power output of the inverter is divided by the total power output of a series of modules in this calculation, as determined by Equation 6. This phase is essential for the proper scaling of the system and the prevention of inverter saturation is reached.

$\text{Strings per Inverter} = \frac{\text{Maximum Inverter Power}}{\text{Power per String}}$: (Equation 7)

$$\text{Strings per Inverter} = \frac{75{,}000 \text{ W}}{9{,}350 \text{ W}} = 8$$

Consequently, equation 8 gives the total number of solar modules that can be connected to a single inverter in a photovoltaic system. This quantity is determined by multiplying the number of modules per string as determined by Equation 5, by the number of threads per inverter as determined by Equation 7. To prevent the inverter from being overloaded and to ensure that the system is properly sized, this process is extremely important.

$Modules\ per\ inverter = Modules\ per\ string * String\ per\ inverter$: (Equation 8)

$Modules\ per\ inverter = 16 * 8 = 136$

In summary, equation 9 calculates the total number of inverters required in the photovoltaic system by examining the total number of solar modules in equation 9.4 and the number of modules that can be connected to a single inverter in equation 8. The efficient utilization of the available inverters is contingent upon this calculation.

$\text{Inverter Cuantity} = \frac{\text{Total Modules Needed}}{\text{Modules per Inverter}}$: (Equation 9)

$$\text{Inverter Quantity} = \frac{1363}{136} = 10$$

Therefore, the PV system necessitates a total of 10 inverters. The inverter values previously derived are briefly summarized in table 7 below.

PV System		Data Origin
Modules per String	17	Equation 9.5
Power per String	9,350 W	Equation 9.6
Strings per Inverter	8	Equation 9.7
Modules per Inverter	136	Equation 9.8
Total Inverters	10	Equation 9.9

Table 7: PV System Inverter Specifications

PV Electrical System Design

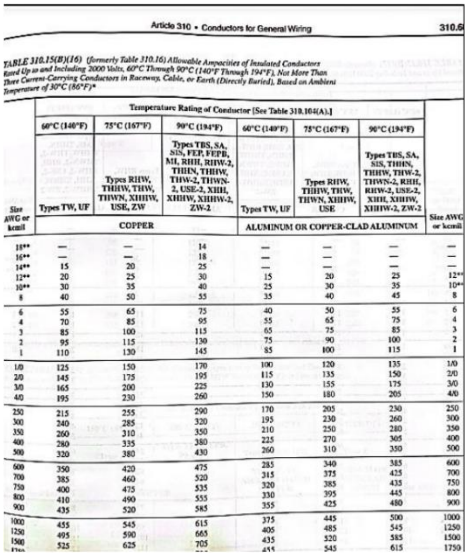
Conductors:

- **PV input to inverter from strings:**

The National Electrical Code (NEC), specifically Article 690 and Section 310, will be used to determine the appropriate wire size. As illustrated earlier, each string produces a short circuit current of 14 amps. The DC photovoltaic brief circuit current must be increased by a factor of 1.25 in accordance with NEC 690.8(A)(1). Consequently, to ascertain the DC conductor's ampacity for the PV system, the short circuit current must be multiplied by Isc*1.25, as illustrated in equation 10.

Ampacity = 11.77 A * 1.25 = 14.71 A: (Equation 10)

The geographical position of Puerto Rico produces diverse weather conditions, given that the island is near the equator. Therefore, the insulation for wiring will be THWN, which is specifically engineered for both dry and wet conditions with copper conductors. Consequently, figure 10.1 indicates a #14 AWG (THWN) wire, based on the computed ampacity. Nevertheless, to address safety concerns and avoid voltage loss, a #10 AWG (THWN) wire will be selected in place of a #14 AWG (THWN).



Article 310 • Conductors for General Wiring 310.6

*TABLE 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)**

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18**	—	—	14	—	—	—	—
16**	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
					545	615	1750

Figure 7: NEC Table 310.15(B)(16)

- **Inverter to the sub-panel:**

The AC output of each inverter will be connected to an AC load sub-panel. The purpose of these sub-panels is to consolidate the individual AC outputs of all inverters into a single AC output that will be directed to the AC main panel. The minimum conductor dimension must have an allowable ampacity that is not less than the non-continuous load plus 125% of the continuous load to calculate the proper AC conductor ampacity, as stated in NEC

Article 210.19(A)(1). The selected inverter has a maximum AC output current as illustrated in table 8. The appropriate conductor ampacity required from the inverter to the sub-panel is illustrated in equation 11.

Maximum Output Current
79.5 A

Table 8: Maximum Current at the output

Ampacity = 79.5 A * 1.25 = 99.37 A: (Equation 11)

Therefore, in accordance with figure 7, a #3 AWG (THWN) size wire is necessary for calculated ampacity. However, a #2 AWG (THWN) size wire will be employed due to safety and voltage drop concerns.

- **From sub-panels to the primary panel of the substation:**

The sub-panels will be divided into three sub-panels. Sub-panels A and B will each contain 5 and 4 inverters respectively, while C will contain only 1. The maximum AC output current for sub-panels A, B and C will be illustrated in table 9. Respectively, based on the maximum inverter current as demonstrated above. According to NEC Article 210.19(A)(1), the minimum conductor size must have an allowable ampacity that is not less than the non-continuous load plus 125% of the continuous load for it to calculate the appropriate AC conductor ampacity. Equations 12, 13, and 14 will be employed to determine the required ampacity for sub-panels A, B, and C.

AC Output Current for Sub-panel A with 5 Inverters	400 A
AC Output Current for Sub-panel B with 4 Inverters	320 A
AC Output Current for Sub-panel C with 1 Inverter	80 A

Table 9: AC Output Current for Inverters

$Ampacity_{sub-panel_A} = 400A * 1.25 = 500A$: (Equation 12)

$Ampacity_{sub-panel_B} = 320A * 1.25 = 400A$: (Equation 13)

$Ampacity_{sub-panel_C} = 80A * 1.25 = 100A$: (Equation 14)

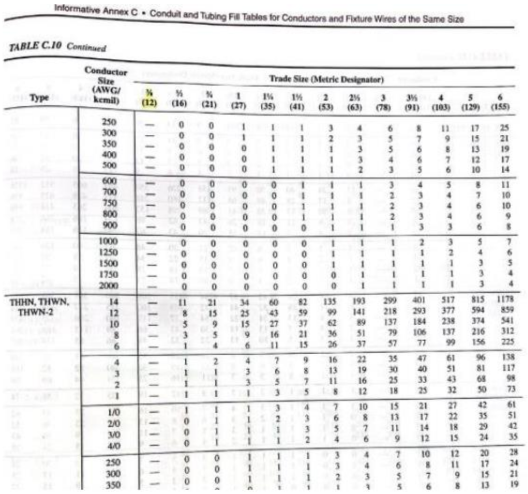
Therefore, in accordance with figure 7, a #500 Kcmil (THWN) size wire is necessary to achieve the calculated ampacity for sub-panels A and B. A #2/0 AWG (THWN) size wire is necessary for sub-panel C to meet the calculated ampacity. Nevertheless, the highest gauge wire that is recommended is #500 Kcmil (THWN) for the sake of simplicity of installation and voltage loss considerations. As a result, a parallel wire run will be implemented to decrease the ampacity necessary for sub-panels A and B.

Junction Box:

Junction Boxes, as depicted in figure 8, are typically constructed from PVC material, and can be installed either grounded or ungrounded. Furthermore, these boxes serve as junctions where electrical wires are merged or introduced to continue their journey through a conduit. Evertec's PV system comprises 10 inverters with 8 strings, each of which contains 17 PV modules. As a result, 25 junction boxes measuring 8 inches by 8 inches by 4 inches are required, with each box capable of accommodating 17 modules. The cables from the PV modules will be connected to a 20A fuse within these receptacles for overcurrent protection (see section 10.3) prior to being directed to the input of the inverter's Maximum Power Point (MPP) tracking system.

Figure 8: Junction Box 8' x 8' x 4"

Referring to figure 9, the conductor size calculations and NEC table C.10 will be employed to determine the appropriate conduit sizes. The appropriate grounding wire size will be determined by referring to NEC Table 250.66 (see figure 10). PVC Schedule 40 was chosen as the material for all conduits.



Informative Annex C • Conduit and Tubing Fill Tables for Conductors and Fixture Wires of the Same Size

TABLE C.10 Continued

Type	Conductor Size (AWG/ kcmil)	⅜ (12)	½ (16)	¾ (21)	1 (27)	1¼ (35)	1½ (41)	2 (53)	2½ (63)	3 (78)	3½ (91)	4 (103)	5 (129)	6 (155)
		Trade Size (Metric Designator)												
	250	—	0	0	1	1	1	3	4	6	8	11	17	25
	300	—	0	0	1	1	1	2	3	5	7	9	15	21
	350	—	0	0	0	1	1	1	3	5	6	8	13	19
	400	—	0	0	0	1	1	1	3	4	6	7	12	17
	500	—	0	0	0	1	1	1	2	3	5	6	10	14
	600	—	0	0	0	0	1	1	1	3	4	5	8	11
	700	—	0	0	0	0	1	1	1	2	3	4	7	10
	750	—	0	0	0	0	1	1	1	2	3	4	6	10
	800	—	0	0	0	0	1	1	1	2	3	4	6	9
	900	—	0	0	0	0	0	1	1	1	3	3	6	8
	1000	—	0	0	0	0	0	1	1	1	2	3	5	7
	1250	—	0	0	0	0	0	1	1	1	1	2	4	6
	1500	—	0	0	0	0	0	1	1	1	1	1	3	5
	1750	—	0	0	0	0	0	0	1	1	1	1	3	4
	2000	—	0	0	0	0	0	0	1	1	1	1	3	4
THHN, THWN, THWN-2	14	—	11	21	34	60	82	135	193	299	401	517	815	1178
	12	—	8	15	25	43	59	99	141	218	293	377	594	859
	10	—	5	9	15	27	37	62	89	137	184	238	374	541
	8	—	3	5	9	16	21	36	51	79	106	137	216	312
	6	—	1	4	6	11	15	26	37	57	77	99	156	225
	4	—	1	2	4	7	9	16	22	35	47	61	96	138
	3	—	1	1	3	6	8	13	19	30	40	51	81	117
	2	—	1	1	3	5	7	11	16	25	33	43	68	98
	1	—	1	1	1	3	5	8	12	18	25	32	50	73
	1/0	—	1	1	1	3	4	7	10	15	21	27	42	61
	2/0	—	0	1	1	2	3	6	8	13	17	22	35	51
	3/0	—	0	1	1	1	3	5	7	11	14	18	29	42
	4/0	—	0	1	1	1	2	4	6	9	12	15	24	35
	250	—	0	0	1	1	1	3	4	7	10	12	20	28
	300	—	0	0	1	1	1	3	4	6	8	11	17	24
	350	—	0	0	1	1	1	2	3	5	7	9	15	21

Figure 9: NEC Table C.10

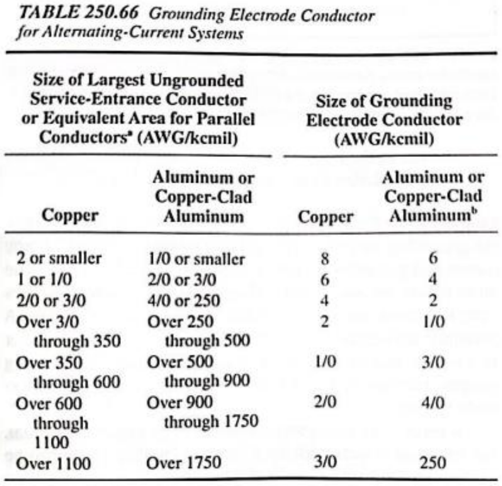


***TABLE 250.66** Grounding Electrode Conductor for Alternating-Current Systems*

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors^a (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	**Aluminum or Copper-Clad Aluminum**	**Copper**	**Aluminum or Copper-Clad Aluminum^b**
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Figure 10: NEC Table 250.66

String to Inverter:

- Total number of wires = 3
- 1 positive #10 AWG wire
- 1 negative #10 AWG wire
- 1 ground #10 AWG wire
- Conduit size = ¾ inch
- Total number of conduits = 108

Inverter to Sub-panels:

- Total number of wires = 5
- 3 live #2 AWG wire
- 1 neutral #2 AWG wire
- 1 ground #8 AWG wire
- Conduit size = 2 inch
- Total number of conduits = 4

Sub-panel A to Substation Main Panel:

- Total number of wires = 5
- 3 live #500 Kcmil wire
- 1 neutral #500 Kcmil wire
- 1 ground #1/0 AWG wire
- Conduit size = 4 inch
- Total number of conduits = 2 (Parallel wire run)

Sub-panel B to Substation Main Panel:

- Total number of wires = 5
- 3 live #500 Kcmil wire
- 1 neutral #500 Kcmil wire
- 1 ground #1/0 AWG wire
- Conduit size = 4 inch
- Total number of conduits = 2 (Parallel wire run)

Sub-panel C to Substation Main Panel:

- Total number of wires = 5
- 3 live #2/0 AWG wire
- 1 neutral #2/0 AWG wire
- 1 ground #4 AWG wire
- Conduit size = 2 inch
- Total number of conduits = 1

In an effort to prevent electrocution of responders in the event of a conflagration during daylight, the National Electric Code (NEC) mandates that a rapid shutoff device be connected to each PV module (article 690.12(A) through (B). The sole exception to this code is when the voltage of the PV array is less than 80V. The primary objective of a rapid shutoff switch is to rapidly halt the flow of DC power from individual solar modules and deactivate the entire PV system, even when the sun is still beaming. This is essential for the safety of firefighters during emergencies. This is especially crucial when employing string inverters, as the DC wiring from the solar panels remains energized even when disconnected from the rest of the system in the absence of rapid shutoff switches, which poses a safety hazard. The JMS-F rapid shutoff switch (figure 11) will be installed on the aluminum frame of each PV module for this project. A black cable is utilized to connect the output connector of each module to the input connector of the JMS-F. Red cables are used to connect the output connectors of adjacent JMS-F switches within each string. The 80V limit specified by the NEC is exceeded by the sequences of modules in this proposed system. It is for this reason that JMS-F shutoff devices will be installed on every inverter.

Figure 11: SunSpe model JMS-F Rapid Shutdown System

Protection from Overcurrent:
Conductor ampacity calculations must incorporate a factor of 125% of the maximum current of the PV system, as stipulated in NEC Article 690.8 (A)(1). DC breakers or fuses must be rated for a minimum of 125% of the ampacity determined in NEC Article 690.8(A)(1), as per NEC Article 690.9 (B)(1). Therefore, to guarantee that the system is adequately safeguarded, the subsequent total system current calculations were conducted with a total factor of 156%.

PV Module Short Circuit Current	Data Origin
14 A	Table 9.3

Table 10: Short Circuit Current

String to Inverter:

$\mathrm{I_{string} = I_{SC} * 1.56 = (14) * (1.56) = 21.84A}$: (Equation 15)

Where:

$Istring$ = $PV\ string\ ampacity$

Isc = $PV\ module\ short\ circuit\ current$

AC breakers or fuses must be rated for a minimum allowable ampacity that is not less than the non-continuous load plus 125% of the continuous load, as per NEC Article 210.19(A)(1). For the purpose of preventing the occurrence of superfluous breaker trips, the appropriate AC triple pole breaker diameters will be determined using the following equations 16 to 20.

Inverter Output Current
79.5A

Table 11: Inverter Current Data

Inverter to AC sub-panel:

$\mathrm{I_{Max\ \_Inverter} = I_{inv} * 1.25 = (79.5A)(1.25) = 99.37A}$: (Equation 16)

Where:

$I_{Max\_Inverter}$ = $Inverter\ ampacity$

I_{inv} = $Inverter\ output\ current$

AC sub-panel A to AC main panel:

$\mathrm{I_{sub\_panel\_A} = I_{inv} * Q_{inv} * 1.25 = (99.37A)(5) = 500A}$: (Equation 17)

Where:

$I_{\mathrm{sub\_panel\_A}}$ = $Subpanel\ A\ ampacity$

$I_{Max\_Inverter}$ = $Inverter\ ampacity$

Q_{inv} = $Total\ number\ of\ inverters\ per\ subpanel$

AC sub-panel B to AC main panel:

$\mathrm{I_{sub\_panel\_B} = I_{inv} * Q_{inv} * 1.25 = (99.37A)(4) = 400A}$: (Equation 18)

Where:

$I_{\mathrm{sub\_panel\_B}}$ = $Subpanel\ \mathrm{B}\ ampacity$

$I_{Max_{-Inverter}}$ = Inverter ampacity

Q_{inv} = $Total\ number\ of\ inverters\ per\ subpanel$

AC sub-panel C to AC main panel:

$\mathrm{I_{sub\_panel\_C} = I_{inv} * Q_{inv} * 1.25 = (99.37A)(1) = 100A}$: (Equation 19)

Where:

$I_{\mathrm{sub\_panel\_C}}$ = $Subpanel\ \mathrm{C}\ ampacity$

$I_{Max_{-Inverter}}$ = Inverter ampacity

Q_{inv} = $Total\ number\ of\ inverters\ per\ subpanel$

Substation AC main panel:

$\mathrm{I_{main\_panel}} = \mathrm{I_{inv}} * \mathrm{Q_T} * 1.25 = (99.37\mathrm{A})(10) = 1000\mathrm{A}$: (Equation 20)

Where:

$I_{Max\_Inverter}$ = Inverter ampacity

Q_T = $Total\ number\ of\ inverters$

In addition, it is imperative to install a 20A fuse for each PV string and a 100A triple pole breaker to connect the inverter to the AC load sub-panel, as per equations 15 and 16. A 500A main breaker is necessary to connect 5 inverters to sub-panels A, 4 inverters to sub-panel B with a 400A main breaker, and 1 inverter to subpanel C with a 100A main breaker, as illustrated in equations 17, 18 and 19. For the protection of the AC main panel at the substation, a 1000A main breaker will be installed, as illustrated in equation 20. In the event of an overcharge or short circuit, these breakers and fuses are designed to protect the system. Table 12 provides a summary of the overcurrent protection devices.

Protection	**Triple Pole Breaker**	**Fuse**
PV strings to inverter	N/A	20A
Inverter to AC sub-panel	100A	N/A
AC sub-panel A to AC main panel	500A	N/A
AC sub-panel B to AC main panel	400A	N/A
AC sub-panel C to AC main panel	100A	N/A
Substation AC main panel	1000A	N/A

Table 12: Overcurrent protection devices for the PV system

A tolerable voltage drop of 3% is allowed for the most distant receptacle in a branch circuit, according to the National Electrical Code (NEC). Nonetheless, a maximum voltage variation of 5% is allowed when considering the feeders connected to the branch circuit panel. A maximum voltage variation of 3% is allowable for both DC and AC systems due to the load side connector type. The NEC's tables 8 and 9 will be used for calculating DC and AC voltage drop in this project, respectively, since the utilization of ohms per kilofoot (ohms/kft) for voltage drop assessment.

Furthermore, manual calculations will be performed using specific equations that are designed for both AC and DC systems. In accordance with NEC regulations, the precise determination of voltage drop is guaranteed by Equations 21, 22, and 23:

$\mathrm{Vdrop_{DC}} = \frac{\mathrm{M*I*L*R}}{\mathrm{P}}$: (Equation 21)

Where:

$Vdrop_{DC}$ = DC voltage drop in volts

M = Multiplier: 2 for DC voltage drop

I = Current in amps

L = Length of conductor

R = Resistance in ohms/kFT

P = Parallel wire runs

$\mathrm{Vdrop_{AC}} = \frac{\mathrm{M*I*L*R}}{\mathrm{P}}$: (Equation 22)

Where:

$Vdrop_{AC}$ = AC voltage drop in volts

M = Multiplier: $\sqrt{3}$ for three phase AC voltage drop

I = Current in amps

L = Length of conductor

R = Resistance in ohms/kFT

P = Parallel wire runs

$\%\mathrm{Vdrop} = \frac{\mathrm{Vdrop}}{\mathrm{V_{L-L}}} * 100\%$: (Equation 23)

Where:

$\%Vdrop$ = Percentage of voltage drop

$Vdrop$ = $Voltage\ drop\ in\ volts$

$\mathrm{V_{L-L}}$ = $Line\ voltage$

DC Voltage Drop:

An Excel spreadsheet tool was developed using equations 21 and 23 to compute and recommend the suitable conductor size for the PV system based on DC voltage loss.

DC Voltage Drop	
Multi-Level Parking	
Distance (ft)	613.80
Wire Gauge	10 AWG
Wire Resistance(ohm/kft)	1.24
Wire Runs	1
Voltage Drop (V)	13.37
%Vdrop	1.59%

Ground-Level Parking	
Distance (ft)	478
Wire Gauge	10 AWG
Wire Resistance(ohm/kft)	1.24
Wire Runs	1
Voltage Drop (V)	10.41
%Vdrop	1.23%

Table 13: DC Voltage Drop Calculation Results

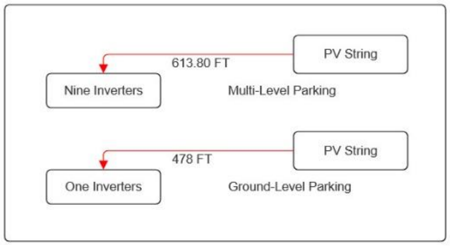


Figure 12: Longest Distance measurement of Multi-Level and Ground-Level Parking for DC voltage drop calculation.

AC Voltage Drop:
The distance from the inverters to the AC sub-panels A, B, and C may be considered negligible owing to their closeness. Consequently, the AC voltage loss will be exclusively assessed for the wire route from the AC sub-panels A, B, and C to the main panel of the AC substation

AC Voltage Drop	
Multi-Level Parking	
Distance (ft)	868.9
Wire Gauge	500 Kcmil
Wire Resistance(ohm/kft)	0.0258
Wire Runs	4
Voltage Drop (V)	3.86
%Vdrop	0.80%
Ground-Level Parking	
Distance (ft)	468.2
Wire Gauge	2/0 AWG
Wire Resistance(ohm/kft)	0.0967
Wire Runs	1
Voltage Drop (V)	6.23
%Vdrop	1.30%

Table 14: AC Voltage Drop Calculation

Figure 13: Longest Distance measurements of Multi-Level and Ground-Level Parking for AC voltage drop calculation.

PV Civil System Design

A carport is a covered structure that is employed to provide limited protection to vehicles, predominantly automobiles, from the elements such as the sun, rain, and snow. Carports, in contrast to garages, are typically open on one or more sides and may be either freestanding or affixed to a wall. Additionally, carports are available in a variety of materials and designs, including metal, wood, and composite materials, and can be either temporary or permanent structures.

Benefits of Carports:

1. Cost-effective: In general, it is less expensive to construct and maintain than a completely enclosed garage.
2. Installation simplicity: The installation of a carport is generally less complex and more efficient than the construction of a garage.
3. Weather protection: Although carports are not entirely enclosed, the encloser still offers protection from the sun, rain, and precipitation, which can help prolong the lifespan of a vehicle's interior and paint.

4. Ventilation: Carports are open-air structures, which facilitate superior ventilation in comparison to garages. This can mitigate the risk of mildew or pollutants.

5. Versatility: Equally important, carports function as shaded outdoor spaces for activities other than parking vehicles, such as a covered area for barbecues, gatherings, or outdoor storage.

Specifications in accordance with the Puerto Rico Electric Code:

The local building and electrical codes in Puerto

Rico require specific considerations when constructing a carport. These codes are in accordance with the National Electrical Code (NEC) but may include specific amendments.

1. Electrical Wiring and Outlets: The wiring must adhere to the NEC and local amendments if the carport has illumination, outlets, or other electrical installations. This encompasses the utilization of components that are both outdoor-rated and weather-resistant in order to endure the humid and coastal climate. Improving the system's safety, it is necessary to install Ground Fault Circuit Interrupter (GFCI) protection on all outdoor receptacles.

2. Lightning Protection: In view of Puerto Rico's frequent thunderstorms, it may be prudent to evaluate lightning protection for carports with metal structural elements. The structure can be protected by the implementation of lightning rods or ground mechanisms.
3. Adherence to Zoning Regulations and Setbacks: The carport must comply with zoning regulations that define the maximum height, coverage limits for impermeable surfaces, and setbacks from property lines.
4. Wind Load Requirements and Structural Integrity: Carports must be constructed to withstand high wind loads, which can typically reach 165 mph or higher, depending on the location, due to Puerto Rico's hurricane-prone status. This may entail the utilization of reinforced anchoring systems or heavier materials to ensure the pergola is securely fastened to the earth.

This is optimal for situating the PV system in this endeavor. Section 16.3 of Chapter 16 contains information regarding the materials and prices.

Cogen. Load Analysis

Calculations for the energy produced will be done using the data provided by the manufacturer of the cogeneration plant and Evertec. Firstly, defining energy produced, which refers to the total amount of usable energy generated by the system, typically measured in kilowatt-hours (kWh). This includes the electrical energy output and, where applicable, the thermal energy recovered and used in the system. In a cogeneration system, energy production reflects the generator's ability to efficiently convert fuel into electricity and heat.

The generator's maximum wattage is known, and how many loads. Additionally, knowing that 7.43 ft³ of natural gas is required to generate 1 kWh of electricity under standard conditions. This value is based on the energy content of natural gas, which is typically 1,030 BTU/scf, and the conversion ratio 1 kWh = 3,412 BTU.

The energy generated is directly related to the output of the generator, as outlined in equation 24 below. Additionally, converting the natural gas flow rate from ft³/h to m³/h to comply with local regulations, then use the energy content of natural gas to compute the equivalent kWh for energy generation. In the absence of precise fuel data, using conventional values for the composition and energy content of natural gas. The conversions and energy content data facilitate the calculation of the generator's energy output, as seen in equation 25.

$$\text{Energy Consumed} = (\text{Max Wattage of generator}) \cdot (\text{Loads}) \cdot (7.43\ \text{ft}^3)$$
(Equation 24)

$$\text{Energy Consumed} = (1{,}200\text{kWh})(1)(7.43\text{ft}^3) = \mathbf{8,916\ ft^3/h}$$
(Equation 25)

$$\left(\frac{8{,}916\text{ft}^3}{\text{h}}\right)\left(\frac{1\text{m}^3}{35.315\text{ft}^3}\right) = \mathbf{252.471m^3/h}$$

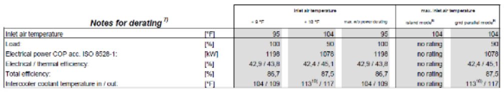
$$\left(\frac{252.471\text{m}^3}{\text{h}}\right)\left(\frac{35.31\text{scf}}{1\text{m}^3}\right) = \mathbf{8,914.75\ scf/h}$$

$$\frac{\left(\frac{8{,}914.75\text{scf}}{\text{h}}\right)(\text{Energy Content})}{3{,}412\ \text{BTU}} = \frac{\left(\frac{8{,}914.75\text{scf}}{\text{h}}\right)\left(\frac{1{,}030\text{BTU}}{\text{scf}}\right)}{3{,}412\text{BTU}} = \mathbf{2691.15kWh}$$

Power kW	Energy Produced (scf/h)	Energy Produced (kWh)
1,200	8,914.75	2,691.15

Table 15: Calculations results for energy produced and peak wattage.

Calculations of the electrical energy consumed (EC) are shown below. Additionally, table 15 shows the data sheet for heat exhaust, from the manufacturer, where the calculations are referenced from.



Notes for derating [7]		Inlet air temperature			max. inlet air temperature	
		+ 9 °F	+ 18 °F	max. w/o power derating	island mode[8]	grid parallel mode[8]
Inlet air temperature	[°F]	95	104	95	104	104
Load:	[%]	100	90	100	no rating	90
Electrical power COP acc. ISO 8528-1:	[kW]	1198	1078	1198	no rating	1078
Electrical / thermal efficiency:	[%]	42,9 / 43,8	42,4 / 45,1	42,9 / 43,8	no rating	42,4 / 45,1
Total efficiency:	[%]	86,7	87,5	86,7	no rating	87,5
Intercooler coolant temperature in / out:	[°F]	104 / 109	113[10] / 117	104 / 109	no rating	113[10] / 117

Figure 14: Generator plant datasheet.

The following values are taken from the generators data sheet (figure 14), and with some simple calculations, the values needed for the load analysis can be achieved. The conversion from BTU to kWh can be seen in equation 25 above. Additionally, some values like the enthalpy of feed water and steam enthalpy at 8 BARS were taken from another analysis done in Evertec, by Group 162, and were taken as reference for the analysis.

- Exhaust heat with temp. after heat exchanger (Q) = 33,184 BTU/min= **583.63 kW**
- Exhaust heat with 10% losses = 583.63*90%=**525.267 kW**
- Available heat = **525.267 kW or 525.267 kJ/s**
- Enthalpy of feed water at 91.84℃ = **385 kJ/kg**
- Steam Enthalpy at 8 BAR = **2768 kJ/kg**
- Net enthalpy = (2768 kJ/kg) – (385 kJ/kg) = **2383 kJ/kg**

The values obtained from the generator's data sheet, the next step calculate the steam generated to move the turbine and express it in kg/h. This is done in equation 26, and in equation 27, the conversion to kW was made.

$Steam\ generated\ (m) = \frac{\frac{kJ}{s}}{\frac{kJ}{kg}} = \frac{\frac{525.267kJ}{s}}{\frac{2383kJ}{kg}} = \frac{0.22kg}{s} = \mathbf{792\ kg/h}$: (Equation 26)

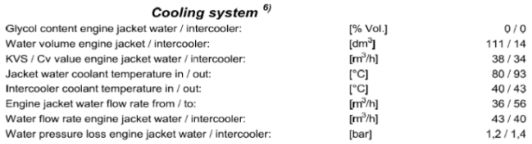
$m = \frac{steam*net\ entahlpy}{3{,}600sec} = \frac{\left(\frac{792kg}{h}\right)\left(2383\frac{kJ}{kg}\right)}{3{,}600s} = \mathbf{524\ kW}$: (Equation 27)

Below, in table 16, are the results for the steam generated. The weekly average peak wattage of Evertec was taken from the 2024 electrical bills, where an average of 9 months since the data was collected from January to September of 2024 (actual).

Average Peak Production (kW)	839.388
Available heat (kW)	525.267
Inlet water temperature (℃)	93
Generated steam (kg/h)	792
Steam (kW)	524

Table 16: Results for the generated steam.

Now the calculations of the hot water and steam generation for chillers.



Cooling system [6)]

Glycol content engine jacket water / intercooler:	[% Vol.]	0 / 0
Water volume engine jacket / intercooler:	[dm^3]	111 / 14
KVS / Cv value engine jacket water / intercooler:	[m^3/h]	38 / 34
Jacket water coolant temperature in / out:	[°C]	80 / 93
Intercooler coolant temperature in / out:	[°C]	40 / 43
Engine jacket water flow rate from / to:	[m^3/h]	36 / 56
Water flow rate engine jacket water / intercooler:	[m^3/h]	43 / 40
Water pressure loss engine jacket water / intercooler:	[bar]	1,2 / 1,4

Figure 16: Cooling system data sheet.

