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Low-Air Emission, Renewable Energy Powered Mobile Micro-Grid Installations for Border Colonias

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Final Report to the
Texas Commission on Environmental Quality

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Executive Summary

In early 2007, the Texas State Energy Conservation Office (SECO) engaged the Texas Engineering Experiment Station and its partner, Xtreme Power, Inc., to develop and install a hybrid microgrid system for underserved communities along the Texas-Mexico border. This system consisted of a proprietary energy storage technology, high efficiency charging and inverting systems, photovoltaic cells, a wind turbine, and a bio-diesel generator. This combination of technologies is able to provide 24 hour power to dwellings that are not grid connected, with a significant savings in fuel by allowing power generation at highly efficient operating conditions to generate the total amount of electricity needed for 24 hours of operation in a short time and storing the electricity for later distribution.

The objectives of this project are twofold. First, to provide an additional instance of the microgrid system providing additional data for evaluation of the design providing minimal electrical to residences not connected to the commercial power grid. The second objective was to collect system energy utilization and air emission data to determine the economic viability of the system. This report provides a summary and an analysis of the data collected.

Overall, we achieved our objectives by providing additional data to evaluate the microgrid system design in providing minimal electrical to residences not connected to the commercial power grid. Also, we determined the economic viability of the system. The lifetime of the hybrid system is significantly longer and provides effectiveness in reducing amortized capital costs. The cost for fuel and maintenance overwhelm the capital costs with total operational costs achieved $1.72/KWh (including both capital amortization and operational costs). The addition of wind would help to offset the evening load of the system. The genset requires additional optimization as well, due to the load characteristics.

Overall, the system performed very well. The overall efficiency of the system (ratio of power provided to colonia residents to total power produced by all generation systems) is measured to be 83%. The average utilization of power per residence was 74.69 KWh/month. When examining the percentage of time that the residents were without power, due to other factors such as late fuel delivery and generator failure, the system reliability comes in at 97% (5 days without power/181 total days).

Unless their use is required to address other environmental concerns, we found that the use of bio-fuels to reduce emissions in areas that are compliant with air quality regulations are not cost effective. . The normalized fuel and maintenance cost for the bio-fuel was $7,638 when compared to using only #2 low sulfur diesel, the cost would have been $6,472.

Introduction

Background

In early 2007, the Texas State Energy Conservation Office (SECO) provided a grant to the Texas Engineering Experiment Station (TEES) and its partner, Xtreme Power, Inc., to develop and install a hybrid microgrid system for underserved communities (known as Colonias) along the Texas-Mexico border. This system consisted of a proprietary energy storage technology, high efficiency charging and inverting systems, photovoltaic cells, a wind turbine, and a bio-diesel generator. This combination of technologies is able to provide 24 hour power to dwellings that are not grid connected, with a significant savings in fuel over conventional generators by allowing power generation at highly efficient operating conditions to generate the total amount of electricity needed for 24 hours of operation in a short time and storing the electricity for later distribution. SECO provided funding to develop and install these micro-grids in Colonias in the Laredo, TX area. The location chosen was the La Presa Subdivision, a Colonia about 5 miles south of Laredo on US Highway 83. In 2008, SECO suggested that the project team expand the effort by applying for additional funding available from the federal Environmental Protection Agency (EPA) through the Texas Commission on Environmental Quality (TCEQ). This project is the result of that grant request.

The SECO funding provided for the development and integration of the various technologies making up the microgrids from existing technologies. Using that funding, the team was able to select and develop three sites in the La Presa community.

Project Objectives

The objectives of this project are twofold. First, to provide an additional instance of the microgrid system providing additional data for evaluation of the design providing minimal electrical to residences not connected to the commercial power grid. The second objective was to collect system energy utilization and air emission data to determine the economic viability of the system. This report provides a summary and an analysis of the data collected.

Team Members

Texas Engineering Experiment Station (TEES – the Engineering Research Agency for the State of Texas) was the technology integrator and analyst of the project. TEES was the prime grantee and was responsible for the overall management of the project and coordinated all grant team activities. TEES provided engineering oversight of the design projects submitted by Xtreme Power or other vendors. TEES provided financial control for the project and was responsible for fulfilling all reporting requirements. TEES issued subcontracts to the various grant team members and provided managerial oversight of each grant team member in their activities related to this grant.

The Center for Housing and Urban Development (CHUD) – Texas A&M University College of Architecture administered the local involvement in the Colonias and provided coordination with local government (Webb County) as required for the installation, testing, and monitoring of the prototype systems. CHUD provided for the direct technology transfer to the residents of the community, especially the Colonia residents through CHUD's promotores. The promotores are residents of the Colonias that have been trained in outreach and are aware of all the available services and technologies provided for Colonia residents. CHUD also assisted TEES and Xtreme Power in the site selection for the prototype systems. CHUD enlisted promotores to help introduce the new micro grid technology and ensure its proper use through education of the residents.

Xtreme Power was the technology provider for this project. Xtreme Power provided test and production systems for the micro-grids and coordinated with TEES, CHUD, and Webb County in the installation and operation of the grids.

System Description and Capabilities

Site Selection

El Paso County

Initially, the project team (TEES and the technology provider Xtreme Power, Inc) sought to locate the system in El Paso County. This desire was the result of requests to SECO from County officials in El Paso as well as the desire to provide an additional project in the region. The team made a site visit to the El Paso area the week of October 20, 2008. Our goal was a higher density installation than the area in La Presa in Webb County and the sites were evaluated against that baseline. Working with the regional Center for Housing and Urban Development (CHUD) office, the team visited several possible implementation sites in area colonias, specifically the candidate area was east of El Paso in an area called Sunset Ranch.

We found no suitable locations in the El Paso/West Texas area. Not only was the density of colonia residents insufficient for a high density installation, it was insufficient for an installation of the micro-grid system at all. The current systems require a maximum distance from the generator of around 1300-1500 ft (about ½ mile in diameter around the generator station). The normal distance between colonia dwellings in the El Paso/West Texas started at ½ mile and ranged up to 20 miles and did not meet the minimum criteria of this project much less the actual capabilities of the design. Each of these dwellings would require an individual power solution which was not the goal of this effort. The team continued searching in the El Paso and Hudspeth County areas through the end of December 2008 and was not successful in locating an area that was suitable for implementation. The team decided to abandon searching for feasible locations in El Paso and surrounding Counties and proceed to other locations. This decision was made with the concurrence of the TCEQ Program Manager.

Hidalgo/Cameron/Willacy Counties

Upon abandonment of the El Paso option, the team began to investigate other locations along the Texas/Mexico border with the metric of higher density that the La Presa installations. Two areas of interest were investigated concurrently. The regional CHUD offices of Laredo/Eagle Pass/Zapata County and the Rio Grande Valley were tasked to identify possible locations in their respective areas of responsibility. Eagle Pass was thought to have opportunities due to a tornado that passed through a colonia in 2007, however, all connections to dwellings damaged by the tornado had been restored and no other locations in the Eagle Pass area were viable.

Investigation in the Rio Grande Valley took a bit longer due to the fact that there are dozens of municipalities and 3 different county governments with multiple precincts in each county. At the conclusion of our investigation in March 2009, we had determined that there are no colonias in the Rio Grande Valley that did not have electrical connections.

