DEVELOPMENT AND DEMONSTRATION OF 50 KW SMALL MODULAR BIOPOWER SYSTEM

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

BioMax® 50 is the final report for the Development and Demonstration of 50kW Small Modular Biopower System project (contract number 500-06-020) conducted by Community Power Corporation. The information from this project contributes to Energy Research and Development Division’s Renewable Energy Technologies Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission’s website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.
This report discussed the design, development, and field testing of a modular BioMax® biomass gasification system. The BioMax® system used on-site biomass residues to generate electricity and heat for Dixon Ridge Farms, a walnut grower/processing company located in Winters, California. The BioMax® was capable of converting around 100 pounds of dry walnut shells per hour into an ultra-clean, nitrogen-diluted synthetic gas, which was used to fuel a spark-ignited engine generator producing up to 50 kilowatts per hour. BioMax® was also capable of delivering up to one million British thermal units per hour of thermal energy for drying by operating industrial axial fan dryers that had previously been powered by propane. The BioMax® system proved to be highly reliable and the system was operated continuously an average of 82 percent of the time over the last 18 months of the field demonstration. The longest continuous run was 31.1 days (745.4 hrs) from June 19 to July 20, 2009. As of March 31, 2010 the BioMax® system had operated on a continuous basis for 14,400 hours since commissioning. Electricity generated by the BioMax system was used primarily to power large refrigeration systems at Dixon Ridge Farms. The thermal energy and recovered waste heat was used to dry walnuts, displacing propane usage during the drying season. Over a thousand people, including the press and television reporters, the California Secretary of Agriculture and representatives from 14 countries visited the site over the past two years. It was technically demonstrated that the BioMax® system could be connected to the utility grid but permission could not be obtained from the local utility. This report included a plan describing how this system could be commercialized for the benefit of California and its rate payers.

Keywords: Public Interest Energy Research (PIER) Program, alternative energy, biomass, gasification, biomass, distributed power, distributed power generation, automation, combined heat and power, CHP

Please use the following citation for this report:

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EXECUTIVE SUMMARY

Introduction
Gasification is a chemical process that converts organic materials into carbon monoxide, hydrogen and carbon dioxide. Gasification is an older technology that was used prior to the widespread availability of natural gas, but this process was not automated or environmentally friendly. There is an abundance of waste plant materials (known as biomass) available as feedstock for conversion to energy, but the equipment to convert it to energy has been limited to relatively large-scale utility boilers. Most of this biomass is spread out over a large area and is not normally concentrated in one location. Feeding these large utility boilers requires gathering materials from a considerable distance from the utility boiler. The transportation of large amounts of biomass is expensive and creates infrastructure problems. There is a need to develop small, distributed-power generation systems that can utilize feedstocks from a relatively small harvesting radius where the electricity and recovered waste heat can be efficiently utilized within that same radius.

Community Power Corporation develops and commercializes small modular, distributed-power generation systems that can use waste biomass and convert it into electricity and thermal energy for such tasks as drying agricultural crops or space heating. To be economically feasible these small systems must be fully automated to minimize labor costs and operate continuously at their full rated power levels.

The ability to fully connect to the electrical grid to export excess electricity is critical to the economic viability of this technology due to the wide variety of electrical loads at the farms or small businesses that could benefit from this technology. Utilities are required to connect alternative electrical energy from solar and dairy biogas to the grid but no such requirement exists for similar power from biomass. The oversight of legislation that does not include biomass power as an alternative energy source is a serious impediment to its widespread use.

Project Purpose
The goal of this project was to demonstrate the feasibility of small scale, modular gasification of biomass materials such as wood chips or agricultural residues to fuel an engine generator to produce combined heat and power.

Project Results
The Energy Commission previously supported the successful demonstration of a small BioMax® 12½ kilowatt (kW) system at Hoopa Valley in northern California that converted forestry waste to electrical and thermal power. That technology evolved to the BioMax® 15 system. The approach taken in this project was to scale-up that small system to a BioMax® 50 system to deliver 50 kilowatts electrical (kWe) and over 80 kilowatts thermal (kWth). This project documented the performance and reliability of that scaled-up system with a two-year field demonstration.

Community Power Corporation accumulated over 75 stop-start cycles and over 360 hours of operation prior to shipping the BioMax® 50 for field testing. The purpose of these repeated tests
was to highlight any issues relating to thermal stresses on the system during heat-up and cool-
down. The tests simulated approximately 18 months of operation since thermal cycling was the
primary limiting factor to component life.

Most system performance measures have been excellent. Stable gas flow rates were established
and gains in electrical (gas conversion) efficiency revealed that system capacity could be
increased significantly simply by boosting the pressure of the air/producer-gas mixture into the
engine. This had significant positive implications with respect to meeting the economic goals of
the project.

Gasifier temperatures and flame front remained extremely stable. System pressure drops were
consistently low, the gas quality was excellent with extremely low residual tars, and the heat
exchanger and filter modules required very little cleaning or maintenance. Char/ash yields were
on the order of 1.2 percent at Community Power Corporation, which meant that the biomass
fuel was very efficiently converted to producer gas. Moreover, these solid char/ash wastes were
certified as non-hazardous in Colorado based on good results from the Environmental
Protection Agency’s toxicity characteristic leaching procedure tests, which analyze whether a
material is hazardous. Low volume and low toxicity of the char/ash implied reduced handling
efforts and disposal costs and also reduced hazards to personnel throughout the disposal
process.

The gasifier system was able to tolerate extremely dry fuel during testing and was able to
supply enough heat to dry feedstock with a moisture content of over 50 percent, meeting the
moisture operating limits of the gasifier. Community Power Corporation assumed almost all of
the potential fuel conditioning and handling burdens to minimize the effort and costs on the
part of the site operator. They developed and tested an automated fuel processing subsystem
that accepted bulk-fuel deliveries and then conveyed, dried, sorted and removed tramp
materials as part of a continuous process stream to the gasifier.

The new automated control system has been operated successfully since late 2004. Numerous
modifications to this system were made during its development and field deployment. A
number of new capabilities were demonstrated, including running the system control software
from the embedded controller and performing monitoring and system control changes remotely
by internet communication links or cell phone.

A comprehensive failure-modes analysis was conducted in May 2005. The recommendations
from the analysis were incorporated into the control system and these alerts and alarms were
incorporated into the system controls. The abnormal conditions for these alerts and alarms were
deliberately staged and verified to determine the specific problem and action required.

A six-day (144-hour) endurance run was successfully completed at Community Power
Corporation in September 2005. The system was operated for 148 hours before the operator
voluntarily shut it down. The researchers met or exceeded nearly all of the technical goals
established at the outset of the project.
A two-year field demonstration was conducted at Dixon Ridge Farms (DRF) near Winters, California. The system daily demonstrated the robustness and reliability of the mechanical design as well as the ability of the automation to control the system without an operator in attendance. One employee was able to monitor the system 24 hours per day and perform all maintenance by himself with the system continually operating as much as 98 percent of the time. The longest continuous run during the two-year field-demonstration period was 31.1 days (745.4 hrs) between June 19 and July 20, 2009, which was believed to be a world record for small modular biomass gasifiers. The BioMax system at Dixon Ridge Farms had operated on a continuous basis for 14,400 hours as of the time this report was written.

This was a highly successful demonstration of this alternative energy technology. The only goal the project was unable to achieve was permission to interconnect with the electrical grid due to two primary barriers:

- California Public Utility Commission’s Rule 21 was a tariff that described the interconnection, operating and metering requirements for generation systems to be connected to the utility’s electrical grid. The Rule did not include this technology as “renewable,” which prevented it from being highly beneficial to California in meeting its Renewable Portfolio Standard.

- The Pacific Gas and Electric (PG&E) process of interconnection was unnecessarily complex and expensive and it punished on-site generation with a departure fee.

Over $40,000 was spent in vain trying to obtain permission from PG&E to permanently connect to the grid. Community Power Corporation demonstrated the technical ability to connect properly to the grid but PG&E refused to accept electrical power made from the biomass onto the grid in the same manner as electricity made from solar photovoltaics or dairy biogas at the same site. PG&E would not grant permission to connect this biomass conversion system to the grid on a permanent basis without performing an ever-increasing list of expensive infrastructure upgrades. The BioMax® 50 could therefore only be used to deliver power within the boundaries of the host site on an off-grid basis. This resulted in inefficient power generation at low levels for much of the time when excess electrical power could have been exported to the grid.

The BioMax® 50 system proved to be very reliable with a demonstrated high availability over the two-year period of the field test. The electricity produced was grid quality, although permission for a permanent grid connection was denied by PG&E. The gas produced was also used directly in modified propane burners to dry walnuts. Waste heat from the process was recovered and was also used to dry walnuts.

Engine emissions were within those allowed by the Yolo-Solano Air Quality Control District, which issued a permit to operate. The by-product char/ash was found to be non-hazardous and a study was underway by Dixon Ridge Farms and the University of California, Davis to use it as a soil amendment, effectively sequestering part of the carbon from the biomass in the soil as bio-char and recycling the nutrients.
The high level of automation allowed unattended system operation, with one employee performing all operating and maintenance functions to run the system around the clock, 24 hours a day, seven days a week. Continuous operation for up to 31 days at a time was achieved in the field. This system to convert biomass to electricity and heat was commercially feasible for those who have an abundance of inexpensive biomass and who pay high prices for electricity, heat and waste disposal.

Based on the success of this scaled up system, larger systems were being developed that would have twice the output of the BioMax® 50 but would still retain their automated, modular nature. These larger systems will have better economics of operation, particularly if they can be grid tied in a favorable environment for permitting. Operating several such systems in a local energy services mode may be a viable mechanism of commercializing this alternative energy technology.

The realization of the commercial potential of this technology can only come to fruition if all alternative energy sources are given equal and favorable access to the grid. This will require action by the California legislature if the interpretation of existing law remains unchanged. Biomass is stored solar energy so the conversion of biomass to electrical power should have similar incentives to what is available for solar energy conversion. The BioMax® systems are well documented and strategies for mass producing it were under development.

The authors recommended that further field testing be conducted, in particular of the new, larger BioMax® 100 once it is sufficiently developed and ready for that level of rigorous testing.

**Project Benefits**

The benefit of this project to California has been the demonstration of the conversion of biomass to heat and power in a reliable and automated system. There have been many tours and demonstrations of this technology at Dixon Ridge Farms that have raised awareness in the public to alternative energy from biomass. This project has demonstrated California’s leadership in the conversion of a waste biomass material into useful electrical and thermal power.

There was a vast amount of biomass waste materials that were being allowed to rot in the field, landfilled, or burned without any energy recovery. The potential exists for the conversion of much of this biomass waste material from both forest and agricultural sources into electricity at a small, distributed scale that could make good use of waste heat from the process. The cumulative effect of widespread application of the BioMax® technology could produce a significant amount of distributed power that could be locally used, reducing electrical transmission loads and losses in the grid. The recovery of waste heat from the process could provide economic benefits by further reducing the use of premium fossil fuels such as propane and natural gas. Use of fossil fuels and their greenhouse gas emissions could also be reduced if this technology becomes more widely used.
CHAPTER 1: Introduction

This section introduces the rationale for alternative energy from biomass and the goals of this project.

1.1 Background And Overview

The demand for electricity in California is growing faster than supplies are being added. New supplies of electricity are needed, but central power plants can take years to build and often raise environmental concerns. California also has an abundant amount of forest and agricultural biomass residues that contribute to dangerous fire conditions. Biomass fueled, distributed power generation offers the State of California an opportunity to supply electricity in an environmentally friendly manner, while also reducing the risk and damage of forest fires and the disposal of agricultural residues.

The recent, successful, Energy Commission cost-share funded Small Modular BioPower (SMB) technology demonstration project with Community Power Corporation (CPC) and the Hoopa Valley Tribe was the first step introducing SMB to the State of California (Commission Contract 500-99-029). The primary goal of that project was to demonstrate technical and operational capability of a prototype, 12½ kW<sub>e</sub> SMB system. Secondary goals included determining the most appropriate power range for economic viability and defining a path to successful commercialization of the product in the State of California.

During 2002, CPC and the Hoopa Valley Tribe operated a SMB system rated at 12½ kW<sub>e</sub> to provide power and heat to a greenhouse that the Tribe used to support their sustainable forestry business at the Tsemeta Forest Regeneration Complex, Hoopa, California. The project successfully met its objectives and demonstrated that a prototype SMB system could use waste forest slash and thinning to provide utility grade power to the complex. The project also provided heat to maintain seedling be temperatures. The SMB system was successfully connected to the PG&E grid. However, further development of the prototype technology and extended on-site testing was needed to meet the demands of the market for distributed power generation systems in California. This project built on the success of that pilot project.

1.1.1 Relationship To PIER Goals

This effort met the PIER goal of providing greater choices for California consumers. The effort developed and demonstrated a 50-kW<sub>e</sub> biopower system capable of using a variety of California’s biomass residues, as alternatives to fossil-fuel fired distributed generation power systems. It also met the secondary goal of improving the environment, and public health and safety of California’s electricity by providing an environmentally friendly means of consuming problematic biomass residues that otherwise would be open-air burned (air quality issues), allowed to rot (increased greenhouse gases with no benefit), or deposited in landfills (at high cost).
This effort met PIER goals of improving the reliability, quality, and sufficiency of California’s electricity by adding new “green” distributed generation capacity. The goal of addressing important research, development, and demonstration gaps was also met by responding to customer demand for a fully automatic, environmentally certified, 50 kWₑ system.

### 1.2 Goals And Objectives

The overall goals of this project were to design, develop, and demonstrate a 50-kWₑ modular gasification system for grid interconnection, and combined heat and power using forest residues (this goal was later changed to agricultural residues, e.g., walnut shells). This project continued the development and advances of the previous PIER supported program that supported the 12½ kWₑ SMB system demonstration. It continued to support the PIER program objectives of improving cost competitiveness of the biomass energy conversion technologies and reducing environmental risks of California’s electricity. Table 1 summarizes the specific goals and the achievements attained in this project. All goals were demonstrated to have been met or exceeded, although permission to permanently connect to the grid was not granted by PG&E, as discussed in detail later in this report.

The specific long-term economic cost objectives for the 50-kWₑ power system were:

- Capital cost of $1,750 per kWₑ;
- Electricity cost of less than 10 cents per kWh; and
- Heat cost of less than $1.00 per therm (100,000 Btu)

Significant progress was made in improving the economics of the conversion of biomass to combined heat and electrical power by meeting the goals of this project. Of great impact on the economics were the demonstrated:

- low tar content of the producer gas;
- high system reliability and availability; and
- the automation that permitted unattended operation by one employee.

This has been a very successful alternative-energy demonstration project with good goal attainment and high public visibility.

**Table 1: Project Goals and Achievements**

<table>
<thead>
<tr>
<th>Goal</th>
<th>Actual</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide up to 50 kWₑ and 80 kW₉th power to the proposed on-site loads</td>
<td>Exceeded</td>
<td>Up to 62 kWₑ at DRF 88 kW₉th at CPC</td>
</tr>
<tr>
<td>Provide 3-phase power in parallel with the grid in net metering mode to displace retail sales and achieve economic advantages for a distributed power system</td>
<td>met</td>
<td>Unable to obtain permission to permanently grid connect</td>
</tr>
<tr>
<td>Goal</td>
<td>Actual</td>
<td>Comments</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>--------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Operate with no more than one operator by achieving full automation of start-up, operation, monitoring, and shutdown</td>
<td>met</td>
<td></td>
</tr>
<tr>
<td>Provide 50 kW(_e) of power with a turndown range of 10 to 1, using forest residue as the renewable fuel source</td>
<td>met</td>
<td></td>
</tr>
<tr>
<td>Operate the SMB continuously for six days</td>
<td>Exceeded</td>
<td>Achieved 31 days</td>
</tr>
<tr>
<td>Demonstrate combined heat and power capabilities of the biopower system by capturing waste heat from the gas production and power generation modules for a period of 24 months, as follows</td>
<td>met</td>
<td>CHP during the drying season</td>
</tr>
<tr>
<td>For the first twelve months of operation, the system will have 60% availability</td>
<td>Exceeded</td>
<td>72%</td>
</tr>
<tr>
<td>For the second twelve months, the system will have 80% availability</td>
<td>met</td>
<td>82% in the last 18 months of field demo, believed to be world record</td>
</tr>
<tr>
<td>Achieve at least an increase of 20% in the electrical efficiency of the 50 kW(_e) system when compared to the 12½-kW(_e) system</td>
<td>Exceeded</td>
<td>Achieved 58% higher</td>
</tr>
<tr>
<td>Achieve at least an increase of 10% in the combined heat and power efficiency of the 50-kW(_e) system, when compared to the 12½-kW(_e) system</td>
<td>Exceeded</td>
<td>Achieved 70% higher</td>
</tr>
<tr>
<td>At a peak power of 50 kW(_e), the SMB shall meet or exceed California Air Resources Board (CARB) emission standards for nitrogen oxides, volatile organic compounds, and particulate matter for a combined heat and power distributed generation system</td>
<td>met</td>
<td>Met at CPC at 45 kW(_e), did not meet at DRF</td>
</tr>
</tbody>
</table>

### 1.3 Gasification Technology

#### 1.3.1 Gasification Of Biomass

The purpose of biomass gasification is to transform it from a solid by partial combustion into a producer-gas mixture containing hydrogen, carbon monoxide, carbon dioxide, methane, and water vapor. If air is used to supply oxygen for the partial combustion, the producer gas will contain nitrogen as well. This producer gas is readily combustible in gas burners and engines, although it has a lower energy volumetric content than natural gas or propane.

Gasification occurs at elevated temperatures with decomposition of biomass to initially form gases, organic vapors, and carbonaceous char. The organic vapors are commonly seen as wood smoke and can be present initially in yields up to 70 wt%. However, these primary vapors rapidly decompose to form more gases and only about 15 wt% of secondary tar vapors that are fairly stable at high temperatures. At higher gasification temperatures, the secondary tars further decompose to about 1 wt% tertiary tars that are very stable and difficult to decompose further by heat alone. Although a tar yield of 1 percent would seem quite low, this amounts to about 3,000 ppm tars in the gas stream. The literature suggests that less than 50 ppm tars are needed for fueling internal-combustion engines. These tars condense on cold surfaces and can accumulate to cause severe maintenance issues and engine malfunctions. Eliminating tars is of utmost importance to the operation of a successful gasification process.
The char formed during gasification has an energy content about 50 percent greater than the original biomass, on an ash-free basis. So, if the char yield is 10 wt% (ash-free basis), about 15 percent of the energy in the biomass is in the char byproduct, which lowers the energy efficiency of the process to make gas.

So, the goal of biomass gasification is to maximize clean gas production and minimize char and tar yields. It is easy to gasify biomass, but residual tars in the gas have been the cause of the failure of most biomass gasification efforts.

1.3.2 CPC’s Gasifier And Gas Clean Up Equipment
1.3.2.1 Gasifier

The BioMax® 50 gasifier used in this project has an open top and does not employ an expensive air-lock or rotary valve. Both feed and part of the air needed for gasification enter through this open top. This downdraft gasifier features downward plug flow of the producer gases. **Figure 1** shows that there are five strata or zones thought to exist in this gasifier: fresh feed, final feed drying; flaming pyrolysis, char oxidation, and char reduction.

Fresh feed is added though the top of the gasifier until the level sensor detects a full gasifier. The computer then shuts off the feeder augers, until the level sensor indicates that the gasifier needs more feed. This zone of fresh feed is several centimeters thick. The feed slowly moves down through the gasifier, as the feed and char are consumed below it.
As the feed particles approach the flaming pyrolysis zone, they are heated by radiation from lower, hotter particles. This heating dries the feed, creating steam. This steam and the primary gasification air that entered through the top of the gasifier travel quickly to the flaming pyrolysis zone below. This drying zone is just above the flaming pyrolysis zone.

As the feed particles travel further downward, they are heated to pyrolysis temperatures by radiation from the flaming pyrolysis zone and begin to emit pyrolysis vapors. This flaming pyrolysis zone is thought to be only a few centimeters thick and tends to move vertically with momentary changes in moisture content and particle size of the feed, producer gas flow rates, and air flow rates. The pyrolysis vapors burn in the flaming pyrolysis zone, which is where most of them are destroyed. The combustion gases and residual tar vapors then travel down to the char oxidation zone, along with the char formed in the flaming pyrolysis zone.

In the “char oxidation” zone, air for secondary gasification is added in a proprietary manner to oxidize the char and residual tar vapors, producing carbon dioxide, hydrogen, water, and heat. In the steady-state condition of the gasifier, the temperatures of the char oxidation zone are moderated by the endothermic reactions of steam and char to form hydrogen and carbon monoxide, as well as, by carbon dioxide reacting with char to form carbon monoxide. These temperature-modering reactions are significant above 800°C and are increasingly faster in the higher temperatures of this zone. The hot char and ash surfaces, along with possible free radicals present in this zone are thought to catalyze the destruction of the residual tar vapors. In the “char reduction zone”, there is no free oxygen to oxidize the char and release heat. So, the reaction of the hot char is to reduce water to form hydrogen and carbon monoxide, as well as, to reduce carbon dioxide to form carbon monoxide. These endothermic reactions cool the
char and the producer gases to a final temperature at the grate of 700°C to 800°C. There is additional tar-vapor destruction in this zone.

Near the bottom of the gasifier is a stainless steel grate that retards the passage of char through the gasifier. Periodically, the gasifier is vibrated to settle the char bed, collapsing channels ("rat holes") and bridges of the feed and char. As the char becomes progressively oxidized, it becomes increasingly more easily broken by the vibration and movement of the grate. The broken char pieces are small enough to pass through the grate. The producer gases and the char leave the gasifier together.

The gasifier is constructed with an inner liner and outer shell made of stainless steel. Insulation between the liner and the shell is a light-weight ceramic-fiber material. The internal temperatures of the gasifier are measured with multiple thermocouples. The pressure drop through the gasifier is measured with a pressure transducer.

A feed gate at the top of the gasifier is opened at the start of operation and is closed at shut down to isolate the gasifier from air and preserve the residual char after the run has ended. Thus, the gasifier is operated with an open top, with the gases passing downwardly. The pressure in the gasifier is slightly less than the local atmospheric pressure.

The gasifier is started with the residual char from the previous day’s operation. The biomass feed is started, only after the char bed is fully ignited and at temperature. The low thermal mass of the gasifier allows it to produce a combustible producer gas from biomass only a few minutes after ignition by an electrical-resistance heater.

1.3.2.2 Heat Exchanger

The hot producer gases and the entrained char are cooled down to about 100°C in a tube-and-shell heat exchanger. The temperature of the producer gas is kept above the dew point to avoid condensation and accumulation of water. The producer gas flows inside of the tubes and cooling air on the shell side.

A blower supplies cooling air to the heat exchanger. The speed of the blower is computer controlled to produce the desired producer-gas exit temperature.

1.3.2.3 Filter

A special fabric filter is used to remove the entrained char fines from the producer gases. During gasifier operation, the fabric filter occasionally flexed to remove accumulated filter cake and to keep the pressure drop at an acceptable value. The computer activated the filter-agitator at a pre-set time interval, when the pressure drop across the filter exceeded a pre-set value. The char fines are collected as a dry powder, due to the low tar content of the producer gas from CPC’s unique gasifier.

1.3.2.4 Engine/Genset

The BioMax® 50 uses a commercially available spark-ignited engine/genset, intended for use with natural gas. CPC modified this engine to burn producer gas cleanly. The engine turns a generator at 1800 rpm to produce grid-quality electricity at 60 Hz and 480 V.
CHAPTER 2: Project Approach

This section addresses the approach taken to achieve the goals of this project. To accomplish the goals of this project, several tasks were established:

Task 1. Managerial Related
- Project kick-off, financial and technical progress reporting, etc.

Task 2. System and Component Design for 50 kW_{e} SMB
- System and technology description, including mass and energy balance
- Scale up of the 12½ kW_{e} gasifier system
- Re-design
- Heat exchanger to cool the hot producer gases
- Filter to remove particulates from the cooled producer gases
- Control system for automated operation for 24 hours per day, 6 days per week
- Feeder/dryer to support the gasifier
- Select an engine/genset to produce 50 kW_{e} continuously
- Re-design the air/fuel management system for the new engine/genset
- Grid intertie system to accommodate the 50 kW peak power as per the local utility
- Use CARB (2007) Regulations for Distributed Power as the design basis
- Prepare an Integrated Power Systems Design Report
- Prepare a Component Design and Specifications Report

Task 3. Design of 50 kW_{e} SMB Modules (Feed Preparation, Gasification, Power)
- Module Design and Specifications Report
- Engineering requirements
- Mechanical, electrical, and control system drawings
- System requirements
- Material requirements
- Incorporate comments from the first Critical Progress Review (CPR) Report

Task 4. Fabricate 50 kW_{e} SMB Modules
• Complete the fabrication of the
• Feedstock Preparation Module (FPM)
• Gas Production Module (GPM)
• Power Production Module (PPM)
• Prepare a Fabrication Report

Task 5. Testing of the 50 kW<sub>e</sub> SMB Modules and Systems at CPC
• Prepare a Test Plan
• Determine operating characteristics of system
• Complete 144 hours of continuous operation
• Testing Report incorporating comments from 2<sup>nd</sup> CPR report

Task 6. Site Design and Supervision
• Assist the Shasta Energy Group and the Siskiyou Opportunity Center prepare to host the 50-kW<sub>e</sub> system (later changed to Dixon Ridge Farms)
• Task 7. Installation and Operation of the 50-kW<sub>e</sub> SMB in the field
• Install the 50-kW<sub>e</sub> system in the field
• Installation and Commissioning Report
• Interconnect the 50-kW<sub>e</sub> SMB with the grid
• Grid connection report with utility approvals
• Prepare a Technical Support Plan
• Provide training and 2 years of technical field support
• Operate until a six-day reliability test is successfully completed
• Operate the SMB system for a period of two years
• Make repairs as necessary
• Provide monthly status reports

Task 8. Technology Transfer Activities
• Prepare Technology Transfer Plan
• Conduct Technology Transfer Activities
• Include key elements of the Technology Transfer Plan in the Final Report
Task 9. Commercialization and Production Readiness Plan (CPC funded)

- Prepare a Commercialization Plan for the 50-kW_e SMB
- Identify critical production needs
- Identify manufacturing facilities and suppliers required
- Project capital costs per SMB
- Prepare a Production Readiness Plan
- Project manufacturing investment capital required
- Implementation Plan to ramp up to full production

These tasks were successfully completed during the execution of the project, although the site for the field demonstration site was changed.
CHAPTER 3:
Task 2 Design Of System/Components

CPC’s approach to achieving a workable design with the BioMax® 50 was to follow a specific research and design process as discussed below.

To begin the design effort, design criteria based on functional and contractual requirements were established for the system modules. Module design options were established and reviewed by the entire CPC design team.

Since the time of the CEC effort with the development and field demonstration of the BioMax® 12½ at Hoopa Valley, the BioMax® system had evolved considerably to the BioMax® 15 system, resulting in superior gasification with lower tar levels and more reliable operation. The design criteria were established early in 2004, as part of a design process that reviewed the existing BioMax® 15 design and generated a list of functional design specifications for each module and subsystem. CPC asked its staff to review all of the testing and maintenance records, as well as, reports and feedback from site operators at previous demonstration sites. The focus was to approach the design process from the standpoint of the end-user, rather than as engineers and designers. With this focus CPC hoped to make the system as easy to operate and maintain as possible.

This section documents the prototype component designs and specifications for the Gas Production Module for the 50 kWc SMB system. These designs include the feeder/dryer, gasifier, the heat exchanger, the filtration system, and the control system, and the engine/genset.

Figure 2 shows the major components of the BioMax® 50, which include the

- Feed Preparation Module
  - Chip conveyer;
  - Chip Sorter; and
  - Chip Dryer
  - Chip Conveyer and Surge Bin
- Gasification Module
  - Gasifier
  - Heat Exchanger
  - Producer-Gas Filter
- Power Production Module
  - Engine/genset
A secondary gasifier was considered in the initial design to reduce all solid char-ash waste to a white ash. The reasons for doing this included a desire to minimize material volume in order to reduce waste handling and disposal requirements and because of concerns about possible toxicity of the carbon and tar remnants in the char-ash. However, progress in two areas has allowed us to eliminate the secondary gasifier.

First of all, char conversion rates were extraordinarily high in preliminary testing of the BioMax® 50. Char conversion efficiencies of 96-98 percent in the BioMax® 15 had been measured. (This was later improved with the BioMax® 50 to over 98 percent). The implication was that the waste solids from the gasification process were almost primarily ash consisting of the mineral constituents of the original biomass fuel source. Therefore no further reduction in volume was necessary.

Secondly, the char had been subjected to EPA TCLP leaching tests and certified as non-hazardous by the State of Colorado. While a similar certification process would have to be completed for the State of California, CPC was confident that the mineral ash wastes from the BioMax® 50 may be disposed by conventional methods and therefore will not pose an undue burden on the site operator at the field demonstration site. In fact, the char appears to have a positive value as a soil amendment or fertilizer.

CPC chose two separate prototyping cycles, in order to expedite progress and minimize design rework. The first round of prototype design and testing involved simple prototype concepts to perform basic proof-of-concept testing of new design approaches. The
second round of prototype design and testing was focused on more developed and integrated design concepts. Follow-on system testing was used to confirm operational integrity of these final prototypes in their final integrated system configuration.

3.1 Results And Discussion

3.1.1 Gasifier Design

The two fundamental areas of improvement in the gasifier design were in the secondary-air injection subsystem and the grate subsystem. These subsystems have the greatest impact on positive control of the gasifier, because they directly affected and controlled bed temperatures, material flow, and fuel conversion rates. Because of their importance and because the new designs were a significant departure from the past design approaches, these gasifier subsystems were the primary target of prototype development and proof of concept testing. These subsystems are explored in detail in following subsections.

The basic gasifier design did not change from the initial conceptual work. Dimensional changes were made to scale up the 15-kW design in order to increase the nominal capacity of the gasifier from 60 NMH (35 SCFM) to 220 NMH (130 SCFM). Figure 3 shows that the gasifier was an open-top cylindrical downdraft gasifier with secondary char air injection.

Figures 4 and 5 show that the first principal change from the old gasifier design was to move the gas seal from the outside insulation shell to the inner gasifier shell. Moving the gas seal to the inner shell allowed the use of horizontally inserted thermocouples and pressure taps. Vertically mounted thermocouples on the previous design had created leak paths through the char bed, affecting quality and skewing the temperature readings. The other benefit of moving the gas seal to the inner gasifier shell was to reduce the problems associated with differential thermal expansion between the inner and outer shells of the gasifier.