The following data is taken from the cooling system data sheet (figure 16). As a result of steam being in units of m^3/h, the necessary conversion was made to change the units to m^3/h. After this, an additional conversion must be made to change the units into kg/h, and this is done by multiplying the water flow rate by the density of water which is 1,000 kg/m^3. Computation gives the mass flow rate of water, and this is done below in equation 28. Finally, in equation 29, the next step is to calculate the change in temperature of water in optimal conditions, and as mentioned before, these values were taken as reference from Group 162, who already made the analysis on Evertec.

- Hot water flow rate = **38 m^3/h**
- Specific Heat of Water = **4.2 kJ/kg**

$Steam\ (m) = \left(38\frac{m^3}{h}\right)\left(\frac{1{,}000kg}{m^3}\right) = \mathbf{38{,}000kg/h}$ (Equation 28)

$Delta\ T = Inlet\ Temp - Outlet\ Temp = 93℃ - 80℃ = \mathbf{13}℃$ (Equation 29)

The formula that expresses the quantitative relationship between heat transfer and temperature change includes three key factors: Q = mcΔT, where Q represents the heat transfer, m is the specific energy needed to increase 1kg of the substance by 1℃, c is the specific heat of water, and ΔT is the change in temperature. This calculation is done in equation 30 and gives the hot water generated in kJ/s, which is kWh too. Lastly, calculating the hot water consumption by using a specific heat for water at 4,186 J/kg ℃, and the process is shown in equation 31.

$Q = \frac{mc*Delta\ T}{3{,}600s} = \frac{\left(\frac{38{,}000kJ}{h}\right)\left(\frac{4.2kJ}{kg}\right)(13℃)}{3{,}600s} = \mathbf{576.33\ kJ/s}$ (Equation 30)

$$Q = \frac{576.33kJ}{s} = \mathbf{576.33kWh}$$

$m = \frac{Q}{c*Delta\ T} = \frac{576.33kW}{4{,}186\frac{J}{kg}℃*13℃} = \mathbf{10.59\ kg/s}$ (Equation 31)

A summary of all data collected and calculated for the load analysis is on table 17 below.

Power (kW)	1,200
Energy Production (scf/h)	8,916
Energy Production (kWh)	2,691.147
Average Peak Production (kW)	839.388
Available heat (kJ/s)	524.7
Inlet Max temperature (°C)	93
Generated Steam (kg/h)	792
Steam (kW)	524
Hot Water Flow Rate (kg/h)	38,000
Change in temperature (°C)	13
Specific Heat of Water (kJ/kg)	4.2
Hot Water Generated (kWh)	576.33
Hot Water Consumption (kg/s)	10.59

Table 17: Summary of all calculations.

The data collected highlights the system's high efficiency in utilizing energy to generate heat and steam. With a substantial power output of 1,200 kW, the energy produced is approximately 2,691.15 kWh, reflecting effective energy conversion from the supplied fuel. A consistent weekly average power output of approximately 839.39 kW further demonstrates stable and reliable performance over time. The system effectively harnesses available heat, producing a heat output of 524.7 kJ/s, which contributes to a steam generation rate of 792 kg/h and a corresponding steam power output of 524 kW. Additionally, the hot water flow rate of 38,000 kg/h with an inlet temperature of 93°C and a temperature differential of 13°C highlights the system's capacity to deliver hot water at a significant rate. By leveraging the specific heat of water (4.2 kJ/kg·°C) and a hot water consumption rate of 10.59 kg/s, the system demonstrates exceptional efficiency in thermal energy delivery. The energy produced is indicative of the system's overall performance in converting fuel into both electrical and thermal outputs. Overall, the data confirms that the system performs with a high degree of efficiency in energy production and heat utilization, making it a robust solution for cogeneration applications.

Cogen. Performance Analysis

In the power plant industry, combined heat and power technology stand out for its high thermodynamic efficiency. Cogeneration plants, designed to challenge traditional methods, focus on maximizing both power output and overall efficiency of the systems where it is installed. Unlike conventional power plants, cogeneration plants generate electricity and capture useful thermal energy from a single fuel source simultaneously. A cogeneration plant's main goal is to enhance efficiency by producing electricity and effectively utilize the heat waste generated by the fuel source. In a combined heat and power (CHP) system, the focus is on delivering multiple benefits, including electricity generation, and supplying useful heat tailored to meet the needs of end users in the way of refrigeration or heating. This client-focused approach offers a more efficient, sustainable, and adaptable power generation solution; by capturing waste heat, cogeneration systems can reach an efficiency of 60 to 80 percent, significantly higher than traditional methods. This improvement is especially noticeable when using natural gas, as it requires less fuel and leads to lower costs compared to buying electricity separately.

Evaluating the theoretical efficiency for the cogeneration plant when it is running at 100 %

- Electrical Efficiency – NELEC is described as the “Net Electrical Efficiency,” and it is the ratio between the output electrical useful energy (EC) and the input fuel power (FC). In table 15, the values for peak energy and energy consumed are present.

Data	Value
Peak Energy (Output)	1,200 kW
Energy Produced (Input)	2,691.147 kWh

Table 18: Data Values from Load Analysis for Electrical Efficiency

$$\text{Net Electrical Efficiency} = \frac{\text{Energy Consumed}}{\text{Energy Produced}} * 100\% : \text{(Equation 32)}$$

$$\text{Net Electrical Efficiency} = \frac{1{,}200\text{kW}}{2691.147\text{kWh}} * 100\% = \mathbf{44.59}\%$$

The NELEC system is a measure of how effectively it converts fuel energy into useful electrical energy. Used the typical efficiency formula, the system's output figure by the input of said system. This case, the output is the electrical energy consumed by the load and the input is the fuel energy injected into the plant. An electrical efficiency of 44.59% of what the generator produces. This means that the system can convert approximately 44.59% of the total energy injected into useful electrical energy. A higher NELEC efficiency rating indicates a more efficient system, as it can produce more electricity with the same amount of fuel injected into the system.

- Mechanical Efficiency - Mechanical efficiency in a cogeneration plant refers to the effectiveness with which the plant converts the input energy from fuel into useful mechanical work, typically to drive turbines or generators. In cogeneration, the goal is to maximize this efficiency by utilizing both the mechanical power for electricity generation and the waste heat for heating or other processes. This dual-use approach improves the overall energy efficiency of the cogeneration plant compared to traditional power plants. Mechanical efficiency in a cogeneration system is influenced by factors like the quality of fuel, turbine performance, and the integration of heat recovery systems. Finally, by optimizing mechanical efficiency, cogeneration plants achieve higher energy output with reduced fuel consumption, resulting in economic savings and a lower environmental impact. This calculation is done in equation 25.

Data	**Value**
Steam Generated (Output)	524 kWh
Energy Produced (Input)	2,691.147 kWh

Table 19: Data Values from Load Analysis for Mechanical Efficiency

$$\text{Mechanical efficiency} = \frac{\text{Steam Generated}}{\text{Energy Produced}} * 100\% \quad :$$
(Equation 33)

$$\text{Mechanical Efficiency} = \frac{524\text{kWh}}{2{,}691.147\text{ kWh}} * 100\%$$
$$= \mathbf{19.47}\%$$

As can be seen in equation 3, the mechanical efficiency for the system is approximately 19.47%. This means that the cogeneration plant utilizes 19.47% of the fuel injected as steam, effectively. This is used to drive the steam turbine and move the generator.

- Hot Water Efficiency - Hot water efficiency in a cogeneration plant refers to the effective utilization of waste heat to produce hot water for heating or industrial processes, maximizing overall system efficiency. In a cogeneration setup, the plant generates electricity, and the excess heat that would otherwise be lost is captured and used to heat water. This hot water can then be distributed for building heating, domestic hot water, or other industrial uses. By effectively using this thermal energy, cogeneration plants reduce the need for additional energy sources to heat water, increasing the plant's overall energy efficiency. This not only lowers fuel consumption, but reduces operating costs and the environmental impact, making the plant more sustainable and economical in the long term. Lastly, considering a typical 3% loss of water in the heat exchanger, the true values of the hot water efficiency are calculated. The computation for the hot water efficiency, considering losses is done below, in equation 34.

Data	**Value**
Hot Water Generated (Output)	576.33 kWh
Energy Produced (Input)	2,691.147 kWh

Table 20: Data Values from Load Analysis for Hot Water Efficiency

$$\text{Hot Water Efficiency} = \frac{\text{Hot Water Generated}}{\text{Energy Produced}} * 100\%$$
(Equation 34)

$$\text{Hot Water Efficiency} = \frac{576.33\text{ kWh}}{2{,}691.147\text{ kWh}} * 100\%$$
$$= 21.41\ \%$$

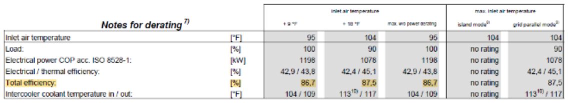
$$\text{Hot Water Efficiency} = 21.41\% - 3\%$$
$$= \mathbf{18.41}\%$$

The hot water efficiency of a system measures how effectively it converts fuel energy into hot water. The system can convert approximately 18.41% of the input fuel energy into hot water. Higher hot water efficiency indicates a more efficient system in terms of producing hot water for industrial processes or facilities. Finally, the overall efficiency of the cogeneration plant system is the sum of all efficiencies, which is done below, in equation 35.

$$\text{Overall Efficiency} = \text{Electrical} + \text{Mechanical} + \text{Hot Water Efficiencies}$$
: (Equation 35)

$$\text{Overall Efficiency}$$
$$= 44.59\% + 19.47\% + 18.41\%$$
$$= \mathbf{82.47}\%$$

In summary, the efficiencies provided for the performance of the cogeneration plant details its ability to convert input fuel into effective energy usage. Based on the calculations done, the maximum overall efficiency of the system is 82.47%, meaning that the system is effectively utilizing most of the available energy to produce power, and can be compared to the efficiency of the manufacturer's data sheet. Additionally, these values are close to each other, meaning that there is proof that the value calculated is correct, and this can be observed below, in figure 17. Finally, table 21 highlights every efficiency calculated.



Notes for derating [7]		inlet air temperature			max. inlet air temperature	
		[illegible]	[illegible]	max. w/o power derating	island mode[8]	grid parallel mode[8]
Inlet air temperature	[°F]	95	104	95	104	104
Load:	[%]	100	90	100	no rating	90
Electrical power COP acc. ISO 8528-1:	[kW]	1198	1078	1198	no rating	1078
Electrical / thermal efficiency:	[%]	42,9 / 43,8	42,4 / 45,1	42,9 / 43,8	no rating	42,4 / 45,1
Total efficiency:	[%]	86,7	87,5	86,7	no rating	87,5
Intercooler coolant temperature in / out:	[°F]	104 / 109	113[10] / 117	104 / 109	no rating	113[10] / 117

Figure 17: Generator Data Sheet.

Electrical Efficiency (%)	Mechanical Efficiency (%)	Hot Water Efficiency (%)	Overall Efficiency (%)
44.59	19.47	18.41 %	82.47

Table 21: Efficiency Results.

Economic Billing Assessment

Starting the Cost analysis and economic consumption of the pre-cogeneration, a careful observation at table 22 below has to made, because it will be the standard for this analysis. This table shows the data taken from the electric bills. In addition, it provides a detailed comparison of the energy consumption and cost for 2019 and 2020, before the installation of the cogeneration system at the Cupey Center Buildings. In context, the calculated values were the average ones, which were made by taking the data given from Evertec and dividing it each year by all the months (12), for energy consumption and cost.

Year	**2019**	**2020**
Total Energy (kWh)	11,515,898	11,079,377
Average Energy (kWh)	959,658	923,281
Total Cost ($)	2,329,939	194,161
Average Cost ($)	2,116,091	176,340

Table 22: Energy Consumption and Cost Comparison Before COGEN Installation

In 2019, the buildings recorded an average monthly energy consumption of 959,658.17 kWh and an average monthly cost of $194,161.62. The high energy usage and associated costs highlight the building's significant operational demands during this period. In 2020, the building's average monthly energy consumption decreased to 923,281.48 kWh, and the average monthly cost dropped to $176,340.97. While there was a reduction in both energy usage and costs, the building continued to face substantial energy expenditures, indicating that efficiency measures had yet to be implemented.

In summary, 2020 reflects improved energy management compared to 2019, with stable energy consumption and reduced costs. This serves as a baseline for comparing the financial and operational impacts after the installation of the cogeneration system.

Now, the post-cogeneration energy consumption and cost evaluation, the standard for this analysis is in table 23, and 24, which has calculated average values and other data given by Evertec. Therefore, this table presents energy consumption from the electric utility and cost data for 2021 to 2024, following the installation of the COGEN system at the Cupey Center Buildings. The significant reduction in energy consumption from the electric utility is directly attributable to the COGEN system, which allowed the building to meet much of its energy needs internally.

Year	**Total Energy (kWh)**	**Average Energy (kWh)**
2021	3,554,410.00	296,200.83
2022	2,789,160.00	232,430.00
2023	1,081,080.00	90,090.00
2024	856,680.00	95,186.67

Table 23: Energy Consumption Analysis After COGEN Installation

Total Cost ($)	**Average Cost ($)**
797,229.16	66,435.76
925,275.77	77,106.31
407,919.12	33,993.26
309,732.38	34,414.71

Table 24: Energy Cost Analysis After COGEN Installation

In 2021, following the COGEN system's implementation, there was a sharp decrease in average monthly energy consumption from the electric utility to 296,200.83 kWh. Along with this reduction, the average monthly cost fell to $66,435.76. This decrease in reliance on external electricity is due to the COGEN system generating a substantial portion of the buildings' power needs internally. The significant drop in both utility-supplied energy consumption and costs highlights the immediate impact of the COGEN system's integration.

In 2022, total energy consumption from the electric utility decreased further to 2,789,160 kWh, with an average monthly usage of 232,430 kWh. However, the total cost increased to $925,275.77, with an average monthly cost of $77,106.31. This rise in costs, despite reduced energy consumption, is likely to reflect the transition to full operational use of the COGEN system, as well as possible changes in energy rates. The building's reliance on external power continued to decrease, but fluctuations in energy pricing led to an increase in expenses.

Subsequently, in 2023 the downward trend in utility energy consumption continued, reaching 1,081,080 kWh, with an average monthly usage of 90,090 kWh. The total cost for energy dropped significantly to $407,919.12, resulting in an average monthly cost of $33,993.26. This reduction in both energy consumption and costs reflects improved efficiency of the COGEN system, which enabled the building to further reduce its dependence on external electricity. The system's increasing efficiency helped lower costs, possibly aided by better operational practices and more efficient energy management.

Now in 2024, the buildings' average monthly energy consumption from the electric utility rose a little at 95,186.67.14 kWh, with an average monthly cost of $34,414.71, keeping in mind this average may lower as the year passes. This continued reduction in energy consumption and costs indicates the ongoing optimization of the COGEN system, allowing the building to minimize its use of external power. The data shows the system's long-term benefits in reducing utility energy consumption.

The data from 2021 to 2024 reflects the building's transition to a more self-sustained energy model, with the COGEN system dramatically reducing the need for external electricity. While energy consumption from the electric utility has steadily decreased, costs have fluctuated, likely influenced by changes in energy rates and external market factors. Overall, the COGEN system has led to a more cost-effective and efficient energy consumption model, as the buildings' reliance on the electric utility diminished significantly.

The implementation of the cogeneration (COGEN) system at the Cupey Center Buildings, along with the integration of chillers within the combined heat and power (CHP) system, resulted in a notable increase in water consumption and related costs demonstrated in table 25.

Metric	**Before COGEN**	**After COGEN**	**Change**
Ave. Monthly Volume	2,218.58 (m^3)	2,738.73 (m^3)	520.15 (m^3)
Ave. Yearly Volume	26,623.00 (m^3)	32,864.80 (m^3)	6,241.80 (m^3)
Ave. Monthly Cost	$15,067.10	$19,715.86	$4,648.76
Ave. Yearly Cost	$180,805.21	$236,590.28	$55,785.08

Table 25: Water Consumption and Cost Breakdown for 2020 and 2021

Before the COGEN system, the building consumed an average of 2,218.58 m³ of water per month. However, after the installation of the system and the use of chillers, the consumption increased to 2,738.73 m³ per month, representing an increase of 520.15 m³. Annually, this increase in water usage rose from 26,623.00 m³ to 32,864.80 m³, with an additional consumption of 6,241.80 m³ each year.

This rise in water consumption was accompanied by an increase in costs. Before the COGEN system was implemented, the average monthly water cost was $15,067.10. After the system became operational, the average monthly cost increased to $19,715.86, reflecting an additional cost of $4,648.76 per month. On a yearly basis, the water costs rose from $180,805.21 to $236,590.28, a total increase of $55,785.08.

The increase in water consumption and costs can be directly attributed to the operational demands of the chillers, which require additional water as part of the cooling process. While the COGEN system effectively reduced the building's reliance on external electricity and helped lower electricity costs, the use of chillers has introduced new operational expenses. This increased demand for water is expected in CHP systems that use absorption chillers to enhance efficiency, but it reflects the trade-offs in resource use associated with such systems.

Subsequently, the COGEN system has successfully reduced electricity consumption and operational costs, the integration of chillers within the CHP system has led to a significant rise in water consumption and costs. This increase highlights the complex balance between improved energy generation efficiency and the additional resources required for system cooling. As the system continues to optimize energy use, the ongoing management of water resources will play a key role in maintaining overall operational efficiency.

Building upon previous research, Table 26 shows the calculated and given data. This table compares the energy consumption and costs, before and after the installation of the COGEN system. The installation of the COGEN system at the Cupey Center Buildings resulted in a significant reduction in the energy consumption sourced from the electric utility. From 2019 to 2020, the building relied entirely on external power provided by the utility company. During this period, the average monthly energy consumption from the electric utility was 941,469.83 kWh, with an average monthly cost of $185,251.29. These figures highlight the substantial energy demand of the building, and the associated excessive costs reflect the reliance on external energy supply, which can be subject to fluctuating market prices.

Metric	**Before COGEN**	**After COGEN**	**Savings (%)**
Average Monthly Energy (kWh)	902,022.00	184,029.56	79.60
Average Yearly Energy (kWh)	10,824,264.00	2,208,354.67	79.60
Average Monthly Cost ($)	175,685.59	54,225.70	69.13
Average Yearly Cost ($)	2,108,227.13	650,708.38	69.13

Table 26: Comparative Analysis of Pre and Post COGEN Energy and Costs

Furthermore, with the installation of the COGEN system, the energy profile of the building shifted significantly. From 2021 to 2024, the average monthly energy consumption from the electric utility decreased dramatically to 180,582.60 kWh, reflecting a reduction of 760,887.23 kWh compared to the pre-COGEN period. This decrease represents an 80.82% reduction in the building’s dependency on the external power grid. Along with this reduction in energy consumption, there was a substantial decrease in costs, with the average monthly cost falling to $53,368.21, saving the building $131,883.08 per month on utility bills, which equates to a 71.19% reduction in costs.

The dramatic reduction in energy consumption from the electric utility after the COGEN system was implemented underscores the system's ability to meet a substantial portion of the building’s energy needs internally. The system allowed the building to reduce its reliance on external power, thereby lowering operational costs. The sharp decline in average monthly utility costs signifies the economic efficiency of the COGEN system, contributing to considerable long-term savings.

Comparing energy consumption and costs before and after the installation of the COGEN system, the system has had a transformative impact on the building’s energy management. The substantial decrease in utility-sourced energy, along with the significant reduction in associated costs, reflects the effectiveness of the COGEN system in optimizing the building’s energy efficiency. This transition to internal energy generation has not only reduced the buildings’ dependency on the electric utility but demonstrated the financial viability of cogeneration technology for long-term operational savings.

Microgrid System Simulations

Helioscope is a photovoltaic system simulator created by Folsom Labs in San Francisco, available by subscription, specifically intended for creating PV system pictures at the client's designated site. Helioscope's advanced modelling capabilities evaluate the system's performance under various conditions, ensuring maximum efficiency. The cloud-based platform utilizes a systematic process that begins with the input of project details, such as location, roof characteristics, and specific system requirements, enabling the assembly of the solar array.

Data including the system's location, chosen solar panels, and inverters will be entered. Utilizing this information, the specified area will be filled with solar panels until the necessary number of modules and the appropriate inverter capacity are attained. This procedure involves carefully positioning solar panels until the determined amount corresponds with the total power consumption needs. Subsequently, Helioscope will provide the site and relevant information of the solar system, delivering a comprehensive visual report along with a detailed cost-benefit analysis.

Additionally, to start a project in Helioscope, users must adhere to the following procedures. The user must first visit Helioscope.com and choose "New Project." The project's name, address, and site classification (commercial, ground-mounted, or residential) must thereafter be recorded. Subsequently, selecting "New Design" followed by "Create New Design" will direct people to the specified URL. Consequently, figure 18 shows that the chosen program was Evertec, located in San Juan, Puerto Rico.

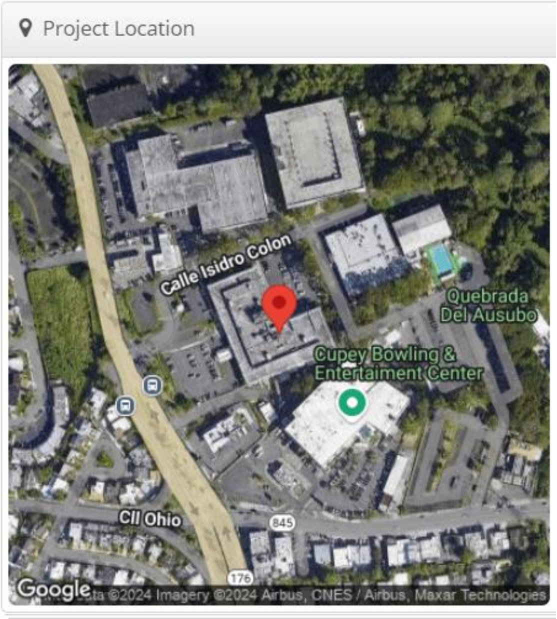


Figure 18: Selected Project Location Evertec

The selected location, as seen in figure 19, is for the carport were identified. This design consists of eight primary carport photovoltaic array sections positioned inside the multi-level parking facility of Evertec, in addition to one smaller part situated in the ground-level parking area.

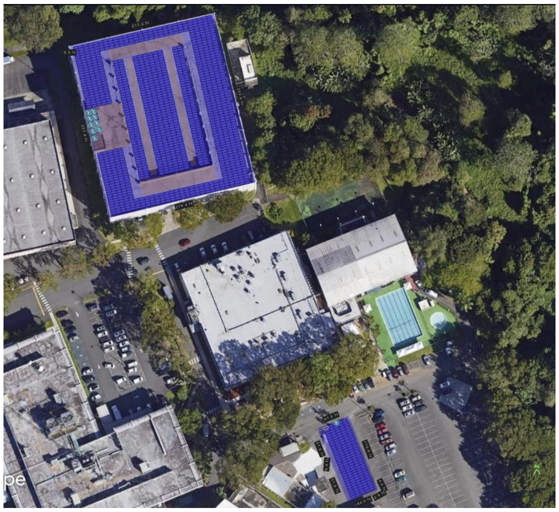
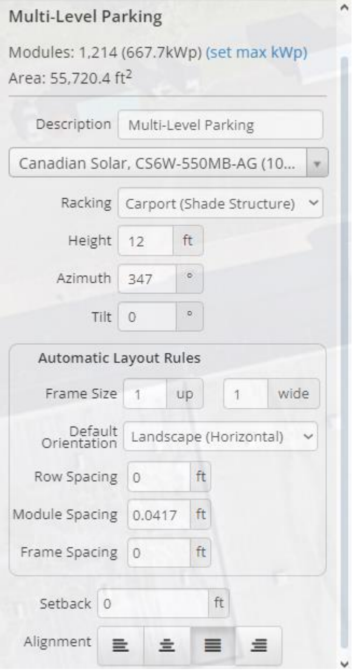


Figure 19: Photovoltaic Module Areas Evertec

Upon selecting the PV module locations, the necessary input data pertaining to the system was entered, as seen in figure 20. For this photovoltaic system design, the chosen module will be identical to that of the photovoltaic design.



Multi-Level Parking

Modules: 1,214 (667.7kWp) (set max kWp)
Area: 55,720.4 ft^2

Description: Multi-Level Parking
Canadian Solar, CS6W-550MB-AG (10...
Racking: Carport (Shade Structure)
Height: 12 ft
Azimuth: 347 °
Tilt: 0 °

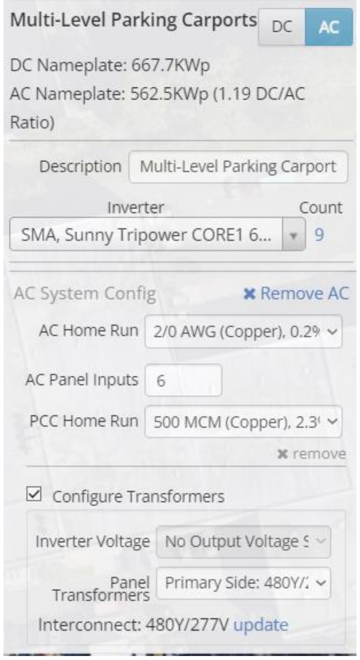
Automatic Layout Rules

Frame Size: 1 up 1 wide
Default Orientation: Landscape (Horizontal)
Row Spacing: 0 ft
Module Spacing: 0.0417 ft
Frame Spacing: 0 ft

Setback: 0 ft
Alignment

Figure 20: Input Data for Multi-Level Parking

Moreover, figure 21 below illustrates the input data for the AC wiring zone of Parque Central. The PV design for Parque Central will use the same inverter as the CDT design, namely the SMA Sunny Tripower CORE1 62-US.



Multi-Level Parking Carports DC AC

DC Nameplate: 667.7KWp

AC Nameplate: 562.5KWp (1.19 DC/AC Ratio)

Description: Multi-Level Parking Carport

Inverter	Count
SMA, Sunny Tripower CORE1 6...	9

AC System Config ✖ Remove AC

AC Home Run: 2/0 AWG (Copper), 0.2%

AC Panel Inputs: 6

PCC Home Run: 500 MCM (Copper), 2.3

✖ remove

☑ Configure Transformers

Inverter Voltage: No Output Voltage S

Panel Transformers: Primary Side: 480Y/2

Interconnect: 480Y/277V update

Figure 21: Wiring Zone AC Input Data for Multi-Level Parking

The configuration of the modules for Evertec's design will be situated on the natatorium's parking lot. As seen in figure 18, the carport installation consists of eight primary portions inside the multi-level parking and one supplementary section located in the ground-level parking. Eight tiers of the multi-level parking include 1,214 modules, whilst the ground-level parking area will consist of 150 modules. A total of 1364 modules will be present. Furthermore, as seen in figure 22, and table 27, the Helioscope presents a production graph indicating output exceeding 80 KWh each month throughout the production period. Moreover, producing over 110 kWh in a minimum of three months annually.

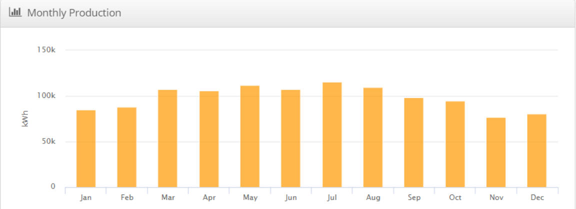
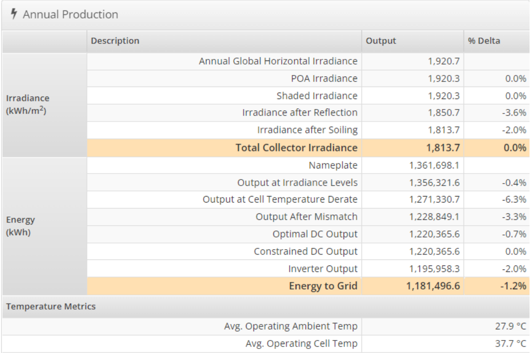


Figure 22: Evertec's Helioscope Monthly Production Simulation

The total collector irradiance accessible to the modules in the Evertec array was estimated to be 1,813.7 kWh/m². The yearly energy output to the grid was determined to be 1,181,496.6 kWh, as seen in figure 23. Table 27 presents a comprehensive analysis of the monthly AC solar output at Evertec.



Annual Production

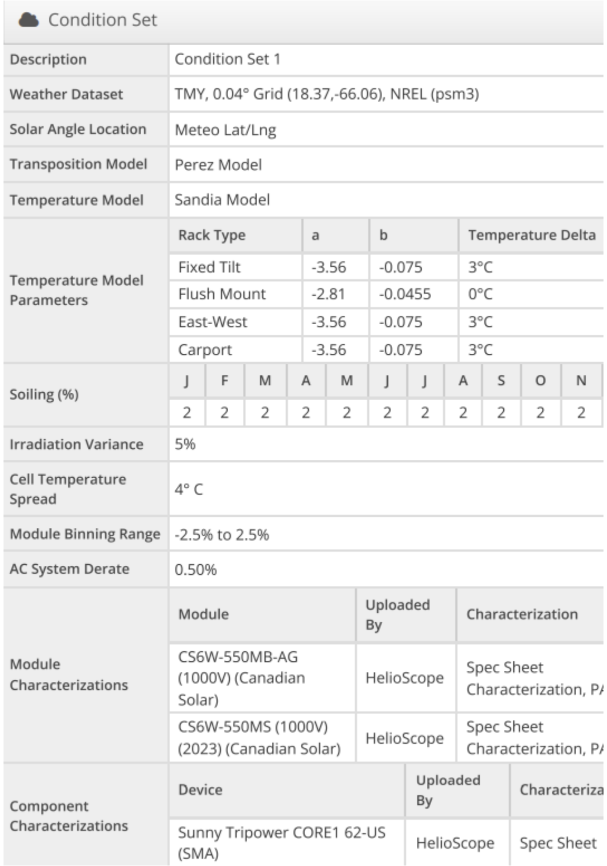
	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,920.7	
	POA Irradiance	1,920.3	0.0%
	Shaded Irradiance	1,920.3	0.0%
	Irradiance after Reflection	1,850.7	-3.6%
	Irradiance after Soiling	1,813.7	-2.0%
	Total Collector Irradiance	**1,813.7**	**0.0%**
Energy (kWh)	Nameplate	1,361,698.1	
	Output at Irradiance Levels	1,356,321.6	-0.4%
	Output at Cell Temperature Derate	1,271,330.7	-6.3%
	Output After Mismatch	1,228,849.1	-3.3%
	Optimal DC Output	1,220,365.6	-0.7%
	Constrained DC Output	1,220,365.6	0.0%
	Inverter Output	1,195,958.3	-2.0%
	Energy to Grid	**1,181,496.6**	**-1.2%**
Temperature Metrics			
	Avg. Operating Ambient Temp		27.9 °C
	Avg. Operating Cell Temp		37.7 °C

Figure 23: Evertec's Helioscope Annual Production Simulation

Month	Energy to Grid (KWh)
January	84,737.6
February	88,028.0
March	107,301.0
April	106,253.5
May	111,839.1
June	107,277.1
July	115,399.8
August	110,002.1
September	98,493.7
October	94,679.6
November	76,546.4
December	80,937.2

Table 27: Evertec's Monthly AC Solar Production

The condition set report for Evertec was furnished, as shown in figure 24. This report delineates all environmental factors that could potentially impact the system's performance.



Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 0.04° Grid (18.37,-66.06), NREL (psm3)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C
East-West	-3.56	-0.075	3°C
Carport	-3.56	-0.075	3°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N
2	2	2	2	2	2	2	2	2	2	2

Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Module Characterizations

Module	Uploaded By	Characterization
CS6W-550MB-AG (1000V) (Canadian Solar)	HelioScope	Spec Sheet Characterization, P
CS6W-550MS (1000V) (2023) (Canadian Solar)	HelioScope	Spec Sheet Characterization, P

Component Characterizations

Device	Uploaded By	Characteriza
Sunny Tripower CORE1 62-US (SMA)	HelioScope	Spec Sheet

Figure 24: Evertec's Condition Set

The generating loss, in figure 25, depicts the generating losses where the predominant energy loss is due to temperature, being 6.3% of the total generation. Mismatch losses are 3.3%, reflection loss is 3.6%, and all other losses are at or below 2%, as seen in the graph.

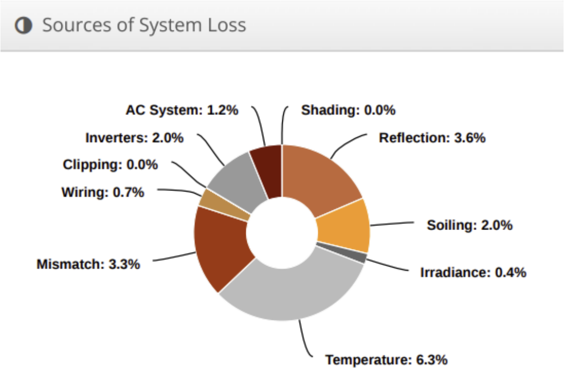


Figure 25: Evertec's System Loss Simulation

Finally, Helioscope assesses the impact of surrounding shadows on the modules and delivers irradiation percentages accordingly. The design indicates that the irradiation level is minimal, as seen in figure 15.8, owing to the height of the multi-level parking and the absence of vegetation in the ground-level parking. Furthermore, Helioscope provides the system metrics for Evertec's comprehensive project, which will be shown in figure 26.

The next step is to incorporate the percentage of losses generated by the electric system, which encompasses wiring, shading, connections, light-induced degradation, nameplate rating, availability, soiling, and incompatibilities. The Helioscope simulation was employed to determine these percentages of losses, as illustrated in table 28. The electric system's calculated loss is in percentage. Consequently, the solar array's total output power can be calculated by employing equation 36 and the power output considering temperature effects is displayed in table 28.

%Ploss
19.5%
Power output considering temperature effect
735,006 W

Table 28: %Ploss of the Electric System and Power Output Considering Temperature Effect Input

$$\mathrm{P} = \mathrm{P}_{\mathrm{arr-t}} - (\mathrm{P}_{\mathrm{arr-t}} * \%\mathrm{P}_{\mathrm{Loss}}): \text{(Equation 36)}$$

Where:

P = Total output power of the solar array

P_{arr-t} = Power output considering temperature effect

$\%P_{Loss}$ = Percentage of power loss

$$\mathrm{P} = 735{,}006\ \mathrm{W} - (735{,}006\ \mathrm{W} * 0.195)$$

$$\mathrm{P} = 591{,}679.83\ \mathrm{W}$$

Therefore, the power loss calculation of the solar array yielded a resultant of 595,513.6 W. The following phase in the calculation of solar array energy production is to ascertain the daily power output that the PV modules will generate, utilizing the resultant total power as described in equation 36.

The average number of peak sun hours in Puerto Rico is 5.5 per day. The solar array will generate the following power in a day, as indicated by equation 37:

$$E_{daily} = 591{,}679.83\ W * \frac{1kw}{1000w} * \frac{5.5hr}{1day}$$

$$E_{daily} = 3{,}254.24\ \frac{KWh}{day}\text{: (Equation 37)}$$

Equations 38 and 39 can be employed to determine the total AC power generation of the solar array over the course of the month and the year.

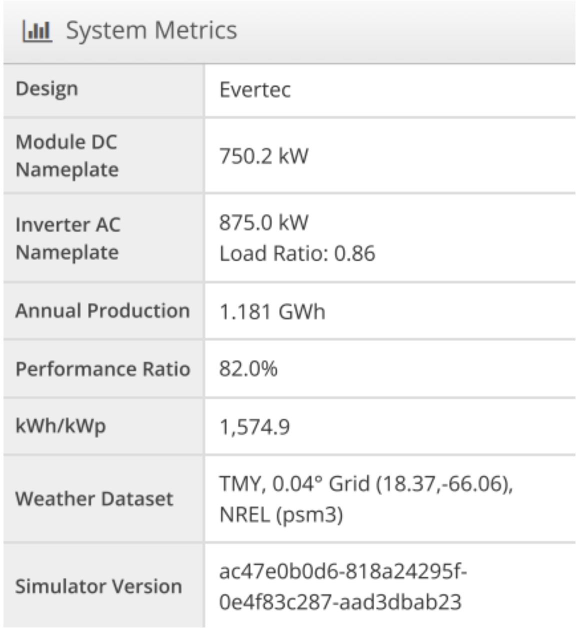
$$E_{month} = 3{,}254.24\ \frac{KWh}{day} * \frac{30\ days}{1\ month}$$

$$E_{month} = 97{,}627.17\ \frac{KWh}{month}\text{: (Equation 38)}$$

$$E_{year} = 97{,}627.17\ \frac{KWh}{month} * \frac{12\ months}{1\ year}$$

$$E_{year} = 1{,}171{,}526.1\ \frac{KWh}{year}\text{: (Equation 39)}$$

Consequently, the solar array's annual AC energy production is estimated to be 1,171,526.1 kWh



System Metrics

Design	Evertec
Module DC Nameplate	750.2 kW
Inverter AC Nameplate	875.0 kW Load Ratio: 0.86
Annual Production	1.181 GWh
Performance Ratio	82.0%
kWh/kWp	1,574.9
Weather Dataset	TMY, 0.04° Grid (18.37,-66.06), NREL (psm3)
Simulator Version	ac47e0b0d6-818a24295f-0e4f83c287-aad3dbab23

Figure 26: Evertec's System Metrics

Analysis of results for Evertec

Upon acquiring the theoretical outcomes for the photovoltaic system regarding system size and yearly output rates, these figures may be similar to those produced by the Helioscope software. The engineering report in Helioscope provides accurate numbers derived from the provided data. Analysis of the findings reveals a minimal percentage error, as seen in Equation 40 and Table 29.

$$\text{Percentage Error \%} = \frac{|\text{Simulation}-\text{Theorical}|}{\text{Theorical}}\, x100\%\text{: (Equation 40)}$$

Evertec	**Theorical Values**	**Helioscope Values**	**%Error**
System Sizing	750,000 W	750,200 W	0.026%
Yearly Energy Production	1,171,526.1 KWh	1,181,496.6 KWh	0.85%

Table 29: Summary of the Comparison of the Theoretical results and Helioscope Results

The Homer simulations provide a comprehensive evaluation of monthly energy generation, energy use, operational expenses, and specific energy output for each contributing system. These systems consist of Luma Energy, cogeneration, and a photovoltaic system. First is to analyze Evertec's electricity use with Luma as the only supplier. Subsequently, model the utility in Evertec alongside CHP. A micro-grid system will be developed to integrate all diverse energy sources. The figures below illustrate the energy distribution from several sources to Evertec, the energy output of these sources, and the potential cost implications associated with each energy source. Three scenarios were analyzed: using just the local utility, employing both the local utility and CHP as energy sources, and finally, integrating CHP, local utility, and a PV system (as per Helioscope findings). The Homer simulation requires the inclusion of a boiler in the system, although under ideal specs, since Evertec lacks a boiler in its electrical system. This component exists only for simulation reasons and will not influence the simulation's result. The electric load and thermal load in the system will remain constant throughout the runs. The conclusive simulation included all systems, linking the photovoltaic specs and system inputs to the Homer simulations from Helioscope. This is the essential element to note.

Initially, in the simulation of Evertec's electric system prior to the construction of the CHP units, Evertec only relies on electricity from the utility. Utilizing the electric consumption data from 2019, together with the price per kilowatt-hour and the sellback rate for the energy produced by Evertec that is not used internally. Evertec does not generate its own energy; hence, the sellback price is irrelevant. All required data for executing this simulation is detailed in table 30 and the data is located in their separate tabs as seen in figures 26 and 27.

Energy Consumed in 2019 (KWh)	Daily Energy Consumed in 2019 (KWh)	Average Grid Power Price in 2019 ($/KWh)
11,515,898	31,550.4	0.205

Table 30: Input Data for Utility Only Homer Simulation

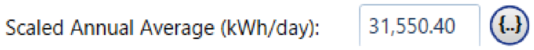
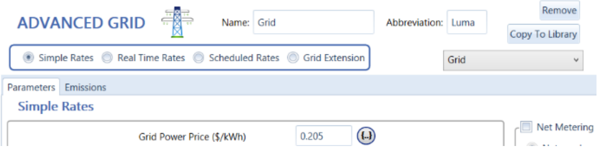

Scaled Annual Average (kWh/day): 31,550.40

Figure 26: Homer Electric Load Input



Name: Grid

Abbreviation: Luma

● Simple Rates ○ Real Time Rates ○ Scheduled Rates ○ Grid Extension

Grid

Simple Rates

Grid Power Price ($/kWh) 0.205

☐ Net Metering

Figure 27: Homer Grid Power Price Input for 2019

Furthermore, figure 28 presents a monoline design illustrating the system's functionality and the interconnection of all components in 2019.

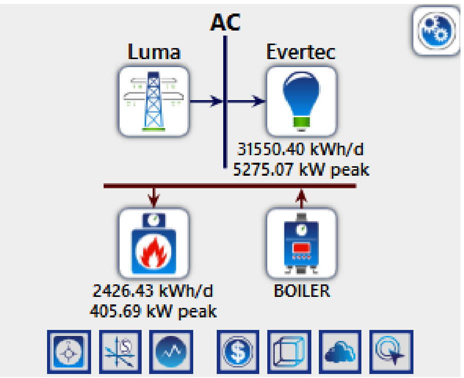
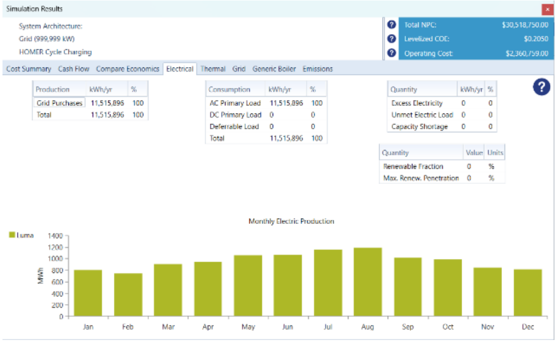


Figure 28: Homer LUMA Breakdown of Energy Transmission.

Upon running all parameters required for the first simulation, figure 29 presents an electric load profile for Evertec's consumption in 2019, while figure 30 provides a comprehensive cost summary outlining the operational and maintenance expenses of the systems.


Simulation Results

System Architecture:
Grid (999,999 kW)
HOMER Cycle Charging

Total NPC: $30,518,750.00
Levelized COE: $0.2050
Operating Cost: $2,360,759.00

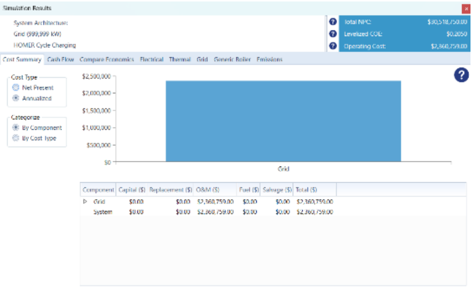
Production	kWh/yr	%
Grid Purchases	11,515,896	100
Total	11,515,896	100

Consumption	kWh/yr	%
AC Primary Load	11,515,896	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	11,515,896	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	0	%

Figure 29: Homer Simulation Results only LUMA (Before Cogeneration Plant).


Simulation Results

System Architecture:
Grid (999,999 kW)
HOMER Cycle Charging

Total NPC: $30,518,750.00
Levelized COE: $0.2050
Operating Cost: $2,360,759.00

Cost Type
○ Net Present
● Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Grid	$0.00	$0.00	$2,360,759.00	$0.00	$0.00	$2,360,759.00
System	$0.00	$0.00	$2,360,759.00	$0.00	$0.00	$2,360,759.00

Figure 30: LUMA Only Costs Results.

Upon simulating the system for the year 2019, the findings align closely with the actual outcomes for Evertec throughout that year. Homer delivers precise and comprehensive figures drawn from the data provided. However, it’s important to note that Homer does not account for fluctuations in grid power prices, maintenance, and shutdowns of the CHP system resulting from various component failures and mismatches. This component influences the error rate between the real numbers and the simulation results. The analysis indicates a minimal error percentage, as seen in equation 41 and table 31.

$$\text{Percentage Error } \% = \frac{|\text{Simulation} - \text{Real}|}{\text{Real}} \text{x} 100\%:$$

(Equation 41)

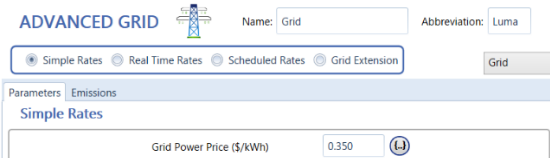
Evertec	Real Values	Homer Values	%Error
Yearly Energy Consumption	11,515,898 KWh	11,515,896 KWh	0.000017%
Grid Cost	$2,235,390.47	$2,360,759	5.60%

Table 31: Summary of the Comparison of the Theoretical results and Homer Results in 2019

Following the simulation of the system with just the utility, the subsequent simulation occurs post-installation of the CHP system. This system offers a comprehensive overview of Evertec's energy use. Evertec's energy production and the sellback price, together with energy demand, are shown in Table 32.

Energy Consumed in 2019 (KWh)	Daily Energy Consumed in 2019 (KWh)	Average Grid Power Price in 2022 ($/KWh)
11,515,898	31,550.4	0.35

Table 32: Input Data for Utility and CHP System Homer Simulation



Grid Power Price ($/kWh): 0.350

Figure 31: Homer Grid Power Price Input for 2022

Clearly, figure 32 delineates all necessary parameters for Homer to replicate the CHP system. In the Generator tab, the capital represents the total cost per kilowatt of the CHP system, totaling $11,000,000. All parameters are specified in table 33. Furthermore, in figure 32, one of the factors required by the Homer simulation software is the fuel price for natural gas in $/m3.

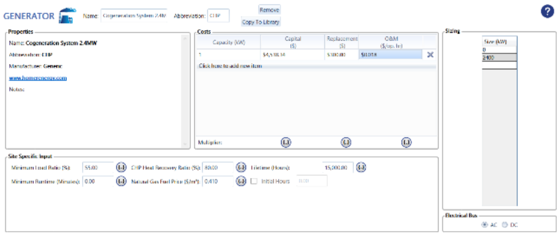
To obtain this data, the $11/mmbtu must be converted to the specified units of $/m³, as previously indicated. This conversion is performed in equation 42 below. Finalizing this conversion requires using the estimate of 1 mmbtu = 26.81 m³.

$$\frac{\$}{m^3} = \frac{\frac{\$11}{1mmbtu}}{\frac{1mmbtu}{26.81m^3}} = \boldsymbol{\$0.41/m^3} \quad \text{(Equation 42)}$$

The value obtained from equation 42 is going to be used in the natural gas fuel price option on figure 32.

Parameters	Values
Capital ($)	4,538.34
O&M ($/op.hr)	0.018
Minimum Load Ratio (%)	55
CHP Heat Recovery Ratio (%)	80
Natural Gas Fuel Price ($/m^3)	0.41

Table 33: CHP Model Parameters for Homer Simulation



Name: Cogeneration System 2.4MW
Abbreviation: CHP
Name: Cogeneration System 2.4MW
Abbreviation: CHP
Manufacturer: Generic
www.homerenergy.com
Notes:

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/op. hr)
1	$4,538.34	[illegible]	$0.018

Click here to add new item

Size (kW)
0
2400

Minimum Load Ratio (%): 55.00
CHP Heat Recovery Ratio (%): 80.00
Lifetime (Hours): 15,000.00
Minimum Runtime (Minutes): 0.00
Natural Gas Fuel Price ($/m³): 0.410
☐ Initial Hours

Figure 32: Homer CHP Specification Input

Similarly, figure 33 presents a monoline design illustrating the system's functionality and the interconnection of all components in 2022 when the CHP system was installed.

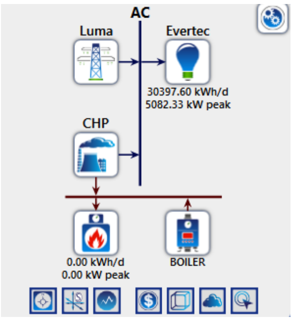
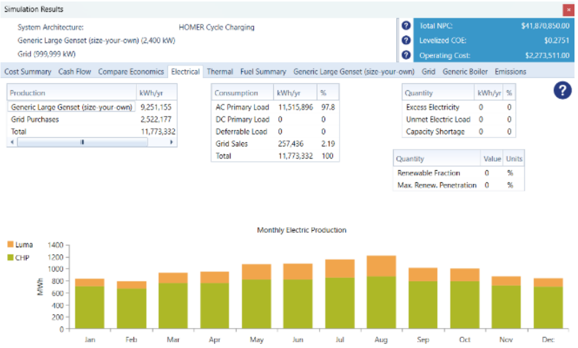


Figure 33: Homer LUMA and CHP Breakdown of Energy Transmission.

Subsequently, executing all parameters necessary for the first simulation, figure 34 illustrates an electric load profile for Evertec's consumption in 2022, while figure 35 offers a detailed cost breakdown delineating the operating and maintenance expenditures of the systems.



System Architecture: HOMER Cycle Charging
Generic Large Genset (size-your-own) (2,400 kW)
Grid (999,999 kW)

Total NPC: $41,870,850.00
Levelized COE: $0.2751
Operating Cost: $2,273,511.00

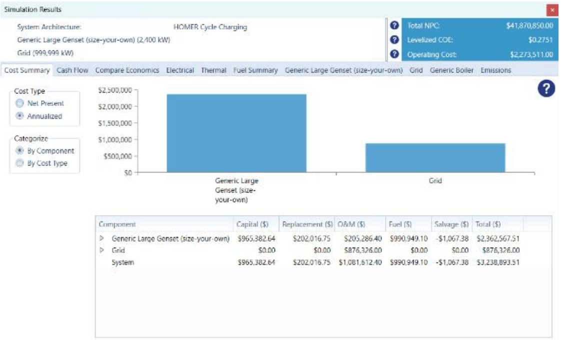
Production	kWh/yr
Generic Large Genset (size-your-own)	9,251,155
Grid Purchases	2,522,177
Total	11,773,332

Consumption	kWh/yr	%
AC Primary Load	11,515,896	97.8
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	257,436	2.19
Total	11,773,332	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	0	%

Figure 34: Homer Simulation Results LUMA and CHP (After Cogeneration Plant).



System Architecture: HOMER Cycle Charging
Generic Large Genset (size-your-own) (2,400 kW)
Grid (999,999 kW)

Total NPC: $41,870,850.00
Levelized COE: $0.2751
Operating Cost: $2,273,511.00

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic Large Genset (size-your-own)	$965,382.64	$202,016.75	$205,286.40	$990,949.10	-$1,067.38	$2,362,567.51
Grid	$0.00	$0.00	$876,326.00	$0.00	$0.00	$876,326.00
System	$965,382.64	$202,016.75	$1,081,612.40	$990,949.10	-$1,067.38	$3,238,893.51

Figure 35: LUMA and CHP Costs Results.

The simulation of the system for 2022 yielded results that closely correspond with Evertec's real performance during that year. Homer presents accurate and thorough statistics derived from the supplied data. Nonetheless, it is crucial to acknowledge that Homer does not include variations in grid power costs, maintenance, and the shutdowns of the CHP system due to diverse component failures and discrepancies. This component affects the discrepancy rate between the actual values and the simulated outcomes. The study reveals a negligible error percentage, as seen in equation 43 and table 34.

$$\text{Percentage Error }\% = \frac{|\text{Simulation} - \text{Real}|}{\text{Real}} \text{x}100\%:$$

(Equation 43)

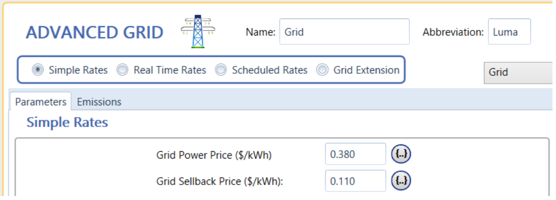
Evertec	Real Values	Homer Values	%Error
Yearly Energy Consumption (Grid)	2,789,160 KWh	2,522,177 KWh	9.57%
Grid Cost	$925,275.77	$876,326	5.29%
Yearly Energy Production (CHP)	8,877,820 KWh	9,251,155 KWh	4.20%

Table 34: Summary of the Comparison of the Theoretical results and Homer Results in 2022

Completing the simulation of the system including the utility, the CHP system, and a newly designed PV system. This system provides a thorough analysis of Evertec's energy use. The energy output of Evertec, the sellback price, the yearly energy production of the PV system, and the energy consumption are shown in Table 35.

Energy Consumed in 2019 (KWh)	Daily Energy Consumed in 2019 (KWh)	Average Grid Power Price in 2024 ($/KWh)	Grid Sellback price ($/KWh)
11,515,898	31,550.4	0.38	0.11

Table 35: Input Data for Utility, CHP System and PV System Homer Simulation



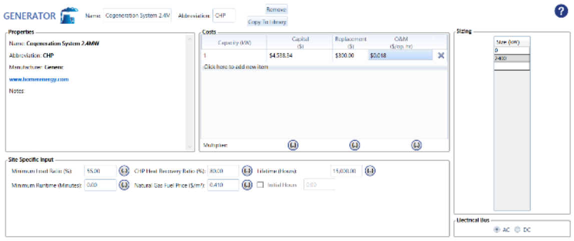
Name: Grid
Abbreviation: Luma
● Simple Rates
Grid Power Price ($/kWh) 0.380
Grid Sellback Price ($/kWh): 0.110

Figure 36: Homer Grid Power Price Input for 2024

Furthermore, figure 37 outlines the essential characteristics for Homer to duplicate the CHP system. All parameters are delineated in table 36. Additionally, in figure 37, a necessary component for the Homer simulation program is the fuel price for natural gas expressed in $/m3. For this data to be obtained, a conversion has to be made from $11/mmbtu to the designated units of $/m3. The contracted price with the LNG provider is $11 per mmbtu. This conversion is performed, and the price is 0.41 ($/m3) as listed below.

Parameters	Values
Capital ($)	4,538.34
O&M ($/op.hr)	0.018
Minimum Load Ratio (%)	55
CHP Heat Recovery Ratio (%)	80
Natural Gas Fuel Price ($/m^3)	0.41

Table 36: CHP Model Parameters for Homer Simulation



Name: Cogeneration System 2.4MW
Abbreviation: CHP
Manufacturer: Generic
www.homerenergy.com
Notes:

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/op. hr)
1	$4,538.34	$300.00	$0.018

Size (kW): 0, 2400

Minimum Load Ratio (%): 55.00
CHP Heat Recovery Ratio (%): 80.00
Lifetime (Hours): 15,000.00
Minimum Runtime (Minutes): 0.00
Natural Gas Fuel Price ($/m³): 0.410
☐ Initial Hours 0.00

Figure 37: Homer CHP Specification Input

Likewise, figure 38 depicts a monoline architecture that illustrates the system's operation and the connectivity of all components in 2024.

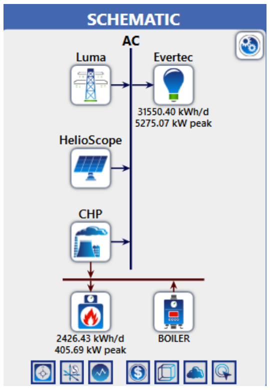


Figure 38: Homer LUMA, PV System and CHP Breakdown of Energy Transmission.

Following the execution of all necessary parameters for the first simulation, figure 39 presents an electric load profile for Evertec's consumption forecast in 2024, while figure 40 provides a comprehensive cost analysis outlining the operational and maintenance expenses of the systems.

System Architecture: Grid (999,999 kW)
HelioScope (1.00) HOMER Cycle Charging
Cogeneration System 2.4MW (2,400 kW)

Total NPC: $36,769,430.00
Levelized COE: $0.2140
Operating Cost: $2,001,731.00

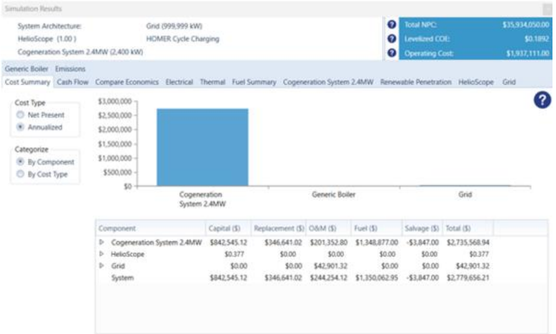
Production	kWh/yr	%
Cogeneration System 2.4MW	10,511,177	80.3
Grid Purchases	1,395,290	10.7
HelioScope	1,181,497	9.03
Total	13,087,964	100

Consumption	kWh/yr	%
AC Primary Load	11,515,896	88.0
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,572,068	12.0
Total	13,087,964	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	67.1	%

Figure 39: Homer Simulation Results LUMA, PV System and CHP (After Cogeneration Plant with PV System).



System Architecture: Grid (999,999 kW)
HelioScope (1.00) HOMER Cycle Charging
Cogeneration System 2.4MW (2,400 kW)

Total NPC: $35,934,050.00
Levelized COE: $0.1892
Operating Cost: $1,937,111.00

Cost Type
○ Net Present
● Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Cogeneration System 2.4MW	$842,545.12	$346,641.02	$201,352.80	$1,348,877.00	-$3,847.00	$2,735,568.94
HelioScope	$0.377	$0.00	$0.00	$0.00	$0.00	$0.377
Grid	$0.00	$0.00	$42,901.32	$0.00	$0.00	$42,901.32
System	$842,545.12	$346,641.02	$244,254.12	$1,350,062.95	-$3,847.00	$2,779,656.21

Figure 40: LUMA, PV System and CHP Costs Results.

The system simulation for the 2024 prediction yields findings that closely align with Evertec's actual projections. Homer provides precise and comprehensive statistics based on the given data. Projection for 2024 is detailed in table 37. It is essential to recognize that Homer omits changes in grid power prices, maintenance, and the shutdowns of the CHP system resulting from various component failures and inconsistencies. This component influences the variance between the real values and the simulated results. The research indicates a minimal error percentage, as seen in equation 44 and table 38. Correspondingly, equation 45 is used to determine the annual KWh consumption of Evertec due to peak load and other discrepancies.

Projection 2024	
AEE y AAA 2019-2020 Cost	2,422,804.23
Operation Cost CHP 2024	157680
Maintenance Cost CHP 2024	182,912.40
Water Billing Cost 2024	214,641.04
Utility Cost 2024	412,976.51
Maintenance Cost Chillers 2024	20,000
LNG Cost 2024	993284.47
Total Cost 2024	1981494.42
Annual Savings 2024	441,309.81

Table 37: 2024 Yearly Cost and Savings Projections

$$\text{Percentage Error } \% = \frac{|\text{Simulation} - \text{Real}|}{\text{Real}} \text{x}100\%:$$

(Equation 44)

$$\text{Grid Estimate Cost} = \frac{\text{Total Annual Grid Cost}}{\text{Average Grid Power Price in 2024}} \text{x}100\%:$$

(Equation 45)

Evertec	Homer Projection
Yearly Energy Consumption (Grid)	112, 897 KWh
Grid Estimate Cost per Year	$42,901.32
Yearly Energy Production (CHP)	10,511,177 KWh

Table 38: Summary of Homer Projections for 2024

Economic Analysis

Starting with the cost analysis of the cogeneration system, table 39 provides a comprehensive summary of all the components necessary to operate the system and generate the energy necessary for the operations of Evertec's facilities. To begin with the economic analysis of the CHP system, it is necessary to examine the initial investment of the undertaking.

Elements	Price ($)
Equipment	5,315,602.01
Two Co-Generators of 1.2MW each	1,735,084.96
Two Absorption Chillers of 350 tons each	1,148,000
Energy Storage System 1.5MW, with 750kW in batteries	1,019,279.00
Step-Up Transformer; 480V to 13.2kV	151,974.50
Incoming/Outgoing Switch setup	172,825.00
Three Cooling Towers, 600 tons each and a sweeper (filter)	763,316.00
Various pumps for chilled water, condensed water, and heat exchanger	146,276.55
Motor Control Center (MCC)	178,846.00
Building for the Combined Heat and Power (CHP) unit	2,535,148.04
Structural Station for LNG	676,076.39
Electrical and Control Systems	675,528.83
Mechanical and Control Installation materials	3,078,291.06
Total Initial Investment	**11,000,000**

Table 39: Project Initial Investment

Evertec of Cupey made a strategic initial investment of approximately 11 million dollars in a cogeneration plant system in 2021, which consists of 2 cogeneration plants of 1.2MW each. The approach towards the data provided by the corporation is to navigate through the company's energy expenditure before and after this significant investment to obtain a simple payback period which will tell the viability of this project.

The previous comprehensible data about the initial investment made by the company for the cogeneration plants was made strategically to ensure effectiveness and efficiency in its implementation, which cost them as mentioned before 11 million dollars and reduced more than 50% from the energy consumption from the utility as it is described in table 22 vs table 23. The investment reflects the corporation's commitment to economic savings and environmental stewardship. This cogeneration system was designed to address the bank's unique energy requirements while maintaining ambitious standards of environmental sustainability, reducing costs and consumption from the utility and reaching a certain quantity of savings under a period in which they can accomplish their objective of recovering the initial investment in the best time possible.

The objective to be completed is to compare the data recorded before and after the Cogeneration System was implemented in the facilities of Evertec. The base time before cogeneration installation is the year 2019, followed by 2020; to start calculating the electric utility energy consumption in kWh by Evertec buildings and their expenses for the same.

Table 22 shows the total electric utility energy consumption in kWh and the total cost of the energy consumed in 2019 and in 2020, which means before the Cogeneration System was implemented. Evertec consumed 11,095,128.00 in 2019 and 10,553,400.00 in 2020, the first one being the peak; paying a total of $2,235,390.4 and $1,981,063.7, respectively. These values are particularly important to compare this data with the consumed energy after the cogeneration was installed because it tells in proportion to the total consumption, how much less is now required from the grid. In addition to this, how much fuel is being paid for the cogenerators. Therefore, by obtaining how much money the company is saving monthly and yearly, it gives the opportunity to calculate a simple payback period.