Webb County (Final Site Selected)

At this point, we realized that time had become of the essence since our experience in La Presa indicated that once the site was identified; the obtaining of easements was a 3 month process. To be able to execute the grant, our fallback position was to locate an additional location within the La Presa colonia that met our selection criteria.

In May 2009, the team identified a location in the La Presa colonia that met the site selection requirements and began the easement acquisition process. This process completed in August and installation of the micro-grid began in August 2009.

The location in La Presa (designated the “near east” site in terms of its relationship to the other microgrid locations in La Presa) is shown in the following map (Figure 1). Figure 2 shows the initial planned layout at the location of the grid. Figure 3 shows the actual installed line locations with respect to the plat map of the La Presa subdivision. The green box is the location of the generator station; the blue lines represent the location of the power distribution lines; and the red open box show the location of a dwelling in the imagery that is served by the grid.

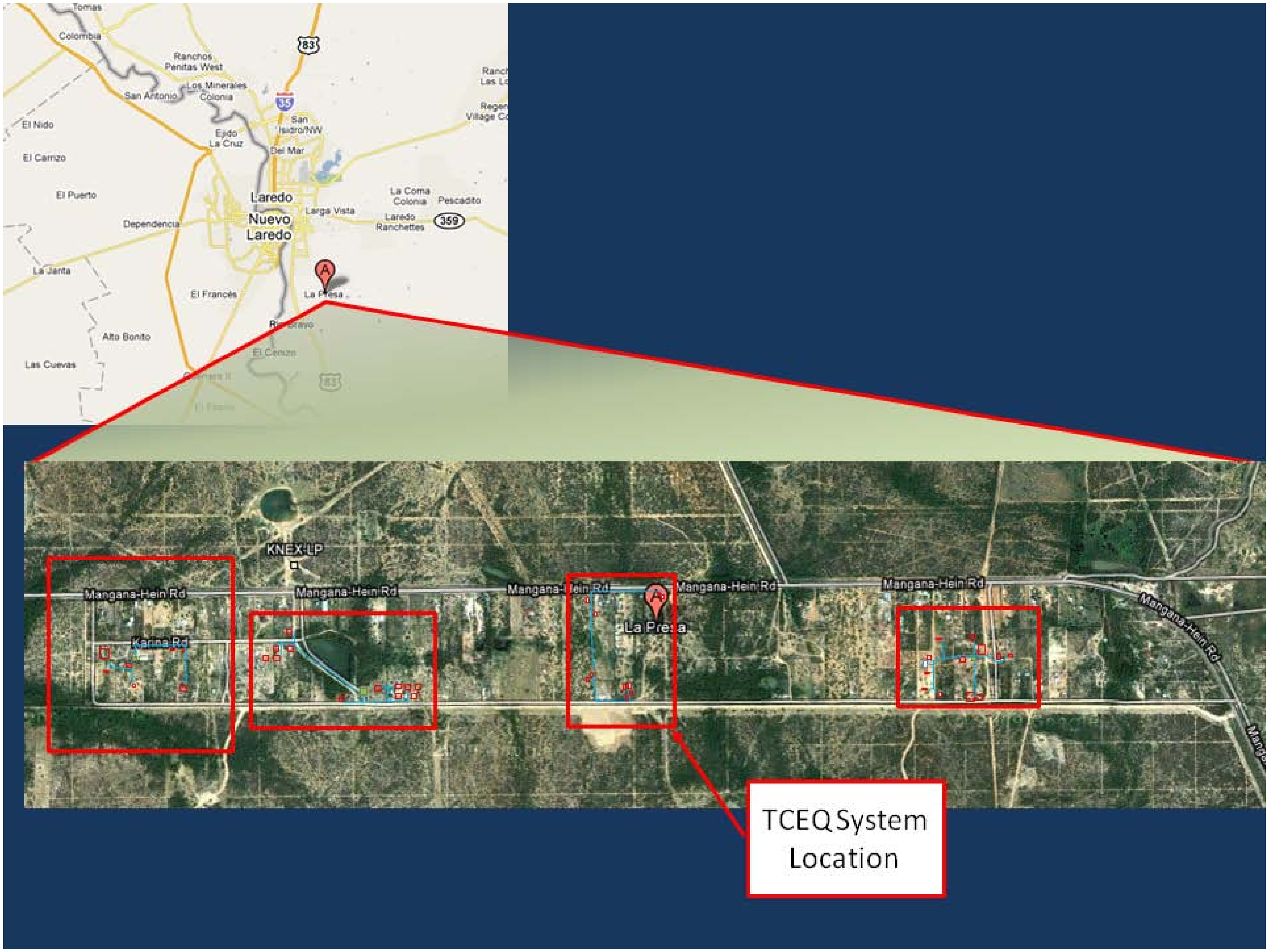

Figure 1. TCEQ Microgrid Site Location

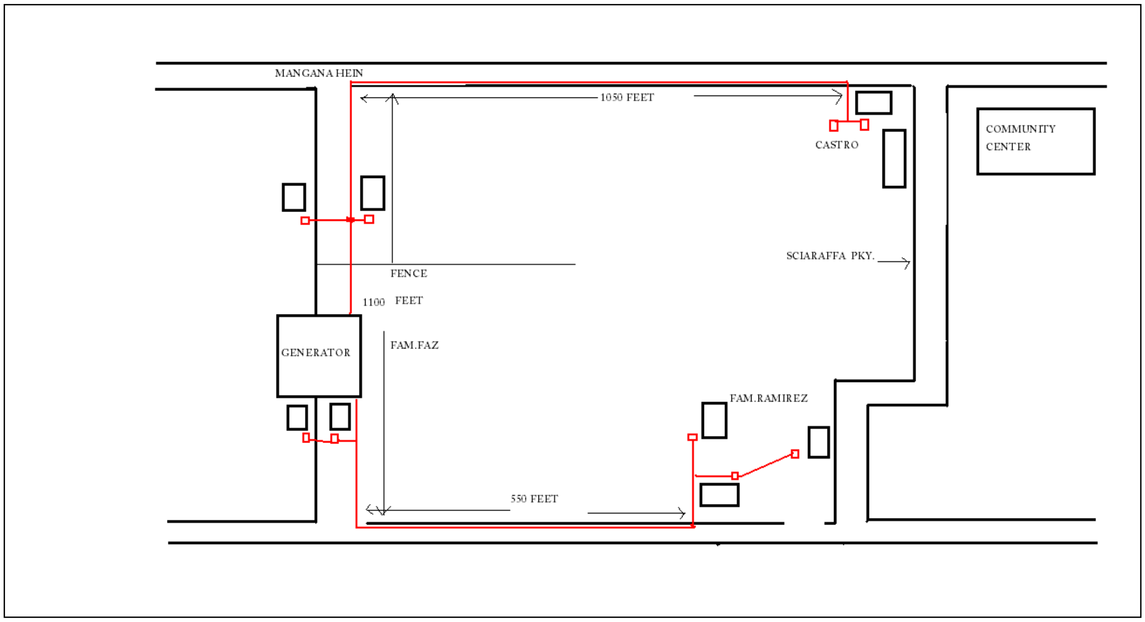

Figure 2. Initial TCEQ Microgrid Site Layout

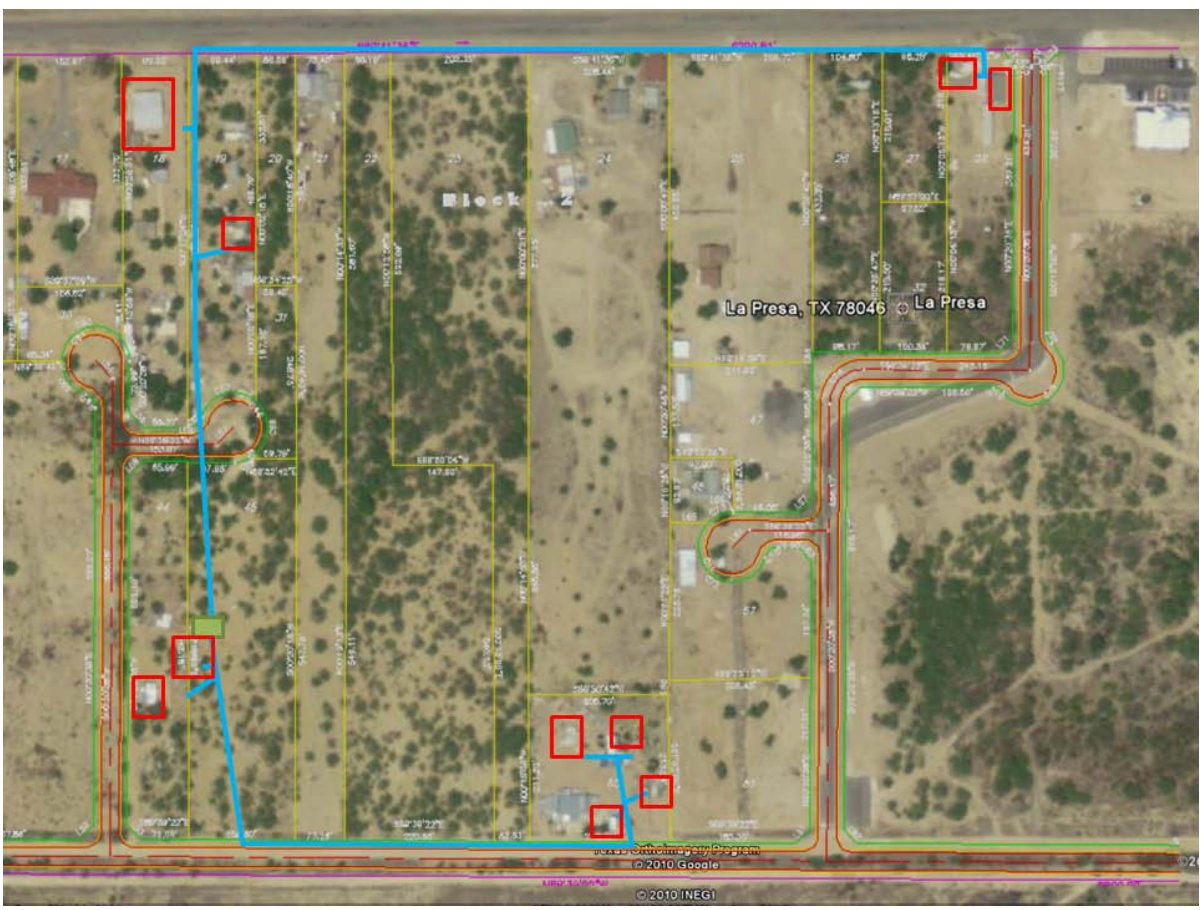