The grate subsystem was also isolated and was removable for servicing. In addition, the grate subsystem functioned simply as a material removal system and was not used for primary flame front control. The gasifier no longer relied on vibration to move material, so this design eliminated much of the metal fatigue problems with the previous design. Material removal was expected to a direct function of the grate-activation frequency and not dependent upon vibration frequency, duration, and interval, as it was with the previous SMB design. Because vibration was not used as a means of removing material, bed porosity could be controlled through vibration. In the case of the current design, the vibrator attached to the upper section of the gasifier settled the bed and collapsed any channels that tried to form.
Figure 3: Prototype Gasifier

Figure 4: BioMax® 50 Gasifier Seal
The gasifier was split into two sections with a ceramic felt gasket sealing the interface between the two sections (this felt gasket was later replaced with a commercial, high temperature flange gasket). The upper section was comprised of the core cylinder, twenty inches in diameter, in which the pyrolysis and gasification reactions took place. Welded around the periphery of the core are seven layers of secondary-air injector receptacles. The top two layers consist of one injector each. These two receptacles were intended to hold sensors to measure pressure and temperature within the upper, unpyrolyzed bed. Each of the remaining lower layers incorporated ten receptacles in each layer. These receptacles were intended to hold injectors to inject secondary air into the gasification zone and also to measure temperature at that location.

The lower section contained the grate assembly with a fixed grate that supported a stainless-steel woven wire screen that could be changed according to fuel specifications. Above the screen was a motorized reciprocating grate, resting on a track, that ground and mobilized char-ash, so that it could pass through the mesh below. (The screen was later replaced with a perforated plate.)

The grate subsystem was designed as a separate unit from the lower gasifier housing in order to minimize distortion due to thermal growth and to facilitate removal for inspection or repair. The grate design was designed to break up the char and clinkers into particles smaller than ¼ inch and to positively meter the amount of material through the gasifier.

The grate agitation subassembly was designed to impart a reciprocating motion to the movable grate, while isolating the drive motor from high heat and allowing the drive mechanism to accommodate thermal growth within the system. The system also was designed to be airtight
and the motor mounting system was designed to tolerate a jam in the event that the grate was
blocked or broken.

Below the grate assembly was a gas-outlet port and flange that attached directly to the inlet of
the heat exchanger. Opposite to the gas-outlet port was a removable plate for gaining access to
the lower grate and heat exchanger during maintenance operations. The plate doubled as a
support and seal for the grate activation rod. This access plate could be removed during
maintenance, if necessary, for removal of tramp material accumulating on the grate. Tramp
material would include rocks and debris in the original feedstock or ash clinkers that formed in
the gasifier over long duration runs.

3.1.2 Secondary-Air Injection System

The secondary-air injectors combined several functions, including temperature measurement,
secondary-air injection, and pressure measurement. The secondary-air injectors were held in
place at their respective locations by the injector receptacles and were attached with sanitary
clamp fittings and gaskets, so as to be removable for cleaning or modification without major
disassembly of the gasifier.

An array of thermocouples was installed throughout the interior of the final gasifier prototype.
These thermocouples were embedded in the secondary-air injectors with the thermocouple tip
residing in a thermal well at the end of the injection finger. Five short fingers injected air into
the outside radius of the gasifier and five long fingers injected air into the center region of the
gasifier. Thermocouples located inside the injection fingers were used to provide closed-loop
temperature control. The thermocouples provided temperature feedback to adjust the volume
of secondary air injected into each level of the gasifier.

Secondary-air injection was performed independently at each layer of fingers in the char
gasification zone with the use of a single char air blower and separate proportional control
valves. The blower was attached to an air distribution manifold and air was delivered equally to
each of the injector layers. Air delivery was thus controllable at each layer and the valves also
served as shutoff valves for sealing the gasifier during shutdown. (This air delivery design was
later changed to a single blower, a manifold, and five independently controlled valves.)

3.1.3 Gasifier Balance Of Systems

Additional components include a feed gate that relied only on gravity for closure in the event of
an emergency shutdown. CPC also introduced an ultrasonic sensor that detected bed depth
inside the gasifier to provide a feedback signal to the fuel delivery subsystem. This level sensor
did not require an unobstructed line of sight between sensors, as was with the BioMax® 15, thus
eliminating sight glasses and their attendant maintenance. (This ultrasonic level sensor was
later replaced with an infrared sensor.)

A vibrator was attached to the body of the gasifier and was used to periodically shake the bed
to promote bed uniformity and avoid channeling or rat-holing. The mounting framework was
designed to support the gasifier through spring mounts, to prevent vibration from being
impacted to fixed structural elements and to allow thermal expansion and growth. The
enclosure was closed on the bottom and four sides and circulation fans were installed to prevent thermal buildup and to keep the exposed ends of the injectors cool.

Ignition was performed automatically using a permanently embedded calrod that was located in an injector receptacle in the wall of the gasifier above the grate.

The gasifier was insulated with ceramic and mineral wool insulation to keep surface temperatures of the exposed shell below the OSHA-recommended surface-temperature limit of 150°F. The insulation was covered with removal panels to immobilize the insulation during operation.

3.2 Heat Exchanger Design

The shell-and-tube heat exchanger design was modeled on the existing design in the BioMax® 15 and was designed to cool the producer gas stream from its initial temperature of 800°C down to a final temperature of about 100°C. The producer gas flowed inside of the tubes, to allow for easy periodic cleaning during scheduled routine maintenance cycles. The cooling air flows through the shell side of the heat exchanger.

The producer gas will entrain all of the char produced by the gasifier. The inside diameter of the heat-exchanger tubing was sized to be larger than the expected char particles. Testing confirmed that the potential for blockage or fouling is significantly reduced because of the lower ratio of particle size to tubing diameter than in the BioMax® 15 design.

The high temperature of the producer gases will cause the tubes to grow over one inch in length, as they heat up to almost 800°C at the hot end. The design allowed for the relief of thermally induced stresses in the tube sheet, which had been shown to be problematic.

The producer-gas entrance to the heat exchanger was directly coupled via a flange connection to the gasifier and the gas out port was provided with a 4” sanitary fitting. The cooling air entered and exited perpendicularly to the heat exchanger. The hot end gas seal used a custom fabricated gasket made of Thermiculite material, which had been proven for this application in the BioMax® 15. The cold end used a conventional silicone rubber gasket. The cooling air entered and exited through the top of the heat exchanger. Cooling air flow was split in order to reduce dP on the shell air side of the heat exchanger. The cooling air was provided by a high-pressure radial blade blower that had excess capacity to allow for decreases in heat-transfer coefficients caused by tube fouling. A variable speed motor controller controlled the speed of the blower and the flow rate of the cooling air. In testing, CPC demonstrated good control of the exit temperature of the producer gas by varying the flow rate of the cooling air.

Experience with a smaller, but similar, heat exchanger in the BioMax® 15 indicated that the periodic cleaning of the heat exchanger was necessary to remove dry, powdery, carbonaceous deposits. Ten-inch diameter sanitary fittings and caps were provided at the cold end of the heat exchanger and on the opposite side of the lower gasifier to allow unobstructed access for inspection and cleaning of the tubes.
Maintenance personnel had unrestricted line of sight through all tubes during cleaning. Cleaning of the tubes was performed with a stainless-steel brush on a long cleaning rod, with a brush spinning on a rotating cable, or flexible tape. The carbonaceous deposits normally could be vacuumed, as they are liberated from the tube surface, to avoid air-borne particulates near the operator. Prior to cleaning, it was necessary to purge the system of CO by turning on the producer gas blower. The blower brought clean air through the heat exchanger and filter to the flare outside.

### 3.3 Filter Design

Filter design was based on the basic baghouse approach used in the 15-kW design. However, the final prototype design has a number of improvements that allowed it to operate continuously in the 50-kW design.

The filter subsystem was a five filter, up flow design. Each filter uses a simple cylindrical filter bag that is inflated by the flow of gas and the dP of the filter material. The five filters are joined by a common trough with an auger in the base to remove the char and filter fines. Four bags are sufficient to maintain an acceptable filter dP, while the fifth bag is automatically taken off line for filter-cake removal.

The char cake is shed by means of a weight located on top of the bag. When gas flow is cut off coming from a bag by an independently operated valve, the weight causes the bag to turn itself inside out. As the bag material folds over, it sheds the cake.

Testing of the prototype under normal operating conditions and at similar flow rates resulted in average cycle times of one hour. Using five filters allowed one filter to be taken off-line at a time without adversely affecting the pressure drop across the filter system. It took approximately 5 minutes to cycle each filter. A timing algorithm was used to cycle the filters on one-hour intervals. If the total filter system pressure drop exceeded normal operating parameters, the cycle time was shortened until the system pressure drop returned to normal.

Individual cycling of the filters requires outlet valves for each filter bag to cut off gas flow. Filter inlet piping is designed to provide equal distribution of char and gas to the five filters. The individual filter inlet pipes were mounted tangentially to the round filter housing in order to provide centrifugal separation of the larger particles from the gas stream. This was done to minimize the risk of a large, hot, char particle burning a hole in the filter fabric.

A safety filter was included in line with each filter bag. In the event of a bag rupture, the safety filter will protect the engine from high amounts of particulates; although the safety filter will rapidly become plugged, the remaining filters will carry the load on an accelerated duty cycle. Individual differential-pressure gauges were installed across the safety filters to reveal the location of the plugged filter and ruptured bag filter.
3.4 Controls Design

CPC selected and tested a commercial Programmable Logic Controller (PAC ) system for the Biomax® 50 to provide the following benefits/features:

- Industrial grade modules for immunity from environmental factors, such as temperature, noise and vibration;
- Plug and play architecture and limited self-diagnostic capability;
- Rapid access worldwide to replacement hardware;
- Full I/O capability;
- Imbedded controller makes external computer unnecessary
- No local user interface required because of PLC’s ability to be monitored via any PC on a local Ethernet or from remote site;
- High reliability due to proven designs, extensive testing and rugged construction;
- Acceptable cost for prototype deployment and reasonable learning curve for designers;
- Low risk path for proof of concept using loaner modules and retrofitting into existing Biomax® 15 systems.

CPC chose to prototype the National Instruments Compact Field Point control system using National Instrument’s latest version of LabView Realtime software and to perform proof of concept testing by retrofitting one of our existing BioMax® 15 systems. This control system was subsequently installed in the BioMax® 50 system and has performed well in all system testing to date.

The control system was based on 16 temperature, 5 differential pressure, 40 discrete output, and 16 variable output channels.

3.4.1 Final Control System Design

The National Instruments control system improved the capabilities, as detailed below.

3.4.1.1 Run the System without External Computer

The BioMax® 15 system required an expensive laptop to run the operating program and to drive the external hardware. The local operating conditions of most sites tended to be dusty and noisy, making the BioMax® environment a poor location for the computer. Longer communication cables were a partial solution, but USB cables over six feet in length proved unreliable and serial cables were only good up to about fifty feet.

The new BioMax® 50 control system features an imbedded processor so that all control functions can run without an external computer. For local connection to an intranet or to the internet, the BioMax® 50 control system uses high reliability Ethernet cables and connectors.
3.4.1.2 Remotely Monitor and Control the Unit

The BioMax® 15 could only be monitored from a local computer hard wired to the control system hardware. This local computer contained the software to run the system and was the sole means of displaying all of the system operating parameters. Because the computer was tied to the control system, environmental constraints, such as ambient temperature, limited the location of the entire system to indoor environments and forced the operator to perform control or monitoring functions alongside the system.

The new BioMax® 50 control system offers much more flexibility in location of the system because it does not require a local computer for control and any remote computer can be used to monitor system parameters.

3.4.1.3 Remotely Retrieve Run Data Stored on the System

Data retrieval from the BioMax® 15 pre-commercial demonstration sites was difficult because it required the operator to download data files onto a CD and mail that CD to CPC. Alternatively they could connect the computer to the internet and send files electronically, but this required the operator to retrieve files and initiate the file transfers.

Since the new BioMax® 50 control system hosts its own website, and has remote monitoring capability, CPC can initiate file transfers at any time from any remote site via the internet. This frees CPC from dependency on the local operator for data retrieval.

3.4.1.4 Remotely Update the Control Software

Just as monitoring and data retrieval are now possible from remote sites, changes to the system operating software can also be downloaded remotely. With the BioMax 15 system, software had to be downloaded via CD or via the internet and then installed on the local computer by the operator.

As with data retrieval, CPC could initiate software downloads at any time from any remote site via the internet. This freed CPC from dependency on the local operator for software program changes.

3.5 Conclusions And Recommendations

CPC was careful at the beginning of the BioMax® 50 design process to identify those areas that were a problem in previous gas production module designs. This drew on our experience from previous demonstration projects and surveyed the entire technical staff to identify problems to solve as well as improvement goals for the new system. Our mission was to improve the design in many ways, not limited to simple increases in capacity and duty cycle.

CPC established a multi-cycle design approach that broke the system down into its constituent elements and performed proof of concept testing on design elements in early rounds of the prototyping process in order to make the most progress in the shortest possible schedule.

3.6 Task 3 And 4. Design And Fabrication Of Modules

The various components required for a BioMax® 50 system can be grouped into three modules:
• Feed Preparation Module (FPM);
• Gas Production Module (GPM); and
• Power Production Module (PPM).

The automated control system supervised and coordinated these three modules to act in concert with each other and was responsible for the ability of the BioMax® system to function without an operator in attendance. The operator monitored and adjusted system-control parameters locally, or remotely via the Internet or mobile phone technology.

3.6.1 Feed Preparation Module

This module performs the combined functions of feedstock preparation and metering including:

• Long term storage of raw feedstock;
• Metering;
• Sorting;
• Conveying from the sorter to the dryer;
• Drying;
• Dried feedstock temporary surge bin; and
• Final conveying into the gasifier.

Figure 6 shows a process flow diagram for the Feed/Dryer Module. With presorted or dried feedstocks, several of these process steps can be eliminated.

3.6.1.1 Fuel Consumption

The BioMax® 50 consumes approximately 0.81 kg of fuel on a dry basis for every kWhr of electricity produced. Therefore at full load the system will consume 89 lbs per hour or a little over one ton per day (dry basis). CPC performed studies of wood from one of its pre-commercial demonstration sites and obtained typical bulk density values of roughly 10 to 14 lbs/ft³, depending on moisture content. The wood tested was a softwood mixture comprised mostly of Douglas Fir species and should be representative of comparable woodchips from the other regions.

Using these bulk density values, engineers at CPC calculated that the system will consume between 2,200 lbs and 3,300 lbs of wood per day (wet basis) depending on incoming moisture.
content (10 to 40 percent). This same amount of wood will occupy a volume of 220 ft³ to 235 ft³, depending on moisture content and variances in chip packing density. Therefore, long-term storage capacity should be at least 8 to 9 yd³ to keep up with the continuous daily demand. Long-term storage should therefore be some multiple of the daily consumption depending on how many days autonomy the site requires between intermittent fuel deliveries. Since a truckload of woodchips varies typically between 80 and 120 cubic yards, long term storage should hold at least this amount and deliveries can be timed at weekly or longer intervals.

### 3.6.1.2 Fuel Storage

Long-term storage and fuel handling will be the responsibility of the site owner. Short-term storage is defined as the storage capacity at the beginning of the automated feeding system that supplies the BioMax® 50 system. This may not be necessary if the site owner has a long term storage system that can convey material directly from the long-term storage pile directly into the automated handling system supplied by CPC. On the other hand, if chips must be manually transported to the BioMax® 50 in a batch mode process, then the temporary storage capacity provided will dictate the frequency of the manual loading operations.

Figure 7 shows that at CPC, there was a small tilting hopper with a capacity of two cubic yards that was manually loaded from the long term storage pile, carried by forklift and dumped into the metering bin. The metering bin could be filled with two loads of the smaller tilting hopper.

### 3.6.1.3 Metering Bin

CPC fabricated a metering bin at the front end of the fuel handling and conditioning process (see Figure 8). This metering bin was designed to contain four cubic yards of material, or enough to require refilling only at eight-hour intervals (three times daily). The metering bin had a reserve of a minimum one cubic yard capacity of feedstock for contingencies. The selected capacity was a compromise between physical size and loading difficulty versus frequency of refilling intervals.

This metering bin was a moving bed design with a chain conveyer at the bottom of the pile. The conveyer fed chips from the bottom of the hopper at a rate that was controlled by a programmable motor controller. The metering delivered raw woodchips into a chip-sorting machine.
Figure 7: CPC's Tilting Hopper on a Fork-Lift

Figure 8: Metering Bin
3.6.1.4 Chip Sorter

Wood chips that are used in the Gas Production Module must be sorted to remove “overs” and “unders”. Particle size distribution and uniformity are physical parameters of the fuel that affect reaction rates and bed dynamics inside the gasifier. These parameters must be constrained for optimum process control and gas quality.

“Overs” can be long aspect ratio ‘stringers’ that cause bridging problems or chips that are simply too large for the design process. The gasifier design and construction was based on:

- a particular size of wood chip (wood chips that are too large may require more residence time for complete conversion than the system can provide in the given bed depth and the size of the wood chip); and
- the resulting charred woodchip may be too large to flow smoothly around the obstructions in the gasifier.

“Unders” are fines, typically sawdust and very small wood chips, that tend to pack the bed and cause an undesirably high pressure drop across the gasifier. The dynamics of gasification in a downdraft bed rely, in part, on void spaces around the woodchips for the easy flow of gases. In addition, heat-transfer rate and the reaction rates of the gasification process are higher with small chips that have a larger surface to volume ratio.

Figure 9 shows the chip sorting mechanism selected for testing at CPC was supplied by an outside manufacturer, Sweco. Sweco is a U.S. Company that specializes in particle-separation and size reduction equipment. The round Sweco separator is a highly compact device that can separate both “overs” and “unders” from the raw fuel for the BioMax® 50.

Figure 9: Sweco Wood Chip Sorter

Wood chips will be conveyed from the metering bin into the sorter by gravity feed. Figure 10 shows that the output chute of the metering bin is located directly above the chip sorter, allowing the raw feed to fall directly onto the top screen of the Sweco separator from the metering bin outlet. Figure 11 shows the “unders” rejected by the Sweco separator.
3.6.1.5 Conveyer

Wood chips were conveyed from the sorter into the dryer by means of an elevated conveyer system, manufactured to CPC’s specifications. Sorted chips dropped onto the conveyer and transported above the dryer to drop into a small storage bin in the dryer. The conveyer is shown in Figures 12 and 13 below.

Figure 10: Sweco Sorter

Figure 11: Fines Collection with the Sweco Separator
3.6.1.6 Chip Dryer

The Feeder Dryer Module for testing the 50-kW SMB system at CPC was a commercial dryer made by B.N.W. Industries. The Belt-O-Matic model 123CX dryer was a stand-alone integrated commercial component that included conveyer, motor, motor controller, and blower.
The model shown in Figure 14 illustrates the simplest of the Beltomatic dryer designs that was the basis for CEC’s dryer. It incorporated one fan and one conveyor. Drying air direction was up through the conveyor belt, and tempering air mixing is performed upstream with air inlet valves in the exhaust air ducting from the heat exchanger. Wood chips were loaded into the inlet hopper from the sorter via the inclined conveyor. Woodchip level was maintained by level sensors retrofitted by CPC. Bed height adjustment allowed the depth of woodchips to be tuned for various feedstock and incoming MC requirements. Dried woodchips were discharged at the opposite end where they fell into the integrated surge bin/feeder. Residence time and material delivery rates were regulated by belt speed, which in turn was controlled by level sensors in the downstream surge bin. Mixed air temperature was monitored just below the belt and maintained at a safe temperature. Figure 15 shows photographs of this dryer.

Figure 14: Dryer

![Diagram of dryer](image)

**FUNCTIONS**
1. Wood chip entrance and inlet hopper
2. Bed height adjustment
3. Wood chip exit
4. Hot air in
5. Conveyor
6. Cooling air
7. Exhaust air
8. Fan inlet

For CEC’s original woodchip application, the dryer was supplied without the usual integrated burner. BNW tested the model being delivered to confirm drying efficiency with the woodchip samples provided. Construction was painted carbon steel. This Belt-O-Matic model was a single stage, single pass dryer. Airflow, residence time, material depth on the conveyer, and air temperature were all controllable functions.

\[1\] From BNW Industry’s website at [http://www.belt-o-matic.com/](http://www.belt-o-matic.com/)
The dryer included a 2’ wide x 12’ long stainless steel permeable mesh belt-conveyor that moved chips through a single-pass plenum where hot air up to @ 3,000 CFM performed drying from 55 percent moisture content (MC) to 15 percent. Hot air to the dryer was supplied by the gas-cooling heat exchanger; this air will be tempered by ambient moderating air to ensure that the air does not exceed the wood chip blue haze limit of 140°C. Figure 16 shows the dried-feed as it exits the dryer.

Wood chips were conveyed from the dryer into the surge bin by gravity feed, with the end of the belt conveyer of the dryer located directly above the surge bin.
3.6.1.7 Chip Conveyer and Surge Bin

Figure 17 shows the surge bin and feeder used at CPC was a Flexicon flexible screw conveyor, also known as a spiral screw conveyor, consisting of a spring steel flexible screw that was enclosed in a semi-rigid plastic tube and driven by an electric motor located at the discharge end of the conveyor.

The lower, intake end of the flexible screw conveyor tube opened into a U-shaped trough, which connected to the bottom of the surge bin. This surge bin held approximately eight cubic feet of material. The flexible screw passed through the charging adapter trough, exposing a section of the screw to material flowing into the trough from above. When rotating, the exposed section of screw fed material into the delivery tube, where it was then drawn up through the tube by the rotating action of the enclosed portion of the screw.

Because the intake end of the screw required no bearing, and since the discharge end was coupled to the motor drive above and/or beyond the point at which material exits the discharge spout, material does not come in contact with seals or bearings. The flexible screw was therefore the only moving part contacting the feedstock. Figure 17 shows the removable clean-out port covers the intake end of the conveyor tube, permitting rapid emptying and flushing of the tube, as well as disassembly and wash-down of components.²

² From Flexicon’s website at [http://www.flexicon.com/us/Products/FlexibleScrewConveyors/index.asp](http://www.flexicon.com/us/Products/FlexibleScrewConveyors/index.asp)
Figure 18 shows that the wood chips were augured via an inclined screw conveyer from the surge bin into the gasifier. The screw conveyer and surge bin were an integrated product manufactured by Flexicon and designed to CPC specifications for conveyance of softwood chips in the 2-in minus size range. CPC added a vibrator to the surge bin to promote flow of chips into the auger throat and lined the surge bin with polyethylene plastic sheet to promote chip flow and prevent bridging. Figure 19 shows the Flexicon feed conveyer at CPC, mounted on a CPC designed rolling fixture. Figure 20 shows the woodchips after delivery into the top of the gasifier.
Figure 18: Chip Conveyor

Screw conveyor motor

Feed into day bin

Feed out

Top of Gasifier

Figure 19: Conveyer / Surge Bin
3.6.2 Gas Production Module

This module included the BioMax® 50 gasifier, producer-gas cooling heat exchanger, and producer-gas filter. These components were all custom designs made by CPC, due to the unusual nature of their requirements. The gasifier is an open-top downdraft gasifier with secondary-air injection with multiple injectors at five different levels. This has proven to result in very low tar levels. The heat exchanger is of the tube-in-shell type with a special thermal-expansion-relief feature, required due to the very large change in temperature of the producer gas. The filter uses cloth bags that are automatically cleaned to maintain a low differential pressure through the filter. This combination results in a producer gas having very low levels of tar and particulates.

3.6.3 Dryer Module Specifications

Table 2 summarizes the component equipment that comprise the Dryer Module, along with their rated electrical consumption and approximate dimensions for perspective. All of the equipment was sized to process considerably more than the nominal gasifier consumption at maximum rated gas production rates. Note that this rated electrical draw is considerably higher than the actual parasitic load, due to the motors being deliberately oversized for the mechanical loads involved and to the intermittent nature of their operation.
Table 2: Dryer Module Equipment Power and Size

<table>
<thead>
<tr>
<th>Component</th>
<th>Manufacturer</th>
<th>Rated Power kW (hp)</th>
<th>Approximate Dimensions, in. W x L x H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metering Bin</td>
<td>CPC</td>
<td>2.25 (3)</td>
<td>30 x 96 x 162</td>
</tr>
<tr>
<td>Sorter</td>
<td>SWECO</td>
<td>0.25(0.33)</td>
<td>29 x 31 x 29</td>
</tr>
<tr>
<td>Conveyer</td>
<td>CPC</td>
<td>2.25(3)</td>
<td>36 x 108 x 156</td>
</tr>
<tr>
<td>Sorter to Dryer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryer</td>
<td>BNW Belt-O-Matic</td>
<td>2.25(3)</td>
<td>63 x 168 x 120</td>
</tr>
<tr>
<td>Conveyer</td>
<td>Flexicon</td>
<td>1.25 (1.5)</td>
<td>40 x 98 x 129</td>
</tr>
<tr>
<td>Surge Bin to Gasifier</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.7 Power Production Module

This module was based on a commercial engine/genset designed to be fueled with natural gas. CPC made numerous modifications to the control system to adapt it to producer-gas fuel with the design goals of meeting strict air emission requirements, delivering grid-quality electricity, and recovered waste energy (CHP). The engine genset selected was a commercially available genset configured to run on gaseous fuels, either propane or natural gas.

3.7.1 Engine/Generator

The engine CPC selected was the Vortec 8.1 Liter engine made by General Motors. The improvements for the 8.1 L, big-block V-8 Vortec 8100 engine were aimed at increased performance and durability. Durability enhancements included the addition of induction hardened intake valve seats and reduced valve spring load to ensure proper valve seating for the life of the engine. Bore and stroke was 107.95 x 111.00 mm and maximum hp was 160 hp at 1800 rpm on natural gas.

In addition, the engine supplier to the genset manufacturer had developed a new camshaft to optimize performance at 1800 rpm for direct drive generator applications and provides a 25 percent improvement over the existing model. The new camshaft also provided more torque through the intended torque range up to 2800 rpm. Table 3 summarizes the engine and its performance.
Table 3: 2004 GM Industrial Engine Power/Torque Levels

<table>
<thead>
<tr>
<th>Engine</th>
<th>Fuel</th>
<th>Displacement</th>
<th>Power</th>
<th>Torque</th>
<th>rpm</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vortec 8100</td>
<td>LPG, NG</td>
<td>8.1 L</td>
<td>160 hp</td>
<td>467 ft-lb</td>
<td>1800</td>
<td>NG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>230 hp</td>
<td>431 ft-lb</td>
<td>2800</td>
<td>NG</td>
</tr>
</tbody>
</table>

The engine genset was supplied by Gillette Generators of Elkhart, Indiana. The specific genset model is the SP-600-3-4 rated for natural gas (dry fuel, spark ignited and naturally aspirated).

There were no GM specifications for the quality and purity of producer gas to be used in this engine, because the engine was not designed to use producer gas as fuel. Table 4 shows the nominal composition of producer gas, which is very different from natural gas that is mostly methane. CPC goals were to provide a producer gas with low levels of tars, solid particulates, and oxygen. The presence of excessive tars in the producer gas could lead to deposits on the intake valves that can cause them to not open and close properly. Excessive levels of particulates in the producer gas would lead to rapid engine wear. Tar levels below 50 ppm and particulate levels below 25 ppm in the producer gas were thought to be necessary to avoid excessive engine maintenance.

Various commercial engine controls were added, including solid state ignition advance control, throttle management and output power conditioning. CPC has also added an engine-coolant/oil-intercooler for long engine life under prime power running conditions.

An exhaust-gas heat exchanger was added to extract heat from the engine-exhaust gases and add it to the liquid coolant system. A separate coolant radiator sized for the thermal load at 100-kW operation was retrofitted to remove the combined heat from the engine block and the engine exhaust, for operation when there was no demand for recovered waste heat. The radiator was located off skid where it could be integrated into ductwork that brings in cool outside air and exhausts waste heat and noise to the outside environment.

Table 4: Nominal Composition of Producer Gas Made from Wood

<table>
<thead>
<tr>
<th>Component</th>
<th>Nominal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>16%</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>18%</td>
</tr>
<tr>
<td>Methane</td>
<td>3%</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>10%</td>
</tr>
<tr>
<td>Water Vapor</td>
<td>9%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>44%</td>
</tr>
<tr>
<td>Tar</td>
<td>&lt;50 ppm</td>
</tr>
<tr>
<td>Particulates</td>
<td>&lt;25 ppm</td>
</tr>
</tbody>
</table>
3.7.2 Generator
The three-phase generator that was supplied with the genset package by the genset integrator was manufactured by Mecc Alte Spa of Italy. It was a directly coupled, industrial four pole brushless generator Model ECO32-1L/4, rated at 60-kW continuous Class H (ΔT = 125°C). Generation efficiency is 92 percent from 75 percent to 100 percent of full load.

The engine/genset was supplied by Gillette Generators of Elkhart, Indiana. The specific genset model was the SP-600-3-4 rated for natural gas (dry fuel, spark ignited, and naturally aspirated).

3.7.3 Engine Intake And Control Modifications
Considerations in choosing a control system for this engine included timing changes, alarm setup, engine interfacing, grid interconnection, and mixture control. Each of these functions needed to be tunable for producer gas. The stock controller on the 8.1L GM Vortec engine was an eControls module developed by GM to monitor engine alarms, mixture, and control timing. Because this module is proprietary, CPC was not able to modify or interface with it in any way. As a result, CPC was forced to remove this module and replace it with components that could be programmed to producer gas specifications. Removing the eControls module required replacing it with new electronics, throttle body/governor, engine monitoring, O2 sensor, and ignition module.

3.7.3.1 Throttle Body / Governor
A Woodward PowerFlow™ 60-mm butterfly valve was chosen to replace the stock 58-mm Bosch integrated throttle-body/governor combo. To control this butterfly valve, a Woodward SG2T governor was used, because of its ability to accept control speed inputs from an outside synchronization module in order to synchronize the generator output with the electric company. A second 50-mm throttle-body/governor combination, the L-Series ITB, was also considered from Woodward.

3.7.3.2 Engine Monitoring
The Woodward GCP-22 replaced the engine monitoring of the eControls module and adds the ability to control the synchronization process to the electric grid. This module also incorporated interconnection monitoring and could operate a protection relay; however, this function has only been approved in Europe and will not be used on the BioMax® 50.

3.7.3.3 Mixture Control
The mixture control of the BioMax® 50 operated using a Wideband O2 control module from TechEdge, an Australian company. The O2 module used a VW 7057 Wideband O2 sensor that was installed into the exhaust manifold and would detect a wider range of mixtures than a standard narrowband sensor. This sensor could detect “air/fuel” ratios between 10 and 20 (14.7 is stoichiometric). Mixture was controlled using a 60-mm PowerFlow™ valve attached just before the throttle plate. Producer gas flow rate was monitored with a BMW flap-style mass-flow sensor. Combustion air flow was measured in the same way with a second mass-flow sensor. Because the stoichiometric mixture of the “average” producer gas was 1:1, the
Combustion Air valve could be quickly changed to enrich or lean the mixture. Tying the Wideband O2 sensor into the calculation closed the control loop to make the mixture stoichiometric.