Total Energy (kWh)	**Total Cost ($)**
11,095,128.00	2,235,390.4
10,553,400.00	1,981,063.7

Table 40: Energy Consumption and Costs BEFORE cogeneration.

Now, the same will happen after the cogeneration plant is installed in the year 2021. The data for subsequent years is going to help with the comparison of energy consumption and its cost before and after the Cogeneration System installation. This approach provides a clearer view of the annual average savings Evertec receives and the reduced reliance on electrical utility. In table 23 and 24, the total electric utility energy consumption in kWh with its monthly average and the total cost of the energy consumed with its monthly average, for years 2021 to 2024.

Achieving better precision at the results, in 2024, which has not ended yet, the total cost was divided between 9 months which are the total months of given data, to obtain an average monthly cost and the same for the average energy consumed. In this data it is noticeable that the reduction from using the electric utility was more than 50% in comparison to table 14.1 and over a million dollars of savings; even almost two million dollars of saving as shown in 2023, $407,919.12 and $309,732.38. While in 2019 it was $2,235,390.4 and in 2020 $1,981,063.7. From the electric utility there is a huge amount of savings from energy consumption and the cost of it. It will be seen down in the last tables of this section (table 41). It must be indicated that these savings apply to the fuel cost by year.

Total Cost ($)
2,235,390.4
1,981,063.7
407,919.12
309,732.38

Table 41: Electric Utility Energy Consumption and Costs AFTER cogeneration, data by Evertec.

Another crucial piece of data for the analysis is shown in table 42, which is the energy production and costs of LNG fuel by year. This table will show the total energy produced in mmBtu with its monthly average energy production and the total cost for that energy produced with its monthly average cost, for years 2021 to 2024. This value of monthly average cost and energy was computed manually using as reference the 4 excel data sheets which are indicated in the table below; just by dividing the total of both categories each year by 12, which is the total months in a year. The total cost was divided by 9 months, which are the total months of given data, to obtain an average monthly cost and the same was done for the average energy consumed.

Year	**Total Energy (mmBtu)**	**Average Energy (mmBtu)**	**Total Cost ($)**	**Average Cost ($)**
2021	66,920.01	5,576.67	736,150.14	61,345.85
2022	80,666.30	6,722.19	885,983.51	73,831.96
2023	93,953.38	7,829.45	1,026,094.23	85,507.85
2024	68,035.76	7,559.53	744,963.35	82,773.71

Table 42: Energy Production and Costs of LNG fuel, data by Evertec.

A total of $797,229.16 in the entire year, and to see the average cost paid to LUMA per month, it was divided by 12, giving $66,435.76/month. The total that was paid in that year was more than 1 million dollars less than what was being paid to the utility services before the cogeneration. These cost breakdowns can be observed below, in table 43.

Total Cost ($)
797,229.16
66,435.76 per month

Table 43: Values obtained from billing tables in Chapter 14.

Upon the establishment of the cogeneration facility that was recently installed in 2021, the cost that the client, Evertec was paying for electricity services to the utility. A total of $797,229.16 in the entire year, and to see the average cost paid to LUMA per month, giving $66,435.76. The total paid in 2021 was more than 1 million dollars less than before the cogeneration.

Metric (Avg)	**Annually**	**Monthly**
Before Cogen (kWh)	10,824,264	902,022
Before Cogen ($)	2,108,227.13	175,685.59
After Cogen (kWh)	2,208,354.67	184,029.56

After Cogen ($)	650,708.38	54,225.7

Table 44: Annual and monthly average Energy Consumption from utility and its costs, Before and After Cogeneration System installation.

Another observation from table above is that the energy consumption after the Cogeneration System was implemented, from the electric utility, was 80% less than before the installation. This reduction in consumption of energy from the grid reduces the cost, which was about 1.6 million dollars approximately. Furthermore, this does not consider the LNG fuel and water consumption cost.

A summary of the values as averages is seen in table 45; is going to present fuel consumption in mmBtu by CHP plants, and their cost. This is calculated using the given data by Evertec of the years 2021 to 2024. Since 2024 is not finished, a projection was necessary to calculate the monthly averages of the pertinent values to then obtain the annual average). The average monthly rate indicated below in table 16.7 uses the months of all the 4 years (with the adjustment of 2024 which is incomplete) and its costs.

Description	**Average Monthly**	**Average Annually**
Energy (mmBtu)	6,682.3032	80,187.64
Cost ($)	73,247.06	878,964.75

Table 45: Annual and monthly averages of fuel Consumed by the CHP plant and its cost.

The savings calculations conducted after the cogeneration plant implementation, which utilizes natural gas as its primary fuel, necessitate an assessment of Evertec's expenditures on water services prior to and following the installation of the cogeneration system. Incorporating these figures into the final calculations is essential for the reliability of the simple payback period.

As shown in Table 44 illustrates the yearly average payment made to the utility. Prior to the establishment of the CHP system, the customer paid $2,108,227.13 to LUMA. Following the cogeneration plant, Evertec paid $650,708.38 monthly. The subtraction from these two quantities yields an average yearly saving of $1,457,518.75. However, this figure does not represent a genuine saving, as it must be adjusted by deducting the annual average expenditures associated with LNG fuel and other charges that will be elaborated upon later. This figure pertains only to the electric utility savings and does not reflect the company's savings after the implementation of the cogeneration system as illustrated in table 46 below.

Avg Annual Saving ($)
1,457,518.75

Table 46: Average Annual Savings calculated

Using table 25 which includes the water billings before and after cogeneration system, this is an additional cost that must be included for the savings and simple payback period, due to the rise in water usage from the chillers implemented with the CHP system. The annual average water billing cost difference between before and after cogeneration system is the value to consider for this additional water cost, which will be included in table 47.

The data shows no substantial difference in terms of the water volume used. Before the cogeneration, the annual average was 26,623m^3 and after, 32,864.8m^3. However, there was a significant difference in price, prior to the cogeneration installation, the annual average of 2019 to 2020 was $180,805.21 and the average for 2021 to 2024 was $236,590.28, meaning that the cogenerators water consumption difference in cost on average is $55,785.08 to the bill annually.

Avg. Water Volume Before	26,623m^3
Avg. Water Volume After	32,864.8m^3
Avg. Yearly Cost Before	180,805.21
Avg. Yearly Cost After	236,590.28,
Avg. Difference Cost Before vs After	55,785.08

Table 47: Annual average water consumption and its cost Before and After Cogeneration System installation.

Concluding the planning costs and obtaining the annual savings for the payback period, the expenses for maintenance and operations of the cogeneration system are to be considered acquiring a correct payback period.

The CHP plant has 4 operators with a total salary of $157,680 paid annually. Given maintenance, there is a variation in costs due to the need for the cogeneration plant in each particular year. These costs, regardless of annual variability, have a contract which established a number indicating the monthly cost that it would be paid for the entire year (which does not change). Evertec supplied data for

CHP's maintenance, which is illustrated in table 48 to 51, and $20,000 in chiller maintenance.

Annual Savings 2021	
AEE y AAA 2019-2020 Cost	2,422,804.23
Operation Cost CHP 2021	157680
Maintenance Cost CHP 2021	148,945.80
Water Billing Cost 2021	240,326.73
Utility Cost 2021	797,229.16
Maintenance Cost Chillers 2021	20,000
LNG Cost 2021	736,150.14
Total Cost 2021	2,100,331.83
Annual Savings 2021	322,472.40

Table 48: Annual Savings 2021

Annual Savings 2022	
AEE y AAA 2019-2020 Cost	2,422,804.23
Operation Cost CHP 2022	157680
Maintenance Cost CHP 2022	148,945.80
Water Billing Cost 2022	245,646.73
Utility Cost 2022	925,275.77
Maintenance Cost Chillers 2022	20,000
LNG Cost 2022	885,983.51
Total Cost 2022	2383531.81
Annual Savings 2021	39,272.42

Table 49: Annual Savings 2022

Annual Savings 2023	
AEE y AAA 2019-2020 Cost	2,422,804.23
Operation Cost CHP 2023	157680
Maintenance Cost CHP 2023	182,912.40
Water Billing Cost 2023	260,506.74
Utility Cost 2023	407,919.12
Maintenance Cost Chillers 2023	20,000
LNG Cost 2023	1,026,094.23
Total Cost 2023	2055112.49
Annual Savings 2023	367,691.74

Table 50: Annual Savings 2023

Annual Savings 2024	
AEE y AAA 2019-2020 Cost	2,422,804.23
Operation Cost CHP 2024	157680
Maintenance Cost CHP 2024	182,912.40
Water Billing Cost 2024	214,641.04
Utility Cost 2024	412,976.51
Maintenance Cost Chillers 2024	20,000
LNG Cost 2024	993284.47
Total Cost 2024	1981494.42
Annual Savings 2024	441,309.81

Table 51: Annual Savings 2024

The first step towards the simple payback period for the cogeneration plant includes LNG fuel and all additional costs. This shows how long the investment will be repaid in terms of years. Firstly, the project's first investment payment and the annual savings from 2021 to 2024 are required to perform equation 46. Additionally, the annual savings were calculated by using the total cost that the client paid before and after the cogeneration plant installation, including electricity, water, and other services. This simple payback period calculation is demonstrated below.

$$\text{Ave. Annual Savings} = \frac{Annual\ Savings\ (2023-2024)}{\text{Total Years}}$$

$$= \frac{\$809{,}001.55}{2}$$

=$404,500.77

$$Simple\ payback\ period(years)$$

$$= \frac{\Pr oject\ First\ Investment\ Payment}{Annual\ Savings\ (2023\ to\ 2024)} \text{:(Equation 46)}$$

$$\text{Simple payback period (years)} = \frac{\$11{,}000{,}000}{\$404{,}500.77}$$

$$= \mathbf{27.19\ Years}$$

The cogeneration plant has the option to use propane gas as fuel, but it does not last long since it operates at 70% efficiency, meaning that you can only refill propane gas up to 33,600 gallons. Unlike LNG fuel, which operates at 90% efficiency, and it can fill storage tanks up to 43,200 gallons. Propane gas is more volatile, and because of this, it loses more energy on heat and can't be filled up all the way. Additionally, propane gas lasts way less than LNG, with 10,000 gallons of propane, the cogeneration plant only lasts 24 hours a day for 4 days, while with LNG fuel it lasts 24 hours a day for 20 days. If it is assumed that both fuel sources are used simultaneously, with 40,000 gallons each, propane gas would last approximately 12 days, whereas LNG would last the same amount of time as mentioned before. Even though propane is less ideal, the cogeneration plant can still use it, and it can be considered for emergency situations, and in this section, the prices per units of LNG and propane will be compared by converting propane gas units of $/gallons to $/mmbtu (since LNG is already in units of $/mmbtu). Gas companies were contacted to find prices of propane, and the average of all the prices found is $4/gallon, whereas the LNG is at $11/mmbtu because Evertec has a contract with New Fortress Energy which buys the fuel at the price mentioned. After researching on the internet, 1 gallon of propane is approximately 0.091500 mmbtu, and with this, the conversion of propane units can be started. This process is shown below on equation 47.

$$\frac{\$4}{\text{gallon}} * \frac{1\text{ gallon}}{0.091500\text{ mmbtu}} = \mathbf{\$43.715/mmbtu}:$$

(Equation 47)

LNG ($/mmbtu)	Propane ($/mmbtu)
11	43.715

Table 52: Comparison of propane and LNG fuel sources.

As observed above, in table 52, propane gas is valued approximately at $43.715/mmbtu, and LNG is valued at $11/mmbtu. With this comparison, LNG is way more cost efficient than propane, and as explained before, it is more energy efficient too. Besides, it is not possible to compare with the historical records the usage of propane gas in the cogeneration plant at Evertec since it has only been used twice because of how expensive and inefficient it is.

The initial expenditure for the Photovoltaic System will be detailed in the subsequent section, including construction, solar panels, and further components to consider. Regarding the projected value of each component for the initial investment, the total final cost to execute this system as an integration into the Evertec Cupey micro-grid includes extra expenses such as solar panel maintenance and any other applicable charges. Furthermore, a projected evaluation of the savings generated by Evertec Cupey via the integration of the PV system into their micro-grid, juxtaposed with the savings realized after the establishment of the cogeneration plant in 2022. In 2023, the integration of the cogeneration plant resulted in total savings of $526,632.84; however, this figure is subject to variability due to the unpredictability of future utility costs. Consequently, this amount will serve as the foundational basis for economic analysis. This comparison will determine the viability of implementing the PV system into their micro-grid, necessitating a final estimate of the payback period required to repay the investment.

The entire payout for the electric bill in 2024 amounts to $412,976.50, as provided by Evertec Cupey. This base value will facilitate the comparison with the savings generated by the implementation of the PV system and its investment payback term to assess its viability. Determining the energy price established by LUMA, a foundational price of $/kWh is required for the planning costs of the PV system and the anticipated savings for Evertec, including the predicted payback time; Equation 48 will facilitate this analysis.

$$\text{LUMA (kWh)} = \frac{\text{Monthly bill price}}{\text{Monthly consumption (kWh)}}:$$

(Equation 48)

Table 53 will be utilized in conjunction with Equation 47, which delineates the billing for the last seven months of 2024; thus, an estimated price per kWh for the year 2024 can be derived, establishing a standard basis for the analysis of subsequent years and calculating the annual savings alongside the payback period of the photovoltaic system investment. Accompanying the 2024 power bill figures used for the computation, $412,976.50 paid by Evertec to LUMA in the previous year (2024) will be included. The savings presented at the conclusion of this chapter will be more precise and authentic; this is due to the significant fluctuations in electric bill costs over short intervals, rendering it impossible to ascertain an exact figure for the actual savings. However, by utilizing the 2024 bills up to September, the most recent one, it is feasible to derive a highly accurate annual savings estimate.

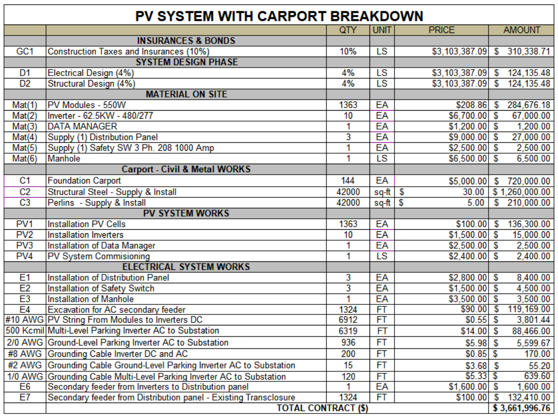
2024 Monthly Utility Bills	Energy Consumed (kWh)	Cost ($)
January	64,680	25,940.54
February	47,520	23,269.11
March	124,800	39,570.79
April	52,800	23,896.92
May	97,020	33,938.53

June	163,020	49,391.05
July	70,356	31,159.58
August	142,824	46,680.96
September	93,060	35,884.90
October	-	-
November	-	-
December	-	-

Table 53: 2024 Electric utility bills costs AFTER Cogeneration, data from Evertec Cupey

A comparison will be conducted using the entire amount Evertec paid LUMA in 2024, factoring in the cogenerators operation. This analysis will simulate yearly usage as if the photovoltaic system were in place, given that the cogeneration plant supplies 2.4MW and the photovoltaic system produces 600kW after DC to AC conversion.

Additionally, Table 54 provides a comprehensive summary of all expenditures associated with the PV system, including design expenses, electrical components, mechanical and civil materials, wiring, feeders, and installation. The total cost for the PV system is listed below.



PV SYSTEM WITH CARPORT BREAKDOWN					
		QTY	UNIT	PRICE	AMOUNT
	INSURANCES & BONDS				
GC1	Construction Taxes and Insurances (10%)	10%	LS	$3,103,387.09	$ 310,338.71
	SYSTEM DESIGN PHASE				
D1	Electrical Design (4%)	4%	LS	$3,103,387.09	$ 124,135.48
D2	Structural Design (4%)	4%	LS	$3,103,387.09	$ 124,135.48
	MATERIAL ON SITE				
Mat(1)	PV Modules - 550W	1363	EA	$208.86	$ 284,676.18
Mat(2)	Inverter - 62.5KW - 480/277	10	EA	$6,700.00	$ 67,000.00
Mat(3)	DATA MANAGER	1	EA	$1,200.00	$ 1,200.00
Mat(4)	Supply (1) Distribution Panel	3	EA	$9,000.00	$ 27,000.00
Mat(5)	Supply (1) Safety SW 3 Ph. 208 1000 Amp	1	EA	$2,500.00	$ 2,500.00
Mat(6)	Manhole	1	LS	$6,500.00	$ 6,500.00
	Carport - Civil & Metal WORKS				
C1	Foundation Carport	144	EA	$5,000.00	$ 720,000.00
C2	Structural Steel - Supply & Install	42000	sq-ft	$ 30.00	$ 1,260,000.00
C3	Perlins - Supply & Install	42000	sq-ft	$ 5.00	$ 210,000.00
	PV SYSTEM WORKS				
PV1	Installation PV Cells	1363	EA	$100.00	$ 136,300.00
PV2	Installation Inverters	10	EA	$1,500.00	$ 15,000.00
PV3	Installation of Data Manager	1	EA	$2,500.00	$ 2,500.00
PV4	PV System Commisioning	1	LS	$2,400.00	$ 2,400.00
	ELECTRICAL SYSTEM WORKS				
E1	Installation of Distribution Panel	3	EA	$2,800.00	$ 8,400.00
E2	Installation of Safety Switch	3	EA	$1,500.00	$ 4,500.00
E3	Installation of Manhole	1	EA	$3,500.00	$ 3,500.00
E4	Excavation for AC secondary feeder	1324	FT	$90.00	$ 119,169.00
#10 AWG	PV String From Modules to Inverters DC	6912	FT	$0.55	$ 3,801.44
500 Kcmil	Multi-Level Parking Inverter AC to Substation	6319	FT	$14.00	$ 88,466.00
2/0 AWG	Ground-Level Parking Inverter AC to Substation	936	FT	$5.98	$ 5,599.67
#8 AWG	Grounding Cable Inverter DC and AC	200	FT	$0.85	$ 170.00
#2 AWG	Grounding Cable Ground-Level Parking Inverter AC to Substation	15	FT	$3.68	$ 55.20
1/0 AWG	Grounding Cable Multi-Level Parking Inverter AC to Substation	120	FT	$5.33	$ 639.60
E6	Secondary feeder from Inverters to Distribution panel	1	EA	$1,600.00	$ 1,600.00
E7	Secondary feeder from Distribution panel - Existing Transclosure	1324	FT	$100.00	$ 132,410.00
	TOTAL CONTRACT ($)				**$ 3,661,996.76**

Table 54: PV System with Carport Breakdown

The PV system economic analysis focuses on the year 2024 which is the year where it is going to be implemented since it does not exist physically yet in Evertec. Moreover, the year has not ended, this is why taking an average cost of the current utility price, and the calculation yielded $0.3852/kWh. Furthermore, the PV system generates 1,181,496.6 kWh annually, and a rough estimate can be made on how much the customer would pay the utility, and this is the savings used for the calculations below. This is done by multiplying the kWh generated by the PV system with the average cost of energy provided by LUMA. This is done below on equation 49, where it is obtained how much Evertec is supposed to pay for energy to the utility grid. Additionally, to calculate the savings that the PV system will produce, a difference must be made between the current price of electricity that the client pays and the price if the PV system was installed. This calculation is done below, in equation 50. Finally, table 55 indicates a breakdown of how much Evertec pays with and without the PV system. It also shows the approximate payback period which uses equation 41, and this calculation is shown below.

$\text{Cost} = \left(\frac{\$0.3852}{\text{kwh}}\right) * 1{,}181{,}496.6 \text{ kWh} = \$\mathbf{455{,}112}$**:** (Equation 49)

$\text{Savings} = |(\text{Cost without PV}) - (\text{Cost with PV})|$: (Equation 50)

$$\text{Savings} = |(\$412{,}976.50) - (\$455{,}112)| = \$\mathbf{42{,}135.5}$$

The simple payback period of 8.04 years represents the investment value, without the consideration of a loan, which is the procedure our customer will follow. Nevertheless, the computation pertaining to the loan is explained in equation 16.7.

Description	**Amount**
Initial Investment	$3,661,996.76
Annual Operational and Maintenance Costs	$0.00
Energy produced by PV System (kWh annually)	1,181,496.6
Annual Energy Cost without PV System (2024)	$412,976.50
Annual Cost of Energy (Average 2024)	$0.3852/kWh
Annual Energy Savings with PV System (2024)	$455,112
Energy Costs Residual (2024)	$42,135.5
Payback Period (Years)	12.3 years

Table 55: PV System costs breakdown with simple payback period.

Table 55 indicates a breakdown of how much our Evertec pays with and without the PV system. It also shows the approximate payback period. The PV system has the potential to produce more energy than demanded by Evertec from the utility. Therefore, at the same rate, this system would cover the annual electric bill for Evertec and produce an additional $42,235.5. This indicates that Evertec can consume more electricity and still pay zero dollars to LUMA.

The annual energy savings from the PV system, amounting to $455,112, represents the overall savings generated by Evertec. Additionally, supposing the customer would proceed with the investment, calculations were conducted for a loan of 3,661,996.76 at an interest rate of 7% and a duration of 12.3 years. Finally, equations 16.7 and 16.8 show the calculations for the true annual payment made towards the loan.

$A = P * (\frac{i(1+i)^n}{(1+i)^n-1})$: (Equation 16.7)

Where:

A = Annual Payment

P = Initial Investment

i = Interest Percentage

n = Total Years

$$A = 3{,}661{,}996.76 * (\frac{0.07(1+0.07)^{12.3}}{(1+0.07)^{12.3}-1})$$

$$A = 3{,}661{,}996.76 * 0.12395 = \$\mathbf{453{,}759.86}$$

Now, we will calculate the total interest paid over a span of 12.3 years, utilizing equation 16.8 below. The number displayed will let us know how much the client is going to pay in interest on the loan.

$I = (A * n) - P$: (Equation 16.8)

Where:

I = Total Interest to Pay

A = Annual Payment

n = Total Years

P = Initial Investment

$I = (\$453{,}759.86 * 12.3 \text{ Years}) - \$3{,}661{,}996.76$ = **$1,915,739.48**

Ultimately, after consolidating all outcomes from prior calculations, the system's output is very feasible. After **12.3 years**, Evertec will realize the whole yearly energy savings from the PV system, so contributing to the payback time of the CHP system and greatly reducing costs annually.

Finalizing the economic analysis, table 16.18 has the comparison between the PV and CHP systems. It summarizes all the calculations done up to this point, and the data given to us by the client. The table has the initial investment, annual cost for electricity, and annual cost for operational and maintenance. Additionally, all these comparisons happen in the current year, 2024.

Description	**Amount**
Initial Investment	$3,661,996.76
Annual PV System Operational and Maintenance Costs	$0.00
Annual Energy Cost without PV System (2024)	$412,976.50
Annual Energy Cost with PV System	$0.00
Payback Period PV System (Years)	12.3 years
CHP Project First Investment Payment	11,000,000
Annual Savings (2021-2024)	$404,500.77
Payback Period CHP System (Years)	27.19 years

Table 56: Payback Period Comparison

Conclusion

The design and implementation of a microgrid system incorporating Photovoltaic (PV) technology and cogeneration offers a sustainable and cost-effective solution to address the energy challenges in areas with unstable grids and high electricity costs. By leveraging Puerto Rico's abundant sunlight, the PV system design provides a renewable source of energy, while the cogeneration system offers backup power and increased efficiency to the system.

The economic analysis compares the initial investment, payback period, and long-term benefits of the cogeneration system and the photovoltaic (PV) system. The following table summarizes the key metrics:

Parameter	Cogeneration System	PV System
Initial Investment	$11 million	$3.6 million
Annual Savings	$404,500.77	$412,966.50
Payback Period	27.19 yrs.	12.3 yrs.
Simulation Error	N/A	0.85%

Table 57: Comparison of PV and Cogeneration Systems.

The cogeneration system requires significantly larger initial investment compared to the PV system. However, this higher upfront expense is offset by the system's ability to generate substantial annual savings, dramatically reducing utility costs over time. Furthermore, the longer payback period of the cogeneration system reflects the scale of its initial cost, yet its substantial annual savings make it a financially viable solution for achieving sustained reductions in operating expenses.

In contrast, the PV system demands a smaller initial investment and provides a much faster payback period, enabling quicker returns on investment. While it may lead to a slight increase in energy costs during its first year due to installation and operational expenses, it offers meaningful annual savings as energy prices continue to rise, making it an effective option for long-term financial planning. Additionally, simulations for the PV system validated its design with an exceptionally low error margin of just 0.85% when compared to manual calculations, underscoring its reliability. Taking together these systems offer complementary benefits: the cogeneration system excels in delivering significant long-term savings, while the PV system provides faster returns and adaptability to future energy demands. Both systems represent robust strategies for enhancing energy efficiency and reducing costs over time for Evertec.

The integration of these systems not only reduces dependence on the local utility but enhances energy resilience and sustainability by reducing greenhouse gas emissions and energy costs over time. The careful consideration of economic factors, fuel alternatives, and system performance ensures that this solution is financially viable, environmentally responsible, and aligned with local and national energy regulations. Ultimately, this project contributes to advancing energy independence and offers a scalable model for addressing similar energy challenges in other regions.

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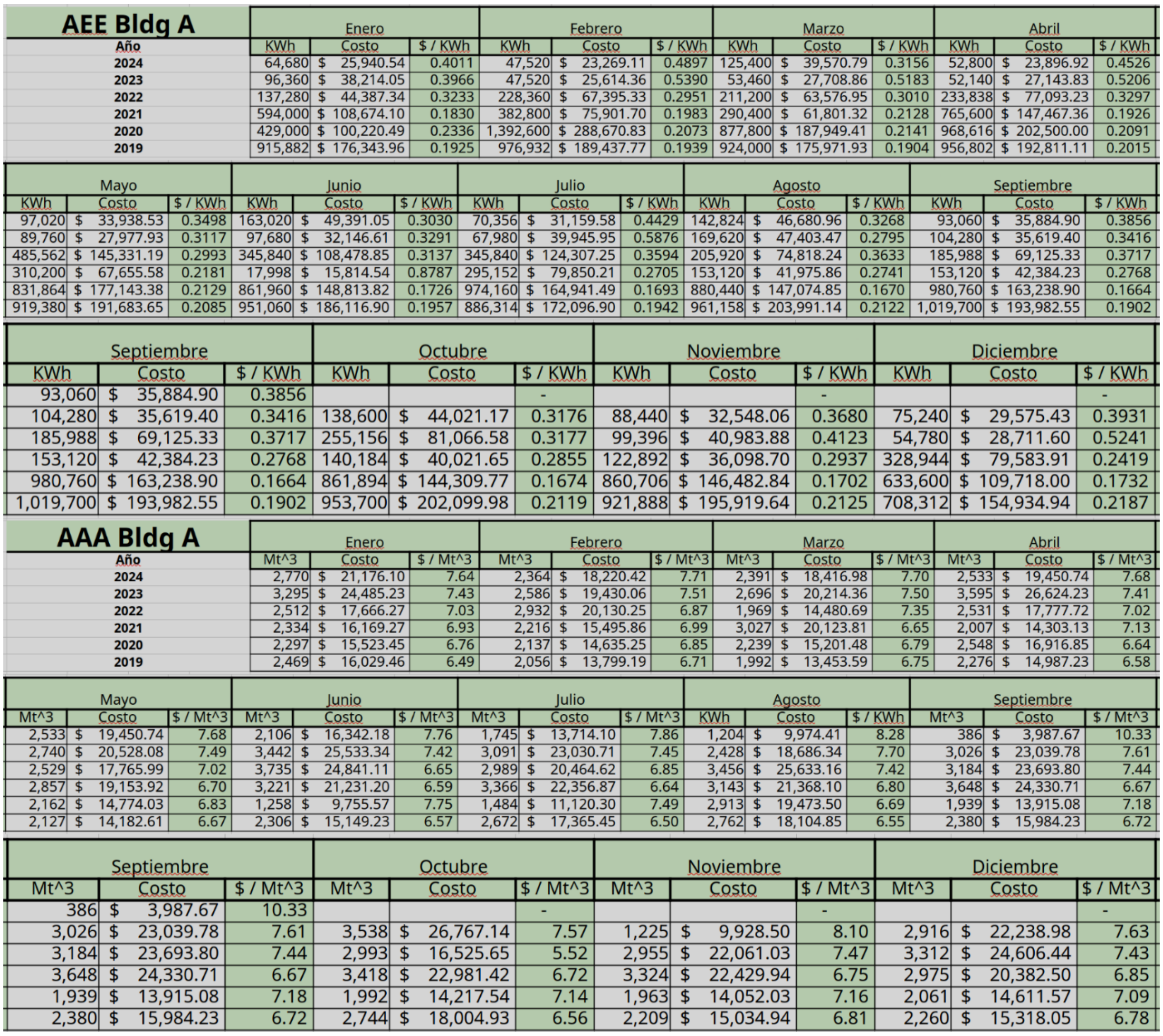
Appendix A: Calculated and Given Data by Customer



AEE Bldg A	Enero			Febrero			Marzo			Abril		
Año	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh
2024	64,680	$ 25,940.54	0.4011	47,520	$ 23,269.11	0.4897	125,400	$ 39,570.79	0.3156	52,800	$ 23,896.92	0.4526
2023	96,360	$ 38,214.05	0.3966	47,520	$ 25,614.36	0.5390	53,460	$ 27,708.86	0.5183	52,140	$ 27,143.83	0.5206
2022	137,280	$ 44,387.34	0.3233	228,360	$ 67,395.33	0.2951	211,200	$ 63,576.95	0.3010	233,838	$ 77,093.23	0.3297
2021	594,000	$ 108,674.10	0.1830	382,800	$ 75,901.70	0.1983	290,400	$ 61,801.32	0.2128	765,600	$ 147,467.36	0.1926
2020	429,000	$ 100,220.49	0.2336	1,392,600	$ 288,670.83	0.2073	877,800	$ 187,949.41	0.2141	968,616	$ 202,500.00	0.2091
2019	915,882	$ 176,343.96	0.1925	976,932	$ 189,437.77	0.1939	924,000	$ 175,971.93	0.1904	956,802	$ 192,811.11	0.2015

Mayo			Junio			Julio			Agosto			Septiembre		
KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh
97,020	$ 33,938.53	0.3498	163,020	$ 49,391.05	0.3030	70,356	$ 31,159.58	0.4429	142,824	$ 46,680.96	0.3268	93,060	$ 35,884.90	0.3856
89,760	$ 27,977.93	0.3117	97,680	$ 32,146.61	0.3291	67,980	$ 39,945.95	0.5876	169,620	$ 47,403.47	0.2795	104,280	$ 35,619.40	0.3416
485,562	$ 145,331.19	0.2993	345,840	$ 108,478.85	0.3137	345,840	$ 124,307.25	0.3594	205,920	$ 74,818.24	0.3633	185,988	$ 69,125.33	0.3717
310,200	$ 67,655.58	0.2181	17,998	$ 15,814.54	0.8787	295,152	$ 79,850.21	0.2705	153,120	$ 41,975.86	0.2741	153,120	$ 42,384.23	0.2768
831,864	$ 177,143.38	0.2129	861,960	$ 148,813.82	0.1726	974,160	$ 164,941.49	0.1693	880,440	$ 147,074.85	0.1670	980,760	$ 163,238.90	0.1664
919,380	$ 191,683.65	0.2085	951,060	$ 186,116.90	0.1957	886,314	$ 172,096.90	0.1942	961,158	$ 203,991.14	0.2122	1,019,700	$ 193,982.55	0.1902