Figure 3. TCEQ Installed Layout with respect to La Presa Subdivision Plat

System Component Descriptions

The Hybrid Trailer can be broken down into 3 basic building blocks:

- Power Systems
- Controls/Data Acquisition
- Structure

Power Systems

The Power systems can be further broken down into the AC components and DC components. The DC components consist of the power cell pack, the chargers, and the solar array. The AC components consist of the inverters, the genset, and the grid.

PowerCells

The PowerCells are configured in a series-parallel matrix that takes advantage of the high power density of Xtreme Power's PowerCells. The pack consists of 40 PowerCells connected by bus bars that are resistance matched to provide an equal and consistent path for power to flow to and from the PowerCell pack. The pack is capable of storing 40 kWh of energy and has a nominal voltage of 48 VDC.

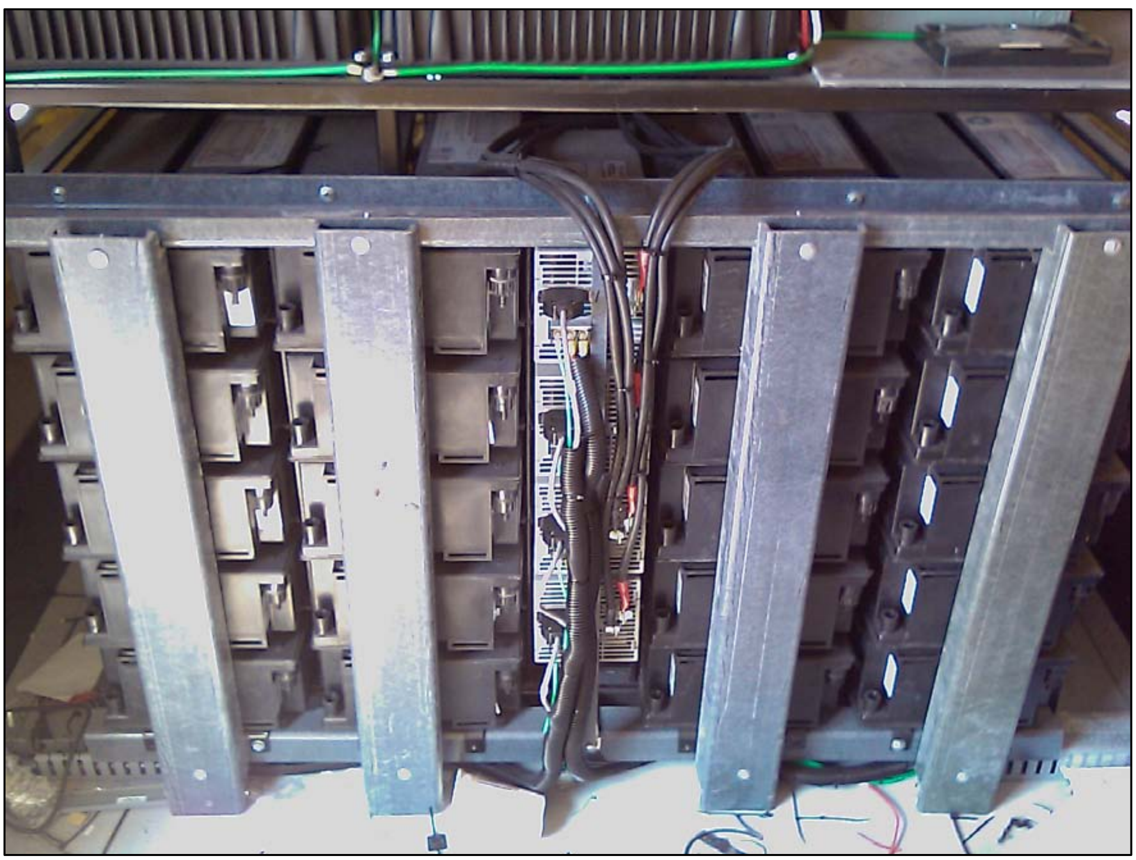

Figure 4. 48VDC PowerCells Pack

Chargers

The charging system consists of four 5 kW Pioneer Magnetics PM33215B-5-1-5-H variable power supplies connected in parallel to the PowerCell pack. The variable power supply allows for a proprietary charging algorithm tailored specifically for the PowerCell. Each power supply is diode isolated to prevent a failed power supply from affecting the bus. The chargers receive power from the 25 kW diesel genset.