3.7.3.4 Ignition Module
Ignition timing used an AutoTronics ignition module with harness pre-wired for the Vortec engine. The ignition advance was continuously variable throughout the RPM range and could be programmed on the fly through a detachable computer.

3.7.4 Exhaust Modifications
A critical grade silencer and sound attenuated enclosure is supplied with the genset. CPC added a shroud around the exposed exhaust pipe for protection against burn injuries. CPC also retrofitted automotive-style 3-way catalytic converters to reduce emissions. A marine exhaust-gas manifold was substituted for the stock exhaust manifold, so that engine coolant could be circulated through the exhaust manifold for the purpose of collecting thermal energy that would otherwise be lost in the exhaust stream. However, this cooled the exhaust gases so much that the function of the catalytic converters was impaired. A Bowman exhaust-gas heat exchanger was used to recover this waste heat and the original exhaust manifold was used. This design is described more fully in the following section dedicated to combined heat and power (CHP) design.

3.7.4.1 Emissions Controls
The BioMax® 50 gasifier/engine/genset was designed to be an environmentally friendly system with extremely low pollution emissions, such as those required by the California Air Resources Board (CARB) 2007 Regulations for Distributed Power Generation for waste gas. The main exhaust emission constituents addressed in the emissions controls design are nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (THC). CPC followed the same design approach that was implemented with the previous BioMax® 15 design, employing an O2-sensor tuned mixture-control system to reduce CO and hydrocarbon emissions and a catalytic converter to mitigate NOx emissions.

3.7.4.2 CHP Modifications
The BioMax® 15 SMB systems relied on engine coolant alone to heat air or water for CHP applications. Thermal energy from the gas cooling heat exchanger was typically dumped to the atmosphere rather than captured for productive use.

On the BioMax® 50 system, thermal energy from the producer-gas-cooling heat exchanger was used to dry raw fuel that is too wet for optimum gasification. However, in addition to the heat extracted from the engine block, an exhaust gas heat exchanger was used to extract heat from the engine exhaust gases and add it to the engine coolant system. Extracting additional heat from the engine exhaust greatly increased efficiency in CHP mode over previous designs and provided up to 130 kWth of thermal energy to site heating loads with the 50-kWe system. The combined thermal sources of the engine coolant system and engine exhaust allowed for a single integrated CHP system based on hot liquid storage and delivery. The liquid storage and
delivery approach was the simplest, safest, and most efficient means of delivering heat from combustion processes to onsite loads.

The next two largest sources of thermal energy in the overall system come from radiant and convective losses (42 kW\textsubscript{th}) from the combined gas production and power generation modules and the gas cooling system (37 kW\textsubscript{th}). The latter heat source is easily captured by the gas cooling heat exchanger in the form of hot air that is suitable, without conversion, but with some mixing with tempering air, for feedstock drying. Feedstock drying from 50 percent to 10 percent moisture content requires a minimum of 31 kW\textsubscript{th} (with a dryer that performs at 100 percent efficiency). Therefore ample thermal energy is available for a simple, low cost and relatively inefficient dryer design that still achieves adequate drying of wet incoming feedstock, especially if inlet air to the heat exchanger utilizes the thermal energy from radiant and convective losses. Efficiency gains in the dryer design combined with reduced requirements for moisture content reduction in the feed will allow more of the available thermal energy in the system to be used for site loads. This gas cooling energy is the obvious choice for integration into the CHP system at a later date, if ambient air is sufficient by itself for feedstock drying.

A line diagram of the CHP system is presented in Figure 21 below.

A commercial flat-plate heat exchanger was installed to extract waste heat from the coolant loop and deliver it to onsite loads. The engine radiator was sized to handle the entire cooling load in the event that thermal energy is not utilized for onsite loads. The engine-mounted water pump was disabled, because it was too small to drive the enhanced cooling system. A separate ¾-hp 3-phase boost pump was added to drive the coolant loop and a three-way control valve was added to manage the thermal load to make sure that the engine was not overcooled.

A temperature-controlled fan replaced the engine mounted fan, so that all of the recovered thermal energy was delivered to the flat-plate heat exchanger; if the energy to this heat exchanger is not used, the temperature controlled fan will remove the excess energy from the engine radiator. An expansion tank and balance valves were used to equalize pressures across the system where needed.
3.7.5 Grid Interface Modifications

Because CPC had to remove the existing controls from our genset package, CPC was able to select an integrated engine control package performed both engine control and grid interface functions. The system was designed to synchronize with an existing grid and provide a specific selectable amount of power from the system. The engine control system consisted of the following:

- Magnetic Pickup
- Current Transformers
- Engine Controller (power factor, grid sync, power ramping, main relay control, load sharing)
- Engine Speed Governor
- Utility Protection (under/over freq, under/over voltage, back current)

3.7.5.1 Magnetic Pickup: Woodward 1680-622

For engine-speed sensing, CPC used a Woodward magnetic pickup to generate a voltage signal, when a tooth of the flywheel passed by the head of the sensor.

3.7.5.2 Current Transformers: Generic (TM)302-214

Current transformers (CT’s) were used in the utility protection modules to monitor currents both into and out of the system. They were typically sold based on a maximum current saturation level. Typically, Protection Relay controllers require a 5A max current input for their current protection circuitry. In the case of the 208V three-phase 50-kW system, a maximum
short circuit current on each leg of 85 A required the use of a current transformer that could handle 100 A.

The system needed a total of four CT’s: one CT for the connection to ground; and three more for each individual leg of the generator’s three phases. This ensured that the generator was not being back-fed from the grid, as well as, making sure there were no faults in the lines.

3.7.5.3 Engine Controller: Woodward GCP-22

The engine control system entailed more than just speed control, when dealing with a prime-power, grid-connected genset. Because of the intricacies of connecting a spinning generator to the grid properly, the engine controller typically included a multitude of components. These included a synchronizer (governor speed adjust), phase angle setting (power-out), generator protection for the main breakers, and islanding protection. Optional equipment often includes power factor (PF) correction, soft-loading, load sharing (multiple gensets in parallel). These various functions were provided by Woodward in a single microprocessor-based digital engine controller (Digital Synchronizer and Load Controller (DSLC). Due to Woodward’s market dominance in the area of engine controls, CPC decided to use the Woodward GCP-22 Mains & Generator Protection & Control. This unit included PF correction for inductive loads.

3.7.5.4 Engine Governor: Woodward SG2T

The Woodward SG2T governor was used in this application because of its ability to accept control speed inputs from an outside synchronization module in order to synchronize the generator output with the electric company. The SG2T governor was pre-configured to receive inputs from the Woodward GCP-22 engine control module and in turn controlled the engine speed via inputs to the PowerFlow™ 60-mm butterfly throttle valve.

3.7.5.5 Utility Protection: SEL-351A

Utility Protection modules are required for grid connection in California. CPC used the SEL-351A Utility Protection relay. It has CT inputs for three phases and main, as well as, voltage inputs for all three phases.

3.8 Task 4. Fabrication

High quality CAD drawings of the various components were made and used as a basis for their fabrication. Fabrication of the CPC designed BioMax® 50 system components was accomplished primarily in CPC’s machine shop, but with some parts fabricated in outside machine shops and sheet metal shops in the local area. CPC performed all assembly and installation of the various component parts in their facility in Littleton, CO.

3.9 Summary

The BioMax® 50 system was designed in detail to:

- prepare a wet feedstock for gasification;
- convert the feedstock to a producer gas having extremely low residual tars;
• cool and filter the producer gas;
• fuel a spark-ignited internal combustion engine; and
• produce combined heat and power (CHP).

The system was documented with CAD generated drawings and fabricated.
CHAPTER 4:
Task 5. Modules Testing at CPC

4.1 Modules To Be Tested

Community Power Corporation’s BioMax® 50 system consisted of a Feed Handling Module, a Gas Production Module, and a Power Production Module. These modules must work together in an integrated fashion to accomplish the desired goal of converting wet wood chips to electrical power and useable recovered heat. This section discusses the testing performed at CPC to verify the proper functioning of the three modules as a system.

4.1.1 Feed Preparation Module

Figure 22 shows the Feed Preparation Module. It consisted of a feed hopper that was loaded by a dump-bin mounted on a manually operated fork-lift. The feed hopper must be refilled several times a day. The feed hopper automatically delivered as-received, wet wood chips to a Sweco separator to remove excessively large woodchips and excessively small sawdust, dirt, and pebbles from the desired wood chips. The Sweco separator used oscillatory vibration and gravity to move the wood chips across two screens, one above the other. The oversized chips were retained on the coarse upper screen and were automatically removed to a “overs” drum. The correctly sized chips were retained on the lower screen and were removed to a conveyor that takes them to drier. The fines fell through the lower screen and were removed to a “fines” drum. The middle fraction of the wet chips exited the Sweco separator and fell past an air-knife to separate the low-density wood chips from high-density rocks, nuts, bolts, and other tramp materials.

The desired middle fraction of the screened wood chips was then conveyed to the dryer. Hot air recovered from the producer-gas heat exchanger in the Gasification and Gas Cleanup Module was used to dry to wood chips to a desired moisture level of between 8 to 15 percent (wet basis). The chips slowly moved through the dryer on a conveying system.

The chips then fell into a surge bin, which provided warm, dry chips to a Flexicon feed auger, which automatically delivers wood chips to the gasifier as needed to maintain the level of wood chips in the gasifier. The Feed Preparation Module used level sensors and two thermocouples acting through a computer to turn motors on and off and to adjust the speed of the tempering air blower. This Module delivered wood chips on demand to the gasifier.
4.1.2 Gas Production Module

Figure 23 shows the Gas Production Module. It consisted of an advanced state-of-the-art, downdraft gasifier, a heat exchanger, a filter, a Roots blower, and a flare. The top of the gasifier was normally open, allowing the feed to fall directly into the gasifier. A feed gate was automatically closed at shutdown to preserve the bed of charcoal for the next system startup. The gasifier was heavily instrumented with thermocouples strategically located to provide a temperature profile of the bed. Thirteen thermocouples were used to control the flow of secondary air into the gasifier. This gasifier design produced a gas having extraordinarily low tar content.

The gasifier was flanged near its bottom to allow the gasifier to be opened for the periodic removal of tramp material and clinkers from the grate, during scheduled weekly (or longer) maintenance. A water mister was located near the top of the gasifier and automatically used to control the flame front, if the feedstock were abnormally dry.
A gasifier vibrator was operated intermittently to settle the char bed, collapsing bridges and rat holes. A grate mechanism was also operated intermittently to remove excess char/ash and friable clinkers.

Three thermocouples were used to monitor the heat exchanger and automatically control the speed of the Cooling Air blower. The hot air produced in the heat exchanger was ducted to the dryer. This hot air could be used for space heating as part of the CHP load, if dry woodchips (<15 percent moisture content, wet basis) were available. Caps with sanitary fittings were removed for inspection and cleaning of the heat exchanger tubes, as needed during scheduled maintenance. During startup, electric heaters in the air duct preheated the heat exchanger prior to gasifier light off to avoid water condensation in the filter. These heaters were automatically shut off after ignition of the gasifier.

The filter consisted of five filter elements using a propriety filter media to remove the char and ash particles. The five filter elements were individually and sequentially valved off from the main gas flow to automatically remove the accumulated filter cake from the filter media. The char and ash fell to the bottom of the filter housing, where an auger continuously moved it out of the filter into a Char Receiving Drum lined with a plastic bag for easy disposal. The Char Receiving drum was valved-off temporarily from the filter auger and the drum switched out during continuous operation, as needed. Additional electrical resistance heaters were present in the Filter Enclosure to preheat the filter and avoid water condensation during startup. These heaters were automatically shut off after feeding has begun.

The flow rate of producer gas was determined with a venturi meter mounted in the filter enclosure, through the use of pressure transducers and a thermocouple. The computer used these measurements to calculate the flow rate of producer gas and display it in real time. An oxygen sensor was mounted at the exit of the filter and monitored by the computer to warn of combustible mixtures in the gas cleanup system.

During startup or when engine consumption of producer gas was low, a Roots blower moved the gas through the system and sent it to a vortex flare. The vortex action in the flare mixed the producer gas with air to form a combustible mixture. The flare was equipped with an electrically powered glow plug to insure ignition of the producer gas, as soon as it was combustible.

4.1.3 Power Production Module

The Power Production Module consisted of a 496 in³, V-8 Chevy Vortec engine driving a generator rated to produce up to 60-kW of 3-phase 240 VAC 60 Hz electricity. This commercial system was modified to control the flow of producer gas and combustion air. A commercial oxygen sensor was used to control the air/fuel ratio with CPC proprietary software and controllers, but with commercial control valves. The produced electricity powered a variable load bank that was monitored with an Ohio Semitronics power meter. Figure 24 shows that waste heat was recovered from the engine coolant and the exhaust gases for space heating (and potentially cooling) purposes at temperatures less than the local boiling point of the heat-
transfer liquid. The amount of heat recovered was determined using a liquid flow meter, and three thermocouples.

**Figure 24: Power Production Module**

![Power Production Module Diagram]

### 4.2 Rationale For Tests

The tests of the BioMax® 50 prototype were designed to demonstrate the successful integration of the three component modules: Feed Preparation Module; Gas Production Module; and Power Production Module. This was to show that this integration included sufficient automation, so that one operator would be able to operate the system 24/7. CPC would measure and report the system’s CHP values and conversion efficiencies to compare to the previous BioMax® 12.5-kWe system operated on the Hoopa Indian Reservation. This testing was an attempt to discover any design changes that needed to be made to meet the objective of continuous operation for 6 days (144 hrs) and other contractual objectives listed below. These design changes could most expeditiously be accomplished while the unit was still at CPC with its in-house machine shop. CPC needed to show that the system was ready for the fuel and the operating environment at Field Test Site. CPC needed to characterize maintenance, operating requirements, and performance parameters. The system would be operated on successive endurance runs at CPC, until the required 144 hours of continual operation had been met in one run, or until it was time to ship the unit to the Field Test Site for installation.

### 4.3 Facilities, Equipment, And Instrumentation

The hot shakedown testing and the subsequent endurance testing were performed at the CPC facility in Littleton, CO. The two testing bays were used to house the Feed Handling Module and the Gasifier and Gas Cleanup Module. The Power Module sat outside on the dock and was connected to the Gas Cleanup Module with a flexible rubber hose to deliver the producer gas to the engine.
Producer gas during startup was moved through the system with a Roots blower and sent to a vortex flare at an inch or so of water-column pressure and combusted. Excess producer gas during periods of low electrical demand was compressed and sent to the flare for disposal. An electrical glow-plug igniter in the flare was activated at all times during each run to provide instant ignition of any producer gas sent to it for disposal. Combustible producer gas was not vented directly to the atmosphere.

The electrical power produced was monitored with a three-phase power meter made by Ohio Semitronics. This electrical power was sent to a balanced load bank consisting of 36 500-Watt light bulbs and other resistive electrical loads for a total of up to 75 kW_e.

Recovered waste heat from the engine was monitored with a rotameter to measure the flow rate of coolant and the temperatures of the coolant entering the engine, leaving the engine, and leaving the exhaust gas heat exchanger. This information was used to verify the predicted waste heat recovery and provide confidence to the CHP design. The coolant manufacturer’s published data was used for the heat capacity in our CHP calculations.

The composition of the producer gas was monitored with our wall mounted NOVA gas analyzer model 7905 AM. The moisture content of the producer gas was not be directly measured, but inferred by the apparent water dew point of the producer gas using water vapor pressure and temperature data from the literature to calculate the percent of water vapor in the producer gas.

CPC’s engine-emissions gas analyzer was Infrared Industries’ model FGA 4005, which measured ppm hydrocarbons, percent carbon monoxide, percent carbon dioxide, ppm NO_x, percent oxygen, and lambda (the air to fuel volume ratio based on the oxygen needed for gasoline).

Pressure transducers purchased from Dwyer, Inc sensed pressures and differential pressures of the producer gas in various locations in the system. Temperatures were sensed with type K thermocouples purchased from Omega, Inc. and digitized by National Instruments’ analog to digital converters.

The weight of dried feed was determined with a CD-11 Ohaus scale, weighing to the nearest 0.05 kg. The recovered char was weighed on the same scale.

The moisture content of the feed was determined with an A and D infrared moisture analyzer to the nearest 0.1 percent using a 5-gram grab sample of wood chips from each barrel of feed added to the feed hopper or hourly during the endurance runs fed directly by the Feed Handling Module.

4.4 Test Procedures

A copy of the individual test objectives and the test procedure was at the Operator’s station to act as a check list during the startup, operation, and shutdown of the system.
The parameters that were automatically recorded include the time of day, temperatures of the dryer hot air in and out, the gasifier, heat exchanger, filter, venturi meter, engine coolant into and out of the engine, engine coolant out of the exhaust-gas heat exchanger, pressure drops through the gasifier, grate, heat exchanger, filter, and venturi meter, the flow rate of producer gas, oxygen content of the producer gas, and the secondary air valve settings.

The parameters that were manually recorded included the weight of feed added to the surge bin, the moisture content of the feed, composition of the producer gas (oxygen, carbon monoxide, carbon dioxide, methane, and hydrogen), flow rate of the engine coolant (at constant engine speed, this will also be constant, so an inexpensive rotameter was used and manually recorded), and the delivered electrical power, voltage, and frequency.

4.5 Data Analysis Procedures

The files generated by the data acquisition system initially included data from approximately 65 thermocouples (one at each secondary-air injection port), 5 pressure transducers, the producer gas flow, the oxygen content of the producer gas and the exhaust gas, and the Char Air Valve settings. After each shakedown test or daily during the endurance runs, CPC downloaded the data files and plotted the data as a function of time to help identify long term trends, such as increasing pressure drops, etc. CPC calculated the recovered energy from the engine for on-site loads, as well as, the energy recovered by the producer-gas heat exchanger for feedstock drying.

4.6 Quality Assurance Procedures

The NOVA gas analyzer model 7905 AM was zeroed with high purity nitrogen and spanned with air and a Matheson calibration gas containing 20.00 percent carbon monoxide, 12.00 percent carbon dioxide, 2.00 percent methane, and 16.00 percent hydrogen. This calibration was performed within two months of the testing, as recommended by the manufacturer.

The thermocouples and the converted digital signal were assumed to be sufficiently accurate for these tests.

The pressure transducers were zeroed and then spanned using a Dwyer liquid manometer for reference. They did not need re-calibration for the duration of these tests at CPC.

The venturi meter coefficient was calibrated in place using an orifice meter that was calibrated gravimetrically. CPC relied on traditional flow calculations to determine the flow rate of producer gas, based on pressure, pressure drop, temperature, and an average molecular weight of 23 for the wet producer gas. The venturi meter did not need re-calibration for the duration of these tests.

The calibration of the Ohaus scale was on a yearly cycle and was current during these tests.

The engine emissions gas analyzer, Infrared Industries’ model FGA 4005, was calibrated with air and an automotive calibration gas standard Blend Code 32-97LOW made by Praxair Specialty Gases and Equipment, containing 0.5 percent carbon monoxide, 6 percent carbon
dioxide, 201 ppm propane, and 301 ppm NO. The manufacturer suggested a calibration check every six months.

Figure 25 shows the BioMax® 50 system, except for the day bin, woodchip conveyor which are behind the dryer in this photo. Also not shown is the engine/genset, which is located outside of this room.

**Figure 25: BioMax® 50 Fuel Handling and Gasifier Modules at CPC**

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### 4.7 SMB Prototype Module Cold Shakedown Results

The cold functioning of the system was tested as the individual modules were installed and were ready for testing.

In the cold shakedown testing, CPC verified the functioning of the individual modules to the extent possible at room temperature. This included verifying that all of the thermocouples were properly identified by the control computer; each thermocouple was temporarily disconnected and an open thermocouple response for that thermocouple was verified.

The pressure transmitters were zeroed and spanned using a liquid manometer for reference. The pneumatic connections to the pressure transmitters were verified by momentarily disconnecting them and watching for the proper response of the control computer.

The venturi meter was calibrated using a reference orifice meter that had been gravimetrically calibrated.
4.7.1 Feed Handling Module

4.7.1.1 Feed Bin
The feed bin was loaded with the Transport Bin mounted to a fork lift. The ability of the Transport Bin to dump the raw wood chips into the Feed Bin was verified. The function of the CPC designed Feed Bin was verified to deliver raw wood chips on demand. The Feed Bin had paddles mounted on a continuous chain that pulls out wood chips from the bottom of the Feed Bin. Preliminary testing verified that it would deliver chips at a rate considerably higher than the gasifier was expected to consume. Minor modifications were made to reinforce the unit in the housing covering the returning paddle chain. In addition, it was decided to install a motor/transmission with a lower output speed to better match the throughput of the Feed Sorter. A level sensor was mounted on the Dryer Hopper and verified that it activated the Feed Bin to maintain the level of wood chips in the Dryer Hopper. A polyethylene sheet of plastic was added to one wall of the Feed Bin to encourage the raw wood chips to slide down to the conveying chain.

4.7.1.2 Feed Sorter (Sweco Unit)
The Feed Bin discharged directly onto the Sweco unit’s uppermost of three screens, which separated the chips into “overs,” usable wood chips, and “unders.” After some consultation with the Sweco representative, the proper settings of the two vibratory weights were determined, which provided the proper oscillatory motion to the unit. CPC found that as the long slivers were discharged from the Feed Bin, some of them would spear the top screen. Some of the “spears” passed through the top screen, but the remainder stuck in the screen to interfere with the action of the sorter. This necessitated placing a solid plate on the top screen to re-direct the longer chips to a horizontal position, which then were screened properly. CPC also changed the top and bottom screens, replacing them with flat plates with round perforations. The Sweco unit undergoes relatively violent motion during shutdown and it was driven by a relatively small motor, so it was turned on early in the run and left running for the duration of the run.

4.7.1.3 Air Knife
An air knife was set up at the outlet of the Sweco separator to separate rocks and tramp metal from the wood chips. This was partially successful, but the higher density of wet wood chips made the separation less than complete. The air knife was moved to the outlet of the dryer, where the lighter, dry wood chips were easier to separate from the denser rocks.

4.7.1.4 Conveyor
The CPC designed conveyor was originally fitted with flights that did not cover the width of the conveyor width. This led to excess spillage of feedstock, as it fell from the outlet of the Sweco unit to the conveyor belt. Flights that more closely matched the width of the conveyer were installed, which significantly reduced the spillage. The Conveyor was turned on early in the run and left running during the remainder of the run.
4.7.1.5 Dryer
The dryer was BNW Industry’s Model 123CX. During the cold shakedown of this system, the function of the axial fan and the internal conveyor belt was verified. The hot air outlet of the heat exchanger was connected to the Dryer’s hot air inlet. A tempering air valve was installed to add ambient air to the hot air to form an air mixture with a controllable temperature below “blue-haze” temperatures. The depth of wood chips on the Dryer’s wire-mesh conveyor belt was adjusted to 5½ inches. A level sensor was mounted on the surge bin of the Flexicon feeder to activate the Dryer’s conveyor belt to keep the surge bin full of dried feed.

The ability of the dryer to use ambient air to dry wet wood chips was demonstrated, although it was relatively slow process. With the chips three to four inches deep on the stationary belt, the moisture level was reduced from 34 percent to 7 percent after 1 hour and 27 minutes with the dryer fan blowing ambient, dry Colorado air through the chips in a batch mode. Thus, it was not necessary to operate the dryer with a propane space heater to obtain some dry chips for initial gasifier operation.

4.7.1.6 Flexicon Feeder
Tests with the slightly larger wood chips used in the BioMax® 50 showed an increased tendency to jam in the Flexicon auger-feeder. This would overload the motor and cause it to overheat and cut out. The operator then had to reset the motor to resume feeding. A control algorithm was put in place that sensed a jammed feeder, momentarily reversed the direction of the screw, and automatically restarted feeding. This action was shown to be very reliable to clear the jam, usually with the operator unaware that a jam has occurred.

The wood chips had a distinct tendency to form bridges and rat holes in the surge bin, which eventually prevented feed from reaching the auger in the feeder. A small vibrator was added to the bin to collapse the rat holes before they could starve the auger. In addition, sheets of low-friction polyethylene plastic were added to the inside walls of the surge bin to make it more difficult for bridges to form in the feedstock.

4.7.2 Gasifier And Gas Cleanup Module
4.7.2.1 Gasifier
The function of the gasifier vibrator was verified to vigorously agitate the spring mounted gasifier. The movement of the Grate Shaker mechanism was verified to be as designed. The feed gate was demonstrated to release properly upon a power failure or the computer command. The feed gate would slide into place to effectively seal the top of the gasifier.

The Secondary-Air Injection system was changed from one controllable air blower for each of five levels to one air blower and five control valves (one valve for each of the five levels). The proper response of the control valves to signals from the control computer were verified. The delivered air pressure to the lower 3 levels of fingers was measured with the valves 80 percent open. This was judged sufficiently similar to proceed with hot testing.

The cal-rod igniter was energized and heated up properly.
A water-misting system consisting of a 5-gallon reservoir, small water pump, and spray nozzles was added to the system and checked out. It was used to control the flame front in the upper portion of the gasifier, when the feed was unusually dry.

4.7.2.2 Heat Exchanger
The functioning of the Gas Cooling Blower to move air through the heat exchanger was verified. The Cooling Air diverter valve was set to provide equal air flows to the two shell sides of the heat exchanger. Computer simulations of the heat exchanger showed that the average temperature of the combined two hot-air streams was relative constant over a wide ratio of air going to the two shell sides of the heat exchanger.

4.7.2.3 Filter
The solenoids that control the gas outlet valves of the five filters were checked for function. The action of the horizontal char auger that traverses the bottom of the filter was verified. A new diagonal auger was added to the filter system to move the char from the bottom of the filter housing directly into a 55-gallon drum.

At the outlet of the filter is an oxygen sensor to trigger an alarm if the oxygen in the producer gases exceeds 4 percent. This is to alert the operator if a combustible air/producer-gas mixture is being approached in the system. This sensor was zeroed with nitrogen and spanned with air. It was determined that because of the very low voltage produced by this sensor, that it should be read by a thermocouple analog-to-digital module. The software re-spans the sensor at the beginning of each run, when air is going past the sensor.

4.7.3 Power Module
The power module consisted of a GM Vortec V-8 engine and a flare. During startup and shutdown, the draft for the gasifier system was provided by a Roots gas blower when the producer gases were sent to a flare to be burned. The control of the Roots blower was demonstrated, based on the producer-gas flow rate calculated by the temperature and pressures at the venturi meter. The electrically heated glow plug used for flare ignition was verified to glow red hot when energized. This igniter was normally energized during an entire run, so in case the engine stalls and the flare is needed, there is no time delay before the flare will be ignited and producer-gas emissions minimized.

The control algorithms for the engine were verified to control the producer gas valve and the combustion air valve of the engine. The oxygen sensor in the engine exhaust was also checked out as much as possible.

The engine manifold heat exchanger has been installed to recover waste energy from the engine’s exhaust gases. The rotameter and thermocouples to measure the flow rate and the temperature of the engine coolant were installed. The system was leak checked.

4.8 SMB Module Hot Shakedown Test Results
CPC’s goal was to have the integrated Gas Production Module ready for preliminary system testing in late November and to be generating producer gas and making power in a stable and
sustained manner by December 15, 2004. CPC met these goals by achieving a maximum sustained power run utilizing the both final prototypes of the Gas Production Module and the Power Production Module. Chip handling was partially automated for this run, and power was delivered to local resistive loads rather than onto the grid. Combined heat and power (CHP) components were not yet installed or operative at this time.

In the December 15th test, only the fourth with the new engine genset in place, the system was able to sustain a continuous load of 49.4 kW using 135 Nm³/h (79 SCFM) of producer gas. Correcting this power output to engine performance at sea level resulted in a nominal rating of 60.9 kVA with a normally aspirated engine.

Other system performance measures have been excellent. Sustainable gas flow rates of up to 225 Nm³/hr (132 SCFM) were established and gasifier temperatures and flame front remain extremely stable. System dP’s were consistently low, gas quality was excellent and the heat exchanger and filter modules had not required cleaning or maintenance. Char conversion rates were on the order of 0.5 to 1.0 percent, which implies that the wood fuel was being converted almost all the way to pure ash.

The hot shakedown testing proceeded as soon as the Gasifier and Gas Clean Up Module was ready, which was in advance of the Feed Handling and Power Modules being ready. Although CPC had originally planned on only three hot shakedown tests, there were over 30 hot shakedown tests performed with the round-flanged gasifier, with each one lasting between an hour and 48 hours. CPC had operated the prototype BioMax® 50 gasifier through 32 thermal cycles, equivalent to over 7 months of operation (assuming one thermal cycle per week).

4.8.1 Feed Handling Module
4.8.1.1 Conveyor
The conveyor that moved the sorted feed from the Sweco sorter to the dryer-feed hopper was first operational on April 7, 2005. There was a problem observed with wood chips working their way in under the belt, which was resolved a few days later by the addition of stationary brushes on the sides of the conveyor.

4.8.1.2 Dryer
The dryer was first used with hot air from the producer-gas heat exchanger on April 4, 2005. The hot-air ducts were not initially insulated and the temperature of the hot air delivered to the dryer was only 43°C. However, the moisture content of the wood chips was reduced from 44 percent to 12 percent. The wet feed was manually loaded into the dryer’s feed hopper during these initial drying tests. The control algorithm for the tempering-air valve and the level control on the Flexicon feed hopper that controls the delivery of dry chips from the dryer were operating correctly as of April 6, 2005.

On April 8, 2005, the dryer was reducing the moisture content of the wood chips from 51 percent down to 11 percent to 12 percent, with hot air at 63°C passing up through the wood chips.
Initially, the temperature of the hot air delivered to the dryer was used as the control parameter. However, inside the dryer, additional ambient air is used to cool the fan motor, so the temperature of the air just before passing through the wood chips was much lower than the temperature of the hot air entering the dryer. On April 22, the location of the thermocouple used to control the tempering-air valve was changed to be just below the belt conveying the wood chips through the dryer. On that day, while cooling 140 Nm³/h of producer gas (equivalent to that used to produce 50 kWₑ), the hot air leaving the middle of the heat exchanger was measured at 110°C, from the hot end of the heat exchanger at 156°C, and just below the dryer’s conveyor belt at 65°C.