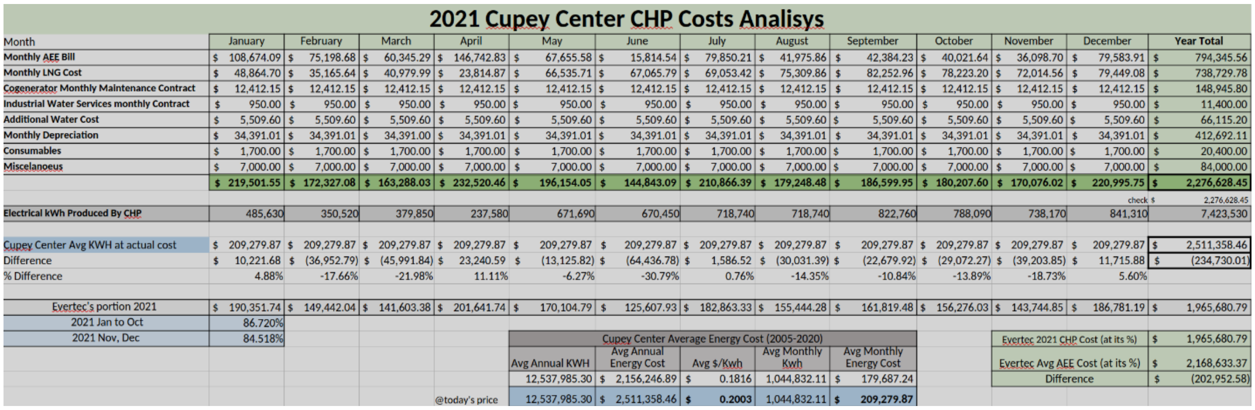
Septiembre			Octubre			Noviembre			Diciembre		
KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh
93,060	$ 35,884.90	0.3856			-			-			-
104,280	$ 35,619.40	0.3416	138,600	$ 44,021.17	0.3176	88,440	$ 32,548.06	0.3680	75,240	$ 29,575.43	0.3931
185,988	$ 69,125.33	0.3717	255,156	$ 81,066.58	0.3177	99,396	$ 40,983.88	0.4123	54,780	$ 28,711.60	0.5241
153,120	$ 42,384.23	0.2768	140,184	$ 40,021.65	0.2855	122,892	$ 36,098.70	0.2937	328,944	$ 79,583.91	0.2419
980,760	$ 163,238.90	0.1664	861,894	$ 144,309.77	0.1674	860,706	$ 146,482.84	0.1702	633,600	$ 109,718.00	0.1732
1,019,700	$ 193,982.55	0.1902	953,700	$ 202,099.98	0.2119	921,888	$ 195,919.64	0.2125	708,312	$ 154,934.94	0.2187

AAA Bldg A	Enero			Febrero			Marzo			Abril		
Año	Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3
2024	2,770	$ 21,176.10	7.64	2,364	$ 18,220.42	7.71	2,391	$ 18,416.98	7.70	2,533	$ 19,450.74	7.68
2023	3,295	$ 24,485.23	7.43	2,586	$ 19,430.06	7.51	2,696	$ 20,214.36	7.50	3,595	$ 26,624.23	7.41
2022	2,512	$ 17,666.27	7.03	2,932	$ 20,130.25	6.87	1,969	$ 14,480.69	7.35	2,531	$ 17,777.72	7.02
2021	2,334	$ 16,169.27	6.93	2,216	$ 15,495.86	6.99	3,027	$ 20,123.81	6.65	2,007	$ 14,303.13	7.13
2020	2,297	$ 15,523.45	6.76	2,137	$ 14,635.25	6.85	2,239	$ 15,201.48	6.79	2,548	$ 16,916.85	6.64
2019	2,469	$ 16,029.46	6.49	2,056	$ 13,799.19	6.71	1,992	$ 13,453.59	6.75	2,276	$ 14,987.23	6.58

Mayo			Junio			Julio			Agosto			Septiembre		
Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3	KWh	Costo	$ / KWh	Mt^3	Costo	$ / Mt^3
2,533	$ 19,450.74	7.68	2,106	$ 16,342.18	7.76	1,745	$ 13,714.10	7.86	1,204	$ 9,974.41	8.28	386	$ 3,987.67	10.33
2,740	$ 20,528.08	7.49	3,442	$ 25,533.34	7.42	3,091	$ 23,030.71	7.45	2,428	$ 18,686.34	7.70	3,026	$ 23,039.78	7.61
2,529	$ 17,765.99	7.02	3,735	$ 24,841.11	6.65	2,989	$ 20,464.62	6.85	3,456	$ 25,633.16	7.42	3,184	$ 23,693.80	7.44
2,857	$ 19,153.92	6.70	3,221	$ 21,231.20	6.59	3,366	$ 22,356.87	6.64	3,143	$ 21,368.10	6.80	3,648	$ 24,330.71	6.67
2,162	$ 14,774.03	6.83	1,258	$ 9,755.57	7.75	1,484	$ 11,120.30	7.49	2,913	$ 19,473.50	6.69	1,939	$ 13,915.08	7.18
2,127	$ 14,182.61	6.67	2,306	$ 15,149.23	6.57	2,672	$ 17,365.45	6.50	2,762	$ 18,104.85	6.55	2,380	$ 15,984.23	6.72

Septiembre			Octubre			Noviembre			Diciembre		
Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3	Mt^3	Costo	$ / Mt^3
386	$ 3,987.67	10.33			-			-			-
3,026	$ 23,039.78	7.61	3,538	$ 26,767.14	7.57	1,225	$ 9,928.50	8.10	2,916	$ 22,238.98	7.63
3,184	$ 23,693.80	7.44	2,993	$ 16,525.65	5.52	2,955	$ 22,061.03	7.47	3,312	$ 24,606.44	7.43
3,648	$ 24,330.71	6.67	3,418	$ 22,981.42	6.72	3,324	$ 22,429.94	6.75	2,975	$ 20,382.50	6.85
1,939	$ 13,915.08	7.18	1,992	$ 14,217.54	7.14	1,963	$ 14,052.03	7.16	2,061	$ 14,611.57	7.09
2,380	$ 15,984.23	6.72	2,744	$ 18,004.93	6.56	2,209	$ 15,034.94	6.81	2,260	$ 15,318.05	6.78

Figure A.1: From 2019_2024_AEE and AAA Cupey Center.xlsx File Provided by Evertec Cupey



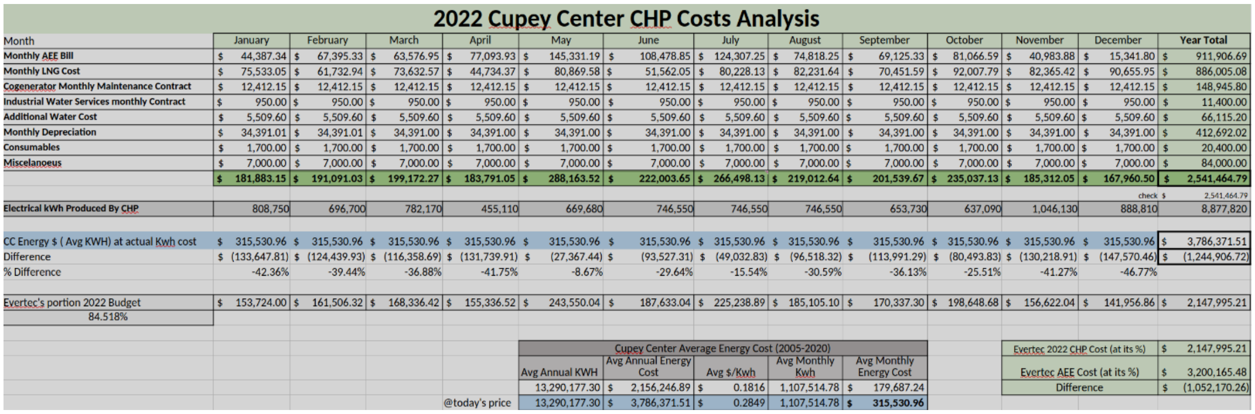
2021 Cupey Center CHP Costs Analisys

Month	January	February	March	April	May	June	July	August	September	October	November	December	Year Total
Monthly AEE Bill	$ 108,674.09	$ 75,198.68	$ 60,345.29	$ 146,742.83	$ 67,655.58	$ 15,814.54	$ 79,850.21	$ 41,975.86	$ 42,384.23	$ 40,021.64	$ 36,098.70	$ 79,583.91	$ 794,345.56
Monthly LNG Cost	$ 48,864.70	$ 35,165.64	$ 40,979.99	$ 23,814.87	$ 66,535.71	$ 67,065.79	$ 69,053.42	$ 75,309.86	$ 82,252.96	$ 78,223.20	$ 72,014.56	$ 79,449.08	$ 738,729.78
Cogenerator Monthly Maintenance Contract	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 148,945.80
Industrial Water Services monthly Contract	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 11,400.00
Additional Water Cost	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 66,115.20
Monthly Depreciation	$ 34,391.01	$ 34,391.01	$ 34,391.00	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 34,391.01	$ 412,692.11
Consumables	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 20,400.00
Miscelanoeus	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 84,000.00
	$ 219,501.55	**$ 172,327.08**	**$ 163,288.03**	**$ 232,520.46**	**$ 196,154.05**	**$ 144,843.09**	**$ 210,866.39**	**$ 179,248.48**	**$ 186,599.95**	**$ 180,207.60**	**$ 170,076.02**	**$ 220,995.75**	**$ 2,276,628.45**
												check	$ 2,276,628.45
Electrical kWh Produced By CHP	485,630	350,520	379,850	237,580	671,690	670,450	718,740	718,740	822,760	788,090	738,170	841,310	7,423,530
Cupey Center Avg KWH at actual cost	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 209,279.87	$ 2,511,358.46
Difference	$ 10,221.68	$ (36,952.79)	$ (45,991.84)	$ 23,240.59	$ (13,125.82)	$ (64,436.78)	$ 1,586.52	$ (30,031.39)	$ (22,679.92)	$ (29,072.27)	$ (39,203.85)	$ 11,715.88	$ (234,730.01)
% Difference	4.88%	-17.66%	-21.98%	11.11%	-6.27%	-30.79%	0.76%	-14.35%	-10.84%	-13.89%	-18.73%	5.60%	
Evertec's portion 2021	$ 190,351.74	$ 149,442.04	$ 141,603.38	$ 201,641.74	$ 170,104.79	$ 125,607.93	$ 182,863.33	$ 155,444.28	$ 161,819.48	$ 156,276.03	$ 143,744.85	$ 186,781.19	$ 1,965,680.79
2021 Jan to Oct	86.720%												
2021 Nov, Dec	84.518%												

Cupey Center Average Energy Cost (2005-2020)					
	Avg Annual KWH	Avg Annual Energy Cost	Avg $/Kwh	Avg Monthly Kwh	Avg Monthly Energy Cost
	12,537,985.30	$ 2,156,246.89	$ 0.1816	1,044,832.11	$ 179,687.24
@today's price	12,537,985.30	$ 2,511,358.46	**$ 0.2003**	1,044,832.11	**$ 209,279.87**

Evertec 2021 CHP Cost (at its %)	$ 1,965,680.79
Evertec Avg AEE Cost (at its %)	$ 2,168,633.37
Difference	$ (202,952.58)

Figure A.2: From 2021_Annual CHP Bill for Evertec.xlsx File Provided by Evertec Cupey



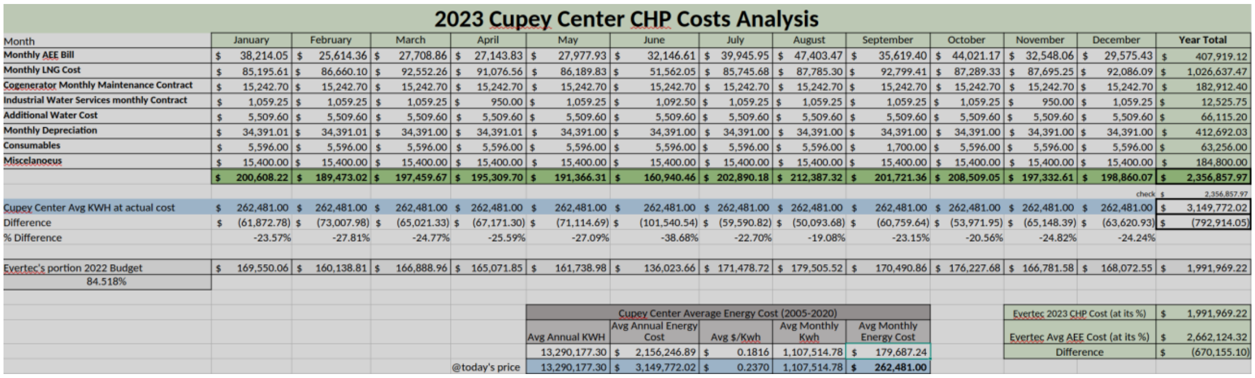
2022 Cupey Center CHP Costs Analysis

Month	January	February	March	April	May	June	July	August	September	October	November	December	Year Total
Monthly AEE Bill	$ 44,387.34	$ 67,395.33	$ 63,576.95	$ 77,093.93	$ 145,331.19	$ 108,478.85	$ 124,307.25	$ 74,818.25	$ 69,125.33	$ 81,066.59	$ 40,983.88	$ 15,341.80	$ 911,906.69
Monthly LNG Cost	$ 75,533.05	$ 61,732.94	$ 73,632.57	$ 44,734.37	$ 80,869.58	$ 51,562.05	$ 80,228.13	$ 82,231.64	$ 70,451.59	$ 92,007.79	$ 82,365.42	$ 90,655.95	$ 886,005.08
Cogenerator Monthly Maintenance Contract	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 12,412.15	$ 148,945.80
Industrial Water Services monthly Contract	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 950.00	$ 11,400.00
Additional Water Cost	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 66,115.20
Monthly Depreciation	$ 34,391.01	$ 34,391.01	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 412,692.02
Consumables	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 1,700.00	$ 20,400.00
Miscelanoeus	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 7,000.00	$ 84,000.00
	$ 181,883.15	**$ 191,091.03**	**$ 199,172.27**	**$ 183,791.05**	**$ 288,163.52**	**$ 222,003.65**	**$ 266,498.13**	**$ 219,012.64**	**$ 201,539.67**	**$ 235,037.13**	**$ 185,312.05**	**$ 167,960.50**	**$ 2,541,464.79**
												check	$ 2,541,464.79
Electrical kWh Produced By CHP	808,750	696,700	782,170	455,110	669,680	746,550	746,550	746,550	653,730	637,090	1,046,130	888,810	8,877,820
CC Energy $ (Avg KWH) at actual Kwh cost	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 315,530.96	$ 3,786,371.51
Difference	$ (133,647.81)	$ (124,439.93)	$ (116,358.69)	$ (131,739.91)	$ (27,367.44)	$ (93,527.31)	$ (49,032.83)	$ (96,518.32)	$ (113,991.29)	$ (80,493.83)	$ (130,218.91)	$ (147,570.46)	$ (1,244,906.72)
% Difference	-42.36%	-39.44%	-36.88%	-41.75%	-8.67%	-29.64%	-15.54%	-30.59%	-36.13%	-25.51%	-41.27%	-46.77%	
Evertec's portion 2022 Budget	$ 153,724.00	$ 161,506.32	$ 168,336.42	$ 155,336.52	$ 243,550.04	$ 187,633.04	$ 225,238.89	$ 185,105.10	$ 170,337.30	$ 198,648.68	$ 156,622.04	$ 141,956.86	$ 2,147,995.21
84.518%													

Cupey Center Average Energy Cost (2005-2020)					
	Avg Annual KWH	Avg Annual Energy Cost	Avg $/Kwh	Avg Monthly Kwh	Avg Monthly Energy Cost
	13,290,177.30	$ 2,156,246.89	$ 0.1816	1,107,514.78	$ 179,687.24
@today's price	13,290,177.30	$ 3,786,371.51	$ 0.2849	1,107,514.78	**$ 315,530.96**

Evertec 2022 CHP Cost (at its %)	$ 2,147,995.21
Evertec AEE Cost (at its %)	$ 3,200,165.48
Difference	$ (1,052,170.26)

Figure A.2: From 2022_Annual CHP Bill for Evertec.xlsx File Provided by Evertec Cupey



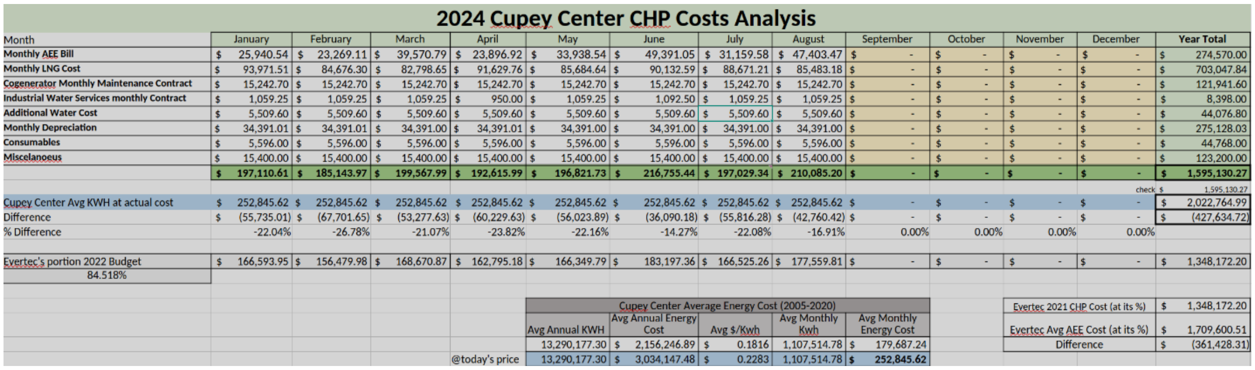
2023 Cupey Center CHP Costs Analysis

Month	January	February	March	April	May	June	July	August	September	October	November	December	Year Total
Monthly AEE Bill	$ 38,214.05	$ 25,614.36	$ 27,708.86	$ 27,143.83	$ 27,977.93	$ 32,146.61	$ 39,945.95	$ 47,403.47	$ 35,619.40	$ 44,021.17	$ 32,548.06	$ 29,575.43	$ 407,919.12
Monthly LNG Cost	$ 85,195.61	$ 86,660.10	$ 92,552.26	$ 91,076.56	$ 86,189.83	$ 51,562.05	$ 85,745.68	$ 87,785.30	$ 92,799.41	$ 87,289.33	$ 87,695.25	$ 92,086.09	$ 1,026,637.47
Cogenerator Monthly Maintenance Contract	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 182,912.40
Industrial Water Services monthly Contract	$ 1,059.25	$ 1,059.25	$ 1,059.25	$ 950.00	$ 1,059.25	$ 1,092.50	$ 1,059.25	$ 1,059.25	$ 1,059.25	$ 1,059.25	$ 950.00	$ 1,059.25	$ 12,525.75
Additional Water Cost	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 66,115.20
Monthly Depreciation	$ 34,391.01	$ 34,391.01	$ 34,391.00	$ 34,391.01	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 412,692.03
Consumables	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 1,700.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 63,256.00
Miscelanoeus	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 184,800.00
	$ 200,608.22	**$ 189,473.02**	**$ 197,459.67**	**$ 195,309.70**	**$ 191,366.31**	**$ 160,940.46**	**$ 202,890.18**	**$ 212,387.32**	**$ 201,721.36**	**$ 208,509.05**	**$ 197,332.61**	**$ 198,860.07**	**$ 2,356,857.97**
												check	$ 2,356,857.97
Cupey Center Avg KWH at actual cost	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 262,481.00	$ 3,149,772.02
Difference	$ (61,872.78)	$ (73,007.98)	$ (65,021.33)	$ (67,171.30)	$ (71,114.69)	$ (101,540.54)	$ (59,590.82)	$ (50,093.68)	$ (60,759.64)	$ (53,971.95)	$ (65,148.39)	$ (63,620.93)	$ (792,914.05)
% Difference	-23.57%	-27.81%	-24.77%	-25.59%	-27.09%	-38.68%	-22.70%	-19.08%	-23.15%	-20.56%	-24.82%	-24.24%	
Evertec's portion 2022 Budget	$ 169,550.06	$ 160,138.81	$ 166,888.96	$ 165,071.85	$ 161,738.98	$ 136,023.66	$ 171,478.72	$ 179,505.52	$ 170,490.86	$ 176,227.68	$ 166,781.58	$ 168,072.55	$ 1,991,969.22
84.518%													

Cupey Center Average Energy Cost (2005-2020)					
	Avg Annual KWH	Avg Annual Energy Cost	Avg $/Kwh	Avg Monthly Kwh	Avg Monthly Energy Cost
	13,290,177.30	$ 2,156,246.89	$ 0.1816	1,107,514.78	$ 179,687.24
@today's price	13,290,177.30	$ 3,149,772.02	$ 0.2370	1,107,514.78	**$ 262,481.00**

Evertec 2023 CHP Cost (at its %)	$ 1,991,969.22
Evertec Avg AEE Cost (at its %)	$ 2,662,124.32
Difference	$ (670,155.10)

Figure A.2: From 2023_Annual CHP Bill for Evertec.xlsx File Provided by Evertec Cupey



2024 Cupey Center CHP Costs Analysis

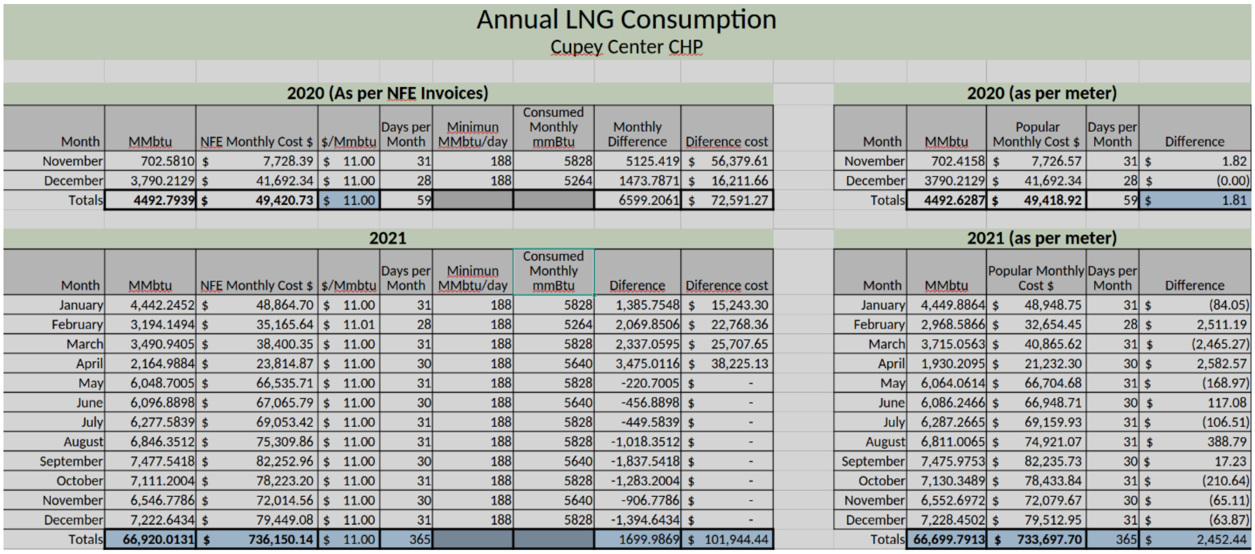
Month	January	February	March	April	May	June	July	August	September	October	November	December	Year Total
Monthly AEE Bill	$ 25,940.54	$ 23,269.11	$ 39,570.79	$ 23,896.92	$ 33,938.54	$ 49,391.05	$ 31,159.58	$ 47,403.47	$ -	$ -	$ -	$ -	$ 274,570.00
Monthly LNG Cost	$ 93,971.51	$ 84,676.30	$ 82,798.65	$ 91,629.76	$ 85,684.64	$ 90,132.59	$ 88,671.21	$ 85,483.18	$ -	$ -	$ -	$ -	$ 703,047.84
Cogenerator Monthly Maintenance Contract	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ 15,242.70	$ -	$ -	$ -	$ -	$ 121,941.60
Industrial Water Services monthly Contract	$ 1,059.25	$ 1,059.25	$ 1,059.25	$ 950.00	$ 1,059.25	$ 1,092.50	$ 1,059.25	$ 1,059.25	$ -	$ -	$ -	$ -	$ 8,398.00
Additional Water Cost	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ 5,509.60	$ -	$ -	$ -	$ -	$ 44,076.80
Monthly Depreciation	$ 34,391.01	$ 34,391.01	$ 34,391.00	$ 34,391.01	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ 34,391.00	$ -	$ -	$ -	$ -	$ 275,128.03
Consumables	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ 5,596.00	$ -	$ -	$ -	$ -	$ 44,768.00
Miscelanoeus	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ 15,400.00	$ -	$ -	$ -	$ -	$ 123,200.00
	$ 197,110.61	**$ 185,143.97**	**$ 199,567.99**	**$ 192,615.99**	**$ 196,821.73**	**$ 216,755.44**	**$ 197,029.34**	**$ 210,085.20**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 1,595,130.27**
												check	$ 1,595,130.27
Cupey Center Avg KWH at actual cost	$ 252,845.62	$ 252,845.62	$ 252,845.62	$ 252,845.62	$ 252,845.62	$ 252,845.62	$ 252,845.62	$ 252,845.62	$ -	$ -	$ -	$ -	$ 2,022,764.99
Difference	$ (55,735.01)	$ (67,701.65)	$ (53,277.63)	$ (60,229.63)	$ (56,023.89)	$ (36,090.18)	$ (55,816.28)	$ (42,760.42)	$ -	$ -	$ -	$ -	$ (427,634.72)
% Difference	-22.04%	-26.78%	-21.07%	-23.82%	-22.16%	-14.27%	-22.08%	-16.91%	0.00%	0.00%	0.00%	0.00%	
Evertec's portion 2022 Budget	$ 166,593.95	$ 156,479.98	$ 168,670.87	$ 162,795.18	$ 166,349.79	$ 183,197.36	$ 166,525.26	$ 177,559.81	$ -	$ -	$ -	$ -	$ 1,348,172.20
84.518%													

Cupey Center Average Energy Cost (2005-2020)

	Avg Annual KWH	Avg Annual Energy Cost	Avg $/Kwh	Avg Monthly Kwh	Avg Monthly Energy Cost
	13,290,177.30	$ 2,156,246.89	$ 0.1816	1,107,514.78	$ 179,687.24
@today's price	13,290,177.30	$ 3,034,147.48	$ 0.2283	1,107,514.78	**$ 252,845.62**

Evertec 2021 CHP Cost (at its %)	$ 1,348,172.20
Evertec Avg AEE Cost (at its %)	$ 1,709,600.51
Difference	$ (361,428.31)

Figure A.2: From 2024_Annual CHP Bill for Evertec.xlsx File Provided by Evertec Cupey



Annual LNG Consumption

Cupey Center CHP

2020 (As per NFE Invoices)

Month	MMbtu	NFE Monthly Cost $	$/Mmbtu	Days per Month	Minimun MMbtu/day	Consumed Monthly mmBtu	Monthly Difference	Diference cost
November	702.5810	$ 7,728.39	$ 11.00	31	188	5828	5125.419	$ 56,379.61
December	3,790.2129	$ 41,692.34	$ 11.00	28	188	5264	1473.7871	$ 16,211.66
Totals	**4492.7939**	**$ 49,420.73**	$ 11.00	59			6599.2061	$ 72,591.27

2020 (as per meter)

Month	MMbtu	Popular Monthly Cost $	Days per Month	Difference
November	702.4158	$ 7,726.57	31	$ 1.82
December	3790.2129	$ 41,692.34	28	$ (0.00)
Totals	**4492.6287**	**$ 49,418.92**	59	$ 1.81

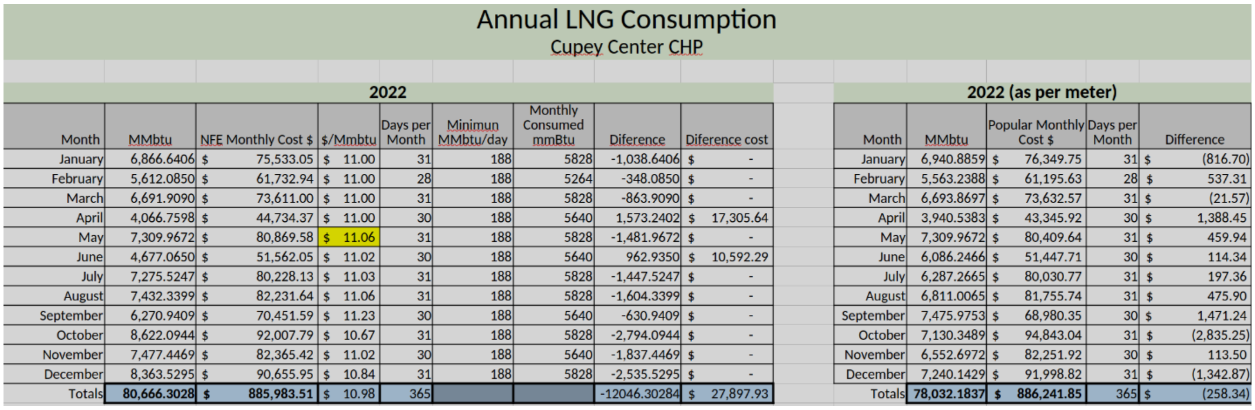
2021

Month	MMbtu	NFE Monthly Cost $	$/Mmbtu	Days per Month	Minimun MMbtu/day	Consumed Monthly mmBtu	Diference	Diference cost
January	4,442.2452	$ 48,864.70	$ 11.00	31	188	5828	1,385.7548	$ 15,243.30
February	3,194.1494	$ 35,165.64	$ 11.01	28	188	5264	2,069.8506	$ 22,768.36
March	3,490.9405	$ 38,400.35	$ 11.00	31	188	5828	2,337.0595	$ 25,707.65
April	2,164.9884	$ 23,814.87	$ 11.00	30	188	5640	3,475.0116	$ 38,225.13
May	6,048.7005	$ 66,535.71	$ 11.00	31	188	5828	-220.7005	$ -
June	6,096.8898	$ 67,065.79	$ 11.00	30	188	5640	-456.8898	$ -
July	6,277.5839	$ 69,053.42	$ 11.00	31	188	5828	-449.5839	$ -
August	6,846.3512	$ 75,309.86	$ 11.00	31	188	5828	-1,018.3512	$ -
September	7,477.5418	$ 82,252.96	$ 11.00	30	188	5640	-1,837.5418	$ -
October	7,111.2004	$ 78,223.20	$ 11.00	31	188	5828	-1,283.2004	$ -
November	6,546.7786	$ 72,014.56	$ 11.00	30	188	5640	-906.7786	$ -
December	7,222.6434	$ 79,449.08	$ 11.00	31	188	5828	-1,394.6434	$ -
Totals	**66,920.0131**	**$ 736,150.14**	$ 11.00	365			1699.9869	$ 101,944.44