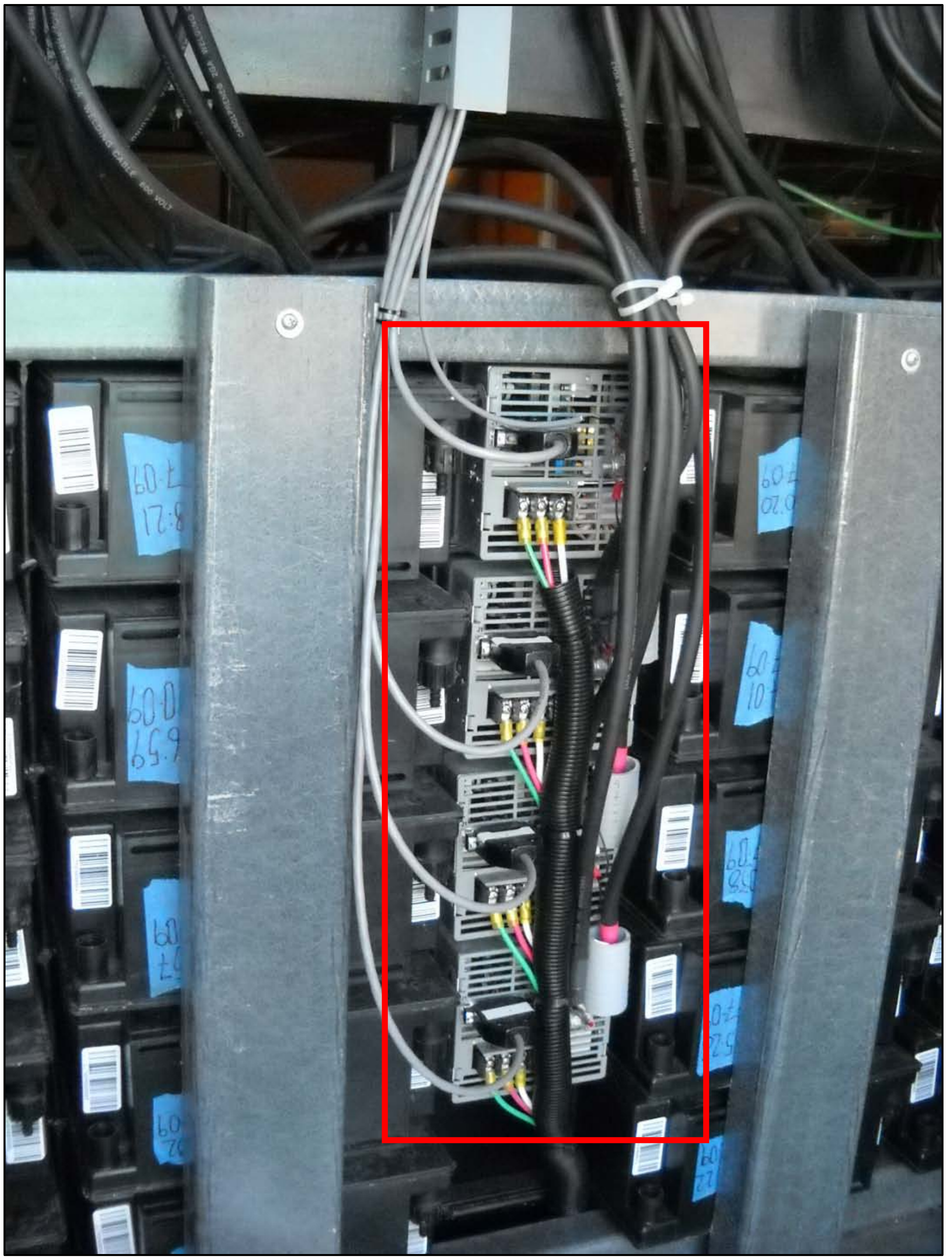

Figure 5. Battery Chargers

Solar Array

The solar array consists of fifty-four (54) BP SX3195B 195W photovoltaic (PV) panels connected in a series-parallel configuration that allows for maximum efficiency. The solar output is regulated by three Outback Power Flexmax 80 charge controllers. This is a 10.5KW array and is 10 times the size of the arrays on the similar SECO funded systems.

Figure 6. 10.5 KW Solar Array Installed

Inverters

The inverters are the main provider of power to the grid. They convert the DC current from the batteries into AC current that is supplied to the distribution system. The inverter system consists of six Outback Power VFX-3648 inverters arranged in a split phase configuration. This allows the inverters to output a more efficient 240 VAC to the grid. Each inverter is capable of continuously providing 3600 VA of power with a surge capability of 6000 VA. This gives a continuous total system power capacity of 21.6 kVA with a maximum surge of 36 kVA. Inverter control and communication is accomplished with an Outback Power HUB10 and MATE. The genset and solar array do not provide power to the grid directly, only indirectly through the PowerCell pack.

Figure 7. Inverters

Genset

The genset is a Cummins 25DSKBA diesel modified for mobile deployment. Although the genset is primarily only used to power the chargers, it can be used as an auxiliary power source for the grid in the event of an inverter failure. The genset is rated for continuous use at 25 kVA. The engine draws fuel from a 1,000 gallon fuel tank located on site. The genset consumes .44 US gph at ¼ of its rated load, .89 gph at ½ its rated load, 1.33 gph at ¾ of its rated load and 1.77 gph at its full rated load. The genset runs on both diesel and bio-diesel. Bio-diesel is used in the late spring, summer and early fall and regular diesel is used in the late fall, winter and early spring months. The genset could not be run year round on bio-diesel because there were problems associated with the bio-diesel gelling during colder weather. As a side note, the diesel fuel tank is provided at no charge by the fuel distributor as long as the fueling requirement remains.

Figure 8. Diesel Genset

Distribution Grid

The distribution grid is made up of 2,300 ft of direct burial #2 AWG cable. This size cable allows for a maximum distance of 1500 ft between the hybrid trailer and the furthest dwelling. The placement of the Hybrid Trailer/genset is very important when the 1500 ft limitation is taken into consideration. To access the grid, each dwelling had a power stanchion with a single 120 VAC 20 amp circuit.

Installation of Distribution Grid   Power Stanchion

Figure 9. Distribution Grid

Controls and Data Acquisition

The Hybrid Trailer uses PLC-based controls to manage PowerCell charging and other functions. The Hybrid trailer is fully automated and only requires an operator for maintenance and troubleshooting. Data acquisition is performed by an industrial PC running custom LabView™ software.