4.8.2 Gasifier And Gas Clean Up Module

The prototype gasifier incorporated a round bottom flange, which replaced the original square flange of the pre-prototype gasifier. The upper portion of the old gasifier with its secondary-air injection tubes was mounted on the new round flange. The new Gasifier and the Gas Clean Up Module were first operational on March 18, 2005. The new cal-rod functioned as designed and ignited the bed of char, as it has in all of the other 32 runs with this new system. This was a short run, feeding woodchips having 11 percent moisture for about an hour. The new secondary-air injection system functioned as intended, with the air-flow rate to each of five levels automatically controlled with its own individual valve. The gasifier was operated with a producer gas flow rate of 130 to 140 Nm³/h, with a brief exploration of higher flow rates of 175 and 190 Nm³/h.

On May 30, 2005, after operating the upper portion of the gasifier for 44 thermal cycles and about 235 hours total run time, the secondary-air-injection nozzles were serviced for the first time. This number of thermal cycles corresponds to over ten months of equivalent operations, with one thermal cycle per week (although less than two weeks of operating 24 hours for 6 days per week). A total of 14 percent of the nozzles were plugged, with the extra-long injection tubes having 19 percent of their nozzles plugged, compared to about 14 percent for the short and long injection tubes. However, the number of nozzles plugged increased significantly below level 3. It was not known whether the nozzle plugging was a function of thermal cycles, total hours of operation, or momentary randomly occurring local temperature excursions. The operator first tried to use compressed air to blow out the nozzles, but this only reduced the plugged nozzles to 11 percent. Each of the remaining plugged nozzles were poked to remove the obstructions.

On April 8, 2005, the mode of water delivery to the water mister was changed from a 5-gallon jug and a water pump to use building water. This was to eliminate the operator chore of refilling the 5-gallon water jug periodically. A solenoid valve now turns the water on and off as required to re-hydrate overly dry wood chips and to control a rising flame front. This new water delivery method has had no problems. On May 19, the number of water misting nozzles was reduced from four to one, to reduce the tendency to excessively hydrate the wood chips. In addition, the water mister only functioned when needed to lower the flame front and only when the wood chips were being fed.
On April 14, 2005, the moisture in the feed going to the gasifier was measured at 37 percent, then 34 minutes later it was measured at 28 percent, and 37 minutes after that at 18 percent. The effect of this slug of wet feed on the gasifier was a falling flame front, which caused the operator to lower the temperature set points in the gasifier from 875°C to 850°C to decrease the secondary air and increase the primary air and encourage the flame front to rise. During this time, the recorded methane levels were 4 percent or less, but the CO level dropped to 14 percent, the CO₂ level climbed to 15 percent, and the hydrogen level stayed at about 20 percent. This suggests that the extra water in the feed was shifting the water-gas reaction to produce more hydrogen and carbon dioxide. The ability of this gasifier to survive this extremely wet feed was amazing. Modifications to the secondary-air algorithms to automatically adjust to a falling flame front with temperature set-point changes were first tested on April 22, 2005.

On April 21, 2005, the new heat exchanger having dual inlets and outlets was installed and tested for the first time. The control algorithm used to control the Cooling-Air Blower with the old heat exchanger appeared to work well with the new heat exchanger.

An auger was added to the filter to lift the recovered char from the bottom of the filter housing to drop it into a 55-gallon drum. Initially this auger was rubbing on the auger tube and causing the electric drive motor to overheat and make a lot of high pitched noise. The auger was removed and reworked several times to remove metal from the flights to finally remedy this problem.

Occasionally the gasifier was opened to inspect the grate. The grate accumulated the tramp materials in the wood chips, e.g., rocks, nuts, bolts, washers, etc. There was some evidence that the grate could break up the rocks to form small pebbles that could pass through the grate. Some of these pebbles were entrained through the heat exchanger and no doubt helped to keep the heat transfer surfaces clean of deposited char and tars. However, some of these pebbles accumulated in the lower tubes of the heat exchanger and in the transfer lines. There was an obvious need to remove more of these rocks and tramp materials from the feedstock.

4.8.3 Power Module

The engine was started for the first time with the prototype system during the run of March 23, 2005. This engine was fueled only with producer gas.

Problems with starting this engine on producer gas were resolved by adding metering valves in the producer gas and in the air supply lines. These metering valves insured that a one-to-one ratio of air to producer gas (approximately a stoichiometric ratio) was fed to the engine at startup. After the engine was started, the air-fuel mixture was controlled to a pre-set low level of oxygen in the exhaust gases, based on the output of the wide-band oxygen sensor in the exhaust gases of the engine.

The actuator for the producer gas valve was found to flutter during high load demands. A new actuator was installed that does not have the undesirable flutter and has two PID equations built into it (one for load jumps and one for steady-state load maintaining). This new actuator allowed the engine to cope with load jumps as high as 15 kW.
The changes made to the actuator and to the automatic control of the engine have been instrumental in attaining electrical power outputs of over 50 kW, with an apparently decreased consumption of producer gas due to increased efficiency.

While learning to operate the dryer and the water misting, problems were encountered on cold days with water condensing in the producer-gas delivery line and causing erratic engine performance. CPC installed a water trap and a small water pump, which helped understand the consequences of excessive water misting or overly wet feed. When the flame front was too high in the gasifier, excessive steam would be generated during the intermittent misting, which passed through the gasifier and caused high concentrations of water vapor in the producer gases. This lowered the dew point of the producer gas and led to condensed water in the lines, as well as, to reduced engine power. With improved control of misting and feedstock moisture levels, the condensation of water in the transfer lines appears to have been eliminated.

An engine backfire was blamed on blowback of the flame from the flare to the engine intake manifold. A check valve was installed just upstream of the flare on April 5, 2005 to prevent this from happening in the future.

Figure 26 shows the results of recovering waste heat from only cooling the engine (not including potential waste heat recovery from the exhaust gases), while fueling the engine with producer gas. The temperature of the hot coolant was expected to increase significantly and the recovered waste heat to about double, when the engine coolant was also circulated through the exhaust-manifold heat exchanger to recover waste heat from the engine exhaust gases. Consequently, the contract goal of 80 kWth and 50 kWe appeared attainable.

Numerous improvements were made to the control system during these hot shakedown runs, after problems were identified with the existing code. These code modifications were directed toward making the integrated system more automatic and smoother operating by incorporating the proper operator response to common gasifier variables. Much of the improvement was in the tuning of the proportional and integrating coefficients of the large number of control algorithms.

**Figure 26: Calculated Waste Heat Recovered from Engine Coolant (w/o Exhaust-Gas Heat)**
The ability to control the system remotely using an Internet connection was demonstrated on May 19, 2005. This would allow one operator to monitor and control several gasifiers simultaneously from a convenient central location.

4.8.4 System Controls
To improve the reliability of the gasifier control, the secondary-air injection was changed to use an average of two temperature measurements per level on March 29, 2005. This allowed control of the gasifier temperatures, if one of the two thermocouples now at each level failed.

Based on the experience gained from the Cold Shakedown and the Module testing, an in-depth Failure Modes Analysis was conducted in the latter part of May 2005 for the Feed Handling Module and the Gasifier and Gas Cleanup Module. This analysis resulted in insights into how to detect failed sensors and how to cope with their loss during a controlled shutdown. Critical thermocouples were then in redundant pairs, e.g., the temperature of the producer gas entering the filter was now measured with two thermocouples. There were now 13 Operator Alerts to suggest system problems that can be fixed during operation and which did not put personnel or equipment in danger. There were 34 Yellow Alarms that indicated severe problems, which could eventually damage the equipment. If the Yellow Alarm was not promptly corrected, the system would go into a Controlled Shutdown Mode. There were 9 Red Alarms that indicated a failure of the system and which required immediate shutdown to minimize danger to personnel and equipment. These alerts and alarms were designed to allow for eventual automatic and unattended operation of the system.

4.9 Preliminary Endurance Testing
The first endurance testing of the integrated prototype BioMax® 50 system was started on April 28, 2005 to try to identify design weaknesses. From the beginning of feeding, the run lasted for 26 hours, until it was shut down for the weekend. The moisture content of the dried feed was quite variable, between 3.8 percent and 33 percent. This variable moisture content was thought to be due to the variable moisture content in the wet, raw feed (it had been raining and snowing on the pile of wood chips stored outside). A moderate electrical load of 42 kW was placed on the engine for about 9½ hours during this run. The high moisture content of the chips, coupled with cold weather, led to water condensation in the hose delivering producer gas to the engine and early shutdown of the engine. This run was finished using the Roots blower to deliver producer gas to the flare. Shortly after this run, CPC installed a water trap and sump pump in the producer gas delivery line near the engine to remove any condensed water.

Another endurance run was started on May 5, 2005. From the beginning of feeding, the run lasted for a little over 24 hours, until it was shut down for the weekend. In this run, the moisture content of the dried feed was between 3 percent and 8 percent, which necessitated using the water mister extensively to maintain the flame front at the desired level. Near the end of this run, the gasifier had developed a high pressure drop, but 6 minutes of grate shaking cleared the grate to decrease this pressure drop from 6.5 in. W.C. down to 1.1 in. W.C.
A third test to demonstrate the robustness of the integrated BioMax® 50 modules was initiated on May 11, 2005 and lasted 48½ hours from the start of feeding to shutting down for the weekend. These three tests demonstrated that the modules were working quite well together.

4.9.1 Analysis

The Feed Bin, conveyer, commercial dryer, the CPC designed heat exchanger and filter all appeared to be working very well. Other than removing the collected char from the filter, CPC had not serviced the filter since it was put into service back in November. The new heat exchanger had been vacuumed out just once after it was installed two months ago. There were deposits of pebbles and char that plugged one of the tubes, but there were no deposits of tars.

The secondary-air injection of the BioMax® 50 appeared to be instrumental in making producer gas that had a very low tar content, which did not foul the heat exchanger, nor the filter with tars. The gasifier appeared to very tolerant of a wide range of moisture contents in the feed, but appeared to make the best gas for the engine with a moisture content in the feed of about 8 percent to 15 percent. The structural integrity of the new gasifier with its round flange appeared to be much better than its square-flanged predecessor. The nozzles in the secondary-air injection tubes appeared to need periodic maintenance to remove accumulated deposits.

Our supply of wood chips had occasional rocks in it. The rocks accumulated at the bottom of the gasifier on the grate. There appeared to be some attrition of the rocks by a combination of the mechanical action of the grate, probably helped along by thermal cycling between runs. Below the grate, pebbles accumulated in the transfer line to the heat exchanger and in the lower tubes. Although using cleaner wood chips would eliminate this rock problem, an air knife was added to remove the rocks and tramp materials from the feedstock.

The engine demonstrated the ability to generate over 50 kW_e at CPC’s elevation of 5720 feet above sea level, using only producer gas as fuel. This suggests that at sea level where the atmospheric pressure is about 2.8 psi higher that the engine could produce over 60 kW_e on producer gas. When operating at an electrical output of 50 kW_e, there appeared to be about the same thermal energy recovered from the engine’s coolant, as electrical power generated. Coupled with the energy available from the exhaust gases, CPC expected to meet the goal of recovering 80 kW_th in hot liquid coolant for heating applications. This thermal power recovery was demonstrated during the system endurance testing.

Based on these extensive tests, CPC concluded that the BioMax® 50 system, as a whole, was functioning quite well. The control algorithms were then upgraded to have a more completely automatic operation and control of the system. CPC made minor modifications to the Feed Bin, the Feed Gate, and the engine heat recovery system to improve their performance.

4.10 144-hr Endurance Test

4.10.1 Summary

The goal of this test was to operate the BioMax® 50 system continuously for a period of 6 days for a total of 144 hours. The BioMax® 50 system was actually operated for a total of 148.2 hours
of wood chip feeding, starting the evening of September 14 at 2007 hours and ending at 0020 hours the morning of September 21, 2005. This did not include the initial warm up period, which was normally about an hour. So, the nominal length of this endurance run was 149 hours. The system was still functional at the end of this period and could have continued operation.

The nominal electrical load was 45 kWe, which is 90 percent of the 50-kWe peak load. Taking into account the 5720 foot elevation of CPC, this was equivalent to the engine producing 55.6 kWe at sea-level (standard conditions). The measured parasitic loads averaged 4.8 kWe, but varied between 3.2 and 6.7 kWe (not including the 0.5-kWe flare igniter, which increases the total average parasitic load to 5.3 kWe). Thus, the net electrical generation at sea level is expected to be a nominal 50 kWe.

Occasional operational problems with the feeding system and the engine required a high level of awareness of the operators. The gasifier occasionally experienced high flame-fronts due to unusually dry feedstock, which required the automatic system to activate the water mister. The heat exchanger and filter required no attention during this run and still exhibited low pressure-differentials across them at the end of the endurance run.

The Bowman heat exchanger, to be used to recover energy from the engine exhaust gases, had not yet arrived at CPC prior to this endurance run, so the rigorous determinations of the mass and energy balances were postponed.

4.10.2 System Performance

4.10.2.1 Metering Bin

During the course of this run, the metering bin jammed on four separate occasions, due to long, thick pieces of wood (e.g., broken boards or long thick “chips”) in the wood chips that it could not break up and power through. The computer detected the jamming of the metering bin because it was on too long and an alarm triggered to alert the operator. The operator had to switch the motor controller to manual operation and the metering-bin motor reversed to clear the jams. The operator then reset the motor controller to automatic control. This was later automated similar to the Flexicon feeder motor controller, so that the excessive power demanded by the stalled motor would be detected and used to automatically reverse the metering bin motor to clear the jams. The metering bin had to be refilled about every 3 to 4 hours, depending upon the relative amounts of “good” chips, ” overs,” and fines in the raw feedstock.

4.10.2.2 Sweco

The Sweco screen system operated quite well to remove the fines and the overs. However, oversized wood chips would accumulate in and blind the upper, coarse screen and eventually prevent the passing of good wood chips. The operator had to periodically remove (every 1 to 2 hours) these stuck oversized chips from the upper screen. If this was not done, the Sweco would stop passing good wood chips and the metering bin would be on too long, triggering an alarm. In addition, the fines screen was cleaned once during this run. The “Overs” drum had to be emptied about every 3 to 4 hours and the “Unders” drum about every 2 to 3 hours.
4.10.2.3 **Conveyor**

The conveyer moved the “good” wood chips upward from the outlet of the Sweco unit to the inlet of the dryer. This conveyer uses a belt made of plastic paddles to move the chips upward, which occasionally would hang up on something (probably a stringer or small board that had gotten through the Sweco unit) and a paddle would break off. The broken paddle pieces found their way through the dryer and jammed the Flexicon feeder on two occasions. Fortunately, the design of the paddles allowed them to break off without destroying the conveying action of the remaining paddles, so it remained functional. The conveyer jammed on eight occasions and had to be cleaned, a broken brush removed, or manually pushed along momentarily.

4.10.2.4 **Dryer**

The commercial belt dryer functioned as designed during this run. However, it had a tendency to overly dry the chips to around 5 or 6 percent moisture content. During most of this run, the temperature of the drying air delivered to the dryer was varied between 40°C and 50°C. The frequency of the fan motor was also adjusted to provide more or less drying air between 40 and 60 Hz. At the lower dryer-fan motor frequency, the parasitic power appeared to be one kW lower.

In this run, CPC demonstrated the ability of the BioMax® 50 gasifier to operate at moisture levels of between 4.7 percent and 19.6 percent. The moisture content of the dried wood chips was determined about every 45 minutes, with most values between 5 percent and 10 percent.

4.10.2.5 **Destoner**

The Destoner is an aerodynamic device (air knife) to remove high-density tramp materials like rocks, metal, and glass from the low-density dry wood chips. The Destoner removed over 4.5 kg of stones from an estimated 5,000 kg of dried wood chips fed during this run (some of the recovered stones were vacuumed out of the Destoner and lost). Several different adjustments of the Destoner were tried during this run, the worst of which contributed to the Dryer outlet jamming up seven times. The Destoner generates a lot of dust, only some of which goes through the dust filters, with much of going out into the room.

4.10.2.6 **Flexicon screw feeder**

The Flexicon feeder jammed twice on the broken plastic paddles from the conveyer, three times on long thick chips, twice on cardboard, and once for no apparent reason. One of the cardboard related “jams” was actually not a jam, but the cardboard shielding the screw from picking up fresh chips. The computerized alarm system would detect that the Flexicon feeder was on too long and alert the operator.

4.10.2.7 **Gasifier**

The gasifier operated with high flame fronts during much of the endurance run. This is thought to have been caused by a combination of low moisture contents in the feedstock, lower intensities of gasifier vibration as the run progressed, and the desire to operate the gasifier at slightly lower temperatures by using a little less char air.
The water mister was used to control the high flame fronts in the gasifier. The water-mister nozzle was cleaned out on two occasions, indicating the need for a larger filter that can be easily serviced. Some of this water reacted with the char bed or with carbon monoxide to form hydrogen, carbon dioxide, and carbon monoxide. However, much of the added water appears to have passed through the gasifier system and found its way to the engine. Some of this water was condensed before it passed into the engine, but excessive water vapor in the producer gas is thought to be the major reason for the engine being unable to maintain power output at times.

The pressure drops through the gasifier bed and across the grate were variable, but the grate shaker was able to pass char and small stones through the grate to maintain total gasifier pressure drops generally between 5 and 9 in. W.C. Because the grate has been visually observed at room temperature to break larger stones into small pieces that would pass through the grate, it is thought that many of the larger stones that had passed through the Destoner had been slowly chipped and reduced in size by the action of the grate shaker at the high grate temperatures. On two occasions, the grate shaker was operated manually for several seconds to successfully lower the pressure drops in the gasifier or the grate.

The Grate finger was removed twice to clean out the holes that allow the gases to transmit pressure changes to the transducer. (Additional holes will be drilled near the sanitary fitting to minimize this problem.)

The grate shaker mechanism vibrated loose and had to be reassembled during this run. (Locking fasteners will be installed on this mechanism.)

The effectiveness of the vibrator appeared to decrease during the run, so the interval between vibrations was shortened on two occasions. This may have been related to heat soaking through the insulation to overheat the vibrator motor. (The vibrator was relocated to minimize this problem.)

Near the end of the run, the strategy for controlling high flame fronts was modified as follows: when the flame front rose excessively, the water mister was set to manual control and turned off, the gasifier was vibrated for 10 seconds to settle the bed, the gasifier allowed to refill, and then the water mister set back to automatic. This technique appeared to result in much better engine operation, due to the greatly reduced flame-front level and amount of water added to the gasifier. (This strategy was incorporated into the control system.)

4.10.2.8 Heat Exchanger
The pressure drop through the heat exchanger remained low during the entire run between 0.3 and 0.6 in. W.C., with no evidence of the pressure drop increasing over time. The Cooling Blower motor typically operated at about one-third to one-half of maximum speed, so there was a lot of reserve cooling available. There were 0.98 kg of pebbles and char removed from the entrance and exit of the heat exchanger. Two of the 15 tubes appeared to be partially plugged with solids, but were readily vacuumed out. After vacuuming, the inside of the tubes appeared to be shiny with no fouling deposits of tar or char.
4.10.2.9 Filter

The filter’s pressure drop stayed around 2 in. W.C. for the entire run, with no evidence of increasing with time. The removal of the char from the bottom of the filter into the char drum worked well, although the char auger blew a fuse on one occasion.

The drum liner interfered with the char-level sensor; apparently air pressure between the bag and the drum caused the bag to collapse inwardly and contact the char level sensor. This caused the char level sensor to erroneously report a high level of char. A method of evacuating the space between the drum liner and the drum or for equalizing the pressure on both sides of the drum liner needed to be employed. For most of the run, the char was collected in unlined char drums, which made emptying the char drum more difficult.

About two 55-gallon drums of char (46 kg) were produced during this 6-day run. Based on the estimated 5,000 kg of wood chips used in this endurance run, the char yield (including ash, dirt, and sand) appears to be a little less than 1 percent. The average bulk density of the char was about 7 lbs/ft³.

4.10.2.10 Water Trap

During this run, about 3 to 4 gallons of condensed water were removed from the water trap located at the producer-gas entrance of the engine, or only about 0.2 percent to 0.3 percent of the estimated dry feed consumed in the run. The water trap was automatically pumped dry about every 15 minutes. Normally the water trap did not have condensate collected in it, unless the water mister had been active recently. There was no visible tar in the water.

4.10.2.11 Engine

The electrical load was set at 45 kWe, except when the engine was struggling to maintain frequency; then the load would be manually reduced temporarily. Often the engine would die before the operator could reduce the load. The busy operators recorded that the engine stalled on 31 occasions, but the computer-logged data suggest that it may have actually occurred 44 times. Total engine-outage time was about 220 minutes, assuming 5 minutes per occurrence.

It was thought that this problem was primarily a function of variable gas quality caused by variable water vapor concentrations in the producer gas. This variable producer gas concentration appears to be related primarily to the intermittent use of the water mister. All but one of the engine stalls occurred during or just after extensive water misting. However, most of the times that the water mister was used, the engine did not stall.

This engine-stall situation appeared to be an artifact of not being grid connected. If the system had been grid connected, the excessive load would have been shed automatically and the engine probably would not have stalled.

Midway through the run, the operator discovered that the cooling fan for the engine controls box had not been turning. This was immediately corrected, but did not appear to have been related to the engine problems.
The engine oil at the end of the run was light brown in color. If the engine had been in a truck traveling an average of 50 miles per hour for the 148 hours of engine operation, it would have traveled nearly 7,500 miles. A sample of this oil was sent to Titan Laboratories for analysis. The used oil still retained the viscosity of a SAE 30 motor oil at 100°C (10 cSt). All “wear” metal values were normal, except for silicon (dirt) at 33 ppm. Considering the relatively long length of time since the oil was changed, it appeared to be still in good shape.

4.10.2.12 Roots Blower/Eductor

A Roots blower was installed in the engine compartment to provide motive air to the producer-gas eductor. This was used to provide suction to move the producer gas through the gasifier system when the engine was not turning. This Roots blower appeared to come up to speed very slowly, resulting in transient smoke emissions from the gasifier, when the engine stalled. Late in the run, it was found that the Roots-blower motor was drawing excessive power and would overheat if left on too long. A little later in this endurance test, the eductor was hooked up to a larger Roots blower that was able to spin up faster and more reliably provide motive air to the eductor. (The control algorithm was changed to bring the original, smaller Roots blower up to speed more quickly.)

4.10.2.13 Tar and Particulate Measurements

Samples of producer gas were taken daily to determine the tar and particulate content. Table 5 shows that gas samples were relatively large and varied between 47 and 83 ft³. These large gas samples were taken to have enough collected solid and liquid materials to accurately weigh. The producer gas was exceptionally clean and averaged 1.4 pm tars and 0.8 ppm particulates. The highest values measured were 1.8 ppm tars and 1.9 ppm total particulates (including ultrafines) in all of the six samples.

<table>
<thead>
<tr>
<th>Date</th>
<th>9/15/05</th>
<th>9/16/05</th>
<th>9/17/05</th>
<th>9/18/05</th>
<th>9/19/05</th>
<th>9/20/05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample volume, ft³</td>
<td>76</td>
<td>83</td>
<td>77</td>
<td>47</td>
<td>64</td>
<td>86</td>
</tr>
<tr>
<td>Tars, ppm</td>
<td>1.3</td>
<td>1.6</td>
<td>1.1</td>
<td>1.8</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Total Particulates, ppm</td>
<td>1.5</td>
<td>0.4</td>
<td>0.1</td>
<td>1.9</td>
<td>0.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

4.10.2.14 Projections of Waste Heat Recovery

Typical engine temperatures showed cold coolant at 86°C, hot coolant at 93°C, and exhaust temperature before the catalytic converter at 560°C. If the exhaust gases were cooled to 110°C (demonstrated with the BioMax® 15’s Bowman exhaust-gas heat exchanger), then the maximum potential waste heat recovery from the exhaust gases was estimated to be about 45 kWth, not including heat losses in the exhaust system downstream of the measuring thermocouple. The energy recovered from cooling the engine, while producing 45 kWₑ, was previously measured to be 47 kWth. This suggests that there was an upper limit of a about 92 kWth available from the engine while producing 45 kWₑ. If the heat losses in the exhaust and
cooling systems are kept to this low level, this suggested that CPC could easily deliver over 80 kWth to the waste-heat load, after the Bowman exhaust-gas heat exchanger is installed on the BioMax® 50 and insulate the exhaust system upstream of the heat exchanger.

The temperature of the producer gas in the heat exchanger was typically entering at 700°C and leaving at 110°C. The calculated heat recovered from the hot producer gases is about 29 kWth. This heat was used to dry the wet feedstock, with excess heat automatically dumped to the atmosphere. Depending upon the value placed on recovered waste heat, it may be economically attractive to find additional uses for this waste heat.

4.10.2.15 Parasitic Loads

The total parasitic load measured during this run was 708.8 kWh. This is an average of 4.8 kWc over the entire run, (not including the flare igniter which would add another 0.5 kWc, if left on at all times). The lowest parasitic load manually recorded was 3.2 kWc and the highest was 6.7 kWc. This reflects that many of the parasitic loads are variable and they are all acting independently of each other. The parasitic load was reduced by about one kWc, when the dryer fan was at the reduced speeds used with dryer woodchips, indicating a fairly small penalty for wetter feeds coming into this system.

4.10.3 Post-Endurance Test Maintenance

After the endurance test, the system was in good working order. The gasifier was opened and inspected for wear and tear. From on top of the grate, 4.9 kg of mostly small rocks and some char were removed. From immediately below the grate, 8.8 kg of small pebbles and some char were recovered. The broken paddles on the conveyer were replaced. The gasifier shell did not appear to have deformed during this long time at the elevated temperatures. There did not appear to be excessive oxidation or scaling that was observed with previous gasifiers, perhaps due to the slightly lower gasifier temperatures employed during operation.

4.10.4 Endurance Test Conclusions

During this 149-hour endurance test, the feeding system needed to be monitored frequently to keep it operating, requiring frequent operator intervention. The source of these problems was the poor quality of wood chips used in this test with occasional small broken boards or poorly chipped wood that would jam the equipment. The gasifier, heat exchanger, and filter performed without significant breakdowns, nor significant operator intervention.

The air-knife removed the larger stones. The gasifier grate appeared to be able to maintain the gasifier and grate pressure drops within reasonable values by breaking up the smaller stones that then passed through the grate. Whether or not the gasifier grate was breaking up many of the stones, the pressure drop across the grate did vary from time to time, but always recovered to a reasonable average value.

The heat exchanger did not become fouled, due to the extremely low levels of residual tars present in the producer gases. The char and tar aerosols collected on the filter bags remained sufficiently dry and did not blind the filter cloth. The producer gas samples taken for tar and
particulate determinations verified that the final gas going to the engine was exceptionally clean.

The quality of the producer gas appeared to vary significantly and appeared to have a lower heating value (based upon increased engine demand for gas) when the water mister was operating to control the flame front in the gasifier. The engine was unable to sustain 45 kWe during some of the times when the water mister was operating and would stall, because it could not maintain frequency with full load applied. It is anticipated that when grid connected, that the system will automatically shed load, as needed, to prevent the engine from stalling.

Overall, the system performed very well, with some need for improvement in the Metering Bin controls, air-knife, Roots blower/eductor, locking hardware for the gasifier shaker mechanism, gasifier control algorithm during high flame fronts, water-mister, gasifier vibrator location, and char drum. These improvements are in progress.

4.11 Mass And Energy Balance Test (10/25/05)

The heat exchanger to recover the waste energy from the engine’s exhaust gases was not available during the endurance run. Therefore, the determination of the mass and energy balances was postponed until this heat exchanger was installed and functional. On October 25, 2005, an 8-hour run (including warm-up time) was made with the BioMax® 50 system to determine its mass and energy balance while producing 45 kWe. In addition to the usual measurements made, CPC weighed the dried feed going into the gasifier, the moisture content of each drum of feed added, the char recovered, the dew point of the producer gases going to the engine, and the heat delivered to a dummy heat load. Samples of the woodchips and of the char were taken to Hazen Research, Inc., for Ultimate and Proximate analyses.

4.11.1 Wood Fed

Figure 27 shows the cumulative weight of dry wood fed to the system, based on the weight of each drum of wet wood fed in the Mass and Energy Balance run of 10/25/05 and the measured moisture content of a grab sample taken from each drum. A linear equation was fit to the data with a slope of 0.6085 kg/min or 36.3 kg/hr (R² = 0.997), showing very steady operation.

4.11.2 Gas Energy Content

The dry gas composition of the producer gases after the filter was manually recorded about every 15 minutes during this run, as well as, the dew point. The dew point of the producer gas varied between 31.8°C and 43.3°C, with an average value of 38.9°C. These dew points correspond to water vapor contents of 5.9 vol percent to 10.3 percent. The average wet gas composition was 8.8 vol percent water vapor, 19.8 percent CO, 9.3 percent CO₂, 2.8 percent methane, 17.0 percent H₂, and 42.4 percent N₂. This wet gas had an average lower heating value (LHV) of 5.3 MJ/Nm³, an average molecular weight of 23.9, an average flow rate of 114 Nm³/h, and average energy content of 606 MJ/h (575,000 Btu/hr). Most of the sulfur appears to be retained by the char.
### 4.11.3 Char and Ash Production

Table 6 shows the results of the Ultimate and Proximate analyses of the wood chips and char from the mass and energy balance test of 10/25/05. Using a mass balance based on the ash contents of the woodchip feed and the product char, the yield of char was 1.2 wt%. The actual weight of char recovered from the filter was 3.22 kg (the knock-out pot was no longer in the system, so all char was entrained to the filter). The amount of dry woodchips fed was 260.5 kg. Based on the weight of char recovered and the dry woodchips fed, the average char yield was 1.2 wt%, which matches the char yield predicted by the ash mass balance. This represents a carbon conversion to gases of over 99.5 wt%.