2021 (as per meter)

Month	MMbtu	Popular Monthly Cost $	Days per Month	Difference
January	4,449.8864	$ 48,948.75	31	$ (84.05)
February	2,968.5866	$ 32,654.45	28	$ 2,511.19
March	3,715.0563	$ 40,865.62	31	$ (2,465.27)
April	1,930.2095	$ 21,232.30	30	$ 2,582.57
May	6,064.0614	$ 66,704.68	31	$ (168.97)
June	6,086.2466	$ 66,948.71	30	$ 117.08
July	6,287.2665	$ 69,159.93	31	$ (106.51)
August	6,811.0065	$ 74,921.07	31	$ 388.79
September	7,475.9753	$ 82,235.73	30	$ 17.23
October	7,130.3489	$ 78,433.84	31	$ (210.64)
November	6,552.6972	$ 72,079.67	30	$ (65.11)
December	7,228.4502	$ 79,512.95	31	$ (63.87)
Totals	**66,699.7913**	**$ 733,697.70**	365	$ 2,452.44

Figure A.3: From 2020_LNG_METERS_COST.xlsx File Provided by Evertec Cupey



Annual LNG Consumption

Cupey Center CHP

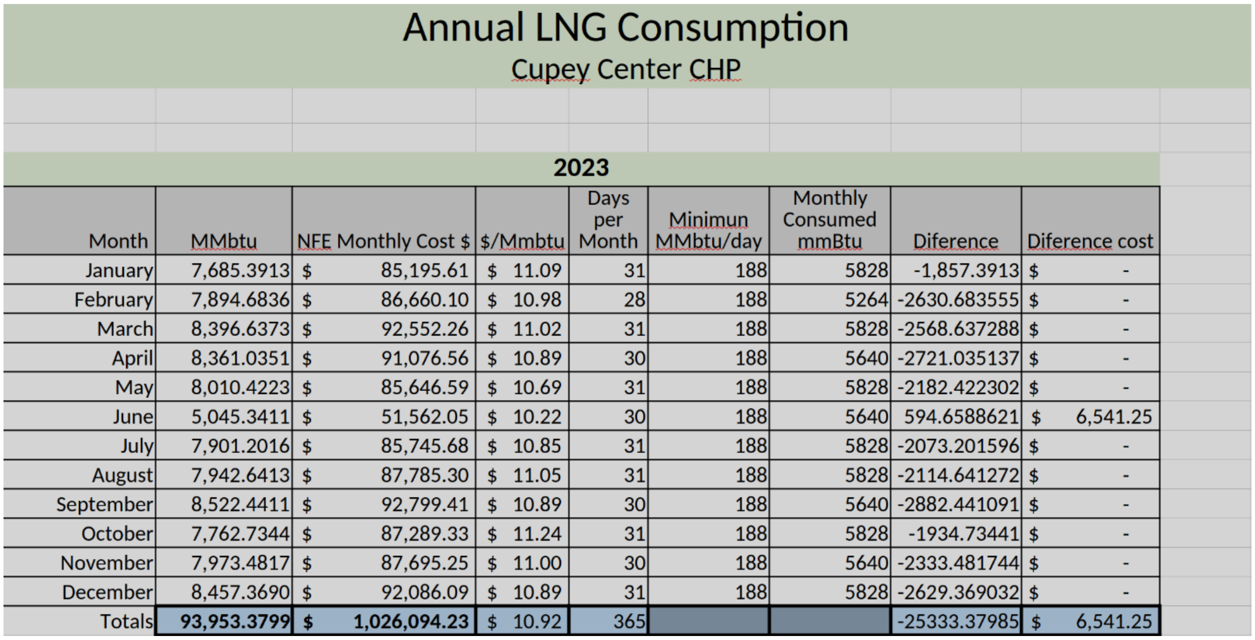
2022

Month	MMbtu	NFE Monthly Cost $	$/Mmbtu	Days per Month	Minimun MMbtu/day	Monthly Consumed mmBtu	Diference	Diference cost
January	6,866.6406	$ 75,533.05	$ 11.00	31	188	5828	-1,038.6406	$ -
February	5,612.0850	$ 61,732.94	$ 11.00	28	188	5264	-348.0850	$ -
March	6,691.9090	$ 73,611.00	$ 11.00	31	188	5828	-863.9090	$ -
April	4,066.7598	$ 44,734.37	$ 11.00	30	188	5640	1,573.2402	$ 17,305.64
May	7,309.9672	$ 80,869.58	$ 11.06	31	188	5828	-1,481.9672	$ -
June	4,677.0650	$ 51,562.05	$ 11.02	30	188	5640	962.9350	$ 10,592.29
July	7,275.5247	$ 80,228.13	$ 11.03	31	188	5828	-1,447.5247	$ -
August	7,432.3399	$ 82,231.64	$ 11.06	31	188	5828	-1,604.3399	$ -
September	6,270.9409	$ 70,451.59	$ 11.23	30	188	5640	-630.9409	$ -
October	8,622.0944	$ 92,007.79	$ 10.67	31	188	5828	-2,794.0944	$ -
November	7,477.4469	$ 82,365.42	$ 11.02	30	188	5640	-1,837.4469	$ -
December	8,363.5295	$ 90,655.95	$ 10.84	31	188	5828	-2,535.5295	$ -
Totals	**80,666.3028**	**$ 885,983.51**	$ 10.98	365			-12046.30284	$ 27,897.93

2022 (as per meter)

Month	MMbtu	Popular Monthly Cost $	Days per Month	Difference
January	6,940.8859	$ 76,349.75	31	$ (816.70)
February	5,563.2388	$ 61,195.63	28	$ 537.31
March	6,693.8697	$ 73,632.57	31	$ (21.57)
April	3,940.5383	$ 43,345.92	30	$ 1,388.45
May	7,309.9672	$ 80,409.64	31	$ 459.94
June	6,086.2466	$ 51,447.71	30	$ 114.34
July	6,287.2665	$ 80,030.77	31	$ 197.36
August	6,811.0065	$ 81,755.74	31	$ 475.90
September	7,475.9753	$ 68,980.35	30	$ 1,471.24
October	7,130.3489	$ 94,843.04	31	$ (2,835.25)
November	6,552.6972	$ 82,251.92	30	$ 113.50
December	7,240.1429	$ 91,998.82	31	$ (1,342.87)
Totals	**78,032.1837**	**$ 886,241.85**	365	$ (258.34)

Figure A.3: From 2022_LNG_METERS_COST.xlsx File Provided by Evertec Cupey



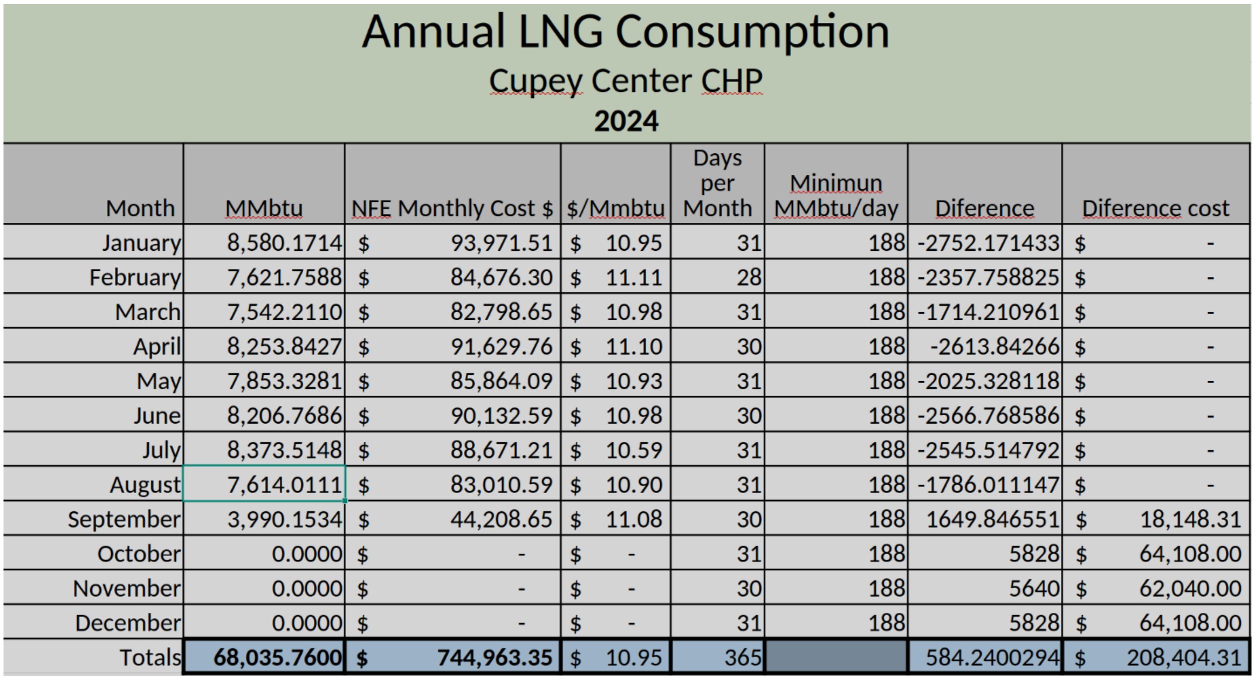
Annual LNG Consumption

Cupey Center CHP

2023

Month	MMbtu	NFE Monthly Cost $	$/Mmbtu	Days per Month	Minimun MMbtu/day	Monthly Consumed mmBtu	Diference	Diference cost
January	7,685.3913	$ 85,195.61	$ 11.09	31	188	5828	-1,857.3913	$ -
February	7,894.6836	$ 86,660.10	$ 10.98	28	188	5264	-2630.683555	$ -
March	8,396.6373	$ 92,552.26	$ 11.02	31	188	5828	-2568.637288	$ -
April	8,361.0351	$ 91,076.56	$ 10.89	30	188	5640	-2721.035137	$ -
May	8,010.4223	$ 85,646.59	$ 10.69	31	188	5828	-2182.422302	$ -
June	5,045.3411	$ 51,562.05	$ 10.22	30	188	5640	594.6588621	$ 6,541.25
July	7,901.2016	$ 85,745.68	$ 10.85	31	188	5828	-2073.201596	$ -
August	7,942.6413	$ 87,785.30	$ 11.05	31	188	5828	-2114.641272	$ -
September	8,522.4411	$ 92,799.41	$ 10.89	30	188	5640	-2882.441091	$ -
October	7,762.7344	$ 87,289.33	$ 11.24	31	188	5828	-1934.73441	$ -
November	7,973.4817	$ 87,695.25	$ 11.00	30	188	5640	-2333.481744	$ -
December	8,457.3690	$ 92,086.09	$ 10.89	31	188	5828	-2629.369032	$ -
Totals	**93,953.3799**	**$ 1,026,094.23**	$ 10.92	365			-25333.37985	$ 6,541.25

Figure A.3: From 2023_LNG_METERS_COST.xlsx File Provided by Evertec Cupey



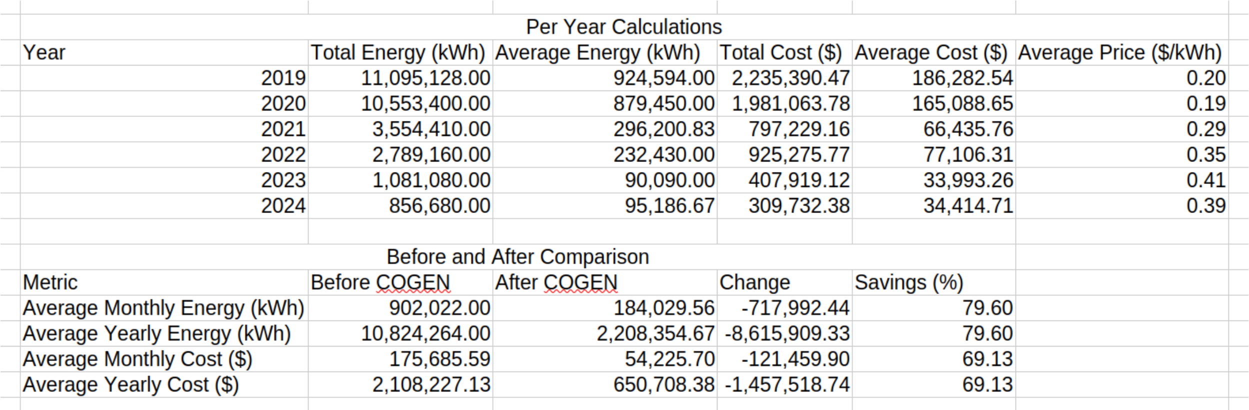
Annual LNG Consumption

Cupey Center CHP

2024

Month	MMbtu	NFE Monthly Cost $	$/Mmbtu	Days per Month	Minimun MMbtu/day	Diference	Diference cost
January	8,580.1714	$ 93,971.51	$ 10.95	31	188	-2752.171433	$ -
February	7,621.7588	$ 84,676.30	$ 11.11	28	188	-2357.758825	$ -
March	7,542.2110	$ 82,798.65	$ 10.98	31	188	-1714.210961	$ -
April	8,253.8427	$ 91,629.76	$ 11.10	30	188	-2613.84266	$ -
May	7,853.3281	$ 85,864.09	$ 10.93	31	188	-2025.328118	$ -
June	8,206.7686	$ 90,132.59	$ 10.98	30	188	-2566.768586	$ -
July	8,373.5148	$ 88,671.21	$ 10.59	31	188	-2545.514792	$ -
August	7,614.0111	$ 83,010.59	$ 10.90	31	188	-1786.011147	$ -
September	3,990.1534	$ 44,208.65	$ 11.08	30	188	1649.846551	$ 18,148.31
October	0.0000	$ -	$ -	31	188	5828	$ 64,108.00
November	0.0000	$ -	$ -	30	188	5640	$ 62,040.00
December	0.0000	$ -	$ -	31	188	5828	$ 64,108.00
Totals	**68,035.7600**	**$ 744,963.35**	$ 10.95	365		584.2400294	$ 208,404.31

Figure A.3: From 2024_LNG_METERS_COST.xlsx File Provided by Evertec Cupey



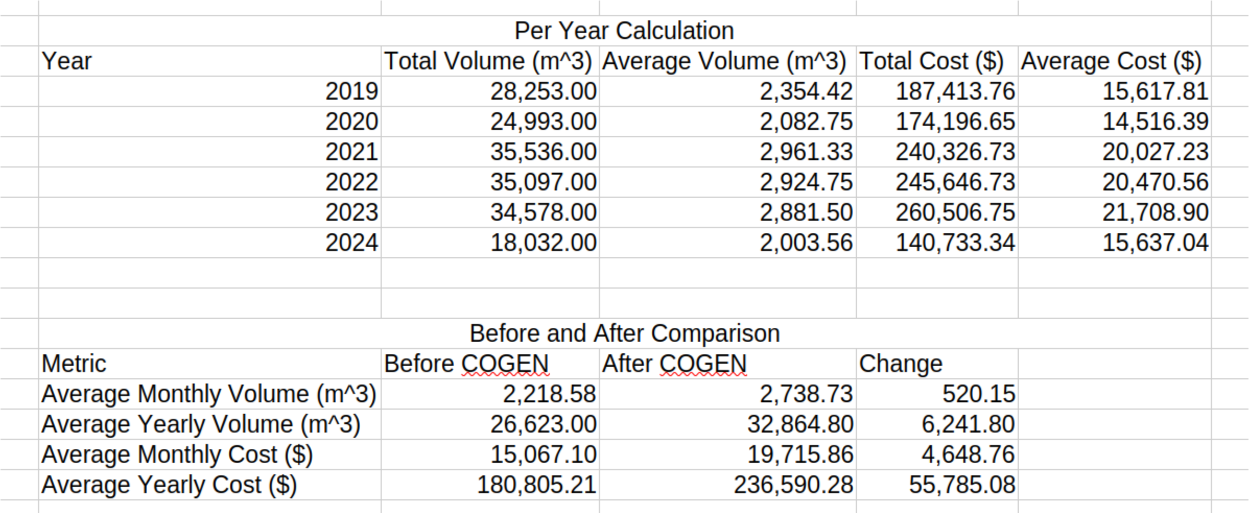
Per Year Calculations

Year	Total Energy (kWh)	Average Energy (kWh)	Total Cost ($)	Average Cost ($)	Average Price ($/kWh)
2019	11,095,128.00	924,594.00	2,235,390.47	186,282.54	0.20
2020	10,553,400.00	879,450.00	1,981,063.78	165,088.65	0.19
2021	3,554,410.00	296,200.83	797,229.16	66,435.76	0.29
2022	2,789,160.00	232,430.00	925,275.77	77,106.31	0.35
2023	1,081,080.00	90,090.00	407,919.12	33,993.26	0.41
2024	856,680.00	95,186.67	309,732.38	34,414.71	0.39

Before and After Comparison

Metric	Before COGEN	After COGEN	Change	Savings (%)
Average Monthly Energy (kWh)	902,022.00	184,029.56	-717,992.44	79.60
Average Yearly Energy (kWh)	10,824,264.00	2,208,354.67	-8,615,909.33	79.60
Average Monthly Cost ($)	175,685.59	54,225.70	-121,459.90	69.13
Average Yearly Cost ($)	2,108,227.13	650,708.38	-1,457,518.74	69.13

Figure A.4: Energy Bills Calculations from Energy Bill Sheet in bills.xlsx File



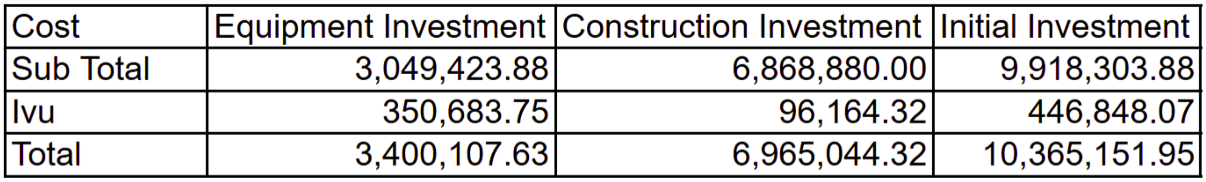
Per Year Calculation

Year	Total Volume (m^3)	Average Volume (m^3)	Total Cost ($)	Average Cost ($)
2019	28,253.00	2,354.42	187,413.76	15,617.81
2020	24,993.00	2,082.75	174,196.65	14,516.39
2021	35,536.00	2,961.33	240,326.73	20,027.23
2022	35,097.00	2,924.75	245,646.73	20,470.56
2023	34,578.00	2,881.50	260,506.75	21,708.90
2024	18,032.00	2,003.56	140,733.34	15,637.04

Before and After Comparison

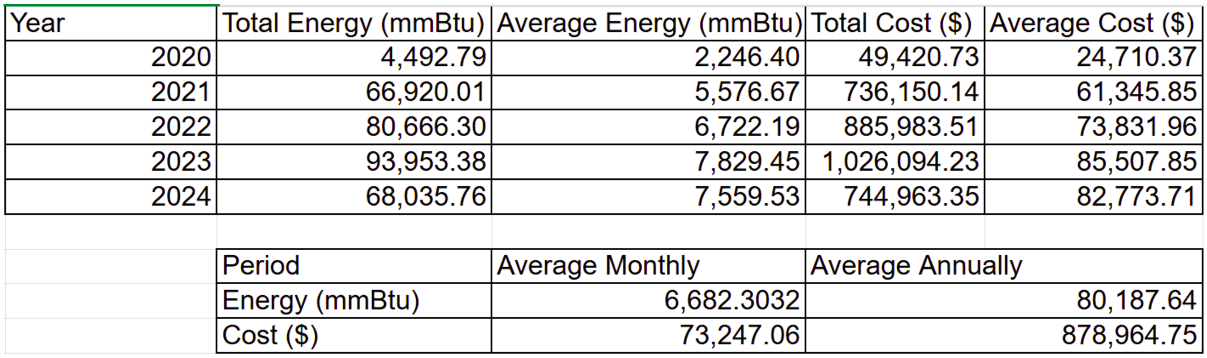
Metric	Before COGEN	After COGEN	Change
Average Monthly Volume (m^3)	2,218.58	2,738.73	520.15
Average Yearly Volume (m^3)	26,623.00	32,864.80	6,241.80
Average Monthly Cost ($)	15,067.10	19,715.86	4,648.76
Average Yearly Cost ($)	180,805.21	236,590.28	55,785.08

Figure A.5: Water Bills Calculations from Water Bill Sheet in bills.xlsx File



Cost	Equipment Investment	Construction Investment	Initial Investment
Sub Total	3,049,423.88	6,868,880.00	9,918,303.88
Ivu	350,683.75	96,164.32	446,848.07
Total	3,400,107.63	6,965,044.32	10,365,151.95

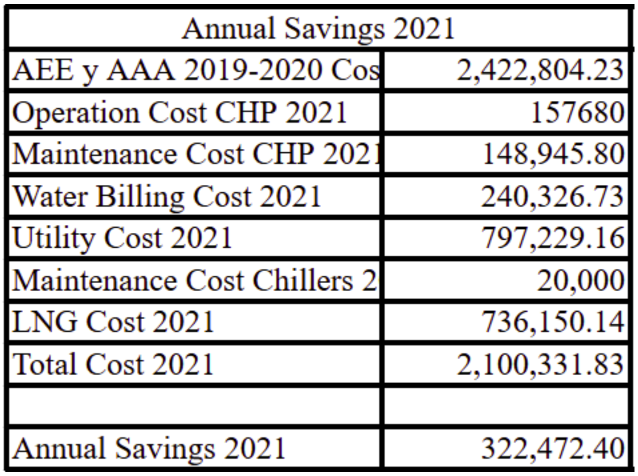
Figure A.6: Initial Investment Calculations from initial cost COGEN Sheet in bills.xlsx File



Year	Total Energy (mmBtu)	Average Energy (mmBtu)	Total Cost ($)	Average Cost ($)
2020	4,492.79	2,246.40	49,420.73	24,710.37
2021	66,920.01	5,576.67	736,150.14	61,345.85
2022	80,666.30	6,722.19	885,983.51	73,831.96
2023	93,953.38	7,829.45	1,026,094.23	85,507.85
2024	68,035.76	7,559.53	744,963.35	82,773.71

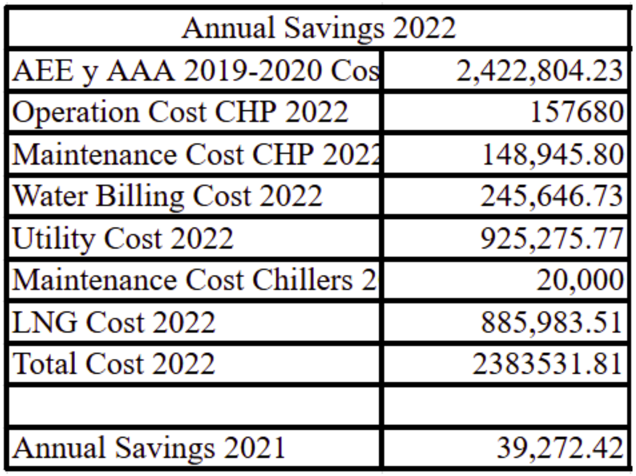
Period	Average Monthly	Average Annually
Energy (mmBtu)	6,682.3032	80,187.64
Cost ($)	73,247.06	878,964.75

Figure A.7: Energy and its cost Calculations from LNG Bill Sheet in bills.xlsx File



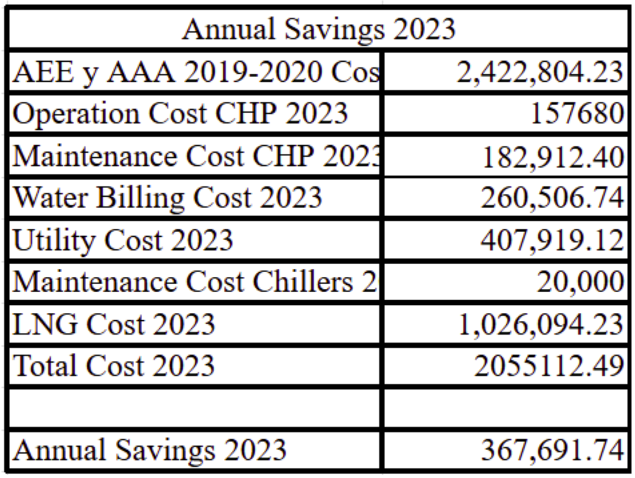
Annual Savings 2021	
AEE y AAA 2019-2020 Cos	2,422,804.23
Operation Cost CHP 2021	157680
Maintenance Cost CHP 2021	148,945.80
Water Billing Cost 2021	240,326.73
Utility Cost 2021	797,229.16
Maintenance Cost Chillers 2	20,000
LNG Cost 2021	736,150.14
Total Cost 2021	2,100,331.83
Annual Savings 2021	322,472.40

Figure A.8: From excel document "Simple Payback Period".



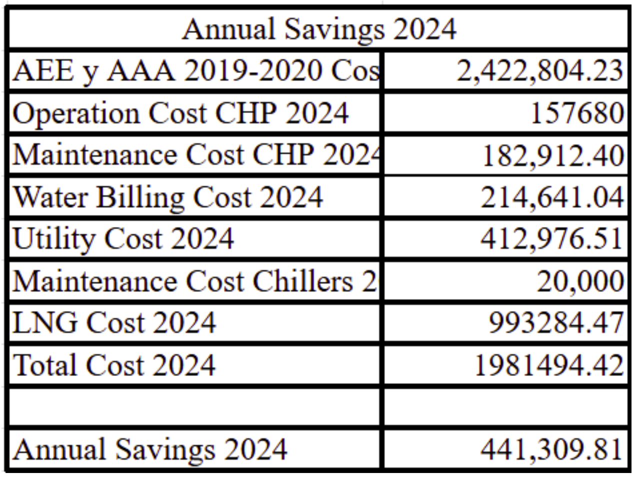
Annual Savings 2022	
AEE y AAA 2019-2020 Cos	2,422,804.23
Operation Cost CHP 2022	157680
Maintenance Cost CHP 202	148,945.80
Water Billing Cost 2022	245,646.73
Utility Cost 2022	925,275.77
Maintenance Cost Chillers 2	20,000
LNG Cost 2022	885,983.51
Total Cost 2022	2383531.81
Annual Savings 2021	39,272.42

Figure A.8: From excel document "Simple Payback Period".



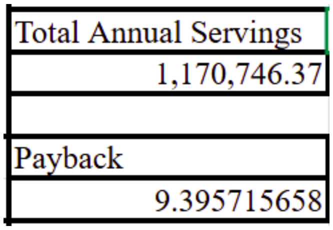
Annual Savings 2023	
AEE y AAA 2019-2020 Cos	2,422,804.23
Operation Cost CHP 2023	157680
Maintenance Cost CHP 2023	182,912.40
Water Billing Cost 2023	260,506.74
Utility Cost 2023	407,919.12
Maintenance Cost Chillers 2	20,000
LNG Cost 2023	1,026,094.23
Total Cost 2023	2055112.49
Annual Savings 2023	367,691.74

Figure A.8: From excel document "Simple Payback Period".



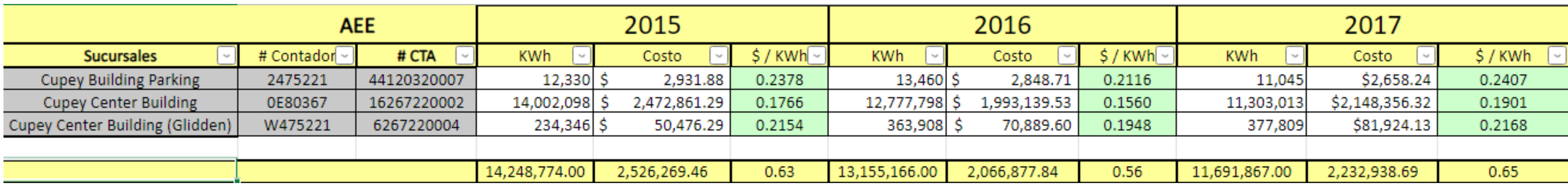
Annual Savings 2024	
AEE y AAA 2019-2020 Cos	2,422,804.23
Operation Cost CHP 2024	157680
Maintenance Cost CHP 2024	182,912.40
Water Billing Cost 2024	214,641.04
Utility Cost 2024	412,976.51
Maintenance Cost Chillers 2	20,000
LNG Cost 2024	993284.47
Total Cost 2024	1981494.42
Annual Savings 2024	441,309.81

Figure A.8: From excel document "Simple Payback Period".



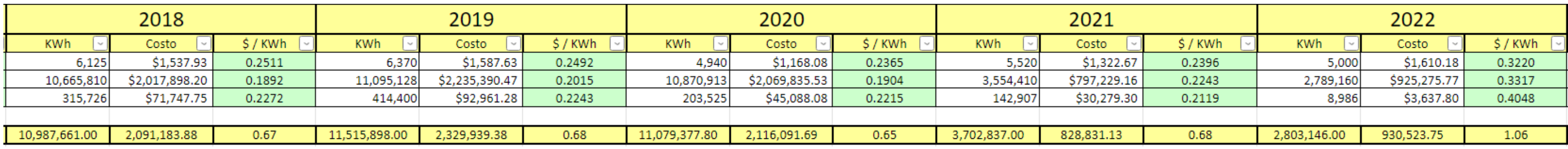
Total Annual Servings
1,170,746.37
Payback
9.395715658

Figure A.9: From excel document "Simple Payback Period".