Figure 10. PLC Controller and LabView™ Computer

Structure

All components except for the genset and solar array are housed in a 7’ x 14’ tandem axle trailer. The PowerCells are secured in a steel frame matrix mounted inside the trailer. The solar panels are mounted on a ground based aluminum frame.

System Specifications

The following tables present the specifications of the system as designed and implemented by Xtreme Power, Inc.

Table 1. Overall Specifications

Specification	Value
Output Power	21.6 KW
Energy Storage	40 KWh
Solar Array	10.5 KW
Charging Capacity	20 KW
Generator	25 KW Diesel
Fuel Capacity	1000 Gallons
Structure	14’ Tandem Axle Trailer
Dwellings Served	11

Table 2. PowerCell Specification

Specification	Value
Cell Voltage	12 VDC
Capacity	1 KWh (85 Ah @ C3 rate)
Efficiency	95%-99%
Cycle Life @ 10% Depth of Discharge (DoD)	250,000
Cycle Life @ 50% DoD	20,000
Weight	58 lbs
Dimensions	30”L x 5” W x 5” H
Quantity used in System	40

Table 3. Inverter Specification

Specification	Value
Nominal DC Input Voltage	48 VDC
DC Input Voltage Range	42.0 to 68.0 VDC
Continuous Power Rating	3600 VA
AC Voltage/Frequency	120 VAC 60 Hz
Typical Efficiency	93%
Maximum Output Current	70 amps AC
AC Overload Capability **Surge**	6000 VA
AC Overload Capability **5 Second**	5000 VA
AC Overload Capability **30 Minutes**	4000 VA
Weight	61 lbs
Quantity used in System	6

Table 4. Charger Specification

Specification	Value
AC Input Range	180 to 264 VAC @ 47 to 63 Hz
Power Factor	.99 @ Full Load
Output	60 VDC @ 83 amps
Overvoltage Protection	Yes
Overcurrent Protection	Yes
Operating Temp	0 - 50°C
Cooling	Forced Air
Weight	14.6 lbs
Quantity used in System	4

Table 5. Genset Specification

Specification	Value
Generator	25 KW @ 60 Hz
Duty Rating	Prime Power
Voltage	120/240, 1 Phase, 3 Wire
Engine	Kabuto Diesel
Specific Fuel Consumption	¼ Load - .44 US gph ½ Load - .88 US gph ¾ Load – 1.33 US gph Full Load – 1.77 US gph

Table 6. Solar Panel Specifications

Specification	Value
Power Rating	195 W
Peak Efficiency	13.85%
Imp	7.96 A
Vmp	24.4 V
Isc	8.6 A
Voc	30.7 V
Max System Voltage	600 V
Weight	33.9 lbs
Quantity used in System	54

Operation

Installation

After site selection completed, the team began the installation process in August 2009. One requirement for installation was that Xtreme Power had obtained a private easement to install the distribution system and power generation system on the selected sites. That process took two months to identify the owners of record for the properties and to arrange for them to sign a private easement with Xtreme Power. This effort was expedited by the participation of the Texas RioGrande Legal Aid (TRLA) who represented the residents of La Presa and accomplished the easements for the project. The easements were completed by the end of September and installation of the grid distribution system was installed in October 2009. The grid was energized in November using a stand-alone genset. The grid supplied power using a 24-hour runtime of the genset until the hybrid system trailer completed its final testing in January. Originally, the trailer was intended to be installed prior to this time; however, problems arose in testing the control system. The problems were resolved and the hybrid trailer was installed in January of 2010 and began service on January 24, 2010. Data acquisition began at this point since the stand-alone generator did not have the capacity to gather energy production and consumption data.

System Operation

Figure 11 shows a block diagram of the system. Except in the case of system failure, all power that feeds into the distribution system comes from the batteries through the inverters. The control system monitors the charge of the batteries and charges the batteries upon need. The charging system will charge from the renewable energy producer (PV array and/or a wind turbine, if present) and will not activate the genset as long as there is enough power from the renewables to both maintain the load on the grid and keep the PowerCell pack at an acceptable voltage. Since the batteries can only store DC power, the AC power from the generator is rectified (AC converted to DC) to provide the current to charge the batteries. This function is performed by the battery chargers. To use the PV array and/or the wind turbine to charge the batteries, a solar/wind turbine charge controller is connected in parallel to the AC charge controllers. The control system monitors the output of the solar array (or wind turbine) and while the solar array has sufficient output, it is used to charge the batteries and the generator remains off. When the output of the renewable source drops below that necessary to charge the batteries, the control system engages the AC chargers and starts the generator. If there is a failure in the battery system, the control system can also use the generator as primary power to the grid through the backup power transfer switch.

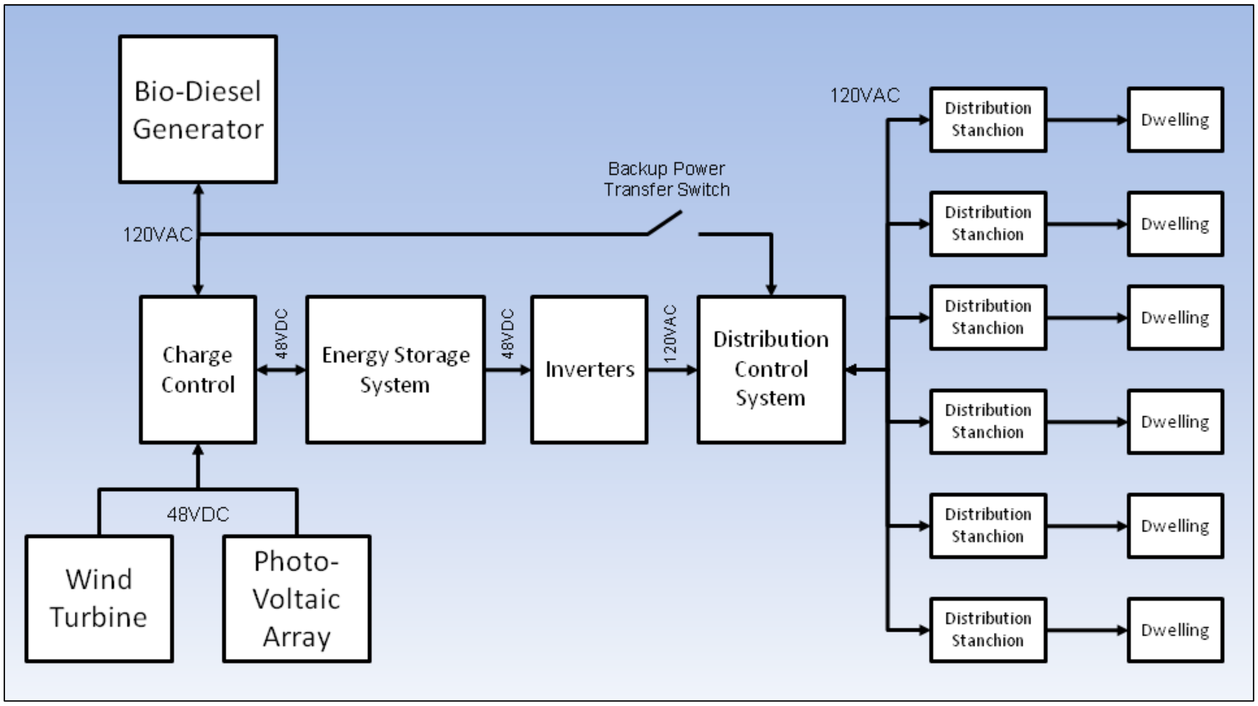

Figure 11. System Operational Block Diagram

The power delivered to each dwelling is a standard 120VAC, 20 Amp circuit with the peak demand limited to 2 KW. This is sufficient to power most small appliances and lights. There are several residences that use the power to run a small air conditioner, but this is usually on an exclusive basis, that is, while the air conditioner is running, no other electrical usage can occur in the residence. If either the maximum current or peak demand limit is exceeded, the system will trip the circuit breaker at the stanchion and the resident will reduce the load and reset the breaker.