**Figure 27: Feed History During the Mass and Energy Balance Run of 10/25/05 System Controllability**

The BioMax® 50 system was controlled automatically, including the feed metering, conveying, drying, gasifier feeding, gasifier, heat exchanger, filter cleaning, and engine. The automatic controls alert the operator to problems that can probably remedied and to problems that will trigger the controlled shutdown of the system, e.g., an empty metering bin. The system will automatically shut itself down if certain severe problems are encountered, e.g., excessively high temperatures in the top of the gasifier. The duties of the operator are to keep fresh raw feed in the metering bin and to remedy any sub-systems problems should they occur.
Table 6: Ultimate and Proximate Analyses of Feed and Char From the Mass and Energy Balance Test of 10/25/05

<table>
<thead>
<tr>
<th>Property</th>
<th>As-Received Woodchips</th>
<th>Dry Woodchips</th>
<th>As-Received Char</th>
<th>Dry Char</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.57</td>
<td>0.66</td>
<td>53.66</td>
<td>54.63</td>
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<tr>
<td>Volatile, %</td>
<td>73.36</td>
<td>84.22</td>
<td>6.05</td>
<td>6.17</td>
</tr>
<tr>
<td>Fixed C, %</td>
<td>13.18</td>
<td>15.12</td>
<td>38.44</td>
<td>39.17</td>
</tr>
<tr>
<td>Ultimate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture, %</td>
<td>12.89</td>
<td>0.00</td>
<td>1.88</td>
<td>0.00</td>
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<tr>
<td>Carbon, %</td>
<td>45.68</td>
<td>52.44</td>
<td>43.04</td>
<td>43.86</td>
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<td>Hydrogen, %</td>
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<td>5.24</td>
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<td>0.08</td>
</tr>
<tr>
<td>Nitrogen, %</td>
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<td>0.27</td>
<td>0.28</td>
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<tr>
<td>Sulfur, %</td>
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<td>Oxygen, %</td>
<td>36.08</td>
<td>41.39</td>
<td>1.04</td>
<td>1.06</td>
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<tr>
<td>(by difference)</td>
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<td></td>
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<tr>
<td>HHV, Btu/lb</td>
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<td>8670</td>
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<td>6204</td>
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<td>HHV, MJ/kg</td>
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<td>LHV, Btu/lb</td>
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<td></td>
<td>6196</td>
</tr>
<tr>
<td>LHV, MJ/kg</td>
<td></td>
<td>19.00</td>
<td></td>
<td>14.40</td>
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</table>

4.11.4 Stability of Gasifier

Figures 28 and 29 illustrate the stability of the gasifier over a 6-hr period near the end of the fifth day of the endurance run. Thermocouple GTC1 is near the top of the gasifier and GTC2 is about a foot below it. Thermocouple A1 is located at the highest level of secondary air injection. Levels 2, 3, 4, and 5 are the average of two thermocouples located in the second, third, fourth, and fifth levels of secondary air injection, with Level 5 closest to the Grate thermocouple.

An inspection of Figure 28 reveals that although the gasifier temperatures experienced large variations near the top of the gasifier due to variable moisture contents in the feed, these variations were much smaller in the lower portion of the gasifier (L-3, L-4, L-5, and Grate). The lower three zones of the gasifier held quite steadily between 840°C and 910°C. These temperatures were sufficient to produce a very clean producer gas that averaged only 1.1 ppm tars over two hours of this 6-hour period. The measured moisture content of the feed during this period varied between 6.0 percent and 12.9 percent.
Figure 29 shows that the pressure drops through the gasifier to grate (Gasifier dP) and across the grate (Grate dP) varied during this time period, in part due to changes in the flow rate of producer gas. Both the gasifier and the grate experienced increased pressure drops due to packing of the bed or to accumulated tramp material on the grate. However, the grate mechanism was able to eventually clear the packed material or tramp material out of the gasifier to recover reasonably low pressure drops in the gasifier.

4.11.5 Electrical Efficiency

Based on the average values of the gas composition and flow rates, the average energy in the producer gases going to the engine was 168 kWth. With the engine/genset producing 45 kWe during these measurements, the gross efficiency of the engine/genset to convert gaseous energy to electricity was 27 percent. Based on the feeding rate of dry wood to the gasifier and lower heating value of the wood, the gross efficiency of the system to convert wood to electricity is 23 percent.

Subtracting the parasitic electrical loads of 5.3 kWe from the gross power produced of 45 kW, results in a net electrical efficiency of the engine/genset of 24 percent, based on the LHV energy content of the producer gases. Based on the LHV of the wood fed into the gasifier, the net electrical efficiency of the gasifier/engine/genset is 20.3 percent. These net efficiency numbers will be higher at sea level, where the parasitic loads will be a smaller fraction of the total power produced.

**Figure 28: Gasifier Temperatures (Toward the End of Day 5 of the Endurance Test)**
4.11.6 Combined Heat and Power (CHP) Efficiency

In order to characterize the performance of the waste heat recovery and cooling system of the BioMax® 50, CPC performed testing using a dummy-load heat exchanger to transfer heat for the genset’s waste-heat-recovery heat exchangers, i.e., the engine cooling system and the Bowman exhaust-gas heat exchanger.

Figure 30 illustrates the configuration of the test bed and the target operating temperatures during the test. The cold-return coolant came from the flat-plate heat exchanger to cool the engine. The hot coolant from the engine then passed through the Bowman exhaust-gas heat exchanger to be further heated. The hot coolant then passed to the flat-plate heat exchanger to transfer its energy to the dummy-load coolant, which traveled to the dummy-load, air-cooled heat exchanger.

To maximize the recoverable heat transfer, the genset cooling radiator was completely bypassed and all genset cooling was provided via the flat-plate heat exchanger. While performing the test with the engine cooling bypassed as described above, the following average conditions were maintained:
Engine side (Primary Coolant):

- 44 gpm primary coolant flow (50/50 Ethylene glycol & water)
- 88.4°C (191°F) at the engine inlet/primary flat-plate outlet
- 93.8°C (201°F) at the engine outlet/Bowman inlet
- 96.9°C (206°F) Bowman outlet/primary flat plate inlet

Dummy-load side (Secondary Coolant):

- 13.8 gpm Secondary coolant flow (100 percent water)
- 59.0°C (138°F) at the Secondary flat-plate inlet/radiator outlet
- 83.6°C (182°F) at the Secondary flat-plate outlet/radiator inlet

Note that CPC achieved the primary (engine) coolant temperatures targeted. This indicates that the operator attained the correct engine-coolant flow rate for the heat gains from the engine and Bowman exhaust heat exchanger at this engine load, as observed under test for our desired engine operating temperatures. However, the heat gains at sea level conditions will increase approximately 19 percent due to the increased power production possible. To accommodate those increased thermal gains, CPC can slightly reduce the engine inlet water set-point temperature (from 88.4°C to ~ 86.7°C for the same coolant flow rate) and/or increase the coolant flow rate (possibly by reducing pipe friction losses).

Notice also that the target dummy-load temperatures were not achieved due to control limitations on the dummy-load fan speed. The target values shown in Figure 30 are what was expected at an actual installation. This should not be a problem, however, the flat-plate heat exchanger will be resized, based on the anticipated temperature and flow-rate ranges of operation on the customer side of the system.
In order to evaluate the capacity of the current genset radiator, the dummy-load was turned off so the genset radiator provided all of the genset cooling. This test was necessary demonstrate that the additional exhaust heat captured by the Bowman could be dissipated along with the heat from the engine water jacket. With relatively cool ambient air at 17°C (63°F), the engine’s VFD tube-axial fan motor was consistently operating at its maximum speed of 60 Hz. While there was sufficient engine cooling at those conditions, these results indicate a need for additional engine cooling capacity for higher ambient temperatures and increased throughput at sea level. This can be accomplished using a larger engine radiator, increasing the cross-flow rate through the radiator, or both. In short, the current engine cooling system was undersized, if there were no heat removed by the thermal load.

With the generator producing 45 kW<sub>e</sub>, the average thermal energy captured by the dummy-load was 88 kW<sub>th</sub>. The engine cooling is recovering 55.7 kW<sub>th</sub> and the engine-exhaust-gas heat exchanger is recovering 32.3 kW<sub>th</sub>. Adjusting for our altitude derating, the system can be expected to continuously produce 55 kW<sub>e</sub> (50 kW<sub>e</sub> net) and a net 105 kW<sub>th</sub> at sea level. This does not include any energy recovered by the producer-gas heat exchanger that was used to dry the wet feed or was dumped to the environment as hot air.
After inputting the observed operational data, our mass and energy spreadsheet suggests that 71 percent of the heat in the exhaust gases was being recovered for a loss of 13.4 kWth in the cooled exhaust gases at 180°C. By difference, it appears that there is a loss of an additional 13.6 kWth from the engine by radiation and air-convection from the hot exhaust pipe surfaces and the engine block.

During the Mass and Energy Balance Test there were about 10 ft of non-insulated exhaust pipe upstream of the exhaust-gas heat exchanger and the twin catalytic converters were not insulated. Insulating these surfaces could gain a few additional kWth of waste heat recovery from the exhaust-gas heat exchanger, if desired.

**4.11.7 Net CHP Efficiency**

Based on the lower heating value of the dry wood, its average feeding rate, the gross production of 45 kWe minus 5.3 kWe for a net 39.7 kWe and the recovery of 88 kWth, the net CHP efficiency is 66.3 percent. This net CHP efficiency is the sum of the recovered waste heat of 45.7 percent and of the net electrical production of 20.6 percent.

The above net CHP efficiency does not include the heat recovered from the producer-gas heat exchanger that can be used for feedstock drying, which amounts to 26.2 kWth, or 13.6 percent of the energy in the dry feedstock.) With a producer-gas heat exchanger designed to heat water or liquid coolant, the net CHP efficiency could be raised to 80 percent, assuming that the 13.6 kW waste heat that is now lost from the engine block and exhaust pipes is used to dry the feedstock in a more efficient manner.

**4.11.8 Effects Of Fuel Moisture Content**

During the 144-hour endurance test, the moisture content of the fuel varied from 4.7 percent to 19.6 percent. During the mass and energy balance test, the moisture content varied from 7.1 percent to as high as 18.7 percent. The feed appeared to have random pockets of wet or dry feed. This variable moisture content of the feed made it difficult to relate the gasifier performance to the moisture in the feed, because of the relatively long time from when the feed was sampled to when the remainder of the sampled feed entered the drying/pyrolysis zone of the gasifier. However, the operators associated the lower moisture content feed with the rising flame fronts and thus increased automatic action of the water mister to control the flame front.

Moisture levels in the feed below 7 or 8 percent will probably need to be re-hydrated with the water mister. Moisture levels above 15 percent require more secondary air to deal with the extra heat load imposed on the gasifier by the evaporation of water. The gasifier controls automatically respond well to the variable moisture contents observed.

**4.11.9 Specific Gasification Rate**

Based on the gross electrical output of 45 kW and the average feeding rate of 36.3 kg of dry woodchips per hour, the gross specific gasification rate is 0.81 kg dry wood/kWe. This is a bit higher, but in close agreement with the value attained during early prototype testing of 0.75 kg dry wood/kWe. Taking into account the 5.3 kW parasitic loads, the net specific gasification rate was 0.91 kg dry woodchips per net kW. 
4.11.10  Superficial Gas Velocities
The average flow rate of the producer gas was 114 Nm³/h. The inside diameter of the gasifier is 19.25 inches. The superficial gas velocity is 0.17 m/s (0.55 ft/sec) at standard conditions of 0°C and 1 atmosphere pressure. The actual superficial velocity at CPC’s 5720-foot elevation and at 825°C is 0.84 m/s (2.74 ft/sec).

4.11.11  Power Output
The gross power output at CPC’s elevation has been 45 kWe. Correcting for altitude, this system should produce 55.6 kWe at sea level. The parasitic electrical loads during the endurance test averaged 5.3 kWe. Thus, the net power produced at CPC was just under 40 kWe, but the expected net power at sea level will be 50 kWe.

4.11.12  Air-Fuel Ratio
The Air-to-Fuel ratio for stoichiometric combustion averaged 1.08 Nm³ air per Nm³ of producer gas during the mass and energy balance test.

4.11.13  Equivalence Ratio
The engine is operated with a very small excess of air. This is to have enough oxygen to combust the CO, but not so much excess oxygen as to encourage the formation of NOx. The oxygen in the exhaust (without added air in the catalytic converters) was measured on August 15, 2005 to be about 0.8 percent. With 0.8 percent oxygen in the exhaust gases, the actual equivalence ratio of air to fuel would be 1.07 relative to the stoichiometric ratio of air to fuel (λ).

4.11.14  Emissions
Initial testing without any emissions reduction equipment showed levels of acquisition:

- 700 ppm NOx
- 0.20 % CO
- 10 ppm HC

After installing a single 3-way automotive catalytic converter into the engine exhaust, emissions levels were measured to be:

- 48.3 ppm NOx
- 0.0875 % CO
- 0 ppm HC
The values permitted under CARB 2003, after taking into account efficiency and CHP contribution are calculated to be:

- 56 ppm NOx
- 0.08 % CO
- 229 ppm HC

With two relatively new catalytic converters in parallel, the engine-exhaust emissions were measured with our Summit Exhaust Gas Analyzer on August 15, 2005. Using the weighting factors called out in the CARB 2003 regulations for distributed power, the weighted average emissions in the exhaust after the catalytic converters were

- 30.4 ppm NOx,
- 0.066% CO, and
- 0.6 ppm Hydrocarbons,

while producing 50 percent, 75 percent, and 100 percent of maximum power. Thus, in this test, the BioMax® 50 appeared to have been in compliance with the CARB 2003 regulations, which were developed to ensure clean burning of natural gas in distributed power generation systems.

4.12 Other Pertinent Parameters

4.12.1 Hardware And Software Modifications

CPC made the following hardware and software modifications:

- **Metering Bin controls** Added an automatic detection of a metering-bin motor stall and alternate between forward and backward movement until the jam clears. The computer would activate the Operator Alert, while the system tried to clear itself. Yellow Alarm would show if the metering bin didn’t clear in a few minutes.

- **Conveyer** The broken paddles of the conveyer were replaced.

- **Destoner** Improved the unit to better handle the dusty air.

- **Roots blower/eductor** Replaced this air blower and eductor with a more efficient gas blower.

- **Roots Blower Algorithm** Changed to spin it up faster, when it first comes on (to minimize the fugitive smoke emissions from the gasifier during engine-to-blower changeovers).

- **Gasifier Flame-Front algorithm** Changed to activate the grate shaker more when the Char Air was unable to control the flame front adequately, keeping the water misting in reserve for flame front control.

- **Water mister** Evaluated using a finer mist or fog to get the water more directly down to the flame front, rather than wetting the chips on top of the gasifier and waiting for the
wet chips to reach the flame front. The water flow rate should be rather small, ideally about enough water flow to add 5 percent to 10 percent moisture to the feed on average. A larger in-line filter needed to be added to remove solids from the water, reducing maintenance time during the run.

- **Gasifier Vibrator** Moved further from the gasifier shell to reduce the amount of heat it received from the gasifier. This appeared to increase its ability to vibrate the gasifier during the run, after reaching steady-state internal temperatures.

- **Gasifier Grate Shaking Mechanism** Installed locking hardware to prevent it from coming apart during operation.

- **Grate Fingers** Additional holes drilled into it near the cold end to insure that at least some of the ports are open for good pressure measurements.

- **Char Drums** Fitted with a means to equalize the pressure on both sides of the drum liner. This allowed the use of plastic drum liners without their collapsing onto the level sensor.

- **Engine** Exhaust pipes within the engine compartment were better insulated to reduce the local compartment temperatures and to preserve waste energy for recovery.

### 4.12.2 Number Of hours Of Feeding

During the Endurance Test, the gasifier was fed for a total of 148 hours of gasifier operation, not including a typical warm up period of about an hour. The weight of wood fed was not measured, but is estimated to be on the order of 5,000 kg.

During the separate Mass and Energy Balance Test, the feeder supplied feed to the gasifier for about seven hours with a total of 260.5 kg of dry wood (293.2 kg dried wood having a residual average moisture content of 11 percent).

### 4.12.3 CHP Produced

In the Mass and Energy Balance Test, the waste-heat recovery system was operated in several modes, including dumping all waste heat through the engine’s radiator to the atmosphere. CPC operated long enough to achieve steady state operation in each of these modes, but the total heat recovered was not representative of operating the system during the whole run to maximize the heat recovery. If CPC had operated the system for maximum heat recovery during the entire test, over about 615 kWth, not including the heat recovered by the producer-gas heat exchanger for feed drying.

### 4.12.4 CARB 2007 Emission Requirements

The CARB 2007 Emission regulations are much more restrictive on the allowable emissions than those of CARB 2003. However, in the calculations of the emissions per kWhr, the CARB 2007 regulations permit the kWhr to be based on the sum of the electrical and the waste heat recovered, if the efficiency of the system’s CHP is over 60 percent. So, with a demonstrated net CHP over 66 percent, the system was well over the minimum CHP required. CPC estimated
that the BioMax® 50 system will be required in 2013 to have emissions of less than 15 ppm NOx, 34 ppm CO, and 6.9 ppm hydrocarbons. It appeared that the CARB 2007 requirements were met only for hydrocarbon emissions and the CO emissions would need to be reduced by a factor of about 20 and the NOx emissions by a factor of about 2.

4.12.5 Performance Of The BioMax® 50 Compared To The 12½ kW_e Hoopa Gasifier/Engine/Genset

The 12.5-kW_e system that was evaluated on the Hoopa Indian Reservation converted wood to exported electricity with only 13 percent efficiency. The BioMax® 50 has a 23 percent gross efficient conversion of wood to electricity and a 20.6 percent net electrical efficiency, taking into account the parasitic electrical loads. Thus, the net electrical efficiency of the BioMax® 50 is 58 percent higher than it was for the Hoopa system, far exceeding the goal of a 20 percent increase in electrical efficiency.

The Hoopa system generated 20 kW_th in addition to the 12.5 kW_e, so the CHP efficiency for the Hoopa system was calculated to be a 39 percent efficient conversion of wood to combined heat and power, excluding engine exhaust heat used for drying feedstock. In comparison, the net CHP efficiency for the BioMax® 50 was 66.3 percent, or an increase of 70 percent over the Hoopa system. Again, this achievement far exceeded the goal of a 10 percent improvement in the CHP efficiency.

The improvement in efficiency of the BioMax® 50 over the Hoopa system was primarily due to more complete gasification of the char from about 8 percent char yields for the Hoopa system down to 1.2 percent with the BioMax® 50 and to a more efficient engine. In addition, the Hoopa system recovered thermal energy only through the engine coolant of the relatively small engine. The smaller engine probably had much higher relative heat losses and appears to have had a much lower efficiency. The Hoopa system did recover heat from the engine’s exhaust gases for drying wet feedstock, but feedstock drying is not an allowable CHP purpose for this systems comparison.

4.12.6 System Upgrades Prior To Deployment

Secondary Air Injection System The Secondary Air Injection system was changed from one controllable air blower for each of five levels to one air blower and five control valves (one valve for each of the five levels). The proper response of the control valves to signals from the control computer were verified.

4.13 Summary

The BioMax® 50 system was thoroughly tested at CPC using woodchips to demonstrate its robustness and ability to function well in the field demonstration. A large number of tests were performed to ensure that temperature cycling in the field would not be a problem. A detailed mass and energy balance was conducted to provide figures of merit for the efficiency of the conversion of biomass to combined heat and power (CHP). A six-day endurance test with continuous operation around the clock was successfully demonstrated. The BioMax® 50 system was then ready to be shipped to a site selected for the field demonstration.
CHAPTER 5:
Task 6. Field Site Design And Supervision

This section describes the site selection for the field demonstration and the design effort to optimize the production of electrical and thermal electrical energy, as well as, the recovery of waste heat.

5.1 Site Selection

5.1.1 Siskiyou Opportunity Center
The original intent of this project was to site the BioMax® 50 system at the Siskiyou Opportunity Center in Mt. Shasta, California. However, after considerable effort was expended, it was mutually agreed by all concerned that this would not be a viable site for this field demonstration.

5.1.2 Harwood Products
This host-site candidate was a lumber business in Northern California. Harwood Products in Branscomb, California was initially selected to replace the Siskiyou Opportunity Center on the basis of a number of factors including a suitable waste stream for utilization as fuel, excellent facilities and manpower infrastructure to support the BioMax® operation during the demonstration period, and a commitment to the support and promotion of alternative energy technologies.

Harwood Products was teaming with a pellet mill manufacturer to install a pellet mill on site to take advantage of the sawdust byproducts generated by the mill. The mill would, in turn, utilize the energy produced by the BioMax® system and would fund the infrastructure upgrades necessary to support the BioMax® demonstration.

However, the contract with the pellet mill manufacturer was not concluded within a nine month period following a site visit by CEC and CPC in the Fall of 2006, or within seven months of concluding a Cooperation Agreement between Harwood Products and CPC (December 4, 2006). Because the Cooperation Agreement with Harwood Products stipulated that the system would be installed within six months of the signing of the Cooperation Agreement, and because Harwood could not predict when progress would be forthcoming with the pellet mill, the mutual consensus between Harwood and CPC was to terminate the agreement. This was done at the end of July 2007.

During this time there had been no progress in preparing the site for receiving the BioMax® system at Harwood.

5.1.3 Dixon Ridge Farms
Early in calendar 2007 CPC was contacted by Dixon Ridge Farms, in Winters, California. The owner expressed a strong interest in hosting a BioMax® site. The farm is family owned and is a leader in organic walnut farming and has demonstrated a strong interest in adopting
sustainable energy practices in addition to their sustainable organic farming practices. They had already installed a PV system and viewed the BioMax® technology as a way to eliminate their walnut-tree residues while offsetting a significant amount of nonrenewable fuels (propane and electricity) then being consumed. The addition of a BioMax® to their operation would have a significant positive impact on fuel savings.

Similar to Harwood, Dixon Ridge Farms had a continuous supply of biomass waste that was well suited for fueling the BioMax®, including five million pounds of shell residues stored on site, for which there was no suitable productive application or economical means of elimination. Unlike Harwood Products, however, Dixon Ridge Farms can quickly provide the funding and necessary site infrastructure to support the BioMax® demonstration. Dixon Ridge Farms also is located within a half hour of Sacramento, convenient to CEC and other government agencies that would be interested in visiting the site and monitoring the progress of the PIER funded demonstration.

Given the mandate from CEC to have a system installed by the end of October 2007, CPC felt that the only chance of having a system operating in the field by this time would be to adopt Dixon Ridge Farms as the new host site. In anticipation of this, CPC and CEC visited the site together on July 12, 2007. A new agreement was drafted with Dixon Ridge Farms.

The selection of Dixon Ridge Farms resulted in a major change in the characteristics of the feedstock from wet wood chips, as originally designed, to dried walnut shells. This eliminated the need for a sorter and dryer. The design of the temporary feed-storage bin was changed to one with a conventional auger to move the walnut shells to the surge bin/feeder. The delay in field deployment due to site selection problems, allowed CPC to gain operational experience from the first three BioMax® 50 systems deployed and to continue to evolve the BioMax® 50 system. The system shipped to Dixon Ridge Farms was the fourth BioMax® 50 built and it incorporated many minor design and control improvements.

5.2 Site Design And Site Upgrades Required

5.2.1 Piping and Instrumentation Diagram (P&ID)

The piping and instrumentation diagram shown in Figure 31 shows the P&ID diagram for the BioMax® 50 that was deployed at Dixon Ridge Farms. It incorporated numerous upgrades to both hardware and controls that have been successfully adopted in the one year period since the former host site was originally selected.

5.2.2 Electrical One-Line Diagram

The electrical one-line diagram shown in Figure 32 shows the electrical configuration for the BioMax® 50 at Dixon Ridge Farms. The system was configured as a 3-phase 480 Volt system. Output of the generator was fed onto the site’s electrical grid through a 100A breaker at the field sub-panel near the drying bins. This circuit is connected to the rest of the site loads through a 200A breaker at the main distribution panel for the site. Genset control was handled by a Woodward EGCP-2 engine controller. The engine controller controlled engine speed to maintain generator frequency. It also maintained voltage and power factor integrity. Grid
protection was provided by a Basler 700-V controller that opens a contactor in the event of waveform degradation from the generator or loss of power from the utility grid.

### 5.2.3 On Site Energy Consumption

Dixon Ridge Farm consumed energy in several forms:

- Diesel fuel
- Electricity
- Propane

Liquid fuels were used to power motive farm equipment, including tractors, tree shakers and harvesting equipment. The BioMax® supplied under this contract did not have the capability of producing liquid fuels. However, progress with CPC’s LiquiMax™ technology will present an opportunity in the future to add a module that will convert producer gas into high quality synthetic diesel for utilization by farm machinery.

Electricity was used to power site loads, including lighting, conveyers, processing equipment and cooling loads. The cooling loads were the largest loads and were used to maintain low temperatures in a produce warehouse for pest control and storage while whole walnuts are stored for further processing. CPC’s BioMax® system would contribute up to 50kW of continuous power to the site’s electrical loads. Although the system would be grid tied, it was anticipated that the onsite demand would rarely fall below the output of the BioMax® system; thus the system would offset onsite electrical demand (at the rates paid by Dixon Ridge Farms).

The electrical power would not be exported back to the utility under a Purchase Power Agreement (PPA), because utility PPA’s rarely reimburse small producers at retail rates.
Figure 31: BioMax® 50 P & ID
Thermal energy was produced through the combustion of propane in crop-drying burners. The thermal energy was consumed in a drying process that consists of heating air and using the heated air to aerate raw walnuts in drying bins. At that time, the hot air was used in a single pass through the drying bins and was not recovered, even though the air has not achieved saturation with water vapor. Propane consumption was very high and represented the best opportunity for efficiency gains in onsite energy consumption.

CPC’s BioMax® system would contribute up to 1MM BTU/hour of thermal energy and deliver this thermal energy to the walnut-drying process on one of several ways:

- CPC could convert producer gas to heat through direct combustion in a modified crop drying burner;
- Waste heat from various sources could be used to contribute heat to a pool of heated recirculation air that will be re-used in multiple passes through the drying beds; or
- These two methods could be combined for maximum reduction of drying energy using fossil fuels.

Waste heat sources included heat from the combustion of producer gas in the flare. Waste heat from the gas production module was available in the form of hot air from the cooling exhaust of the producer-gas heat exchanger. When the engine was operating, waste heat was available in the form of exhaust air from the cooling system’s radiator and from the engine exhaust, either directly or through the recovery of waste heat in the form of hot water from an engine exhaust gas heat exchanger.

All of the forms of thermal energy listed above were used productively, because Dixon Ridge Farms installed a tent-canopy over the drying bins to permit the recovery of drying air for recirculation through the drying bins. This canopy was later replaced by a permanent steel building for the 2008 drying season. By configuring the drying system as a multiple pass system, energy consumption was expected to drop significantly.³

The ways in which the various forms of energy could be produced, captured and utilized are explained in the following section.

Waste heat from various sources will be used to contribute heat to a pool of heated recirculation air that will be re-used in multiple passes through the drying beds. Waste heat sources include heat from the combustion of producer gas in the flare. Waste heat from the gas production module is available in the form of hot air from the cooling exhaust of the gas heat exchanger. When the engine is operating, waste heat is available in the form of exhaust air from the cooling system’s radiator and from the engine exhaust, either directly or through the recovery of waste heat in the form of hot water from an engine exhaust gas heat exchanger.

³ Dixon Ridge Farms estimated up to 40% reduction in propane usage based on consulting design inputs from the University of California.
The first three forms of waste heat listed above can be used productively by collecting the heat under a canopy over the drying bins to permit recovery of drying air for recirculation through the drying bins. By configuring the drying system as a multiple pass system, energy consumption was expected to drop significantly. These three forms of waste heat recovery were demonstrated on November 13th, 2007. The flare, engine cooling air, and HEX cooling air were all dumped into the area below the drying canopy.

The fourth form of energy recovery, the engine exhaust gas heat exchanger is not yet operating, because the site does not have a hydronic heating system that can utilize the hot water produced by the exhaust gas HEX.

The host site erected a permanent building over the drying area before the 2008 drying season. CPC would like to work with the site to develop a hydronic heating and storage system that could utilize the waste heat from the engine exhaust of the current system, and possibly install another system that could meet all of the heating and cooling needs of the new building. However, if the engine/genset were operated during the drying season, the waste heat from the engine would rise to the ceiling, where it could be brought down to the dryers through the large ducts installed.

5.2.4 CHP Configuration

The thermal energy contribution to the site will change depending on five variables:

- Whether the system is operated during the drying season
- Whether a crop-dryer burner is operated on producer gas during the drying season
- Whether the engine is operated during the drying season
- Whether the engine exhaust is used as a source of thermal energy
- Whether engine exhaust energy is captured by an exhaust gas HEX

Combinations of these variables lead to four distinct operating scenarios as follows:

**Scenario 1 – Drying Season operation w/ crop dryer and w/o engine**

Under this scenario, the BioMax® gas production module would deliver all available gas to one or more of the crop-drying burners during the short drying season. The engine would not be operated to produce electricity during this time. Instead, the producer gas would be converted to thermal energy in the burner and used directly in the drying process. When used in this way, the thermal energy produced offsets in propane consumption on a one to one basis (one BTU of energy from producer gas offsets one BTU of energy from propane). This represents the highest value application of the producer gas because, after efficiencies of electrical production are taken into account, the benefit of offsetting propane consumption (on an equivalent BTU basis) is higher.
than that of offsetting electrical consumption. As discussed in a later section, CPC was able to modify the propane burners, used to supply heat for drying the walnut shells, to burn producer gas, producer gas and propane, or propane.

The flare is a secondary source of heat derived from the combustion of producer gas but would contribute indirectly to crop drying by heating the air being collected under the canopy for recirculation to the crop dryers. Under this scenario, the flare would only operate during startup and in the event of a crop-dryer burner failure.

During the drying season, waste heat from in the Gas Production Module would be directed to the canopy over the dryers. This heated drying air would then ducted to the combustion air intakes of the crop drying burners and recycled through the drying bins. It is expected that recirculating unsaturated drying air and achieving multiple passes through the drying beds should reduce propane consumption and contribute to efficiency gains of up to 40 percent in the energy used during the walnut drying process.

Under this scenario, effectively all of the waste heat from the BioMax® system would be available for productive use, with the gas being used directly and various sources of waste heat being used indirectly in the drying process. Combined with the direct conversion of producer gas to heat in the crop-dryer burner this would effectively be a CHP mode of operation with 100 percent efficiency. This scenario is represented by the process flow diagram in Figure 33.

**Scenario 2 – Drying Season operation w/ engine and w/exhaust**

This scenario is represented by the process flow diagram in Figure 34. Under this scenario, producer gas would be used to run the engine rather than a crop-drying burner. The engine would, in turn, produce electricity for the site. Waste energy from the gas production module would contribute to the heating of recirculated drying air just as it would be under Scenario 1. In addition, waste energy from the engine cooling system would be added to the waste energy from the gas production module and make a positive contribution to drying efficiency. Finally it may be possible to direct engine exhaust under the canopy for use in directly heating the recirculated drying air. The engine exhaust would be mixed with the exhaust air supplied by the engine cooling system and further diluted with normal air exchange taking place as saturated air under the canopy is replaced with unsaturated air outside the canopy.

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4 Dixon Ridge spends roughly $0.16/kWhr for electricity and approximately $1.50/gallon for propane. On a BTU basis, this is $0.047/kBtu for electricity and $0.016/kBtu for propane. Therefore electricity is almost three times as valuable to Dixon Ridge Farms as is propane. However, if the 28% conversion efficiency of the genset is taken into effect, the value of using producer gas to displace propane exceeds that using producer gas to generate electricity by 22%.