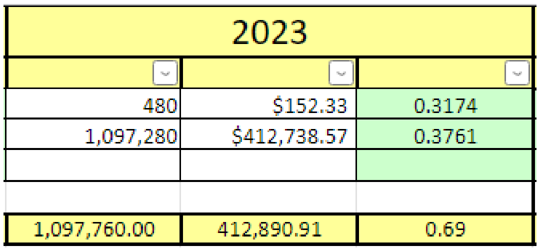
AEE			2015			2016			2017		
Sucursales	# Contador	# CTA	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh
Cupey Building Parking	2475221	44120320007	12,330	$ 2,931.88	0.2378	13,460	$ 2,848.71	0.2116	11,045	$2,658.24	0.2407
Cupey Center Building	0E80367	16267220002	14,002,098	$ 2,472,861.29	0.1766	12,777,798	$ 1,993,139.53	0.1560	11,303,013	$2,148,356.32	0.1901
Cupey Center Building (Glidden)	W475221	6267220004	234,346	$ 50,476.29	0.2154	363,908	$ 70,889.60	0.1948	377,809	$81,924.13	0.2168
			14,248,774.00	2,526,269.46	0.63	13,155,166.00	2,066,877.84	0.56	11,691,867.00	2,232,938.69	0.65

Figure A.10: 2015_2023_Energy Consumption Analysis Cupey Center



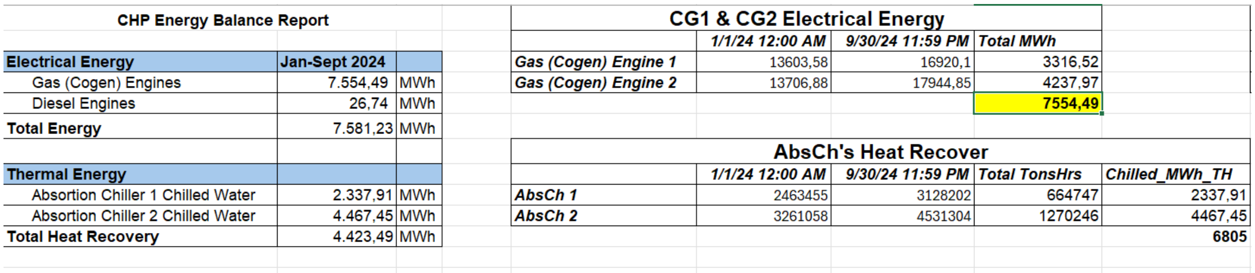
2018			2019			2020			2021			2022		
KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh	KWh	Costo	$ / KWh
6,125	$1,537.93	0.2511	6,370	$1,587.63	0.2492	4,940	$1,168.08	0.2365	5,520	$1,322.67	0.2396	5,000	$1,610.18	0.3220
10,665,810	$2,017,898.20	0.1892	11,095,128	$2,235,390.47	0.2015	10,870,913	$2,069,835.53	0.1904	3,554,410	$797,229.16	0.2243	2,789,160	$925,275.77	0.3317
315,726	$71,747.75	0.2272	414,400	$92,961.28	0.2243	203,525	$45,088.08	0.2215	142,907	$30,279.30	0.2119	8,986	$3,637.80	0.4048
10,987,661.00	2,091,183.88	0.67	11,515,898.00	2,329,939.38	0.68	11,079,377.80	2,116,091.69	0.65	3,702,837.00	828,831.13	0.68	2,803,146.00	930,523.75	1.06

Figure A.10: 2015_2023_Energy Consumption Analysis Cupey Center



2023		
480	$152.33	0.3174
1,097,280	$412,738.57	0.3761
1,097,760.00	412,890.91	0.69

Figure A.10: 2015_2023_Energy Consumption Analysis Cupey Center



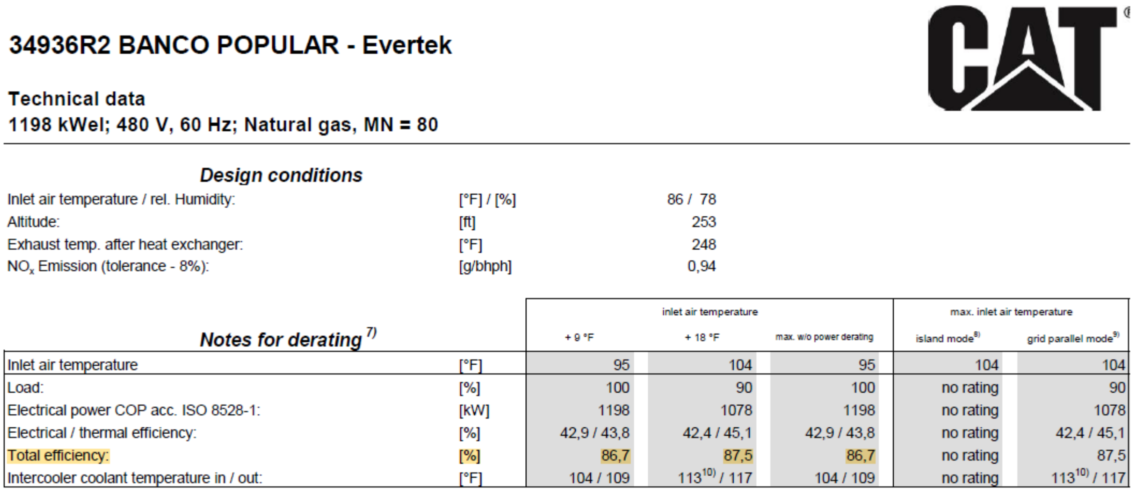
CHP Energy Balance Report		
Electrical Energy	**Jan-Sept 2024**	
Gas (Cogen) Engines	7.554,49	MWh
Diesel Engines	26,74	MWh
Total Energy	7.581,23	MWh
Thermal Energy		
Absorption Chiller 1 Chilled Water	2.337,91	MWh
Absorption Chiller 2 Chilled Water	4.467,45	MWh
Total Heat Recovery	4.423,49	MWh

CG1 & CG2 Electrical Energy			
	1/1/24 12:00 AM	*9/30/24 11:59 PM*	*Total MWh*
Gas (Cogen) Engine 1	13603,58	16920,1	3316,52
Gas (Cogen) Engine 2	13706,88	17944,85	4237,97
			7554,49

AbsCh's Heat Recover				
	1/1/24 12:00 AM	*9/30/24 11:59 PM*	*Total TonsHrs*	*Chilled_MWh_TH*
AbsCh 1	2463455	3128202	664747	2337,91
AbsCh 2	3261058	4531304	1270246	4467,45
				6805

Figure A.11: Cupey_2024_Energy_Production_table

Appendix B: CHP Equipment's Submittals



34936R2 BANCO POPULAR - Evertek

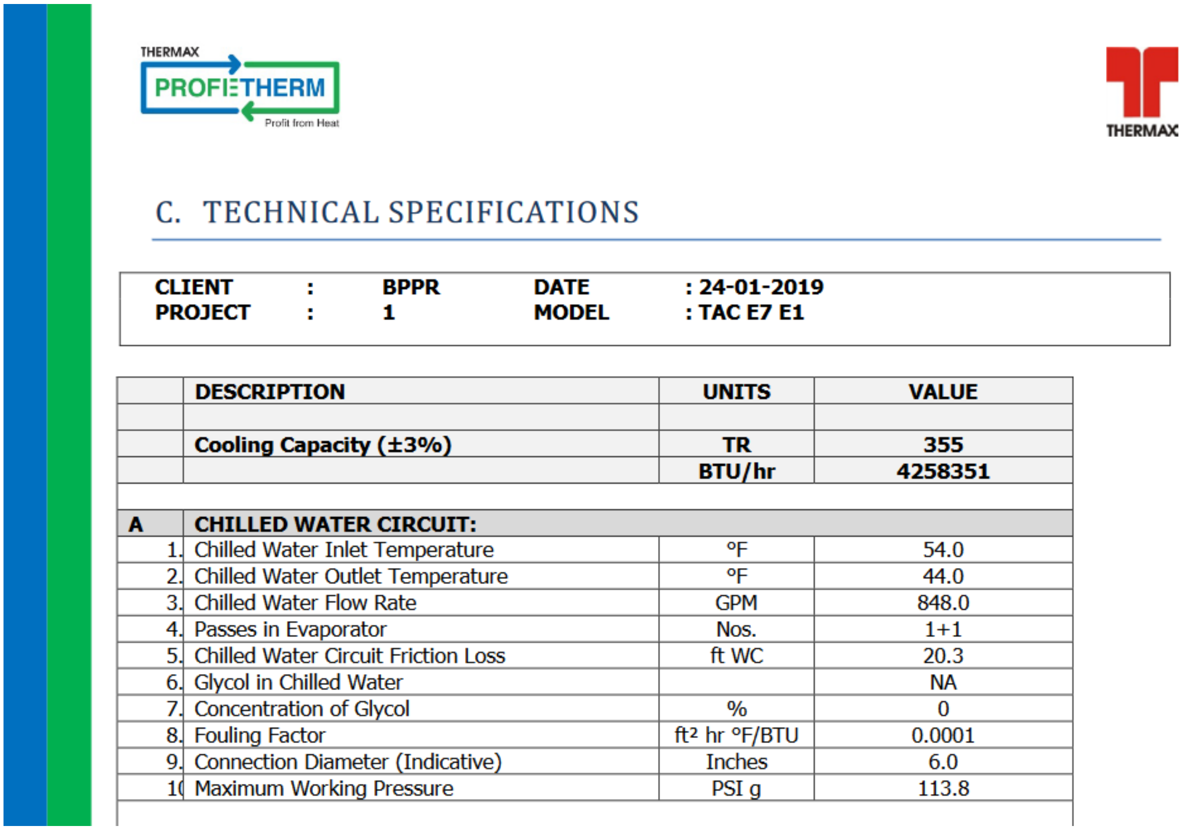
Technical data
1198 kWel; 480 V, 60 Hz; Natural gas, MN = 80

Design conditions

Inlet air temperature / rel. Humidity:	[°F] / [%]	86 / 78
Altitude:	[ft]	253
Exhaust temp. after heat exchanger:	[°F]	248
NO_x Emission (tolerance - 8%):	[g/bhph]	0,94

Notes for derating [7)		inlet air temperature			max. inlet air temperature	
		+ 9 °F	+ 18 °F	max. w/o power derating	island mode[8)	grid parallel mode[9)
Inlet air temperature	[°F]	95	104	95	104	104
Load:	[%]	100	90	100	no rating	90
Electrical power COP acc. ISO 8528-1:	[kW]	1198	1078	1198	no rating	1078
Electrical / thermal efficiency:	[%]	42,9 / 43,8	42,4 / 45,1	42,9 / 43,8	no rating	42,4 / 45,1
Total efficiency:	[%]	86,7	87,5	86,7	no rating	87,5
Intercooler coolant temperature in / out:	[°F]	104 / 109	113[10) / 117	104 / 109	no rating	113[10) / 117

Figure B.1: Generator Datasheet.



THERMAX PROFITHERM Profit from Heat

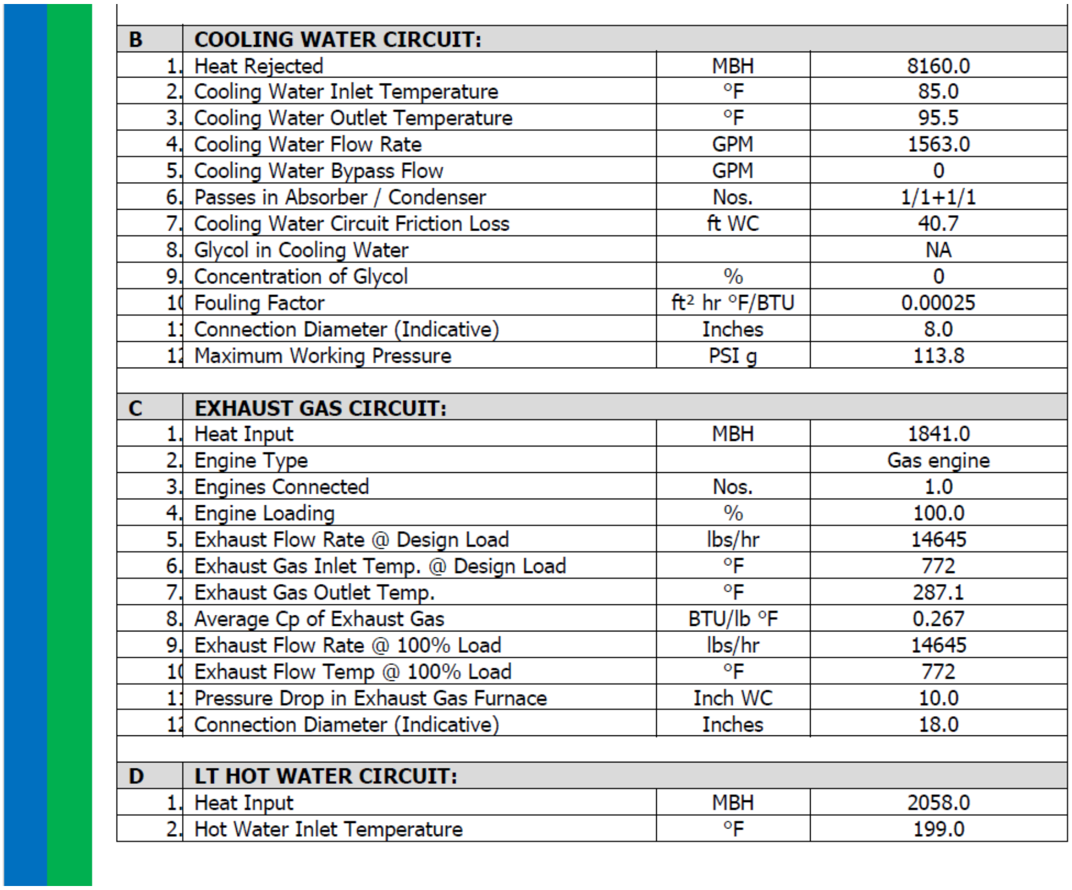
THERMAX

C. TECHNICAL SPECIFICATIONS

CLIENT : BPPR
PROJECT : 1
DATE : 24-01-2019
MODEL : TAC E7 E1

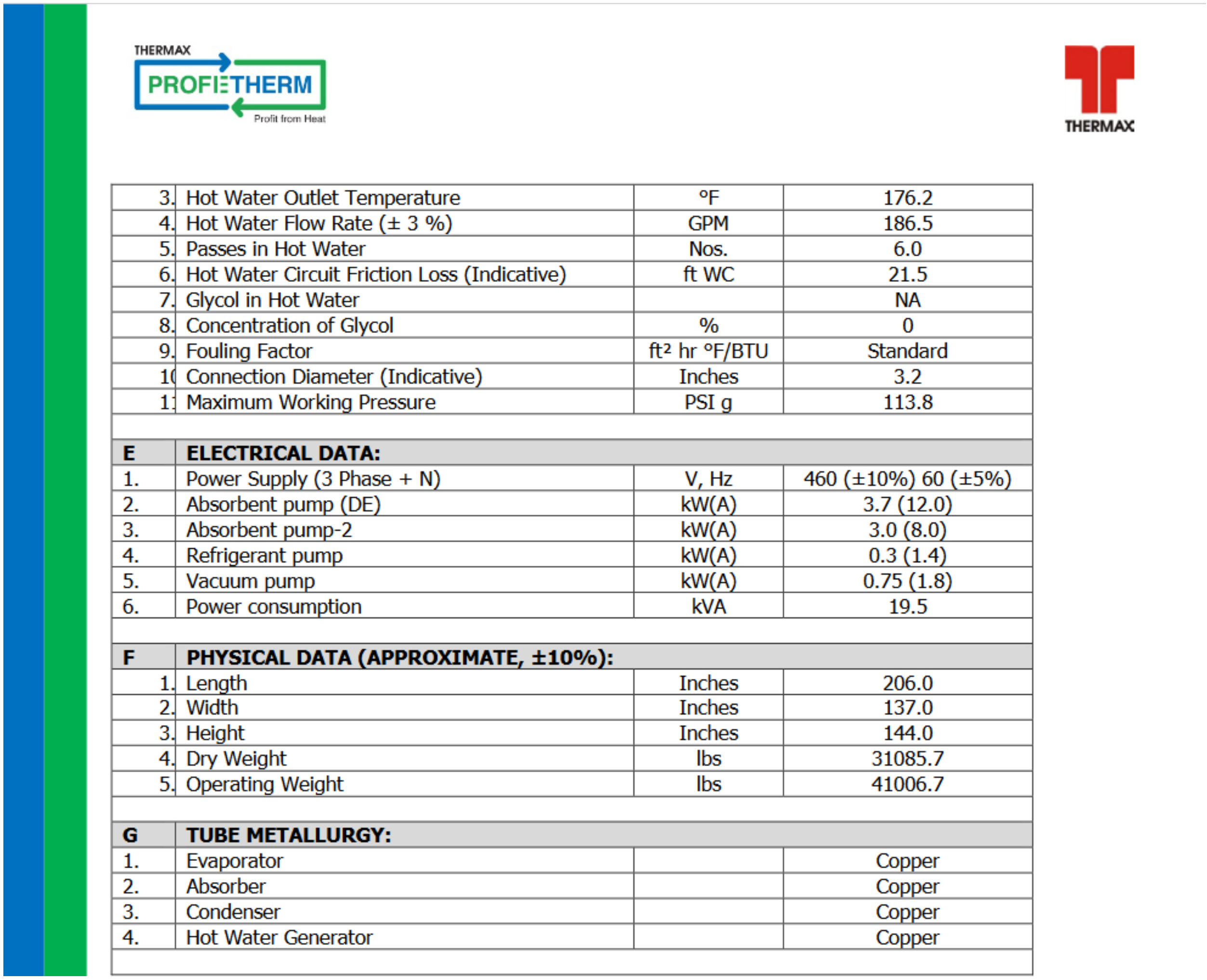
	DESCRIPTION	**UNITS**	**VALUE**
	Cooling Capacity (±3%)	**TR**	**355**
		BTU/hr	**4258351**
A	**CHILLED WATER CIRCUIT:**		
1.	Chilled Water Inlet Temperature	°F	54.0
2.	Chilled Water Outlet Temperature	°F	44.0
3.	Chilled Water Flow Rate	GPM	848.0
4.	Passes in Evaporator	Nos.	1+1
5.	Chilled Water Circuit Friction Loss	ft WC	20.3
6.	Glycol in Chilled Water		NA
7.	Concentration of Glycol	%	0
8.	Fouling Factor	ft² hr °F/BTU	0.0001
9.	Connection Diameter (Indicative)	Inches	6.0
1(	Maximum Working Pressure	PSI g	113.8

Figure B.2: Absorption Chiller #1 Chilled Water Circuit



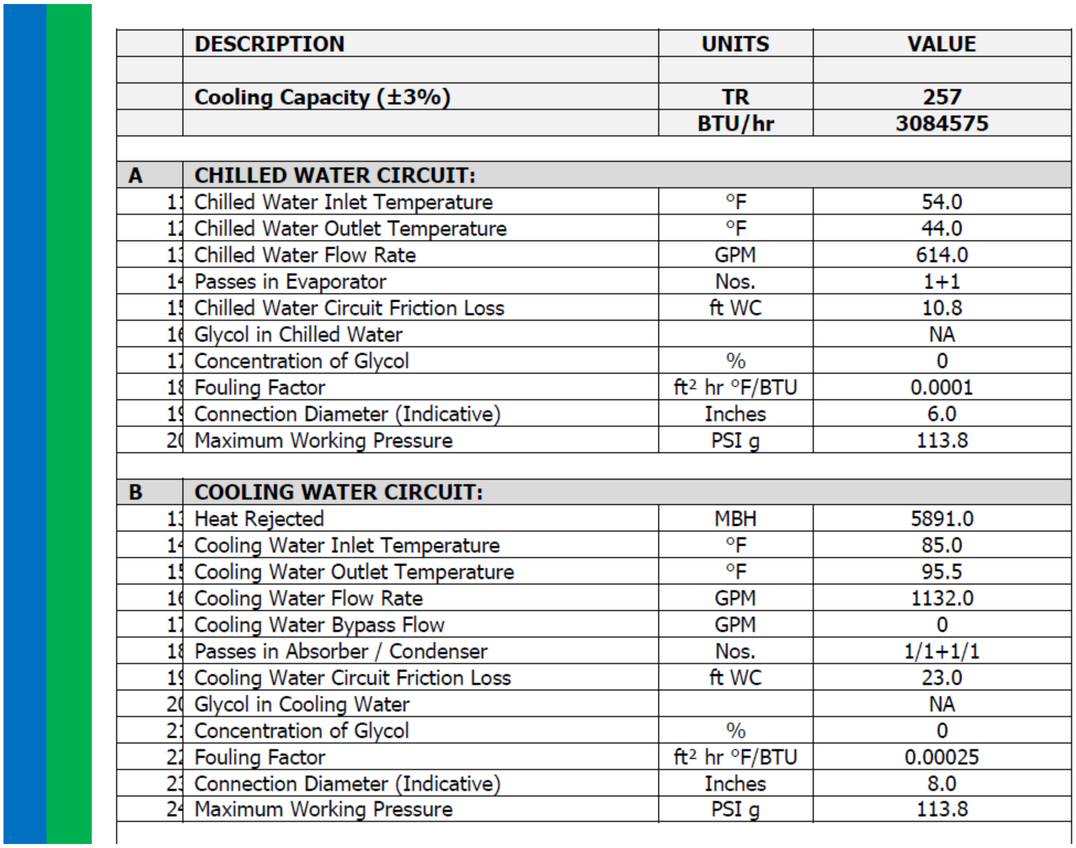
B	**COOLING WATER CIRCUIT:**		
1.	Heat Rejected	MBH	8160.0
2.	Cooling Water Inlet Temperature	°F	85.0
3.	Cooling Water Outlet Temperature	°F	95.5
4.	Cooling Water Flow Rate	GPM	1563.0
5.	Cooling Water Bypass Flow	GPM	0
6.	Passes in Absorber / Condenser	Nos.	1/1+1/1
7.	Cooling Water Circuit Friction Loss	ft WC	40.7
8.	Glycol in Cooling Water		NA
9.	Concentration of Glycol	%	0
10	Fouling Factor	ft^2 hr °F/BTU	0.00025
11	Connection Diameter (Indicative)	Inches	8.0
12	Maximum Working Pressure	PSI g	113.8
C	**EXHAUST GAS CIRCUIT:**		
1.	Heat Input	MBH	1841.0
2.	Engine Type		Gas engine
3.	Engines Connected	Nos.	1.0
4.	Engine Loading	%	100.0
5.	Exhaust Flow Rate @ Design Load	lbs/hr	14645
6.	Exhaust Gas Inlet Temp. @ Design Load	°F	772
7.	Exhaust Gas Outlet Temp.	°F	287.1
8.	Average Cp of Exhaust Gas	BTU/lb °F	0.267
9.	Exhaust Flow Rate @ 100% Load	lbs/hr	14645
10	Exhaust Flow Temp @ 100% Load	°F	772
11	Pressure Drop in Exhaust Gas Furnace	Inch WC	10.0
12	Connection Diameter (Indicative)	Inches	18.0
D	**LT HOT WATER CIRCUIT:**		
1.	Heat Input	MBH	2058.0
2.	Hot Water Inlet Temperature	°F	199.0

Figure B.2: Absorption Chiller #1 Cooling Water, Exhaust Gas and LT Hot Water Circuit



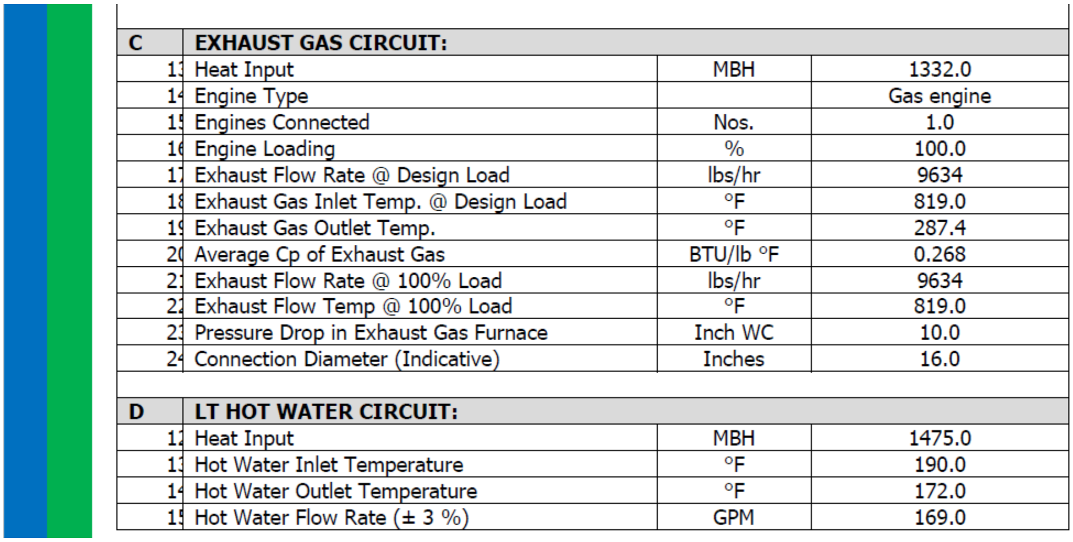
3.	Hot Water Outlet Temperature	°F	176.2
4.	Hot Water Flow Rate (± 3 %)	GPM	186.5
5.	Passes in Hot Water	Nos.	6.0
6.	Hot Water Circuit Friction Loss (Indicative)	ft WC	21.5
7.	Glycol in Hot Water		NA
8.	Concentration of Glycol	%	0
9.	Fouling Factor	ft² hr °F/BTU	Standard
10	Connection Diameter (Indicative)	Inches	3.2
11	Maximum Working Pressure	PSI g	113.8
E	**ELECTRICAL DATA:**		
1.	Power Supply (3 Phase + N)	V, Hz	460 (±10%) 60 (±5%)
2.	Absorbent pump (DE)	kW(A)	3.7 (12.0)
3.	Absorbent pump-2	kW(A)	3.0 (8.0)
4.	Refrigerant pump	kW(A)	0.3 (1.4)
5.	Vacuum pump	kW(A)	0.75 (1.8)
6.	Power consumption	kVA	19.5
F	**PHYSICAL DATA (APPROXIMATE, ±10%):**		
1.	Length	Inches	206.0
2.	Width	Inches	137.0
3.	Height	Inches	144.0
4.	Dry Weight	lbs	31085.7
5.	Operating Weight	lbs	41006.7
G	**TUBE METALLURGY:**		
1.	Evaporator		Copper
2.	Absorber		Copper
3.	Condenser		Copper
4.	Hot Water Generator		Copper

Figure B.2: Absorption Chiller #1 Electrical. Physiscal and Tube Metallurgy Data



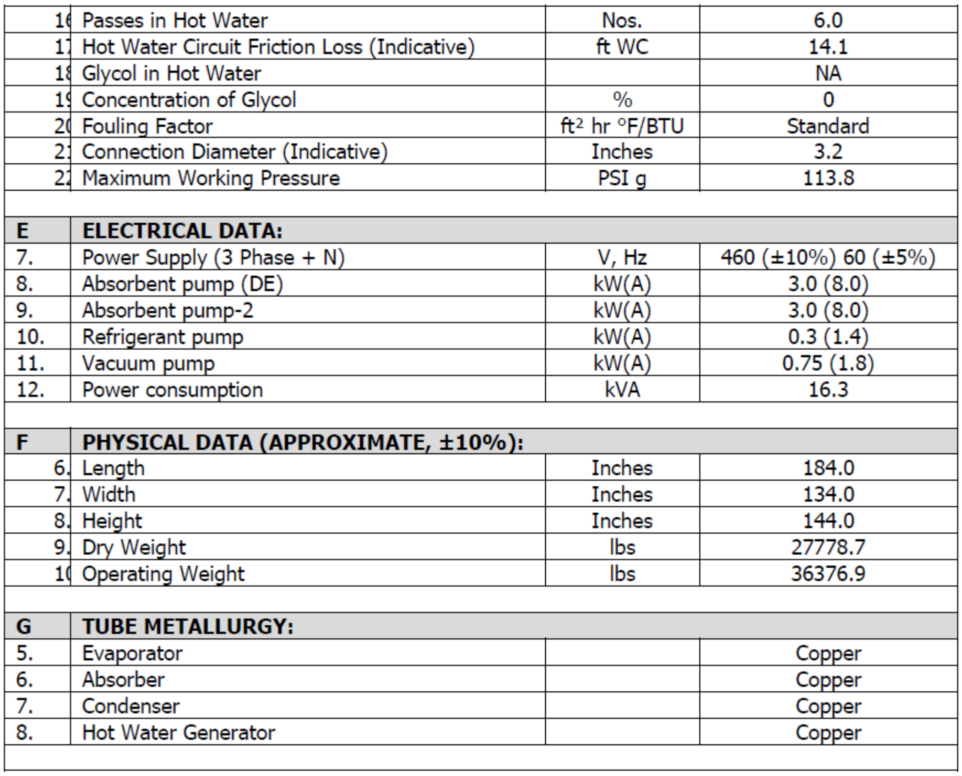
	DESCRIPTION	UNITS	VALUE
	Cooling Capacity (±3%)	**TR**	**257**
		BTU/hr	**3084575**
A	**CHILLED WATER CIRCUIT:**		
11	Chilled Water Inlet Temperature	°F	54.0
12	Chilled Water Outlet Temperature	°F	44.0
13	Chilled Water Flow Rate	GPM	614.0
14	Passes in Evaporator	Nos.	1+1
15	Chilled Water Circuit Friction Loss	ft WC	10.8
16	Glycol in Chilled Water		NA
17	Concentration of Glycol	%	0
18	Fouling Factor	ft² hr °F/BTU	0.0001
19	Connection Diameter (Indicative)	Inches	6.0
20	Maximum Working Pressure	PSI g	113.8
B	**COOLING WATER CIRCUIT:**		
13	Heat Rejected	MBH	5891.0
14	Cooling Water Inlet Temperature	°F	85.0
15	Cooling Water Outlet Temperature	°F	95.5
16	Cooling Water Flow Rate	GPM	1132.0
17	Cooling Water Bypass Flow	GPM	0
18	Passes in Absorber / Condenser	Nos.	1/1+1/1
19	Cooling Water Circuit Friction Loss	ft WC	23.0
20	Glycol in Cooling Water		NA
21	Concentration of Glycol	%	0
22	Fouling Factor	ft² hr °F/BTU	0.00025
23	Connection Diameter (Indicative)	Inches	8.0
24	Maximum Working Pressure	PSI g	113.8

Figure B.3: Absorption Chiller #2 Chilled Water and Cooling Water Circuit



C	**EXHAUST GAS CIRCUIT:**		
13	Heat Input	MBH	1332.0
14	Engine Type		Gas engine
15	Engines Connected	Nos.	1.0
16	Engine Loading	%	100.0
17	Exhaust Flow Rate @ Design Load	lbs/hr	9634
18	Exhaust Gas Inlet Temp. @ Design Load	°F	819.0
19	Exhaust Gas Outlet Temp.	°F	287.4
20	Average Cp of Exhaust Gas	BTU/lb °F	0.268
21	Exhaust Flow Rate @ 100% Load	lbs/hr	9634
22	Exhaust Flow Temp @ 100% Load	°F	819.0
23	Pressure Drop in Exhaust Gas Furnace	Inch WC	10.0
24	Connection Diameter (Indicative)	Inches	16.0
D	**LT HOT WATER CIRCUIT:**		
12	Heat Input	MBH	1475.0
13	Hot Water Inlet Temperature	°F	190.0
14	Hot Water Outlet Temperature	°F	172.0
15	Hot Water Flow Rate (± 3 %)	GPM	169.0

Figure B.3: Absorption Chiller #2 Exhaust Gas and LT Hot Water Circuit



16	Passes in Hot Water	Nos.	6.0
17	Hot Water Circuit Friction Loss (Indicative)	ft WC	14.1
18	Glycol in Hot Water		NA
19	Concentration of Glycol	%	0
20	Fouling Factor	ft² hr °F/BTU	Standard
21	Connection Diameter (Indicative)	Inches	3.2
22	Maximum Working Pressure	PSI g	113.8
E	**ELECTRICAL DATA:**		
7.	Power Supply (3 Phase + N)	V, Hz	460 (±10%) 60 (±5%)
8.	Absorbent pump (DE)	kW(A)	3.0 (8.0)
9.	Absorbent pump-2	kW(A)	3.0 (8.0)
10.	Refrigerant pump	kW(A)	0.3 (1.4)
11.	Vacuum pump	kW(A)	0.75 (1.8)
12.	Power consumption	kVA	16.3
F	**PHYSICAL DATA (APPROXIMATE, ±10%):**		
6.	Length	Inches	184.0
7.	Width	Inches	134.0
8.	Height	Inches	144.0
9.	Dry Weight	lbs	27778.7
10	Operating Weight	lbs	36376.9
G	**TUBE METALLURGY:**		
5.	Evaporator		Copper
6.	Absorber		Copper
7.	Condenser		Copper
8.	Hot Water Generator		Copper