Data is gathered on all aspects of system operation. The total power generated from all sources is measured and recorded as well as the total power distributed across the grid. Battery charge status, engine run state, engine fuel usage, PV panel voltages, and currents are also monitored. Data is stored in a file and is available for retrieval during regular maintenance.

The system also has the capability to allow for pay-as-you go (also known as prepaid) metering. Each stanchion has a power meter installed that tracks the usage of the power being dispensed from the stanchion. A resident would pay for a block of power and the meter would let the resident know how much power was remaining out of the purchased block of power. This concept is widely used in the developing world by utilities and several systems are available. However, those systems are large scale and are not appropriate to small, distributed systems such as this. Xtreme Power conceptualized a pre-paid system and tested it. The resident would go to a nearby Western Union™ location and wire a payment to their individual meter account. The state of the meter account would be monitored by the system and by wiring money to their meter account, the credit would be uploaded over the cell modem to the control system and the available block of power would be displayed on the stanchion meter. Unfortunately, the project was not able to implement the prepaid power system due to the Utility Code of the State of Texas. If we accepted payment for power, then the project would be classified as an electric utility and we would be prevented from performing the project by the same regulations that prevent the resident's connecting to the commercial grid. Xtreme Power has elected to continue to provide fuel and maintenance to the microgrid until the residents qualify for grid power as a philanthropic endeavor.

Energy Delivered

Since the data collection began on January 24, 2010, the following table presents the cumulative performance metrics through August 5, 2010 when the last data was retrieved from the system in preparation of development of this report.

Table 7. Summary of 6 Months of Power Generation

Total Power Generated	Genset Power Generated	Solar Power Generated	Total Power Consumed
4,840 kWh	3,238 kWh	1,601 kWh	4,033 kWh

Based upon the data above, the overall efficiency of the system (ratio of power provided to power produced) is measured to be 83%. The average utilization of power per residence was 74.69 KWh/month. The 17% loss in power comes mostly from the conversion from DC current to AC current and vice versa. Power is lost at the inverters when they convert the DC power in the batteries into AC power for the grid. Power is also lost at the genset and chargers when renewables are not enough to maintain the system (e.g. the power lost through the chargers converting AC power from the genset into DC power for the PowerCells, then back to AC power through the inverters for the grid). The rest of the efficiency power losses can be traced back to voltage line losses on the grid.

Overall, the system performed very well. The amount of power provided by the 10.5 KW solar array fully supported the grid demand during daytime hours and also had enough additional power to keep the batteries fully charged. During cloudy or nighttime operations, the diesel generator supplied all the power needed. Even though the generator did not operate during the daylight hours, it still provided the majority of the power produced due to the fact that grid demand was highest during the evening and nighttime hours when the solar panels were not operational. However, a significant emissions reduction was still realized because of the fact that the genset was not constantly run during operation. An example of the daily performance can be seen in the following graphs of data (Figure 12). This graph shows the operation of the system, specifically the operation of the PowerCell pack during a typical 24 hour period.

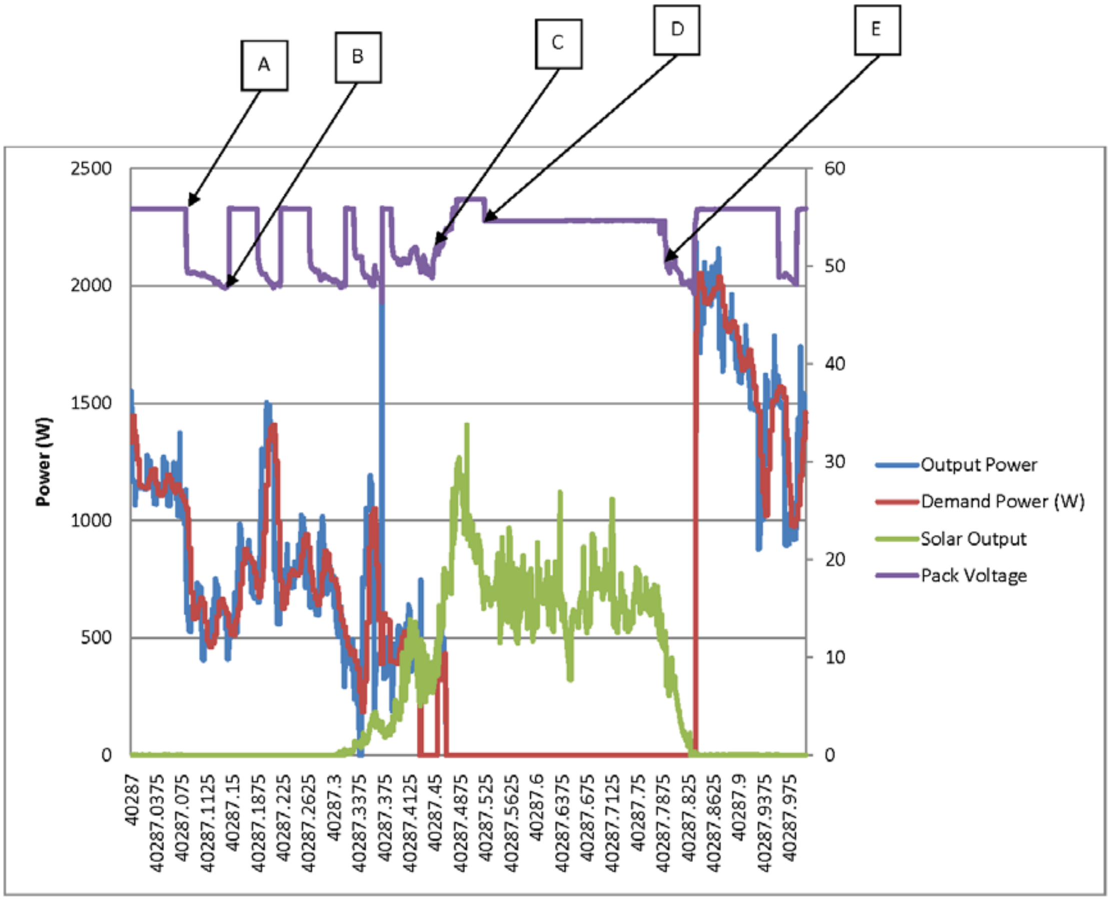

Figure 12. Operation of the PowerCell Pack (Typical 24 hour Period)

Point A represents the end of a charging cycle. During a charge cycle, the PowerCell pack is held at a constant voltage as energy is stored in the pack. During a charge cycle, the chargers must provide power in excess of the load on the grid in order to charge the PowerCell pack. The sharp drop in voltage shows where the charge cycle ends and the chargers turn off. At this point, the PowerCells are once again providing all of the power to the grid, and the pack voltage slowly drops until point B

Point B is the trigger voltage for the start of a charge cycle. When the PowerCell pack reaches the trigger voltage, the control system activates a charge cycle. The sharp rise in voltage occurs when the chargers turn on and start providing power to the pack.