5 While all of the thermal energy of the BioMax would be captured for productive use, it is not yet known how efficiently the waste energy was utilized during the drying air recirculation process.
There is a real concern about the buildup of CO from the engine exhaust under the canopy so CPC considered the effect of dilution with the engine cooling air. This calculation is given below in Table 7.

The production rate of CO in the exhaust has been measured at CPC to be in the range of 500 ppm. Using a worst-case measured value of 583 ppm, if the exhaust gases are mixed with the engine cooling air, the resulting dilution is 37 ppm CO under the canopy. This concentration is lower than the OSHA permissible exposure limit (PEL) on a time weighted average basis (see table below) and would be further reduced as saturated air inside the canopy is exchanged with ambient air outside the canopy during the drying process.

The OSHA limits for CO exposure are given in Table 8 for comparison with the expected rates of CO concentration under the canopy. Since the canopy will be monitored continuously for CO, actual CO concentrations can be measured and a final decision to mix engine exhaust air with other heat sources can be made after onsite testing.

**Table 7: Dilution of CO with Cooling Air**

<table>
<thead>
<tr>
<th>Dixon Ridge Drying Tent with BioMax 50 exhausting into tent mixed with cooling air</th>
<th>8/15/2007 James Diebold</th>
</tr>
</thead>
<tbody>
<tr>
<td>BioMax 50 Davidson Ridge tent- CO.xls</td>
<td>Assumed independent variables are highlighted in yellow</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>129 Nm³/h PG</td>
<td>0.24 Cp air, Btu/lb°F</td>
</tr>
<tr>
<td>500 T exhaust, °C</td>
<td>932 T exhaust, °F</td>
</tr>
<tr>
<td>50 T cooling air in, °F</td>
<td>10.0 T cooling air in, °C</td>
</tr>
<tr>
<td>150 T cooling air out, °F</td>
<td>65.6 T cooling air out, °C</td>
</tr>
<tr>
<td>5 LHV, MJ/Nm³</td>
<td>0.28 Engine/genset efficiency to electricity</td>
</tr>
<tr>
<td>1 vol Air / vol Fuel</td>
<td>0.257 mean Cp exhaust gas, Btu/lb°F</td>
</tr>
<tr>
<td>32 molar of exhaust gas, kg/kg mol</td>
<td>32 mw of exhaust gas, kg/kg mol</td>
</tr>
<tr>
<td>583 ppm CO in exhaust</td>
<td>0.0583 vol. % CO in exhaust</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>642.8571 MJ/h PG thermal energy into engine</td>
<td>(TRC measured 180 MJ/h electricity produced 50 kW electricity)</td>
</tr>
<tr>
<td>583 ppm CO ave.</td>
<td>462.8571 MJ/h waste heat from engine and exhaust 128,5714 kW waste heat at 100% power)</td>
</tr>
<tr>
<td></td>
<td>438,727 Btu/h waste heat from engine and exhaust</td>
</tr>
<tr>
<td></td>
<td>177,829 Btu/h waste heat from exhaust</td>
</tr>
<tr>
<td></td>
<td>260,898 Btu/h waste heat from engine coolant and hot manifold, etc. (by difference)</td>
</tr>
<tr>
<td></td>
<td>257.1429 Exhaust gas, Nm³/h 809 lbs exhaust gas/hr</td>
</tr>
<tr>
<td></td>
<td>3811 Cooling air, Nm³/h 10,871 lbs cooling air/hr</td>
</tr>
<tr>
<td></td>
<td>4069 Total hot air and exhaust gas from engine, Nm³/h 6.3% exhaust in air flow</td>
</tr>
<tr>
<td></td>
<td>209 Temperature of mixed hot air + exhaust gases, °F 3255 ACFM hot air+exhaust</td>
</tr>
<tr>
<td></td>
<td>37 ppm CO in mixed exhaust and cooling air</td>
</tr>
</tbody>
</table>
If engine exhaust were mixed with the other heat sources, effectively all of the waste heat from the system would be available for productive use, also making this a CHP mode with 100 percent efficiency. If engine exhaust were mixed with the drying air, the benefit of an exhaust gas heat exchanger would be rendered moot. Although one will be provided, it is not shown in Figure 34 for sake of clarity. Use of the exhaust gas heat exchanger is covered in scenario 3 below.

As with Scenario 1, the flare would only operate during system startup or in the event of an engine failure. During flare operation the heat generated from combustion of producer gas would be captured under the canopy and also contribute to heating the recirculated drying air.

Table 8: OSHA Carbon Monoxide Exposure Limits

<table>
<thead>
<tr>
<th>EXPOSURE LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>* OSHA PEL</td>
</tr>
<tr>
<td>The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for carbon monoxide is 50 parts per million (ppm) parts of air (55 milligrams per cubic meter (mg/m(3))) as an 8-hour time-weighted average (TWA) concentration</td>
</tr>
<tr>
<td>* NIOSH REL</td>
</tr>
<tr>
<td>The National Institute for Occupational Safety and Health (NIOSH) has established a recommended exposure limit (REL) for carbon monoxide of 35 ppm (40 mg/m(3)) as an 8-hour TWA and 200 ppm (229 mg/m(3)) as a ceiling [NIOSH 1992].</td>
</tr>
<tr>
<td>* ACGIH TLV</td>
</tr>
<tr>
<td>The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned carbon monoxide a threshold limit value (TLV) of 25 ppm (29 mg/m(3)) as a TWA for a normal 8-hour workday and a 40-hour workweek [ACGIH 1994, p. 15].</td>
</tr>
</tbody>
</table>

* Rationale for Limits

The NIOSH limit is based on the risk of cardiovascular effects [NIOSH].
The ACGIH limit is based on the risk of elevated carboxyhemoglobin levels [ACGIH 1991, p. 229].

Scenario 3 – Drying Season operation w/ Engine and Exhaust Gas HEX Only

This is the same as Scenario 2 except that waste heat from the engine exhaust is used indirectly rather than directly. Due to concerns about CO from the engine exhaust, the exhaust may be ducted away from the drying canopy. In this case waste heat from the engine exhaust can still be captured in the form of hot water circulating through an exhaust gas heat exchanger.

This exhaust gas heat exchanger system will be supplied with the engine genset, because even if the exhaust is used directly to heat the recirculated drying air, drying is only conducted for approximately 6 weeks out of the year. The rest of the year the output of
the exhaust gas heat exchanger would be the only available source of thermal energy\(^6\) and is of particular interest to the host site for use in the processing buildings during the winter months.

This scenario is represented by the process flow diagram in Figure 35.

**Scenario 4 – Regular Season operation w/ Engine and Exhaust Gas HEX Only**

When the crop driers were not operating, the engine would be operated on producer gas to generate electricity on a full time basis. Waste heat from the gas production module would not be captured; in any case during the summer season this waste heat would probably not be useful due to the high ambient temperatures.\(^7\)

Some of the waste heat from the engine will be available for productive use in the form of hot water from the engine exhaust. It was anticipated that a hydronic system will be installed by the site host to deliver this hot water for use by personnel inside the main processing building.

This scenario is represented by the process flow diagram in Figure 36.

The original system with a canopy is illustrated in Figure 37 below. Canopy and multi-pass dryers are shown in Figure 38 to illustrate the method of warm air recirculation.

---

\(^6\) Although waste heat in the form of hot air will be generated from the gas production module this, unlike hot water, cannot be efficiently transported to remote thermal loads.

\(^7\) Waste heat in the form of hot air, if not used for drying, would be limited to use in space heating
Figure 33: Scenario 1 - Crop Drying Burner Operation Only

Process Diagram for Dixon Ridge Farms BioMax 50 CHP System

(Crop drying burner operation only)
Figure 34: Scenario 2 - Engine Only, with Engine Exhaust Contribution to Drying

Process Diagram for Dixon Ridge Farms BioMax 50 CHP System

(Engine exhaust diverted outside canopy)
Figure 35: Scenario 3 - Engine Only, w/ Engine Exhaust Gas HEX Only

Process Diagram for Dixon Ridge Farms BioMax 50 CHP System

(Engine exhaust captured under canopy)
Figure 36: Scenario 4 - Electricity and Hot Water Operation Only

Process Diagram for Dixon Ridge Farms BioMax 50 CHP System

(Electricity and hot water only)
**Existing single pass dryers**
- Burners are variable output (0.5-5.0 MBTU/hr), propane fueled
- Drying time is 4 hrs – 4 days, depending on MC and Relative Humidity
- Bins are not sheltered from rain, increasing drying time during wet weather
- Final MC of walnuts must be under 7.5% for long term storage

**Multi pass dryers**
- Drying efficiency expected to increase 40 - 50%
- Burners are augmented by heat from BioMax
- BioMax sends gas to flare and also contributes HEX exhaust energy
- BioMax contribution is approx 1 MBTU/hr
- BioMax efficiency is > 90%
- Bins are sheltered from rain
- Additional heat supplied by propane burners as needed
5.3.4 Site Built Shelter

The building design was for a 40’ x 50’ fabric structure with three bays 16’ 8” wide and an eave height of 8’. This was modified to be a 40’ by 210’ structure with 14 bays 15’ wide and an eave height of 15’. There was fabric only down to the eave height and on the gables down to the eave height, effectively making it a “pole barn”. The leg trusses would be lengthened and strengthened. They would be anchored with 30 appropriately sized poured in ground concrete piers and metal bolts. The weight of the fabric would be about 1600 pounds with 22 oz fabric and the trusses would weigh about 500 pounds each, making the entire structure very light, but sturdy. It was designed for Midwest wind conditions and should easily meet the local wind design requirements. Earthquake standards should be easily exceeded, as the weight is low and strength is high. However, the canopy was replaced by the larger permanent structure.

Maximum air temperature desired for walnut drying is 110°F. Therefore the maximum air temperature desired in the tent is the same. Galvanized metal ducts would be attached to the existing dryers to pull in warm air from near the top of the tent. Six driers would pull in about 22,000 cfm each and one large drier pulls in about 12,000 cfm. Make up air temperature is supplied by the existing totally-enclosed, axial, in-line propane fired heaters. They are variable output, thermostatically controlled units with safety shutdown devices for gas as well as fan. The cold, moist air that comes off the tops of the bins at the beginning of the drying cycle will fall down to the ground and exit the area. The ability to recirculate the warm, dry air that eventually rises off the tops of the tanks and is captured by the tent should save about 40 percent of Dixon Ridge Farms current propane usage thereby reducing energy consumption, air pollution, carbon dioxide generation, and expenses.

With between 12,000 to 144,000 cfm of air flowing through the tent, the large volume of the tent “attic” (about 56,000 cu. ft.) and with open sides, the trapped air should never rise much above 110°F, well below normal design temperatures for these tents and fabrics of 158°F.

5.3.5 System Layout

The basic site layout is given in Figure 39 below. The BioMax® system was installed under this canopy in one of the allocated bays as shown in Figure 40.
Figure 39: Basic Site Layout

Figure 40: BioMax® System Layout (Engine Exhaust Diverted Outside Canopy)
5.3.6 Sukup Dryer Burner Modifications

Dryer-burner modifications for producer gas at CPC, Dickson Ridge Farms sent CPC one of their commercial Sukup propane burners and blower combinations used in their walnut drying operation. This Sukup burner, model V26V-T (SN 45806) rated at 2-MM Btu/hr was converted from a propane-only burner to a dual-fuel burner capable of burning propane only, mixtures of propane and producer gas, or producer-gas only. This new dual-fuel burner features two CPC-designed concentric motive nozzles in the stock air-eductor body and a modified burner having enlarged orifices. At the same propane pressure, the new propane motive nozzle had essentially the same propane flow rate as the original stock motive nozzle. Function and operation of the modified burner appeared to be unchanged from the stock burner, when burning only propane. No hardware changes needed to be made, when switching from propane-only to producer-gas operation, other than opening and closing fuel-line valves. Figure 41 shows the modified Sukup burner when burning propane only, whereas, Figure 42 shows that the same burner when fueled with only producer gas has a similar appearance but with a fainter blue flame.

The burner ignition was attained with propane at low pressures in the usual manner and then transitioned from propane to producer gas. This transition to producer gas occurred several minutes after the feeding of the gasifier had started and the producer gas had ignited in the flare. The burner did not flame-out during repeated transitions from propane to producer gas, whether the manual diversion valves were operated slowly or quickly.

Combustion of producer gas in the modified burner appeared to be nearly as complete as with propane, based on CO measurements of the hot air from the blower being down in the ppm range. Calculations suggest that the burner was achieving a 98 percent carbon conversion to CO2 with propane and 96 percent with producer gas or with a combination of producer gas and propane. Combustion of producer gas appeared to be robust, with no indication of flame instability or flame out during the few tests conducted in this accelerated development.

With this modified burner, CPC demonstrated the delivery of 1.0 MM Btu/hr (HHV) with producer gas only and up to 1.4 MM Btu/hr by co-firing producer gas and a minimum propane setting of 1 psig. Very stable combustion was demonstrated at all propane and producer gas flow rates investigated, with no evidence of chuffing or flame out. Higher co-firing rates are thought to be possible at higher propane delivery pressures.
The modified burner was shipped back to Dickson Ridge Farms on October 5, 2007. The producer-gas control algorithms were developed to control to the desired hot-air temperature, to open and close the valves that divert the producer gas to the flare, and the safety shut-off in the event of flameout or excessive hot-air temperatures.

The tests with this modified burner were very successful in the field, so three more burners were modified and installed at Dixon Ridge Farms for a total of four dryers that could be fueled with producer gas from the BioMax® 50 system for the 2008 drying season.
5.4 Summary

Dixon Ridge Farms, Winters, California was selected as the host site for the field demonstration. Due to the lengthy site selection process, the field demonstration was delayed. Dried walnut shells will used as the feedstock, rather than woodchips. This change in feedstock eliminated the feedstock sorter and dryer equipment from the Feed Preparation Module.

The primary use for heat at this site is to dry whole walnut shells immediately after they are harvested in the fall. The dried walnuts are typically then placed in refrigerated storage, until further processed for sale. Due to the high price of propane used for drying, producer gas was to be diverted to the dryers’ burners to displace the use of propane. In addition, the waste heat from the BioMax® 50 was to be added to the drying air to make the best use of the system, whether or not the engine/genset was in operation.
CHAPTER 6:
Task 7. Field Installation And Commissioning At Dixon Ridge Farms

This section describes the field installation and commissioning of the BioMax® 50 system at Dixon Ridge Farms in Winters, California.

6.1 Site Preparations

The concrete pad was completed in early November, as shown in the previous design report, but the canopies for the dryers and BioMax® system were not erected until after CPC’s equipment arrived on site and were installed on the new pad. After CPC’s equipment arrived trenches were dug and wiring conduit was buried between the sub feeder panel and the new pad. Figures 43 and 44 show the site just before arrival of equipment on site.

Figure 43: Equipment Slab Looking Towards Drying Canopy
6.2 Shipping And Assembly

CPC’s equipment shipped on Tuesday October 23, 2007 and arrived on Thursday afternoon October 25, 2007, as shown in Figure 45. It was met by CPC’s project manager and lead field technician.

Figures 46 through 49 show that after removal from the truck, the modules were placed on the pad using the farm’s boom crane. The system was erected over the following eleven days and completed on Saturday November 3, 2007, as shown in Figures 50 and 51.
Figures 52 and 53 show that internal wire harnesses and pipe connections were run between modules, utilizing conduit installed by the site’s electrician. Following installation of wire conduit and piping, the hot air duct was installed between the modules and extended to below the drying canopy. Figures 54 shows the guyed flare on top of the gas production enclosure. Figure 55 shows an example of the wiring. The piping was run to the Sukup crop dryer.

**Figure 46: Gasifier Module Being Placed on Pad**

![Figure 46: Gasifier Module Being Placed on Pad](image)

**Figure 47: Heat Exchanger Module Being Placed on Pad**

![Figure 47: Heat Exchanger Module Being Placed on Pad](image)
Figure 48: Genset Being Placed On Pad

Figure 49: Filter Module Being Placed on Pad
Figure 50: Completed Gasifier and Hex

Figure 51: Feeder-Daybin and Gasifier Module Safety Railing in Final Position
Figure 52: Digging Trench for Electrical Conduit

Figure 53: Typical Electrical Conduit and Plumbing (Filter To Genset)
After the modules were placed and the conduit, piping and wiring was in place, Dixon Ridge Farm workers completed the erection of the carport style canopy over the BioMax® system.
Figures 56 through 58 show that the temporary drying canopy was erected over the walnut drying systems to demonstrate the recirculation of heat for the tour and the final duct runs were installed to deliver waste heat from the HEX to the drying canopy. This canopy was later replaced with a permanent steel building to house the BioMax® 50 and the drying operations.

Figure 56: Installing Canopy

Figure 57: Installing Temporary Canopy Over Walnut Drying Bins
6.2.1 Testing And Commissioning

Two CPC engineers were on site for 16 days from 10/30 to 11/14 to perform debugging, testing and commissioning, which culminated in a flawless run on the day of the demonstration tour.

CPC’s lead test engineer, Carl Peterson, and lead electrical engineer, Bien Espago, arrived on site on October 30th, while the PM, King Browne, and lead technician, Mark Stewart, were completing the installation of the system. For the first three days all four individuals worked on finishing up the mechanical and electrical assembly. On Friday November 2, electrical debugging of the system was started, and finished the following day on Saturday November 3. A short hot trial run on charcoal was also completed on Saturday November 2. The only electrical problem was with the gasifier junction box, where some mislabeled and reversed wires were found.

Everything went well on Saturday, so on Sunday they did a full automatic run. The filter auger didn’t turn on and they found out that the fuse was blown; Bien replaced it with a bigger fuse (10A). On Sunday they tuned the engine, and by the end of the day it would start reliably. For the next few days, they ran the system to do additional fine tuning on Walnut shells, while Bien was working on the engine and AVR.

CPC hired a dedicated operator, Brad Roberts, who arrived on site on November 8th, for his first day on the job. Between the 8th and the 13th, additional testing and tuning was conducted. Tuesday the 13th was the demonstration and they run all day with no issues.
The engineering team left on Wednesday the 14th to return to Denver. On November 26th Brad Roberts came to CPC for a week of training. On December 2nd, Carl Peterson and Bien Espago returned to the site to finish the grid connection and to complete the training of Brad Roberts. This follow up trip was necessary because the original AVR would not work and a replacement had to be flown in from the manufacturer in Italy. After two runs, there were signs of an air leak either at the gasifier flange or the HEX transition flange. On Wednesday the 5th the team checked all the connecting bolts and found the HEX transition bolts were loose. They tightened them and the system resumed normal operation. On Thursday December 6th the team was able to achieve grid connection. They were able to get a maximum load of 58 kW, but kept getting the over-current alarm on the EGCP-2, which would kill the engine.

The only outstanding issue was that the grid voltage was unstable and vulnerable to large motors starting on and off site. These caused over current alarms on the EGCP-2 engine controller and kept shutting down the generator. This was solved by increasing the over current setting on the EGCP-2. The current setting was still well under the generator over-current capability of 300 percent load for 20 seconds.

6.2.2 Demonstration

Shortly after the commitment was made to site the BioMax® 50 at Dixon Ridge Farms, a date was set for an on-site inaugural demonstration on November 13th, 2007. The demonstration was chosen to coincide with a local seminar and farm tour entitled Smart Energy Management in Agriculture, sponsored by the Ecological Farming Association headquartered in Watsonville California. Dixon Ridge Farms and the BioMax® 50 were the centerpiece of the tour.

The system was operated in full CHP mode for the tour, demonstrating electricity production and delivery of gas to the crop dryer.

The demonstration was attended by several press organizations and the coverage was picked up by the regional video news stations. The following links lead to the video coverages.

San Francisco – KTVU Channel 2 (6 pm newscast aired live from the farm)

Sacramento – ABC Channel 10 (6 pm newscast)

Sacramento – CBS Channel 13 (5 pm newscast)
http://www.cbs13.com/video/?id=27243@kovr.dayport.com
6.3 Summary

The BioMax® 50 system was installed at Dixon Ridge Farms in Winters, California. After delivery, the system was rapidly re-assembled and made ready for a demonstration featuring both simultaneous electricity generation and the use of producer gas to fuel a walnut dryer’s burner, displacing propane as fuel. Local new media and an Eco Tour group were in attendance for the successful demonstration.
CHAPTER 7:  
Field Testing At Dixon Ridge Farms

This section describes the two-year field demonstration of the BioMax® 50 system at Dixon Ridge Farms from January 2008 through December 2010.

7.1 Field Testing Plan

In November of 2007, CPC hired a full time operator to operate the BioMax® 50 system at Dixon Ridge Farms, located near Winters, California. The tasks of the operator were to operate, maintain, repair and upgrade the system, support long term testing, be the primary contact for the host site, host visitors and tours, compile operating data, and write reports on system operation and performance.

CPC provided the site and operator with all necessary equipment and tools required to support the BioMax®. Figure 59 shows the portable office that was secured and placed next to the BioMax® 50. Note that all of this system is now within the large steel shed erected to replace the canopy. The office was connected to the onsite electrical system through a 5.0 KVA transformer. Office equipment including computer, printer, routers, large display computer monitor and other office furnishings were placed in the office. Wireless internet was acquired from Winter Broadband to provide a means of remote communication and monitoring. Figure 60 shows the office area. Figure 61 shows small storage/shop area in the portable office structure.

7.1.1 Training

The operator received training at the CPC headquarters training and onsite at DRF. During the first week of employment, he received one-on-one training from CPC personnel at the site. He was first introduced to the BioMax® Control System and walked through its operation. There are many subsystems to the overall BioMax®. He was trained in each of the subsystems and each process was described. Each of the various mechanical components and their purpose to the operation of the system were shown. He was instructed on what to check and observe before a run would be started, during a run, as a run was ended, and at the end of the run. All of the different triggers for the alarms and operator alert were described and shown. He was shown the procedure to try to correct different scenarios, if an alarm was triggered. Most of the operator alerts and alarms tell why they had been triggered and ways to correct the problem, or what to look for during the next maintenance cycle. He was trained in the correct processes for starting and shutting down of the BioMax System. The onsite training also consisted of the proper training for the technique of running the system. Maintenance on the gasifier, heat exchanger, and filter module were performed during the onsite training to show how to preformed the tasks associated with the maintenance process and also to give a better understanding of the internal components of the system.

The new operator then went to CPC headquarters for an additional week of training on operation and non-operation systems at CPC. There he received training on debugging the electrical system on a unit that was being assembled at the time. During the week of
headquarter training, he began to operate a BioMax® 25 under the supervision of CPC personal. Engine debugging was being performed on the BioMax® 25 system that he was running. As the debugging was taking place, he received training on the engine configuration and the EGCP2 “the device that allows the generator to interface to the local electrical grid”.

Figure 59: Portable Office (Includes Office, Workshop, and Spares Depot)
Figure 60: Interior of Portable Office (Office Area)

Figure 61: Storage/Shop Area of Portable Office
7.1.2 Tools And Equipment
The shop area was supplied with a work bench and shelving. The shop was also outfitted with all the appropriate tools required to run and maintain the BioMax® 50. CPC provided the following tools.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cordless drill</td>
<td>25’ tape measure</td>
</tr>
<tr>
<td>Drill bit index</td>
<td>Spring loaded wire strippers</td>
</tr>
<tr>
<td>Socket wrench set</td>
<td>Manual wire stripper/crimper</td>
</tr>
<tr>
<td>Hole saw set</td>
<td>Soldering iron</td>
</tr>
<tr>
<td>Mini cutter/pliers set</td>
<td>Linesman pliers</td>
</tr>
<tr>
<td>Tap set</td>
<td>Cable cutter</td>
</tr>
<tr>
<td>Tap &amp; drill set</td>
<td>Precision screwdriver set</td>
</tr>
<tr>
<td>Combination wrench set</td>
<td>Insulated screwdriver set</td>
</tr>
<tr>
<td>Tweezers</td>
<td>Jig saw</td>
</tr>
<tr>
<td>Flashlights</td>
<td>Reciprocating saw</td>
</tr>
<tr>
<td>Permanent marker</td>
<td>4” level</td>
</tr>
<tr>
<td>Razor cutter</td>
<td>Pry bar</td>
</tr>
<tr>
<td>Organizer pouches large</td>
<td>Box cutters</td>
</tr>
<tr>
<td>Pipe wrench</td>
<td>Center punch</td>
</tr>
<tr>
<td>Claw hammer</td>
<td>1/4 in drive handle</td>
</tr>
<tr>
<td>Adjustable wrench</td>
<td>Torpedo level</td>
</tr>
<tr>
<td>Channel lock pliers</td>
<td>Hacksaw</td>
</tr>
<tr>
<td>Vice grips</td>
<td>Hacksaw blade set</td>
</tr>
<tr>
<td>Tin snips</td>
<td>Screw extractor set</td>
</tr>
<tr>
<td>Allen wrench sets</td>
<td></td>
</tr>
</tbody>
</table>

Any other tools required for supporting the BioMax were purchased on an as needed basis.
7.1.3 Spare Parts

The required supplies and spare parts for operation and maintaining the BioMax® 50 were provided by CPC as follows:

- Gasifier flange gasket
- Lower gasifier transition gasket
- Gasifier cleanout gasket
- Gas piping gaskets
- Rupture disk gaskets
- Char air gaskets
- Char ash drum gasket
- Rupture disks
- Filter bags
- Safety filters
- Producer gas O2 sensor
- Assorted fuses
- Assorted relays
- Gasifier flange hardware
- Gas cooling blower filters
- Hex tube cleaner and brushes
- System cleaning supplies
- Filter auger bearings
- Bearing grease
- Assorted hardware
- Reusable filter cleaning product
- Generator O2 sensor
- Sparkplugs
- Thermocouples
- Gasifier starting charcoal
- Generator oil
- Generator oil filters
- Pressure testing kit
- HEPA vacuum and accessories
- Char drum liners
- Flare and Sukup igniters

Extra supplies that were needed were purchased or sent from CPC to the remote site.

7.1.4 Onsite Support

The operator received remote support from CPC headquarters via phone, e-mail, and remote access through the internet to the BioMax® Control System. The operator was able to log on through a smart phone to monitor and make parameters changes. The system was also capable of sending text or e-mail alarm notifications and operational updates to the operator.

Farm personal at Dixon Ridge Farms were trained in different aspects of the systems operation in case they need to intervene in operations or perform routine maintenance when the operator is not on site. The focus of onsite personal training focused on normal day-to-day maintenance, involving only a short time. The onsite personal have been trained in filling the surge bin with walnut shells, removing and installing the char/ash collection drum liners, and operating the heat-exchanger blocking plate. These routine tasks are normally performed by the operator, unless he is absent from the site and unable to perform them in a timely manner.
7.2 Initial Operation At DRF

The operator began to run the system daily after returning from CPC headquarters. During the first three months of operation, finalizing of the installation and commissioning took place. During this time the system was operated Monday through Friday eight hours a day as the system was debugged. This is when the operator became familiar with the detailed operational requirements of the system.

During these runs there were two aspects that continually caused maintenance to be performed. There would be a buildup of char/ash on the grate that would cause a high differential pressure through the gasifier or the heat exchanger would become clogged causing a high differential pressure that would lead to an uncontrollable heat exchanger out temperature.

When a buildup of ash on top of the grate would form, the system would have to be shut down and the gasifier would have to be allowed to cool down. When the temperatures in the gasifier had cooled to below 50°C, the charcoal inside would be evacuated and the gasifier flange could be split apart. Once the gasifier was split the buildup of ash could then be removed from the grate. Running the grate with a higher duration and a lower interval would prevent ash buildup on the grate. However, this would cause a larger amount of char to pass through the lower gasifier, where it would collect at the inlet of the heat exchanger, where it would clog the lower tubes of the shell-and-tube heat exchanger.

This would require the heat exchanger to be cleaned. This was an improvement, because the heat exchanger maintenance did not require as long as grate maintenance with its long cool down period. From these findings CPC developed a heat-exchanger blocking plate that when operated would block the top two rows of the heat exchanger causing a higher pressure differential through the bottom row, which would blow the deposited char through the heat exchanger to clean it.

By working through these main problems, the system’s availability improved substantially as longer and longer runs were achieved. The system was able to be left unattended after all alarms were verified to operate correctly. This gave the operator the opportunity to precisely tune other aspects of the system. Through the following months of operation, the char air injection levels, gasifier vibration, alarm set points, and engine parameters were finely tuned.

Currently the operator attends the site during normal working hours, 40 hours per week. During this time, he performs routine maintenance and monitors system performance. The time to perform routine maintenance averages about 32 hours per month. Average system availability is about 80 percent or 576 hrs/month. Monthly availability in the second year of operation has varied from 55 percent to 97 percent. Down time averaged 144 hrs per month. Much of the down time was caused by the requirement of the system to cool down (24-48 hrs) so that repairs or long term maintenance can be performed. Only a small part of the down time was required for unscheduled maintenance or repairs.

During normal hours, the operator also maintained the appearance of the system and hosted visitors or tours of the system. He also supported experimental initiatives, such as, the
demonstration of CPC’s LiquiMax system and initiatives to analyze and recycle the char/ash byproduct as an on-farm soil amendment.

During continuous running of several weeks in duration, the system operated 24 hours a day automatically and without the need for continuous operator attendance. If the system operation is interrupted for any reason, it automatically shuts down and notifies the operator. During the operator’s next scheduled shift, he investigated the cause of the shutdown and performed any necessary maintenance or repairs to get the system back up and running.

7.2.1 Routine Maintenance
The operator performed the following short term maintenance during the periods of continuous operation:

- Fill feed storage hopper
- Empty char/ash storage drums
- Change engine oil
- Clean air filters (gas cooling blower, char air blower, engine combustion air inlets)
- Cycle the HEX blocking plate to clear lower tubes
- Maintain Roots blower (grease and oil change)
- Maintenance performed between continuous runs after a longer interval were:
  - Inspect grate and fingers
  - Clean gasifier shell and fingers as necessary
  - Clean entrance to heat exchanger
  - Replace faulty components

7.2.2 Data Logging And Performance Summaries
Data logging of the thermocouples and pressure transducers, etc. occurs automatically. Each day at midnight, the computer automatically starts a new data file named for the date. This allows easy access to historical data.

The operator spends some of his time preparing operational logs and data summaries from the logged data. From this he derives long term trends and performance measures. The following is a typical monthly operating report:

**DRF Monthly Operating Report – December 2009**

Summary

Total run hours: 612.2

Availability (run hours, voluntary down time/total hours): 82 percent
Fuel consumption: 57,151.1 lbs
Energy production: 11,383.4 KWh(net)
Total maintenance hours: 32
Ratio of maintenance time to run time: 5 percent

**Run summaries**

**Run #1**

Length of run: 168.51 hours

When started: 12/01/09  4:27 PM
When stopped: 12/08/09  8:16 PM

Reason for stopping: Code update caused system to shut down unexplained.