Figure B.3: Absorption Chiller #2 Electrical, Physical and Tube Metallurgy Data

Appendix C: PV Equipment's Submittals

NEW

Preliminary Technical Information Sheet

CanadianSolar

BiHiKu6

520 W ~ 550 W

BIFACIAL MONO PERC

CS6W-520|525|530|535|540|545|550MB-AG (IEC1000 V)

CS6W-520|525|530|535|540|545|550MB-AG (IEC1500 V)

MORE POWER

550 W Module power up to 550 W
Module efficiency up to 21.4 %

Up to 12.3 % lower LCOE
Up to 5.2 % lower system cost

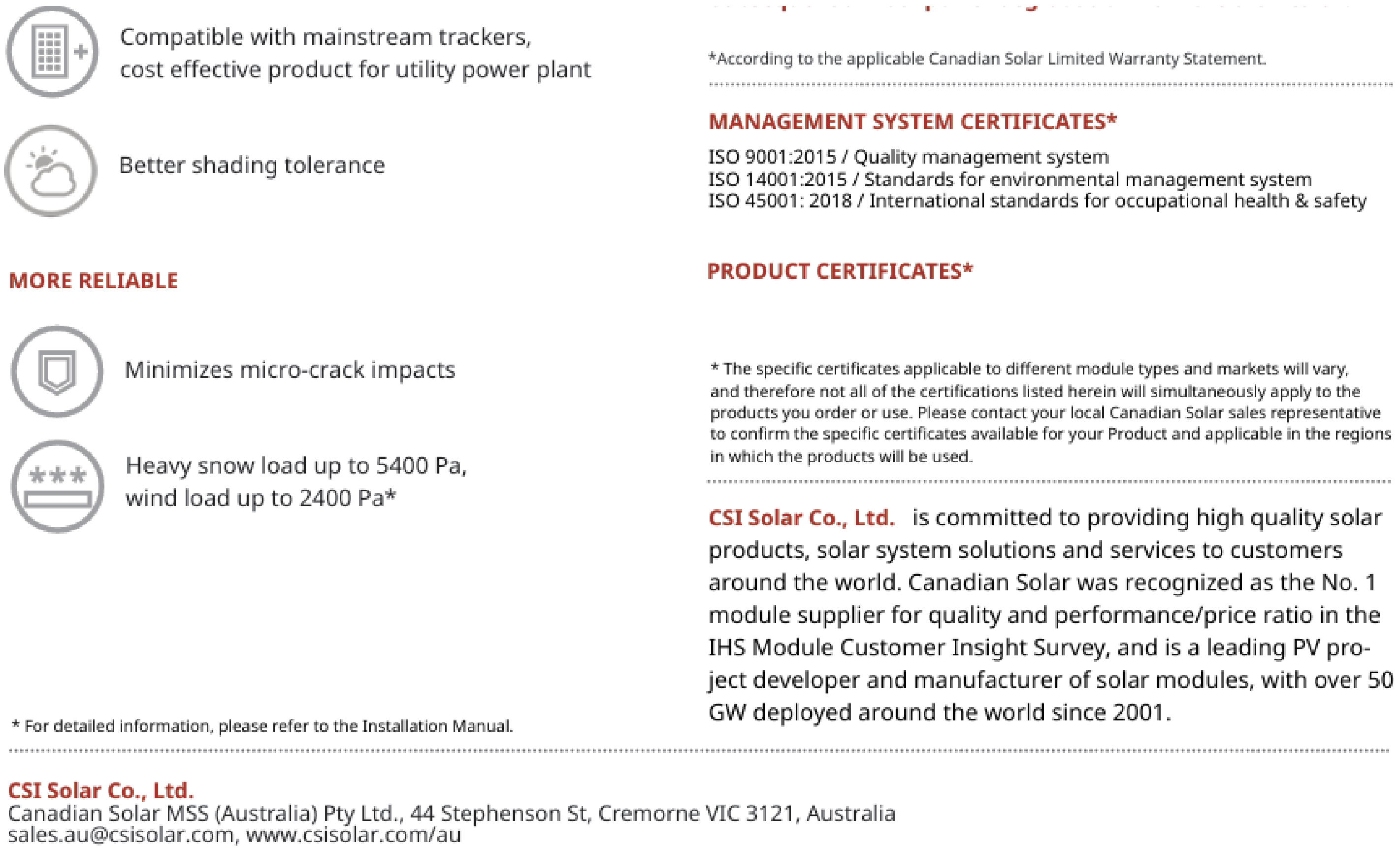
Comprehensive LID / LeTID mitigation technology, up to 50% lower degradation

12 Years **Enhanced Product Warranty on Materials and Workmanship***

30 Years **Linear Power Performance Warranty***

1st year power degradation no more than 2%
Subsequent annual power degradation no more than 0.45%

Figure C.1: Canadian Solar BiHiKu6 550W Datasheet



Compatible with mainstream trackers, cost effective product for utility power plant

Better shading tolerance

MORE RELIABLE

Minimizes micro-crack impacts

Heavy snow load up to 5400 Pa, wind load up to 2400 Pa*

* For detailed information, please refer to the Installation Manual.

*According to the applicable Canadian Solar Limited Warranty Statement.

MANAGEMENT SYSTEM CERTIFICATES*

ISO 9001:2015 / Quality management system
ISO 14001:2015 / Standards for environmental management system
ISO 45001: 2018 / International standards for occupational health & safety

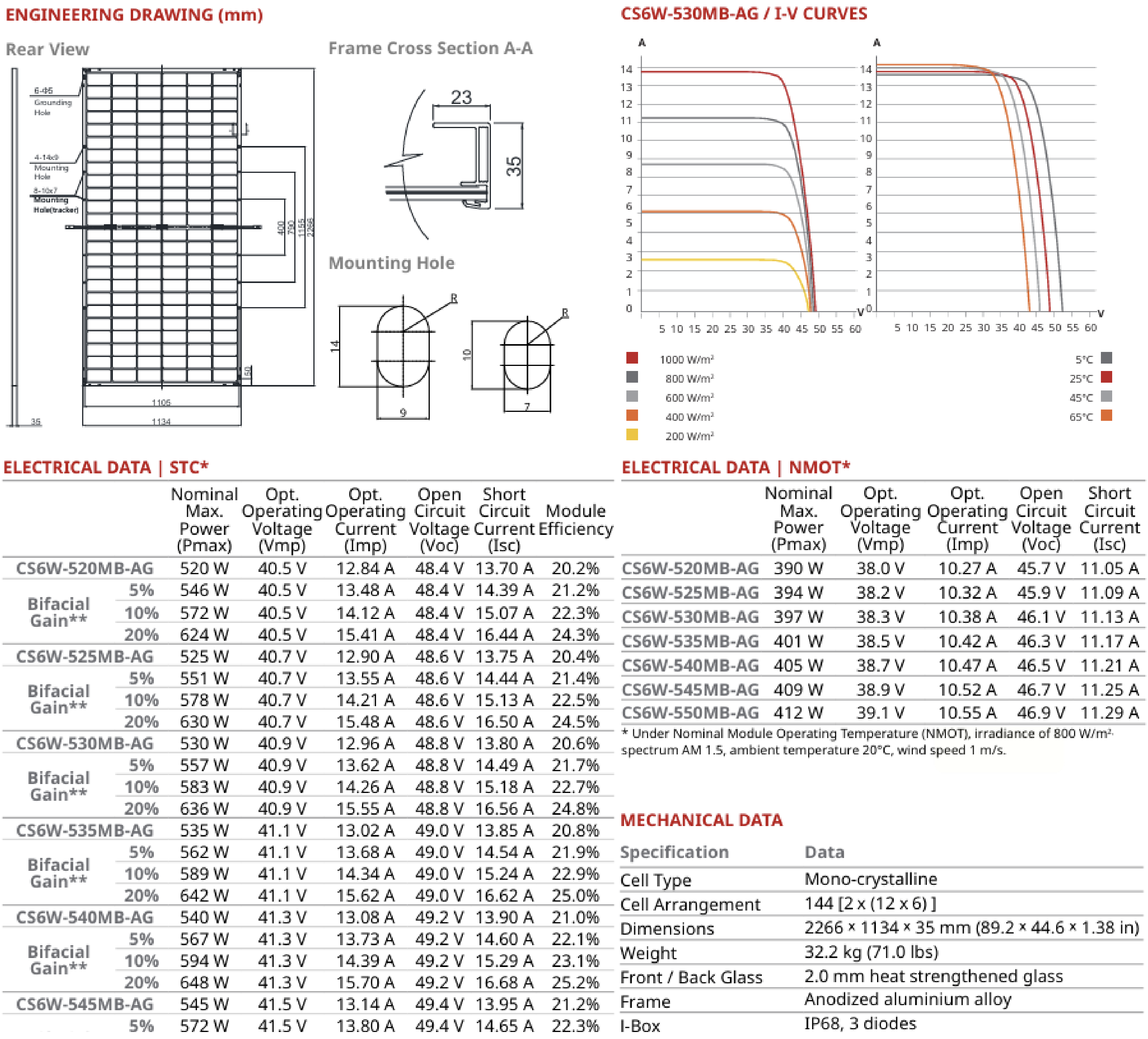
PRODUCT CERTIFICATES*

* The specific certificates applicable to different module types and markets will vary, and therefore not all of the certifications listed herein will simultaneously apply to the products you order or use. Please contact your local Canadian Solar sales representative to confirm the specific certificates available for your Product and applicable in the regions in which the products will be used.

CSI Solar Co., Ltd. is committed to providing high quality solar products, solar system solutions and services to customers around the world. Canadian Solar was recognized as the No. 1 module supplier for quality and performance/price ratio in the IHS Module Customer Insight Survey, and is a leading PV project developer and manufacturer of solar modules, with over 50 GW deployed around the world since 2001.

CSI Solar Co., Ltd.
Canadian Solar MSS (Australia) Pty Ltd., 44 Stephenson St, Cremorne VIC 3121, Australia
sales.au@csisolar.com, www.csisolar.com/au

Figure C.1: Canadian Solar BiHiKu6 550W Datasheet



ENGINEERING DRAWING (mm)

Rear View

Frame Cross Section A-A

Mounting Hole

CS6W-530MB-AG / I-V CURVES

🟥	1000 W/m²	5°C	■
■	800 W/m²	25°C	🟥
■	600 W/m²	45°C	■
🟧	400 W/m²	65°C	🟧
🟨	200 W/m²		

ELECTRICAL DATA | STC*

		Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Module Efficiency
CS6W-520MB-AG		520 W	40.5 V	12.84 A	48.4 V	13.70 A	20.2%
Bifacial Gain**	5%	546 W	40.5 V	13.48 A	48.4 V	14.39 A	21.2%
	10%	572 W	40.5 V	14.12 A	48.4 V	15.07 A	22.3%
	20%	624 W	40.5 V	15.41 A	48.4 V	16.44 A	24.3%
CS6W-525MB-AG		525 W	40.7 V	12.90 A	48.6 V	13.75 A	20.4%
Bifacial Gain**	5%	551 W	40.7 V	13.55 A	48.6 V	14.44 A	21.4%
	10%	578 W	40.7 V	14.21 A	48.6 V	15.13 A	22.5%
	20%	630 W	40.7 V	15.48 A	48.6 V	16.50 A	24.5%
CS6W-530MB-AG		530 W	40.9 V	12.96 A	48.8 V	13.80 A	20.6%
Bifacial Gain**	5%	557 W	40.9 V	13.62 A	48.8 V	14.49 A	21.7%
	10%	583 W	40.9 V	14.26 A	48.8 V	15.18 A	22.7%
	20%	636 W	40.9 V	15.55 A	48.8 V	16.56 A	24.8%
CS6W-535MB-AG		535 W	41.1 V	13.02 A	49.0 V	13.85 A	20.8%
Bifacial Gain**	5%	562 W	41.1 V	13.68 A	49.0 V	14.54 A	21.9%
	10%	589 W	41.1 V	14.34 A	49.0 V	15.24 A	22.9%
	20%	642 W	41.1 V	15.62 A	49.0 V	16.62 A	25.0%
CS6W-540MB-AG		540 W	41.3 V	13.08 A	49.2 V	13.90 A	21.0%
Bifacial Gain**	5%	567 W	41.3 V	13.73 A	49.2 V	14.60 A	22.1%
	10%	594 W	41.3 V	14.39 A	49.2 V	15.29 A	23.1%
	20%	648 W	41.3 V	15.70 A	49.2 V	16.68 A	25.2%
CS6W-545MB-AG		545 W	41.5 V	13.14 A	49.4 V	13.95 A	21.2%
	5%	572 W	41.5 V	13.80 A	49.4 V	14.65 A	22.3%

ELECTRICAL DATA | NMOT*

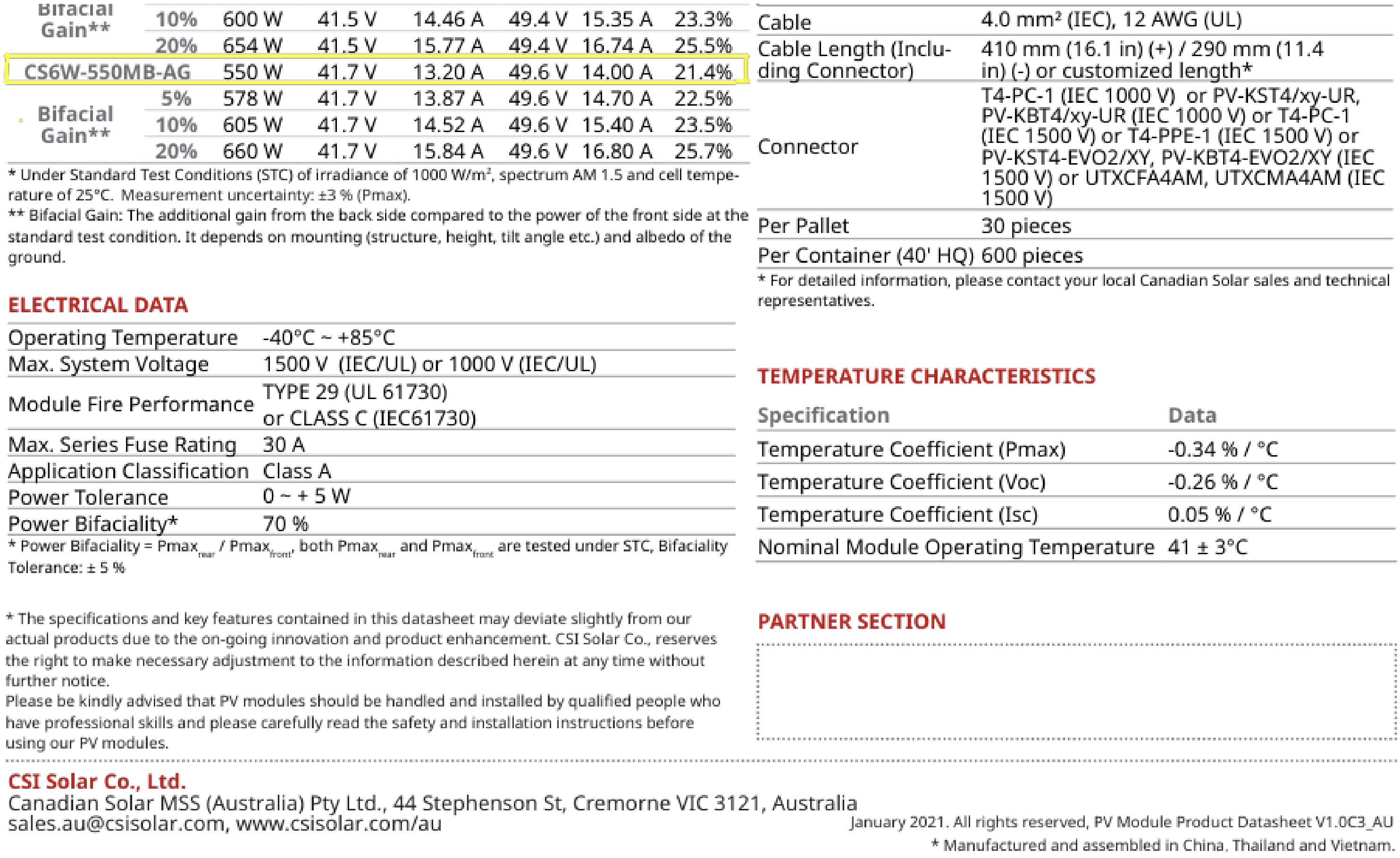
	Nominal Max. Power (Pmax)	Opt. Operating Voltage (Vmp)	Opt. Operating Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)
CS6W-520MB-AG	390 W	38.0 V	10.27 A	45.7 V	11.05 A
CS6W-525MB-AG	394 W	38.2 V	10.32 A	45.9 V	11.09 A
CS6W-530MB-AG	397 W	38.3 V	10.38 A	46.1 V	11.13 A
CS6W-535MB-AG	401 W	38.5 V	10.42 A	46.3 V	11.17 A
CS6W-540MB-AG	405 W	38.7 V	10.47 A	46.5 V	11.21 A
CS6W-545MB-AG	409 W	38.9 V	10.52 A	46.7 V	11.25 A
CS6W-550MB-AG	412 W	39.1 V	10.55 A	46.9 V	11.29 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

MECHANICAL DATA

Specification	Data
Cell Type	Mono-crystalline
Cell Arrangement	144 [2 x (12 x 6)]
Dimensions	2266 × 1134 × 35 mm (89.2 × 44.6 × 1.38 in)
Weight	32.2 kg (71.0 lbs)
Front / Back Glass	2.0 mm heat strengthened glass
Frame	Anodized aluminium alloy
J-Box	IP68, 3 diodes

Figure C.1: Canadian Solar BiHiKu6 550W Datasheet



Bifacial Gain**	10%	600 W	41.5 V	14.46 A	49.4 V	15.35 A	23.3%
	20%	654 W	41.5 V	15.77 A	49.4 V	16.74 A	25.5%
CS6W-550MB-AG		550 W	41.7 V	13.20 A	49.6 V	14.00 A	21.4%
Bifacial Gain**	5%	578 W	41.7 V	13.87 A	49.6 V	14.70 A	22.5%
	10%	605 W	41.7 V	14.52 A	49.6 V	15.40 A	23.5%
	20%	660 W	41.7 V	15.84 A	49.6 V	16.80 A	25.7%

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C. Measurement uncertainty: ±3 % (Pmax).

** Bifacial Gain: The additional gain from the back side compared to the power of the front side at the standard test condition. It depends on mounting (structure, height, tilt angle etc.) and albedo of the ground.

ELECTRICAL DATA

Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1500 V (IEC/UL) or 1000 V (IEC/UL)
Module Fire Performance	TYPE 29 (UL 61730) or CLASS C (IEC61730)
Max. Series Fuse Rating	30 A
Application Classification	Class A
Power Tolerance	0 ~ + 5 W
Power Bifaciality*	70 %

* Power Bifaciality = $Pmax_{rear}$ / $Pmax_{front}$, both $Pmax_{rear}$ and $Pmax_{front}$ are tested under STC, Bifaciality Tolerance: ± 5 %

* The specifications and key features contained in this datasheet may deviate slightly from our actual products due to the on-going innovation and product enhancement. CSI Solar Co., reserves the right to make necessary adjustment to the information described herein at any time without further notice.
Please be kindly advised that PV modules should be handled and installed by qualified people who have professional skills and please carefully read the safety and installation instructions before using our PV modules.

Cable	4.0 mm² (IEC), 12 AWG (UL)
Cable Length (Including Connector)	410 mm (16.1 in) (+) / 290 mm (11.4 in) (-) or customized length*
Connector	T4-PC-1 (IEC 1000 V) or PV-KST4/xy-UR, PV-KBT4/xy-UR (IEC 1000 V) or T4-PC-1 (IEC 1500 V) or T4-PPE-1 (IEC 1500 V) or PV-KST4-EVO2/XY, PV-KBT4-EVO2/XY (IEC 1500 V) or UTXCFA4AM, UTXCMA4AM (IEC 1500 V)
Per Pallet	30 pieces
Per Container (40' HQ)	600 pieces

* For detailed information, please contact your local Canadian Solar sales and technical representatives.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.34 % / °C
Temperature Coefficient (Voc)	-0.26 % / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	41 ± 3°C

PARTNER SECTION

CSI Solar Co., Ltd.
Canadian Solar MSS (Australia) Pty Ltd., 44 Stephenson St, Cremorne VIC 3121, Australia
sales.au@csisolar.com, www.csisolar.com/au

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* Manufactured and assembled in China, Thailand and Vietnam.

Figure C.1: Canadian Solar BiHiKu6 550W Datasheet

SUNNY TRIPOWER CORE1 33-US / 50-US / 62-US

UP TO 60% FASTER INSTALLATION FOR COMMERCIAL PV SYSTEMS

Fully integrated

- Innovative design requires no additional racking for rooftop installation
- Integrated DC and AC disconnects and overvoltage protection
- 12 direct string inputs for reduced labor and material costs

Increased power, flexibility

- Multiple power ratings for small to large scale commercial PV installations
- Six MPP trackers for flexible stringing and maximum power production
- OptiTrac™ Global Peak shade tolerant MPP tracking

Enhanced safety, reliability

- Integrated SunSpec PLC signal for module-level rapid shutdown compliance to 2017 NEC
- Next-gen DC AFCI arc-fault protection certified to new Standard UL 1699B

Smart monitoring, control, service

- Advanced smart inverter grid support capabilities
- Increased ROI with SMA ennexOS cross sector energy management platform
- SMA Smart Connected proactive O&M solution reduces time spent diagnosing and servicing in the field

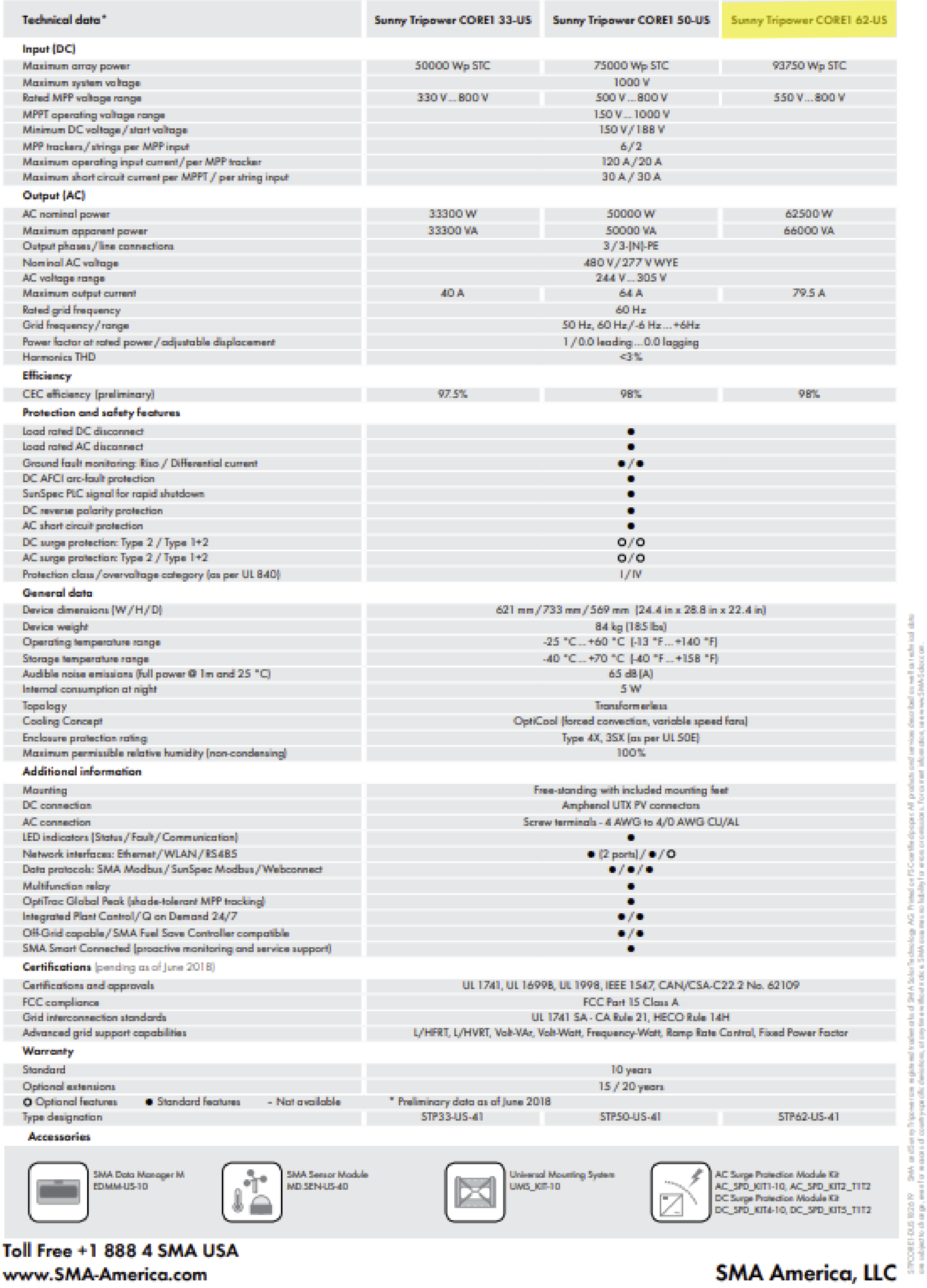
SUNNY TRIPOWER CORE1 33-US / 50-US / 62-US

It stands on its own

The Sunny Tripower CORE1 is the world's first free-standing PV inverter for commercial rooftops, carports, ground mount and repowering legacy solar projects. Now with expanded features and new power classes, the CORE1 is the most versatile, cost-effective commercial solution available. From distribution to construction to operation, the Sunny Tripower CORE1 enables logistical, material, labor and service cost reductions. Integrated SunSpec PLC for rapid shutdown and enhanced DC AFCI arc-fault protection ensure compliance to the latest safety codes and standards. With Sunny Tripower CORE1 and SMA's ennexOS cross sector energy management platform, system integrators can deliver comprehensive commercial energy solutions for increased ROI.

www.SMA-America.com

Figure C.2: SMA Sunny Tripower Core1 62US Datasheet



Technical data*	Sunny Tripower CORE1 33-US	Sunny Tripower CORE1 50-US	Sunny Tripower CORE1 62-US
Input (DC)			
Maximum array power	50000 Wp STC	75000 Wp STC	93750 Wp STC
Maximum system voltage	1000 V		
Rated MPP voltage range	330 V ... 800 V	500 V ... 800 V	550 V ... 800 V
MPPT operating voltage range	150 V ... 1000 V		
Minimum DC voltage / start voltage	150 V / 188 V		
MPP trackers / strings per MPP input	6 / 2		
Maximum operating input current / per MPP tracker	120 A / 20 A		
Maximum short circuit current per MPPT / per string input	30 A / 30 A		
Output (AC)			
AC nominal power	33300 W	50000 W	62500 W
Maximum apparent power	33300 VA	50000 VA	66000 VA
Output phases / line connections	3 / 3-(N)-PE		
Nominal AC voltage	480 V / 277 V WYE		
AC voltage range	244 V ... 305 V		
Maximum output current	40 A	64 A	79.5 A
Rated grid frequency	60 Hz		
Grid frequency / range	50 Hz, 60 Hz / -6 Hz ... +6Hz		
Power factor at rated power / adjustable displacement	1 / 0.0 leading ... 0.0 lagging		
Harmonics THD	<3%		
Efficiency			
CEC efficiency (preliminary)	97.5%	98%	98%
Protection and safety features			
Load rated DC disconnect	●		
Load rated AC disconnect	●		
Ground fault monitoring: Riso / Differential current	● / ●		
DC AFCI arc-fault protection	●		
SunSpec PLC signal for rapid shutdown	●		
DC reverse polarity protection	●		
AC short circuit protection	●		
DC surge protection: Type 2 / Type 1+2	○ / ○		
AC surge protection: Type 2 / Type 1+2	○ / ○		
Protection class / overvoltage category (as per UL 840)	I / IV		
General data			
Device dimensions (W / H / D)	621 mm / 733 mm / 569 mm (24.4 in x 28.8 in x 22.4 in)		
Device weight	84 kg (185 lbs)		
Operating temperature range	-25 °C ... +60 °C (-13 °F ... +140 °F)		
Storage temperature range	-40 °C ... +70 °C (-40 °F ... +158 °F)		
Audible noise emissions (full power @ 1m and 25 °C)	65 dB(A)		
Internal consumption at night	5 W		
Topology	Transformerless		
Cooling Concept	OptiCool (forced convection, variable speed fans)		
Enclosure protection rating	Type 4X, 3SX (as per UL 50E)		
Maximum permissible relative humidity (non-condensing)	100%		
Additional information			
Mounting	Free-standing with included mounting feet		
DC connection	Amphenol UTX PV connectors		
AC connection	Screw terminals - 4 AWG to 4/0 AWG CU/AL		
LED indicators (Status / Fault / Communication)	●		
Network interfaces: Ethernet / WLAN / RS485	● (2 ports) / ● / ○		
Data protocols: SMA Modbus / SunSpec Modbus / Webconnect	● / ● / ●		
Multifunction relay	●		
OptiTrac Global Peak (shade-tolerant MPP tracking)	●		
Integrated Plant Control / Q on Demand 24/7	● / ●		
Off-Grid capable / SMA Fuel Save Controller compatible	● / ●		
SMA Smart Connected (proactive monitoring and service support)	●		
Certifications (pending as of June 2018)			
Certifications and approvals	UL 1741, UL 1699B, UL 1998, IEEE 1547, CAN/CSA-C22.2 No. 62109		
FCC compliance	FCC Part 15 Class A		
Grid interconnection standards	UL 1741 SA - CA Rule 21, HECO Rule 14H		
Advanced grid support capabilities	L/HFRT, L/HVRT, Volt-VAr, Volt-Watt, Frequency-Watt, Ramp Rate Control, Fixed Power Factor		
Warranty			
Standard	10 years		
Optional extensions	15 / 20 years		
○ Optional features ● Standard features - Not available	* Preliminary data as of June 2018		
Type designation	STP33-US-41	STP50-US-41	STP62-US-41

Accessories

SMA Data Manager M
EDMM-US-10

SMA Sensor Module
MD.SEN-US-40

Universal Mounting System
UMS_KIT-10

AC Surge Protection Module Kit
AC_SPD_KIT1-10, AC_SPD_KIT2_T1T2
DC Surge Protection Module Kit
DC_SPD_KIT4-10, DC_SPD_KIT5_T1T2

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SMA America, LLC

Figure C.2: SMA Sunny Tripower Core1 62US Datasheet