Point C corresponds to the rising of the sun and the activation of the solar panels. The difference in behavior between the solar charging and the AC charging is very distinct. Instead of producing an instant 20 kW of power like the chargers do, the solar array slowly ramps up power production as the sun rises in the sky. The solar panels are mounted in a southern direction and as the sun rises from the east, more power is being provided as the sun moves overhead and it's rays can directly impact the arrays, rather than obliquely as in the case in the morning and evening times.

Point D represents the end of the solar charge cycle. Unlike the AC chargers, the solar array does not turn off when the charge cycle is finished; the array only stops producing power after the sun sets. So instead of a sharp drop in voltage followed by a slower decline, the solar charge controllers drop the PowerCell pack to a safe float voltage and then all excess power from the array is indirectly funneled to the grid through the PowerCell pack. If one looks at the power demand of the system, we see that demand drops to zero during the daytime. This is the time that all the residents are at work during the day and they consume relatively zero power during this time.

Point E signifies dusk when the power output of the solar array declines to zero. At this point, the grid is once again completely powered by the energy stored in the PowerCell pack. When the pack reached the threshold voltage, the genset charge cycles begin again.

Operational Issues

Biofuel usage

One of the objectives of this project included the maximization of renewable energy sources. Part of this objective was met by enlarging the solar power component over the systems funded by SECO from 1 KW to 10.5 KW. The other part of this objective was the use of biodiesel. Initially, we started using biodiesel in the SECO systems in the fall of 2009. We found that the biodiesel gelled at temperatures lower than 40ºF which causes the generators to shut down causing a power outage when the battery charge ran out. This caused the team to only use standard #2 diesel over the winter months and switched back to biodiesel in the warmer months. This systems diesel usage is very low compared to the other SECO units due to the large amount of solar cells installed. Thus, switching to biodiesel has taken a longer time since the fuel usage is lower. The table below shows fuel usage at this site.

Table 8. Fuel Usage

Fill Date	Fuel Type	Fuel Cost Per Gallon	Total Fuel Cost
10/3/09	Diesel	$2.42	$2,420
1/7/10	Diesel	$2.4845	$2,484
4/8/10	Bio-diesel	$3.65	$3,650
7/26/10	Bio-diesel	$3.65	$3,650

Maintenance Requirements

A majority of the components in the Hybrid Trailer are solid state devices so there is very little maintenance involved. The genset is by far the most maintenance intensive component of the system, and also the main source of failure. Like any engine, the genset requires regular oil, oil filter, and air filter changes. In addition to the maintenance costs, there were four different occasions when the genset failed. Three of the failures were covered under warranty at no additional cost, but the fourth failure happened after the warranty period and was quite expensive. The total maintenance costs to date are shown in the following table. The oil and filter changes are performed monthly under a contract to a local resident in La Presa. The only other maintenance required is a periodic cleaning of the solar panels if there has been no rain to rinse accumulated dust from the array.

Table 9. Maintenance and Repair Costs

Maintenance or Repair Event	Cost
Oil, Oil Filter and Air filter changes	$1,414.30
Fuel Filter Changes	$90.40
Genset parts, labor, and mileage	$3,131.45
Total Maintenance and Repair Costs	**$4,636.15**

Figure 13. Cleaning the Solar Panels.

Reliability of the generation system

Overall, the system has performed well; however, as expected, the system reliability is not as high as the commercial grid. System availability is defined as the ratio of uptime to the sum of the uptime and the downtime:

$$\frac{Percentage\ uptime\ (132\ days)}{Percentage\ uptime\,(132\ days) + Percentage\ Downtime\,(49\ days)}$$

Using the runtime data, the system availability was 73%. This is not to say that the residents went without power during downtime. Whenever there was a failure with the system as a whole, the generator was switched over to auxiliary mode and provided the power to run the grid. When examining the percentage of time that the residents were without power, due to other factors such as late fuel delivery and generator failure, the system reliability comes in at 97% (5 days without power/181 total days).

In examining the runtime of the diesel generator, we found that the generator had a total runtime of 1925.5 hours. The total system time in which this runtime occurred was 4344 hours. This number includes periods when the generator was run 24 hrs/day during system failure.

Economic Analysis

Return on Investment

There are two approaches to examining the ROI. The first is on the overall cost and the ability to amortize the cost of the overall system. The second assumes that the initial costs are subsidized and the operational and maintenance costs are paid by the users. In this particular case, we have not and will not receive reimbursement from the residents (See explanation in the Systems Operations Section)

Total System Cost Amortization

The Total system cost (not including labor to assemble and test) is shown in Table 10.

Table 10. Microgrid System Costs

Component	Cost
PowerCell Pack	$20,000
Inverters	$13,927
Genset	$18,287
Solar Panels and Mounting Frames	$31,780
Battery Chargers	$7,356
Control System	$16,212
Distribution System	$9,946
Misc Parts & Supplies	$8,562
Total System Cost	**$126,069**

If the system only consisted of the minimal generator system and grid, the total cost would be $36,795 (assuming that the misc parts & supplies would be incurred for the installation and initial operation of the site). This represents 29% of the total cost. Of concern is the actual lifetime of the equipment involved. The diesel genset that is used in this system has a warrantee period of 1 year from “date in service” (with unlimited hours, a possible maximum of 8,760 hours). Internet searches have resulted in useful lifetimes of diesel generators of this class in the range of 10,000 to 40,000 hours depending upon usage. The most common usage is as standby generators, rather than prime power providers and most have seen 8 hours per day rather than the 24 hour continuous duty cycle these microgrid system experience. These estimates are also contingent upon proper maintenance. If one uses the optimistic estimate of 40,000 hours of life, this results in a maximum lifetime of the genset itself of 4.5 years. Thus, the amortized value of the genset is about $8,200 per year (at 24 hour operation with no depreciation). However, Xtreme Power's experience in the lifecycles of the PowerCells shows that the batteries will last 6 years at the charge/discharge rate that is being utilized in this project. With proper maintenance, the system will last an estimated 6 years before the PowerCells require replacement. During this time, the genset itself will have a runtime of 2.7 years (around 23,600 hours), assuming an equivalent runtime that we have experienced during the operation of the grid to date. The amortized cost over this time (assuming no depreciation) is $21,012. Assuming the same load characteristics over the lifetime, this provides a per kilowatt hour cost of **$0.384/KWh** (normalizing the 6 month load to the year and dividing by the projected 6 year life). The number with the genset costs only system is **$0.986/KWh** over the 4.5 year life of the genset. Neither of these figures includes fuel and maintenance costs.