Post run maintenance: N/A

**Figures of Merit**

**Load – Engine**

- Fuel type and moisture content: Walnut shell (half’s and quarters). 14 percent MC
- Feeder on time – 3,050.27 minutes @4.6 lbs/min
- Fuel consumption rate (lbs/hr): 83.7 lbs per hour
- Flow rate (average): 125.0 SCMH
- Gas production total: 21,061.49 SCM
- Engine on time – 165.09 hours
- Engine load (avg) – 24.1 kW
- Energy production: 3,375.61KWh (net)
- Parasitic load: 4.07 kW (avg)

**Run #2**

Length of run: 240.52 hours

When started: 12/09/09  11:11 AM
When stopped: 12/19/09  11:40 AM

Reason for stopping: Proactive maintenance

Post run maintenance: Gasifier / Hex
Figures of Merit

- Load – Engine
- Fuel type and moisture content: Walnut shell (halves and quarters) 14 percent MC
- Feeder on time – 4,855.70 minutes @ 4.6 lbs/min
- Fuel consumption rate (lbs/hr): 93.3 lbs per hour
- Flow rate (average): 124.9 SCMH
- Gas production total: 30,046.94 SCM
- Engine on time – 220.67 hours
- Engine load (avg) – 22.7 kW
- Energy production: -4,443.62 KWh (net)
- Parasitic load: 4.22 kW (avg)

Run #3

Length of run: 116.07 hours
When started: 12/21/09  7:30 PM
When stopped: 12/26/09  3:34 PM
Reason for stopping: Large surge bins auger became jammed.
Post run maintenance: Cleared auger and lubed gearbox.

Figures of Merit

- Load – Engine
- Fuel type and moisture content: Walnut shell (halves and quarters) 14 percent MC
- Feeder on time – 2,447.93 minutes @ 4.6 lbs/min
- Fuel consumption rate (lbs/hr): 97.5 lbs per hour
- Flow rate (average): 114.5 SCMH
- Gas production total: 13,286 SCM
- Engine on time – 105.07 hours
- Engine load (avg) – 19.3 kW
- Energy production: 1,889.62 KWh (net)
- Parasitic load: 2.99 kW (avg)
Run #4

Length of run: 87.08 hours

When started: 12/28/09  8:54 AM
When stopped: 12/31/09  11:59 PM

Reason for stopping: End of month – Run actually continued

Post run maintenance: N/A

Figures of Merit

- Load – Engine
- Fuel type and moisture content: Walnut shell (halves and quarters) 14 percent MC
- Feeder on time – 2,008.44 minutes @ 4.6 lbs/min
- Fuel consumption rate (lbs/hr): 106.6 lbs per hour
- Flow rate (average): 125 SCMH
- Gas production total: 10,887.08 SCM
- Engine on time – 86.62 hours
- Engine load (avg) – 22.4 kW
- Energy production: 1,674.52 KWh (net)
- Parasitic load: 3.14 kW (avg)

7.3 BioMax® 50 Design Changes

7.3.1 System Field Modifications After Commissioning

Innumerable control system software upgrades were provided to the BioMax® 50 system after its commissioning. The system can no run for long periods of time without operator intervention.

Due to frequent maintenance being required for the inlet of the heat exchanger to remove large char and ash particles, a modification was made to allow the temporary blocking of the upper tubes during normal operation. This increased the pressure drop and gas velocity in the remaining open tubes, which served to blow the accumulated debris out of the heat exchanger.

After the successful demonstration of the Sukup burner modification to give it a dual-fuel capability, three more burners were similarly modified and installed for the 2008 drying season.
7.4 Environmental Impact

7.4.1 Air Emissions And Permitting

As a part of the permitting process at Dixon Ridge Farms in the Yolo-Solano Air Quality Management District (YSAQMD), The Avogadro Group, LLC, performed engine emission measurements on February 27, 2009. The Avogadro Group is certified by the California Air Resources Board (CARB) as an independent source test contractor for gaseous and particulate emissions.

The BioMax® 50 system was fed walnut shells and operated at full power to produce 50 kW\textsubscript{e}. The gaseous emissions were continuously monitored using a sampling method compliant with EPA method 1A criteria. Calibration gases met EPA Protocol 1. Table 9 shows the EPA or CARB methods used, the measured emissions, along the emissions converted to 15 percent oxygen in the flue gas and the YSAQMD permit limits. An inspection of Table 9 shows that the system was well within the permitted emission limits. The emission levels for SO\textsubscript{x}, VOC, and PM\textsubscript{10} were exceptionally low for an engine, which reflects the low sulfur content of the feedstock, as well as, the low hydrocarbon content, clean burning of the producer gas, and the low particulate levels in the producer gas. A comparison to the CARB regulations is given in a later section of this report.

7.4.2 Byproduct Char Disposal

The use of black “ash” from mass burning of biomass in boilers, as a soil amendment has been studied in California. A typical carbon content of this black ash was reported to be relatively close to that in the char from the BioMax® 50 gasifier. In the past, CPC has tested char made from softwood chips and found that it had characteristics that classified it as a non-hazardous waste for disposal purposes in the State of Colorado. CPC sought to satisfy the authorities in California that the char made from walnut shells was also non-hazardous.

7.5 Agricultural Wastes As Feedstocks

There are a large number of agricultural wastes that are suitable for gasification in the BioMax® 50 system. Particularly suitable are those wastes that are already dry, about the correct size and shape for rapid gasification, concentrated by previous processing, and in need of expensive disposal (as opposed to being widely dispersed in the field, where they could contribute to mulch).

Table 9: BioMax® 50 Engine Emissions Measured by the Avogadro Group at Dixon Ridge Farms

<table>
<thead>
<tr>
<th>Emission</th>
<th>Average</th>
<th>YSAQMD Permit Limit</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppm, vol. dry</td>
<td>1269</td>
<td>NA</td>
<td>EP 10</td>
</tr>
<tr>
<td>ppmwd, 15% O\textsubscript{2}</td>
<td>361.5</td>
<td>2,823</td>
<td></td>
</tr>
<tr>
<td>lb/day</td>
<td>19.36</td>
<td>161.8</td>
<td></td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>204.0</td>
<td>NA</td>
<td>EPA 7E</td>
</tr>
<tr>
<td>ppm, vol. dry</td>
<td></td>
<td>98.8</td>
<td></td>
</tr>
<tr>
<td>ppmwd, 15% O\textsubscript{2}</td>
<td>58.14</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>lb/day</td>
<td>5.120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emission</td>
<td>Average</td>
<td>YSAQMD Permit Limit</td>
<td>Method</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>---------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>SO₂</td>
<td>&lt;1.283</td>
<td>NA</td>
<td>EPA 6C</td>
</tr>
<tr>
<td></td>
<td>&lt;0.366</td>
<td>28.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.045</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>VOC</td>
<td>ND &lt;0.653</td>
<td>NA</td>
<td>EPA 18</td>
</tr>
<tr>
<td></td>
<td>ND &lt;0.185</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ND &lt;0.006</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>PM₁₀</td>
<td>0.0005</td>
<td>0.012</td>
<td>CARB 5 (F½ only)</td>
</tr>
<tr>
<td></td>
<td>0.0006</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0135</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Stack Gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂, % vol. dry</td>
<td>&lt;0.200</td>
<td>NA</td>
<td>EPA 1, 2, and 4</td>
</tr>
<tr>
<td>CO₂ % vol. dry</td>
<td>19.72</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Flow Rate, dry SCFM</td>
<td>146.1</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Moisture content, %</td>
<td>15.25</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Stack Temp., °F</td>
<td>715.0</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Examples of these preferred agricultural wastes are walnut shells and almond shells. Less preferred wastes are those which would be suitable, but need extensive drying before gasification, e.g. grape pomace. Agricultural wastes that would need to be ground and pelletized, or briquetted prior to gasification involve additional process costs and less preferred. Finally, some agricultural wastes are known to present gasification problems due to their ash content; they present even additional processing to leach out the water soluble salts that create clinkers in the gasifier.

### 7.5.1 Agricultural Wastes Tested

After Dixon Ridge Farms was selected for the field demonstration, large quantities of dried walnut shells were shipped to CPC in agricultural tote bags for extensive testing of the BioMax® 50 gasifier prior to shipping. These tests demonstrated excellent gasification with this feedstock, confirming the site selection.

Due to the expense of shipping large quantities of agricultural wastes to CPC for testing in the BioMax® 50 gasifier, normally CPC has conducted agricultural waste testing at CPC using the smaller BioMax® 12½, BioMax® 15, or BioMax® 25 gasifiers that use less feedstock than the larger BioMax® 50 gasifier. Examples of agricultural wastes that have shown promise in these preliminary gasification tests in the past have included grape pomace, grape-pomace pellets, switchgrass pellets, Timothy-hay pellets, cotton-gin-trash pellets, orange-peel pellets, alfalfa-stem pellets, almond hulls, coconut shells, and woodchips (hardwood and softwood).
7.6 Electrical Grid Connection

7.6.1 Summary

One of the contract goals of this project was to demonstrate a “grid-connected” system. In terms of the project’s relationship to PIER goals of “improving the reliability, quality, and sufficiency of California’s electricity by adding new “green” distributed generation capacity” the system should be “designed for continuous grid-tied operation in California”.

CPC approached this project with the expectation that it would be able to grid connect the system as had been done with nine other systems around the country, including the Hoopa system also funded by CEC, with the same utility (PG&E) that provides power to the Dixon Ridge Farms system. When the site was chosen (after the first Harwood Lumber site fell through) this was part of the selection criteria and, because the site already had in place a grid connected PV system, CPC expected that grid connection would be possible.

The system was designed and built with grid-connection capability and CPC demonstrated grid connected operation at the site. However, the grid connection application process was a long and drawn out process consuming considerable time and resources that did not, in the end, result in grid tie approval from PG&E. By the end of the process, Dixon Ridge Farms elected to dedicate site loads to the BioMax system output, rather than accept the conditions that PG&E would have imposed for grid connection. These problems with the process are discussed in detail below.

CPC demonstrated that the BioMax® 50 system could be successfully grid connected during the first few months in the field at Dixon Ridge Farms. However, permission for a permanent grid tie in was not granted before the end of the contract period. Despite spending more than $2,000 in permitting fees, $9,000 in hardware, $11,000 in consulting fees and over $22,000 in engineering costs, the site host was unable to conclude a satisfactory grid interconnection agreement with PG&E. Nevertheless, the system provided considerable benefit to the site by supporting the dedicated loads.

7.6.2 Procedure For Interconnection Applications

Our standard procedure for pursuing grid-tie approval was as follows:

- Customer Information gathering;
- Get recent power bills to verify Meter & Pole number and Utility company;

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8 Contract 500-03-020 T&C P. 3 of 27 Paragraph 2. AGREEMENT PURPOSE
9 Contract 500-03-020 Exhibit A P. 2 of 20 Relationship to PIER Goals
10 Contract 500-03-020 Exhibit A P. 3 of 20 Relationship to PIER Goals
• Get any customer service contact information if the customer deals with any specific engineers;
• Contact Utility;
• Get information about interconnection application from website or Interconnection Liaison;
• Many times it helps to notify the Utility that you’re starting an Interconnection Application so that they can clue you in to hurdles or stumbling blocks;
• Fill out Interconnection Application (IA);
• IA generally requires at least the following:
  • Generator size
  • Voltage, Power Factor, Wiring Configuration
  • Qualifying Facility (QF) status
  • QF is a self-proclaimed and filed notice to the FERC that says your facility operates with a certain efficiency and with concern for CHP and greenhouse gases. The application for this is straightforward and involves answering a set of questions. The application can be found on the FERC website.
  • Maximum export power
  • Type of generating facility (Net Meter, Parallel, Co-Gen)
  • Owner, Operator, Address
  • IA will occasionally require the following:
    • Primary and secondary reactances of generator (Generator spec sheet)
    • Maximum Three-Phase Fault Current
  • Submit IA to Utility
  • Utility Approves IA and replies with a negotiable Power Purchase Agreement (PPA) and Interconnection Agreement
  • Interconnection Agreement may have provisions for additional commissioning tests.
  • Commissioning tests generally require Utility Engineer or 3rd party test engineer to witness interconnection equipment on-site.
  • Customer signs PPA and new IA.
  • Final Witness Tests and Commissioning.
• The utility may have an idea of what the commissioning tests are, however if they do not, the general tests are for under/over voltage, reverse power, and over/under frequency disconnect verification.

In Mt. Shasta, the tests with a BioMax® 25 had been just with a test-set and the SEL-547 relay. At Mount Wachusett Community College, Massachusetts, the utility required a witness test to be performed, which involved a Utility Engineer watching the tests.

7.6.3 Current Status Of Grid Applications Under PG&E’s Rule 21

• Applicable generation capacity
• Solar and wind – 0 kW-30 kW, special simplified application with no fees, separate program outside of Rule 21
• Solar and wind - above 30 kW but less than 1,000 kW, fall under Rule 21 application
• All other energy types – 0 kW – 1,000 kW, fall under Rule 21

Grid Interconnection
• Only are required to grid interconnect “renewable” energy sources
• Renewable defined and limited to wind, bio-gas from dairy cattle, fuel cell or photovoltaic generated power
• Not required to grid interconnect “non-renewable” energy sources
• Defined as everything else not listed above
• Includes co-generators, CHP (combined heat and power), Hydro (large as well as micro), Bio-gas from anything other than dairy (such as bio-gas from plants, non-dairy animals, sewage treatment plants, landfills), natural gas, nuclear, coal, etc.

Rule 21 Application Status
• Exempted
• Limited to solar, dairy bio-gas, wind and fuel cell (“renewable”)
• Not subject to application fee, paid out of rate payer supported renewable programs
• Simplified/shorter application review
• Non-exempted
• All other fuel types (“non-renewable”)
• Subject to application fee – minimum is $800, if fail screen 2 then $1400, could be more if PG&E needs more review, not paid for by rate payer supported renewable programs
• Application process longer/more complicated
• No guarantee that they will allow exported power

• Metering Structure

• Net Metering - renewable

• CPUC requires PG&E to take exported power

• Limited to exempted fuel sources

• Meter allows flow of electricity both ways

• Customer is credited for exported power, at various levels (see below) within annual true-up period

• Non-Net Metering – non-renewable

• PG&E not required to take exported power

• PG&E may or may not allow electricity to flow to grid

• Customer receives no credit for exported power

• Multiple Type (Tariff)

• Customer has an exempt, renewable (solar, dairy bio-gas, wind) generator on the service and is adding a non-exempt, “non-renewable” generation

• Could be net metering or not

• Only the exempt power generator is allowed to build credits for the exported power, the non-exempt power generator is not allowed to build credits for exported power

• PG&E is more likely to take exported power because of requirement to take the exempt power generated, but as this is combination of exempt and non-exempt power generation, PG&E may “block” the exportation of the non-exempt power

• Tariff (Rate) Structure

• Solar

• Electricity generation credit based on the retail value of electricity, based on time of day, of the energy used on-site and/or exported

• Customer pays all Non-Energy Charges, which are taxes, public service fees, PG&E Energy Cost Recoupment charges, Bureau of Reclamation bond payback, PG&E infrastructure and generation capacity payments and PG&E infrastructure service repayments

• All non-exported power offsets on-site used power on 1:1 basis
• All exported power credited to the customer on a 100 percent of value of electricity generated, at time of use (TOU) rate (available to offset use above production within the “True-up Year”)

• Net annual energy used (used powerless the power generated) is paid by the customer annually during the True-Up month

• Wind, Biogas (dairy based), Fuel Cell

• Electricity generation credit based on the retail value of electricity, based on time of day, of the energy used on-site and exported

• Customer pays all Non-Energy Charges (as stated above)

• All non-exported power offsets on-site power used on 1:1 basis

• All exported power credited to the customer at 30-40 percent of value of electricity generated (available to off-set use above production within the “True-up Year”)

• Net annual energy used (used powerless the non-exported power generated and less the exported power credited at 30-40 percent) is paid by the customer annually during the True-Up month

• All other

• Electricity generation credit based on the retail value of electricity, based on time of day, of the energy used on-site

• Customer pays all Non-Energy Charges (as stated above)

• All non-exported power offsets on-site used power on 1:1 basis

• All exported power credited to PG&E (not available to customer to off-set use above production during any other period)

• Monthly net energy used (used power less non-exported power generated) is paid monthly

• Electric Credit Transfers

• Allows transference of energy credits from one meter to another under a customer’s Consolidated Billing Statement

• Only allowed for customers who are exempted, bio-gas from dairy generators

• Allows exported power in excess use from a service with a dairy bio-gas generator to another service that the customer has

7.6.4 Outcome Of Grid Connection Efforts By DRF & CPC
At the end of this process, DRF felt that PG&E was asking them to pay for all DRF site infrastructure upgrades, including those site upgrades (transformers, meters, panels, poles,
wires and labor) on PGE’s side of the meter, main infrastructure upgrades (their side of the meter and upstream on the bigger grid for an as yet undetermined distance, because their system cannot handle any more load), to pay for departed load, to pay for standby, to pay for the increased electricity use that the farm would have and be using more of, to pay for the utility wide infrastructure charges, to pay for the utility generation charges, and so forth. To complete the grid-tie process would cost more than what the electricity is worth that they would be generating with the new biomass generating system.

The BioMax® 50 biomass-fed electrical generating system served dedicated loads only and was not grid connected due to the problems encountered with the local utility company, PG&E. Changes in the California rules for distributed power generation from biomass will need to be changed before California can realize the full potential benefits from this technology.

7.6.5 Changes Needed In Rule 21 (With Suggestions from Dixon Ridge Farms)

Definition of “Renewable Energy” should include: solar; wind; bio-gas from all sources; micro-hydro (not retention and/or diversion based); tidal; ethanol; synthetic and bio diesel; vegetable and animal based oils; renewable based hydrogen powered fuel cells; agricultural, forestry, manufacturing and processing by-products; CHP and renewable based generation.

Allow future addition of fuel sources that meet the following criterion:

- energy products that are generated annually (or during a short period of time) indefinitely.
- energy sources that are sustainable (those that require less input energy to produce than is derived, while being available for many years without depletion of non-renewable resources).
- By-products of existing production, processing, and waste are probably a good source of immediately available, sustainable, renewable energy sources that won’t degrade the environment during any part of the production period levels and types of prohibited toxics are not produced.

Expand “Exempted” Category to:

- Include all energy sources and types in the “Renewable Energy Category” above into the exempted category.
- Retain all benefits included in the current Exempted Category
- Expand fuel types allowed in the “Net Metering” Category
- Include all energy sources and types in the “Renewable Energy Category” above in the Net Metering category

The utility needs to allow interconnection of all renewable-energy based generators.

Tariff/Rate Restructuring to:
• Allow all energy sources and types in the “Renewable Energy Category” above to be treated as solar is now.

• All exported power will be credited to the customer at full retail rate, adjusted for the time of use period, to be used within the year prior to the true-up month

• PG&E will buy annual power produced in excess of the annual power used during the true-up month. This rate will be the same as that paid by the utility to natural gas powered generators based on time of day produced

Expand Electric Credit Transfer

• Allow all energy sources and types in the “Renewable Energy Category” above to be treated as dairy-based bio-gas is now

• The credit to be based on the full retail value of electricity

• Credit will be allowed to customers’ accounts and/or within customers’ consolidated bill

• Expand generation capacity limit in this program to 100,000 kW

7.6.6 Summary Of Grid Connection Issues

7.6.6.1 Complexity of Process

It is very hard to understand all of the applicable regulations. CPC and DRF found that it required a consultant to sort through the options and obstacles. As the process went on, it became apparent that the full costs and burdens were unknown up front.

Cost of process

• (PG&E) Application fees

• $800 – initial application

• $1,400 – supplemental review

• (PG&E) Engineering costs

• Review test plans, monitor on site testing

• cost unknown, assume additional $2,000

• Hardware costs

• Beckwith controllers (4)

• cost - $5,040

• CT’s and misc hardware

• cost – $3,345

• Disconnect
• cost - $500 (est.)
• Consulting costs
• $11,500 to date for Arthur Engineering
• this is not “discretionary”; PG&E’s rules are truly too complex to navigate without expert advice
• Internal engineering costs
• Time expended to meet application requirements is hundreds of hours to date for
• Project manager
• Electrical engineer
• Computer Assisted Drafting (CAD) work
• 300 hrs x $75/hr = $22,500
• Cost of site owner’s (Russ Lester) time not factored in
• Cost to retrofit grid protection equipment on site
• Electrical contractor – $5,000-10,000 (estimated)
• Cost of operating below full capacity on dedicated load for 8 months
• 35 kW vs 50 kW
• (15kW) x 3,014 hrs (April-Sept) x $0.10/kWhr = $4,521
• roughly $900/month if operating at 80 percent availability

Process not favorable to onsite generation in general
• Must pay an ongoing departed load fee
• Cost unknown at this time

Process not favorable to biomass renewables in particular
• Only very small solar and wind producers fall outside of Rule 21
• 0-30kW
• Special simplified application with no fees
• Rule 21 applies to all other grid connected generators
• Some renewables are “exempt” under Rule 21
• Solar, dairy bio-gas, wind and fuel cells
• Not subject to application fee, paid out of rate payer supported renewable programs
• Simplified/shorter application review
• Rule 21 as it applies to biomass is subject to full application process
• Application and review fees
• Detailed documentation requirements
• Site plans
test plans
electrical documentation
• full description of all how generator will meet all of PG&E’s requirements
• Protective hardware requirements
• Testing and inspection requirements
• Cannot export power under Rule 21
• Biomass generators cannot obtain benefit of net metering
• Excess power is uncompensated
• Biomass generators must operate well below threshold of site load
• NEM and non-NEM generators are in conflict with one another
• If non-NEM generators are on site, NEM generators cannot export power either since generating sources would be co-mingled, unless
• Located on a separate feeder back to site entrance
• separately metered
• In practice this means that the site cannot expand NEM (PV) generating sources without removing the non-NEM generating sources
• Investing in separate electrical distribution and metering infrastructure
• Protection schemes required by utility are onerous and unreasonable
• Because cannot export power due to exclusion from Rule 21
• must cut back on generator output when load to site is within 5-10kW of net import, therefore
• cannot offset all of site’s loads
• must operate inefficiently during low demand
• cannot expand capacity to meet peak loads
• cannot expand capacity to become a net exporter
• must invest in large protection class CT’s to detect import current levels
• CT’s are designed for completely different (high current/high saturation) protection application
• CT’s are very expensive
• CT’s are very large and difficult to install in existing cabinets
• must invest in redundant protective relays ($1,200/each)
• cannot use non-approved equipment

7.7 Operational Reports

7.7.1 Operating Status

The system is currently fully operational and running on a 24/7 basis, most often in an unattended manner. Gas made from walnut shells is being delivered to the engine to produce electricity. After demonstrating operation in parallel with the grid, PG&E requested in April 2008 that grid connected operations cease, until a grid connection permit was in place. CPC worked with the site owner to reconfigure site wiring, so that electricity could be utilized by full time dedicated site loads, including compressor and chiller loads for the cold storage building. These loads are connected to the system and to the utility via a transfer switch and average about 45 kW continuous.

The system is running in a fully automated, unattended mode operation. The operator’s presence and purpose at the site is to perform special tests, routine maintenance and to react to any events that might interrupt continuous operation. These events are rare and typically involve grid outages, or the site host not maintaining fuel levels in the fuel storage bin.

Maintenance activities have averaged 32 hours per month or 7 percent of operating time. Maintenance activities include emptying char/ash drums, performing routine fluid and filter changes on the engine, clearing buildup of material at the entrance of the gas cooling heat exchanger, and performing gasifier maintenance (inspecting and cleaning grate and injector components) in between runs.

At the end of December 2009, the system operational statistics included a total of:

• 12,397 hours of gasifier run time;
• 9,514 hours of engine run time on producer gas;
• 297 MWh total gross power produced;
• 254 MWh total net power produced; and
7.8 Grid Connection Status

The system is not expected to be grid connected before the end of the contract period. Despite spending more than $2,000 in permitting fees, $9,000 in hardware, $11,000 in consulting fees and over $22,000 in engineering costs, the site host was unable to conclude a satisfactory grid interconnection agreement with PG&E. Nevertheless, the system is providing considerable benefit to the site by supporting the dedicated loads.

7.9 CHP Status

CPC first demonstrated CHP capability in 2008, producer gas was diverted to the crop dryers and captured waste heat from the engine cooling system, exhaust system and flare. These sources of heat were combined with the exhaust air from the gas cooling heat exchanger and used to heat the re-circulated air being provided to the crop dryers. CPC also simultaneously provided electricity to the crop dryers to turn the blowers.

As designed, the system has an engine-exhaust-gas heat exchanger with the capability of delivering heat to the fluid in an external hydronic heating system. However, there are no thermal loads other than seasonal crop drying to take advantage of this source of thermal energy. The ability of this system to recover waste heat from the engine cooling and from the exhaust gases was demonstrated at CPC.

CPC demonstrated the ability in the Fall of 2008 to divert producer gas to burners to take advantage of all of the energy in the gas and will do so again in the 2009 walnut drying season. CPC modified four standard commercial Sukup burners and assembled the infrastructure (piping, valves, flow meters, sensors and software upgrades to support simultaneous operation of four crop dryers. This approach was necessary to utilize all of the available producer gas without risking over heating any of the dryers. The producer gas supplies the base thermal load with propane supplying peak loads and controlling the temperature at each burner.

7.10 Environmental Permitting Status

7.10.1 Environmental Regulatory And Permitting Requirements

7.10.1.1 Introduction

Under our contract with CEC, CPC was required to demonstrate compliance with the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA). This has been done by meeting all of the applicable environmental regulations as outlined in this summary review.

In June 2008, CPC engaged the ENSR/AECOM (a leading provider of environmental and energy development services to industry and government) to evaluate the regulatory environment surrounding the generation of heat and power at the Dixon Ridge Farm (DRF) and to
recommend a compliance strategy to meet all environmental regulations applicable to the use of the BioMax™ system, including air, water, and waste emissions.

In particular, CPC was concerned with evaluating the air regulations under the Yolo-Solano Air Quality Management District (YSAQMD) and any regulatory standards applicable to the disposal of the solid char/ash waste resulting from operation of the BioMax®.

7.10.1.2 Regulatory Overview

ENSR found that the regulating agencies with possible jurisdiction included:

- Yolo-Solano Air Quality Management District (YSAQMD)
- Yolo County Environmental Health Department (EHD)
- Central Valley Regional Water Quality Control Board (CVRWQCB)
- Department of Toxic Substances Control (DTSC)

According to ENSR,

“The California Air Resources Board (CARB) provides guidance and regulations on matters of statewide concern such as setting emission standards for motor vehicles, fuels, consumer products, and mobile equipment and control measures for airborne toxics. CARB issues permits for mobile sources such as construction machinery that can be used throughout the state. Stationary sources are permitted by the local air district such as YSAQMD.”

Therefore, although one of our goals under the contract with CEC was to meet CARB 2003 air quality standards, CPC was only required to meet local YSAQMD standards to obtain a permit to operate at the DRF site.

7.10.1.3 Air Permitting Process

Under YSAQMD, a new facility that adds or modifies sources of air emissions is required to submit an application for an Authority to Construct (ATC) permit before construction. This was submitted retroactively to YSAQMD on August 8, 2008 after initial construction of the system was completed. The ATC permit was granted on February 19, 2009 and specified the required emissions testing and inspection procedures. Upon satisfying the testing and inspection procedures a Permit to Operate (PTO) would be issued. Testing was completed on February 27th, the test report delivered March 11th and the PTO was granted on March 30, 2009. The PTO is renewed annually and requires the payment of fees based on the level of pollutants generated.

The ATC and PTO only applies to the genset as this is the only system component (excepting the flare – see below) that creates air emissions. The gasification system itself is a closed system that delivers all of its end product to the genset, and so is not a regulated system subject to ATC/PTO permitting. Per YSAQMD Rule 2.32-102, the engine required permitting because it was larger than 50 bhp. Although this rule exempts engines used in “research or teaching
programs”, this exemption did not apply because the demonstration project would be used to produce power to reduce purchase from the electrical grid.

The walnut dryers were not an integral part of the BioMax® system and, although for about six weeks a year they used heat generated by the combustion of producer gas, they did not require permitting as part of the BioMax® system. Emissions from the flare were disregarded by YSAQMD because the emissions were infrequent and low level because the flare was only operated for brief periods during system upset conditions.

7.10.2 Air Permitting Standards

Best Available Control Technology (BACT) emissions thresholds are established by each county in California. If an ATC application or subsequent source testing establishes emissions higher than the BACT thresholds, a BACT analysis is triggered and the generator falls under the requirements outlined below. Under BACT, the California Air Resources Board (CARB) sets spending ‘budgets’ to achieve compliance with emissions limits based on what is currently considered to be achievable for existing emissions controls technology.

Under BACT, a generating facility could be required to spend up to the following budget amounts to achieve a 96 percent reduction in emissions or reach 25 ppm for the following pollutants (90 percent/50 ppm for waste gas, 96 percent/25 ppm for all others, incl. producer gas):

- NO2  - $24,500/ton/year
- VOC’s - $17,500/ton/year
- CO    - $300/ton/year
- PM10  - $5,700/ton/year
- SO2   - $3,900/ton/year

The reason to stay under the BACT emissions thresholds is to avoid having to spend these very large sums of money to comply with the very stringent emissions limits.

YSAQMD requires an applicant for ATC or PTO to apply BACT, if emissions would have the potential to exceed 10.0 pounds per highest day of reactive organic compounds (ROC) or NOx, 80.0 pounds or more of sulfur oxide (Sox) or PM10, or 250 pounds of CO. Based on the results of previous testing of the engine emissions under CARB 2003 protocols at CPC in 2006, the expected emissions from the genset were well below the threshold required to trigger BACT.

Emissions levels that trigger a BACT analysis in the YSAQMD are defined in Rule 3.4” and are as follows:

" YOLO-SOLANO AIR QUALITY MANAGEMENT DISTRICT

RULE 3.4 - NEW SOURCE REVIEW

(Revised August 13, 1997)

300 STANDARDS
NO2 - 10 lbs/day
VOC’s - 10 lbs/day
SO2 - 80 lbs/day
PM10 - 80 lbs/day
CO - 250 lbs/day

Some air quality management districts set BACT levels at 2 or 10 lbs/day for any pollutant, so YSAQMD is one of the more lenient districts in this regard.