Fuel and Maintenance Amortization

Table 8 and Table 9 show the fuel and maintenance costs respectively. Normalizing the data for fuel consumption during the data gathering period, fuel and maintenance costs over that time totals to $7,638 (at the time of the data, very little fuel from the last fill had been used). From Table 7, the total amount of genset power generated was 3,238 KWh, which results in an actual kilowatt hour cost of **$2.36/KWh**. Using the total amount of power generated (4,840 KWh), the cost figure is **$1.58/KWh**. The bio-diesel cost is significantly more than #2 low sulfur diesel fuel. Assuming the same fuel consumption, if we had only been using #2 low sulfur diesel, the fuel and maintenance cost would have been $6,472 which would lower these two figures to **$1.99/KWh** and **$1.34/KWh** respectively.

These figures show that the fuel and maintenance costs completely overwhelm the capital costs of the system. However, an observation should be made at this point. In the next section, we observe that the genset is actually running in the ¼ standby regime when it is running the grid in auxiliary mode (storage and renewable systems off and genset powering the grid directly). This is not an efficient use of the generators capacity in the auxiliary mode. Further study is required to determine if overall fuel costs could be lower by optimizing the size of the genset. A smaller genset would require less fuel, but would require more runtime to give an equivalent charge to the PowerCell pack. However, the net fuel usage could be lower in that situation. A smaller genset would also run more efficiently when powering the grid in auxiliary mode.

One solution that residents of the Colonias previously employed was the use of small portable generators to provide power to their homes. It is interesting to note the comparison of the fuel costs of running a portable generator with the fuel costs of the micro-grid system. A Honda

GX340 was chosen to make this comparison. The GX340 has a rating of 4500 W, which if run continuously provides 108 kWh of power at full load over a 24 hour period. The current average price of gas in Laredo is $2.60 per gallon. Over a 24 hour period, the GX340 uses 19 gallons of gas. Using this data, the resident can expect to pay **$2.18/kWh**. Thus, the economy of scale is realized in that 24 hour power for the hybrid system is almost $1/KWh less than a stand-alone generator running 24 hours.

Emissions Reduction

Appendix A provides the emission data for the diesel genset being used. During the genset charging cycles, the genset is running at its most efficient point (Full Prime Power). The runtime of the generator (from the previous discussion of system reliability and availability) was 1,925.5 hours. The genset provides 31 HP (from the full prime column in the data sheet in Appendix A) at this load. Thus, the figures in Table 11 and Table 12 represent the calculated emissions based on the Appendix A emission data using No. 2 diesel and bio-diesel.

Table 11. Actual Engine Emissions based on Total Runtime at Full Prime Load Using #2 Diesel

Emission Component	Value
HC	2.9845 kg
NOx	161.164 kg
CO	23.876 kg
PM	14.923 kg
Smoke (Bosch)	29.845 kg

Table 12. Actual Engine Emissions based on Total Runtime at Full Prime Load using Bio-Diesel

Emission Component	Value
HC	2.3876 kg
NOx	161.164 kg
CO	21.011 kg
PM	13.132 kg
Smoke (Bosch)	25.965 kg

To examine the avoided emissions, we assume the system to be running for 24 hours with the solar panels disabled. Our data shows that the typical operating regime for the system is best characterized by the 1/4 Standby mode. Based upon the total system runtime 4,344 hours, the emissions from the engine would be as follows:

Table 13. Calculated Engine Emissions based on 1/4 Standby and Total System Uptime Using #2 Diesel

Emission Component	Value
HC	17.593 kg
NOx	242.395 kg
CO	11.729 kg
PM	9.774 kg
Smoke (Bosch)	0 kg

Table 14. Calculated Engine Emissions based on ¼ Standby and Total System Uptime Using Bio-diesel

Emission Component	Value
HC	14.0744 kg
NOx	242.395 kg
CO	10.322 kg
PM	8.601 kg
Smoke (Bosch)	0 kg

The biodiesel values show that a direct savings in the amount of emissions can be made using the renewable fuels. However, the cost considerations make the use of biodiesel undesirable in areas that are compliant with current air quality standards.

Conclusion

We find that these results provide mixed results. While the amortization of capitol costs over the expected life of the system shows a reasonable cost of $0.38/KWh produced, the fuel and maintenance costs far outweigh the capital costs at $1.34/KWh. The combined costs ($1.74/KWh) are still better than a stand-alone generator running for 24 hours in cost ($2.18/KWh), lifetime, and emissions.

We determined that the system genset is oversized and that additional optimization should reduce the operational costs of the system even further. Also, the addition of a wind power component would significantly reduce the KWh cost since wind in this area (South Laredo/Webb County) is generally aligned with the evening load characteristics that we have observed.

We also observe that in areas compliant with air quality standards, bio-fuels provide no incentive for use due to their significant cost impacts when compared with standard #2 low-sulfur diesel fuel.

Appendix A: Exhaust Emission Data Sheet

Power Generation

Exhaust Emission Data Sheet
20DSKBA
60 Hz Diesel Generator Set
EPA Emission

Engine Information:

Model:	Kubota Corporation V2203-M	Bore:	3.43 in. (87.0 mm)
Type:	4 Cycle, In-line, 4 Cylinder Diesel	Stroke:	3.64 in. (92.4 mm)
Aspiration:	Natural	Displacement:	134.1 cu. In .(2.197 liters)
Compression Ratio:	23:1		
Emission Control Device:	Naturally Aspirated		

PERFORMANCE DATA	1/4 Standby	1/2 Standby	3/4 Standby	Full Standby	Full Prime
BHP @ 1800 RPM (60 Hz)	9	17	26	34	31
Fuel Consumption (gal/Hr)	0.6	1.0	1.5	1.9	1.8
Exhaust Gas Flow (CFM)	99	119	143	174	163
Exhaust Gas Temperature (°F)	359	519	722	970	882
EXHAUST EMISSION DATA					
HC (Total Unburned Hydrocarbons)	0.45	0.18	0.08	0.04	0.05
NOx (Oxides of Nitrogen as NO2)	6.20	4.40	3.40	2.20	2.70
CO (carbon Monoxide)	0.30	0.50	2.10	0.40	0.40
PM (Particular Matter)	0.25	0.11	0.11	0.36	0.25
Smoke (Bosch)	0.00	0.00	0.30	0.80	0.50

All values are Grams per HP-Hour

TEST CONDITIONS

Data is representative of steady-state engine speed (± 25 RPM) at designated genset loads. Pressures, temperatures, and emission rates were stabilized.

Fuel Specification:	ASTM D975 No. 2-D diesel fuel with 0.03-0.05% sulfur content (by weight), and 40-48 cetane number.
Fuel Temperature:	99 ± 9 °F (at fuel pump inlet)
Intake Air Temperature:	77 ± 9 °F
Barometric Pressure:	29.6 ± 1 in. Hg
Humidity:	NOx measurement corrected to 75 grains H2O/lb dry air
Reference Standard:	ISO 8178

The NOx, HC, CO and PM emission data tabulated here are representative of test data taken from a single engine under the test conditions shown above. Data for the other components are estimated. These data are subjected to instrumentation and engine-to-engine variability. Field emission test data are not guaranteed to these levels. Actual field test results may vary due to test site conditions, installation, fuel specification, test procedures and instrumentation. Engine operation with excessive air intake or exhaust restriction beyond published maximum limits, or with improper maintenance, may results in elevated emission levels.

Cummins Power Generation   *Data and Specifications Subject to Change Without Notice*   eds-1095

Figure A-1. Cummins 20DSKBA Exhaust Emission Data Sheet