The YSAQMD BACT limits, translated into ppm\(^{12}\) in the DRF exhaust gas are:

NO2 - 376 ppm
VOC - 1,081 ppm (based on methane)
CO - 15,445 ppm (1.5 percent)
SO2 - 2,161 ppm
PM10\(^{13}\) - 133,333 ppm

### 301 BEST AVAILABLE CONTROL TECHNOLOGY

An applicant shall apply Best Available Control Technology to a new emissions unit or modification of an existing emissions unit, except cargo carriers, for each emissions change of an affected pollutant, which would have an increase in emissions according to procedures specified in Section 411, and the potential to emit of the new or modified emissions unit exceeds the levels specified in Section 301.1. If the emissions from the new or modified emission unit triggers major modification requirements, then the applicant shall apply Best Available Control Technology to the new or modified emissions unit. The Best Available Control Technology requirements shall apply even though the emissions from the new or modified emissions unit are less than the levels specified in Section 301.1.

#### 301.1 Pollutant, lb/day

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive organic compounds</td>
<td>10</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>10</td>
</tr>
<tr>
<td>Sulfur oxides</td>
<td>80</td>
</tr>
<tr>
<td>PM10</td>
<td>80</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>250</td>
</tr>
</tbody>
</table>

\(^{12}\) Gases are translated from ppm to lbs/day based on the following formula:

\[
\text{ppm/lb/day} = \left( \frac{\text{ppm}}{1,000,000} \right) \times \left( \frac{\text{molar weight}}{\text{molar volume}} \right) \times \left( 1,440 \text{ min/day} \right) \times \left( \frac{\text{standard flow rate (scfm)}}{\text{measured exhaust flow rate (cfm)}} \right) \times \left( \frac{T_{\text{ambient}} - T_{\text{exhaust}}}{100\%} \right)
\]

\(^{13}\) PM10 in our exhaust gases were estimated as high as 80 ppm or 0.002 lbs/hr
These limits are calculated based on other variables such as flow rate, moisture percent in exhaust gas, O2 in the exhaust and so forth. The limits above were calculated assuming 0 percent O2 and 10 percent H2O in the gas, a measured exhaust flow rate of 426 ACFM and an exhaust temperature of 850 deg F.

7.10.2.1 Selection of Emissions Levels for Permitting Requirements

Since the BioMax® genset was not expected to release emissions that would trigger the application of BACT, CPC was free to designate lower emissions levels that it felt could be supported in testing. Levels set too high would incur excess permitting fees, while levels that were set too low would run the risk of failing the testing criteria.

CPC engaged the Avogadro Group (an approved environmental testing agency for California) to conduct preliminary testing on site to establish suitable emissions levels for the sake of permitting and testing. Values were established that could be reproduced in follow up source testing, and after adding a safety margin, the following values were selected:

- NO2 - 9.30 lbs/day
- VOC - 0.50 lbs/day
- CO - 161.80 lbs/day
- SO2 - 3.70 lbs/day
- PM10 - 0.40 lbs/day

Fees are calculated based on the guaranteed emissions limits established in the ATC application and the claimed duty cycle for the system. Assuming the values on the ATC permit selected above and assuming the most conservative operating duty cycle of 24/7/365, our annual permitted emissions levels were:

- NO2 - 3,395 lbs/year
- VOC's - 183 lbs/year
- CO - 59,057 lbs/year
- SO2 - 1,351 lbs/year
- PM10 - 146 lbs/year

Annual emissions fees are based on the following rates; permit renewal fee - $ 168 and $33 per/ton/each pollutant. The annual fees would therefore amount to:

- NOx - $ 66
- VOC's - $ 33
- CO - $990
- SO2 - $ 33
- PM10 - $ 33
Total - $1,155/year

7.10.2.2 Emissions Testing

The permitting limits given above translate into the following limits for the sake of testing (normalized for oxygen content):

- \( \text{NO}_x \): 98.8 ppmvd @15% O₂
- \( \text{CO} \): 2,823 ppmvd @15% O₂
- \( \text{VOC} \): 14.1 ppmvd @15% O₂
- \( \text{SO}_x \): 28.2 ppmvd @15% O₂
- \( \text{PM}_{10} \): 0.012 grains/dscf [District Rule 3.4]

Source testing was performed on site by Avogadro Group (an independent certified California testing agency) on February 27, 2009. The testing showed compliance with the applicable volatile organic compounds, carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter emissions of the permit. The results were as follows:

- \( \text{NO}_x \): 58.14 ppmvd @15% O₂
- \( \text{CO} \): 361.8 ppmvd @15% O₂
- \( \text{VOC} \): < 0.185 ppmvd @15% O₂
- \( \text{SO}_x \): < 0.366 ppmvd @15% O₂
- \( \text{PM}_{10} \): 0.0005 grains/dscf [District Rule 3.4]

7.10.2.3 Compliance with CARB Standards

CARB certifies engines to streamline the air quality permitting process; however each stationary generating system requires a permit under local air quality district jurisdictions and regulations.

CPC did not try to certify the engine under CARB, because it was a prototype component in an R&D project; however CPC demonstrated that it met the contractual goal of compliance with CARB 2003 emissions standards.

Engine emissions measured at CPC by TRC Environmental on April 11, 2006 under CARB 2003 test protocols and passed.\(^4\) Engine emissions measured at DRF by Avogadro on February 27, 2009 showed higher emissions levels than were seen in previous testing and met some, but not all CARB 2003 test protocols.

\(^4\) Emissions in ppm in the engine exhaust gas, as measured by TRC Environmental on April 11, 2006 in the BioMax 50 system as the CARB 2003 weighted average (0.2*emissions at 100% power + 0.5*emissions at 75%power + 0.3* emissions at 50% power):

- \( \text{NO}_x \): 22 ppm
- \( \text{CO} \): 357 ppm
- \( \text{SO}_x \): 3.5 ppm
- \( \text{VOC} \): 1.6 ppm
- \( \text{PM}_{10} \): Not Measured
all, of CARB 2003, as well as, CARB 2007 emissions standards. The reasons for the higher results from onsite testing are unclear, but are probably the result of a failure to conduct emissions-specific tuning efforts for the new site conditions (lower elevation, etc.)

In any case, the onsite test results show that while the emissions currently meet the most stringent CARB 2013 standards for particulates and VOC’s, CPC has more work to do to reduce NOx and CO levels on future systems. CPC anticipates that it will be able to achieve this by employing very lean burn control strategies combined with state of the art catalytic converters.

A summary of CARB standards and test results is given in Table 10 below. The results under TRC were based on the testing protocol required for CARB 2003, which involved a weighted average of emissions at 50 percent, 75 percent and 100 percent loads levels. Test results are also given for the average obtained at 100 percent load since this is how this testing will be conducted in the future.

<table>
<thead>
<tr>
<th>Table 10: CARB Standard Compared with BioMax® 50 Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx (lb/MW-Hr)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>CARB 2003 (DG w/CHP)</td>
</tr>
<tr>
<td>TRC (2006) (weighted average)</td>
</tr>
<tr>
<td>TRC (2006) (@100% load)</td>
</tr>
<tr>
<td>Avogadro (2009)</td>
</tr>
<tr>
<td>CARB 2007 (waste gas)</td>
</tr>
<tr>
<td>CARB 2013 (all fuels)</td>
</tr>
</tbody>
</table>

7.10.3 Solid Waste Disposal
Char/ash residue produced by the BioMax system is classified as a “solid waste”. The California Department of Toxic Substances Control (DTSC) is the governing body with respect to determining toxicity and managing hazardous waste handling and disposal.

Determination of hazardous nature is a three-tier process

- Determine if solid wastes are
- Ignitable
- Corrosive
- Reactive
• Determine if solid wastes meet federal RCRA (Resource Conservation and Recovery Act) toxicity limits
• Determine if the solid wastes meet California toxicity limits

CPC submitted char/ash samples made from walnut shells to Evergreen Analytical in Colorado for pre-screening and test results indicated that this char/ash waste met all applicable RCRA and CA standards. Follow up testing was performed to determine corrosivity (PH) and screening for some additional compounds missed during the first round of testing; these also came back negative.

Their findings were as follows:
• Ignitability - Char ash is not a liquid with a flash point of 140°F or less. It is not capable of causing fire through absorption of moisture or spontaneous chemical change.

• Corrosivity - In California, a characteristic of corrosivity is a solid which, when mixed with an equal weight of water, generates a liquid where pH < 2 or pH > 12.5. Walnut shell-derived char ash does not generate a corrosive liquid in this test. Its pH was 10.9.

• Reactivity - Char ash is not reactive. It is stable and can undergo violent change without detonating. It does not react violently with water.

RCRA - The Toxicity Characteristic Leachate Procedure (TCLP) is a simulated landfill leachate extraction and analytical test that is used to determine if a waste meets EPA’s definition of toxicity.

The RCRA toxicity threshold limits are given in Table 10. If a waste does not meet any of the RCRA toxicity characteristics, then it is assessed to determine if it meets any of the toxicity threshold limits for California hazardous waste. The California toxicity threshold limits are also given in Table 10.

Finally, CPC submitted a sample of the waste to a California certified testing agency (Test America) to verify compliance with RCA and CA toxicity limits and to conduct fish toxicity testing. These tests also came back negative (low toxicity), (the actual test results of the Test America testing are given in Table 11, showing that our solid wastes are not considered toxic, will not require special handling or hazardous disposal, and will not require oversight by DTSC. In fact, none of the compounds were detected at anywhere close to amounts for concern.
Table 11: Walnut Char/Ash Toxicity Determination

<table>
<thead>
<tr>
<th>Compound</th>
<th>CA Hazardous</th>
<th>Test results for Dixon Ridge gasifier char ash</th>
<th>% of threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EPAR</td>
<td>TCLP (mg/l)</td>
<td>STLC (mg/l)</td>
</tr>
<tr>
<td>Aldrin</td>
<td></td>
<td>0.14</td>
<td>1</td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td></td>
<td>15</td>
<td>500</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>0004</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>Asbestos</td>
<td>n/a</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>0005</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Benzene</td>
<td>0018</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td></td>
<td>0.18</td>
<td>1</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>0006</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0019</td>
<td>0.5</td>
<td>0.015 mg/l RCRA</td>
</tr>
<tr>
<td>Chlordane</td>
<td>0020</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>0021</td>
<td>100</td>
<td>0.039 mg/l STLC</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0022</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>0007</td>
<td>5</td>
<td>560</td>
</tr>
<tr>
<td>Chromium VI (Cr VI)</td>
<td></td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td></td>
<td>0.25</td>
<td>0.7</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td></td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Cresol</td>
<td>0026</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>DDT, DDE, DDD</td>
<td>0029</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>1,1-Dichloroethylene</td>
<td>0030</td>
<td>0.1</td>
<td>0.015 mg/l RCRA</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>0031</td>
<td>0.5</td>
<td>0.015 mg/l RCRA</td>
</tr>
<tr>
<td>1,4-Dichlorobenzene</td>
<td>0032</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>2,4-D (2,4-Dichloro-phenoxyacetic acid)</td>
<td>0033</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>0034</td>
<td>0.8</td>
<td>0.015 mg/l RCRA</td>
</tr>
<tr>
<td>2,4-Dinitrotoluene</td>
<td>0035</td>
<td>0.14</td>
<td>0.015 mg/l RCRA</td>
</tr>
<tr>
<td>Endrin</td>
<td>0036</td>
<td>0.012</td>
<td>0.015 mg/l RCRA</td>
</tr>
<tr>
<td>Fluoride (F-)</td>
<td></td>
<td>180</td>
<td>18000</td>
</tr>
<tr>
<td>Heptachlor</td>
<td>0037</td>
<td>0.008</td>
<td>0.47</td>
</tr>
<tr>
<td>Hexachlorobenzene</td>
<td>0038</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Hexachlorobutadiene</td>
<td>0039</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Hexachloroethane</td>
<td>0040</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Kepone</td>
<td>0041</td>
<td>2.1</td>
<td>21</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0008</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Lead (organic compounds)</td>
<td></td>
<td>n/a</td>
<td>13</td>
</tr>
<tr>
<td>Lindane</td>
<td>0013</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>m-Cresol</td>
<td>0042</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0009</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Methoxychlor</td>
<td>0014</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>0015</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Mirex</td>
<td>0016</td>
<td>2.1</td>
<td>21</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>0017</td>
<td>322</td>
<td>3,100</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td></td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Nitobenzene</td>
<td>0018</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>O-Cresol</td>
<td>0019</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>p-Cresol</td>
<td>0020</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Pentachlorophenol</td>
<td>0021</td>
<td>100</td>
<td>1.7</td>
</tr>
<tr>
<td>Polychlorinated Biphenyls (PCBs)</td>
<td>0022</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>Pyridine</td>
<td>0023</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>0024</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>0025</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>0026</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Thallium (Tl)</td>
<td></td>
<td>7</td>
<td>700</td>
</tr>
<tr>
<td>Toxaphene</td>
<td>0027</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2,4,5-TP (Silvex)</td>
<td>0028</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0029</td>
<td>0.5</td>
<td>204</td>
</tr>
<tr>
<td>2,4,5-Trichlorophenoxy-propanionic acid</td>
<td>0030</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2,4,5-Trichlorophenol</td>
<td>0031</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>2,4,6-Trichlorophenol</td>
<td>0032</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td></td>
<td>24</td>
<td>2400</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0033</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td></td>
<td>250</td>
<td>5000</td>
</tr>
<tr>
<td>Corrosivity - pH &lt;2.0 or &gt;12.5</td>
<td></td>
<td>ph 10.9</td>
<td>non-corrosive</td>
</tr>
</tbody>
</table>

Fish Kill Assay

<table>
<thead>
<tr>
<th>% of threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 out of 20 fish survived</td>
</tr>
</tbody>
</table>

141
All environmental permitting objectives have been met satisfactorily

In November of 2008, CPC advised the DTSC of the negative (low toxicity) results of the testing performed on the char ash residue. The DTSC advised CPC that while it appeared that CPC met all of the criteria for a non-hazardous classification, the DTSC could not validate the classification without performing a special waste-concurrence assessment at a cost of $10,000. Because this special concurrence assessment was not a requirement, CPC elected to follow the advice of the DTSC and simply retain the testing documentation for future reference in the event that the waste classification would be challenged for any reason.

Solid wastes may still be subject to non-hazardous disposal and/or use regulations under CIWMB (California Integrated Waste Management Board). Currently the wastes are being stored on site until the Farm implements recycling procedures for distributing the waste back into the soil.

The site host is currently working with UC Davis to assess the utility and viability of the solid waste as an on-farm soil amendment. In doing so, the farm will be returning the nutrients in the harvested biomass back into the growth cycle.

A comprehensive regulatory review was completed by CPC’s consultant ENSR/AECOM (a leading provider of environmental and energy development services to industry and government) in 2008 as a means of assessing and expediting compliance with all applicable environmental regulations.

7.11 Summary

The two-year field demonstration at Dixon Ridge Farms was performed by one CPC employee tasked to operate the BioMax® 50 system on a continuous basis to accumulate as many hours as possible operation during the period. He was able to run the system with average monthly availabilities that surpassed the goal for the first year and met the increased goal for the second year. Grid connection was successfully established, but permission for a permanent grid connection was not given by PG&E. A permit to operate was obtained from the Yolo-Solano Air Quality Management District, based on engine-exhaust emission measurements performed at the field test site. Samples of the char/ash were analyzed for various toxic compounds and elements, which showed the non-hazardous nature of this byproduct material.
CHAPTER 8: Progress Towards Goals

This section discusses the progress towards the goals of this project during the field demonstration at Dixon Ridge Farms.

8.1 System Availability And Run Time

The system Monthly Availability is shown in Figure 62, with the monthly average availability in dark blue (diamond data points) and the cumulative average of the monthly availabilities shown in magenta (square data points), discounted for voluntary (e.g., elective system upgrades) and down time due to events outside of the operator’s control (e.g., grid outages).

The contract availability goal for the first year of operation was 60 percent. Operation at Dixon Ridge Farms started in January 2008 with intermittent operation. Starting in March 2008, during the first year of operations, the system was operated continuously for ten months as much as possible. During this time of continuous operation, the system ran for 5,056 hours out of an available 7,000 hours for an average availability of 72.2 percent, clearly exceeding the goal of 60 percent.

The contract availability goal for the second year of operation was 80 percent. During the second year of operations, the system was operated continuously for a full twelve months. During this time the system ran for 6,812 hours out of an available 8,603 hours for an average availability of nearly 80 percent, or an increase in availability of 35 percent over the first year of operation.

The average monthly availability (measured as total monthly run time divided by available hours in the month) for the entire period was 76.1 percent.

For 12 out of 22 months of continuous operation, individual monthly availability exceeded 80 percent and the highest recorded availability was 98 percent for the months of September and October 2008. During September, the system was only down for 17 hours out of 720. During the last 18 months of the field demonstration, the average monthly availability was 82 percent.

After the initial six months of the field demonstration, the monthly availability improved significantly. Figure 63 shows the cumulative average monthly availabilities during the last 18 months of the 2-year field demonstration.
Figure 62: Average Monthly System Availability at Dixon Ridge in the First Two Years

Figure 63: Last 18-Month Cumulative Average of Monthly Availability

To our knowledge this is the world’s highest level of system availability ever attained for a small modular biomass gasification-power system during an extended period of field operation.
8.1.1 System Continuous Run Time
The longest continuous run of the BioMax® 50 system at Dixon Ridge Farms was 31.1 days (745.4 hrs) during the period of May 19 to June 20, 2009. The second longest continuous run to date was 30 days, achieved in August 2008. This far exceeds the contract goal of 6 days, which is achieved routinely. This long continuous run time with one operator with unattended operation at night is also thought to be a world record.

8.2 Operating Status
The system is currently fully operational and running on a 24/7 basis, most often in an unattended manner. Gas made from walnut shells is being delivered to the engine to produce electricity. The electricity is being utilized by full time dedicated site loads, including compressor and chiller loads for the cold storage building. These loads are connected to the system and to the utility via a transfer switch and average about 45 kW continuous during the summer months, but less during cooler weather.

The system is running in a fully automated, unattended mode operation. The operator’s presence and purpose at the site is to perform special tests, routine maintenance and to react to any events that might interrupt continuous operation. These events are rare and typically involve grid outages, or the site host not maintaining fuel levels in the fuel storage bin.

Maintenance activities average 32 hours per month or 7 percent of operating time. Full system maintenance is typically performed once a month. Maintenance activities include emptying char/ash drums, performing routine fluid and filter changes on the engine, clearing buildup of material at the entrance of the gas cooling heat exchanger, and performing gasifier maintenance (inspecting and cleaning grate and injector components) in between runs.

As of the date of this report, (March 31, 2010) the system completed 14,400 hours of run time and the engine has completed 11,379 hours of run time. The system has supplied over 959 MWhrs of total energy (power and heat) and consumed 1,224,538 lb of walnut shells. The BioMax system continues to operate on a continuous, 24-hour per day basis.

8.3 Grid Connection Status
The system was not expected to be grid connected before the end of the contract period. Despite spending more than $2,000 in permitting fees, $9,000 in hardware, $11,000 in consulting fees and over $22,000 in engineering costs, the site host was unable to conclude a satisfactory grid interconnection agreement with PG&E. Nevertheless, the system is providing considerable benefit to the site by supporting the dedicated loads.
8.4 CHP Status

CPC first demonstrated CHP capability in 2008 when gas was diverted to the crop dryers and captured waste heat from the engine cooling system, exhaust system and flare. CPC shut the engine down again for approximately six weeks in October and November 2009 in order to provide gas to displace propane for generating heat in the dryers.

As designed, the system has an engine exhaust gas heat exchanger with the capability of delivering heat to the fluid in an external hydronic heating system. However, there are no thermal loads other than seasonal crop drying to take advantage of this source of thermal energy.

The canopy used in 2008 during the drying season was replaced by a very large, tall permanent steel building for the 2009 drying season. In this tall building, all of the waste heat from operating the BioMax® 50 system rose to the ceiling. Ducts were installed to move the hot air from the ceiling down to the blowers that provide hot air to each dryer. In this fashion, higher drying efficiencies were attained with the recirculation of the hot air, until it was close to saturation and exhausted from the building.

8.5 Environmental Permitting Status

All environmental permitting objectives have been met satisfactorily.

8.5.1 Air Quality Permitting

YSAQMD (Yolo Solano Air Quality Management District) is the governing regulatory body with respect to air emissions.

Source testing was performed on site by Avogadro Group (an independent certified California testing agency) on February 27, 2009. The testing showed compliance with the applicable volatile organic compounds, carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter emissions meeting the requirements of the permit.

Approval for the Permit to Operate was granted on March 30, 2009 and will be up for renewal in March 2010.

8.5.2 CARB Certification

Engine emissions measured at CPC by TRC Environmental on April 11, 2006 under CARB 2003 test protocols and passed. However, CPC did not pursue CARB certification at that time, due to the impending expiration of the CARB 2003 Regulations for Distributed Generation at the end of 2006. The CARB 2007 Regulations for Distributed Generation have a more lenient category for waste gases, which the data generated at CPC indicated that could probably be met, although the test protocol has been changed considerably. CPC will need to reduce the emissions significantly to meet the CARB 2013 regulations.

Emissions testing at DRF by Avogadro were considerably higher, than measured by TRC Environmental at CPC. It is not clear why this occurred, but it is under review and is an area for improvement.
8.5.3 Solid Waste Disposal

In November of 2008, CPC advised the California’s Department of Toxic Substances Control (DTSC) of the successful results of the testing performed on the char ash residue. CPC was advised that while testing showed that CPC met all of the criteria for a non-hazardous classification, the DTSC could not validate the classification without performing a special waste concurrence assessment at a cost of $10,000. Since this special concurrence assessment was not a requirement, CPC elected to follow the advice of the DTSC and simply retain the testing documentation for future reference in the event that the waste classification would be challenged for any reason.

The site host is currently working with UC Davis to assess the utility and viability of the solid waste as an on-farm soil amendment. In doing so, the farm would be returning the nutrients in the harvested biomass back into the growth cycle.

8.6 Personnel Required

One CPC employee was tasked to operate the BioMax® 50 system 24 hours per day for as long as possible each month. That he was able to do this over a 24 month period of field testing is a testament to the degree of reliability and automation achieved with the BioMax® system, as well as, to the remote technical and material support by the rest of the staff at CPC in Colorado.

8.7 Impact of Remote Monitoring

The impact of remote monitoring was to enable the single CPC operator to go home at night and be absent for vacations, but to be able to be automatically recalled if an alarm was triggered. As the system became progressively more reliable, this has resulted in lower demands on the operator’s time. In addition, as problems arose in the field, technical support staff in the home office could monitor the performance of the system in the field in real time and aid in trouble shooting, nearly as effectively as if they were physically in the field.

8.8 Endurance Testing

The system was constantly in an endurance mode of operation in the field. The goal of 6 days of operation was quickly met and routinely exceeded, as the system’s availability increased.

8.9 Economics

The economics of the BioMax® systems are highly site specific and vary considerably depending upon the following assumed variables:

- The nature of the feedstock;
- The cost and need for feedstock preparation;
- The cost of the feedstock;
- Whether the system can be grid connected;
• The cost to grid connect;
• Cost of emission controls to satisfy the requirements of the local air quality district;
• Emission permitting costs per year, including any periodic verification testing required;

The percentage availability of the system to operate per year;

• The desired energy product (electricity and/or heat);
• The value of the energy product to the client;
• What the client is now paying for energy;
• The value of exported excess electricity to the utility;
• The cost of the nth unit in production;
• CPC is in a state of rapid cost reduction, as experience is gained in the fabrication of the BioMax® systems, which are currently assembled by technicians and engineers, rather than in a mass production mode;
• The cost of money (interest rate);
• The ratio of debt to equity;
• Lifetime of the project for true amortization costs;
• Maintenance costs;
• Personnel or fraction of personnel required to operate; and
• Labor costs and overhead.
• With this large number of variables, the economics can be made to look very encouraging by selecting all favorable assumptions. However, very few sites would be expected to have all favorable values for these variables. Consequently, it is not very constructive to give brief economic examples for a specific site, such as might be appropriate in this report.

8.10 Summary

All program goals were met, including the ability to grid connect. However, permission was not granted by PG&E for permanent grid connection, in spite of a considerable amount of effort to obtain that permission.
CHAPTER 9:  
Task 8. Technology Transfer Plan

This section describes the results of our efforts in making the public aware of the BioMax® technology for the conversion of biomass to combined electrical power and heat.

The purpose of technology transfer is to:

- Create a public awareness of the technology;
- Make contact with those who need the technology applied to their situation; and
- Commercialize the technology with widespread deployment.

The non-proprietary knowledge gained in this California Energy Commission project to develop and demonstrate a 50 kW modular biopower system has been made widely available to the public via an extensive program of information dissemination composed of the following elements:

- Site visitations;
- Awards;
- Special events;
- CPC website; and a
- Widely distributed video

9.1 Site Visitations

The BioMax® 50 system at Dixon Ridge Farms has been visited by hundreds of people from the United States and countries such as Italy, Ireland, Germany, Netherlands, UK, Czechoslovakia, Canada, Taiwan, Thailand, Japan, Russia, Poland, Brazil, Fiji, and Australia. Figure 64 shows one such visit.

Based on feedback from such visitations, Brad Roberts, CPC’s site engineer, became extremely proficient in hosting visitors and answering their questions.

Many of these visitors have returned to their home locations, and further transferred information about the project. For example, Appendix A is a well written article by a visiting scientist, Liz Hamilton, who published the article in the Central Highlands Agribusiness Forum in Australia.
9.2 Special Events

Russ Lester, President of Dixon Ridge Farms has held several high visibility agricultural events that featured the BioMax®. Russ also hosted the Agriculture Secretary of the State of California, the head of the California Air Resource Board, members of electric utilities, several Universities, and several members of the California Congress. Figure 65 shows the Eco Tour group at Dixon Ridge Farms.

Figure 65: Eco Tour Featuring the BioMax® 50 at DRF
9.3 Awards

In part, due to the presence of the BioMax®, Dixon Ridge has been recognized for their work, outreach, and educational collaboration with local growers, community leaders, and scientists to contribute to and promote the agricultural research necessary for continued growth of the organic industry. They have been recognized with the following awards: California Association for Family Farmers Achievement Award; Yolo County Model Farm; and BIOS (Biologically Integrated Orchard Systems) Model Farm.

In addition, Dixon Ridge won the 2008 California Governor’s Environmental and Economic Leadership Award. Recipients are selected by a large panel of evaluators and the Secretaries of Cal/EPA, the Resources Agency, Business, Transportation and Housing Agency, the Department of Food and Agriculture, the State and Consumer Services Agency, and the Governor’s Office. Figure 66 shows Dixon Ridge Farms accepting this award.

The Governor’s Award provided Mr. Lester the opportunity to make public the inconsistent treatment of modular biopower technology by California legislation concerning barriers to utility interconnection.

Figure 66: Dixon Ridge Farms Accepting the California Governor's Environmental and Economic Leadership Award

9.4 CPC Website

The BioMax® 50 and the field demonstration at Dixon Ridge Farms has been given special attention on CPC’s home page of the website at www.gocpc.com. Figure 67 shows the prominently displayed Project Highlight box, which provides the fact sheet shown in Figure 68 when clicked. This fact sheet shows the current hours the system has run, itemized for electrical and thermal run hours, and total energy provided. This operating information updates each minute.
9.5 Widely Distributed Video

CPC also had made a video on the BioMax® 50 that was featured on the Our Planet series hosted by Greg Gumball. The show was aired in nine major markets around the US and also is featured on our website. Figures 69 and 70 show views from that video.
Figure 69: BioMax® 50 Featured on Our Planet TV Series

Figure 70: Scenes from the Video at Dixon Ridge Farms
CHAPTER 10:
Task 9. Commercialization Plan

10.1 Purpose Of Commercialization Plan

Community Power Corporation (CPC) prepared this plan in preparation for staffing and occupying a new 50,000 sq. ft. manufacturing facility to perform large-scale production of our modular biopower systems. CPC will be hiring up to 80 employees and managers when the manufacturing center is running near capacity within a few years. CPC will be subcontracting millions of dollars of materials and components from contract manufacturers in the nearby area.

This document is designed for potential host communities, to aid them in preparing proposals to highlight why CPC should locate this potential high-growth renewable energy manufacturing facility in their community. This document describes some of the benefits a community might receive by hosting production of this leading supplier’s renewable energy products.

The plant requirements and evaluation criteria that CPC will use in making its selection are provided herein to assist interested organizations in preparing competitive offers.

10.1.1 Objective

The objective of the document is to inform interested communities of CPC’s intent to manufacture its products and describe the many positive impacts CPC’s manufacturing facility would have on their community and to solicit proposals clearly listing why CPC should consider locating its facility in their respective community.

10.2 Introduction To Community Power Corporation (CPC)

10.2.1 History

CPC is a Colorado C-Corp, located in Littleton, CO. The company was founded in 1995 and has emerged as the leading provider of small, automated, modular bioenergy systems in the US. The company’s products have been developed primarily through competitive research and development contracts valued at more than $23M secured from NREL, USDOE, USDA, USDOD, and state government customers such as the California Energy Commission, as well as, electric utilities and institutions of higher learning.

10.2.1.1 Vision - Near Future

The company’s products are at the stage where they can now be sold in volume; however, CPC has been reluctant to take on orders because of its lack of facilities to fabricate them in large numbers.

Therefore, it is our vision to locate a facility, where CPC can commence manufacturing of commercial systems. CPC will adopt a contract manufacturing approach, whereby it will subcontract the manufacturing of sub-assemblies to suppliers who can meet cost and quality
objectives. CPC will hire people in the new manufacturing facility to handle the purchasing, inbound shipping, assembly, quality control, testing, outbound shipping, parts supply, and customer service.

CPC has already begun the search for a Plant Manager, and has located at least three individuals who have substantial experience in mass manufacture of similar products.

CPC will initially fabricate systems for domestic and international customers in the small industrial and commercial markets as well as those in the research and education markets.

10.2.1.2 Vision – Long Term
CPC’s long-term vision is to grow production significantly by serving customers in large, new markets such as the military, farms, disaster relief, liquid fuels, and village power.

10.2.1.3 Overview of Current Operations
To date, CPC has fabricated its systems at its Product Development Facility in Littleton, CO. The current facility has approximately 15,000 sq. ft. of shop facilities. While appropriate for first-of-a-kind development, this is not a cost effective approach for large scale manufacturing.

CPC currently employs approximately 35 people in the Littleton facility.

10.3 Introduction To CPC’s Products
CPC’s proprietary line of modular biopower systems (see a typical system in Figure 71), sold under the registered trademark BioMax®, convert renewable biomass to heat, power, and synthetic diesel fuel. These systems are small and have many advantages for distributed generation customers. Some of these advantages include:

- Modular, standard systems ideal for mass manufacture
- Uses abundant local, low cost biomass residues
- Can use over 30 different biomass feedstocks
- Produces grid quality power
- Easy to site and connect to grid
- Results in small footprint with a high power density
- Dispatches power when needed, as opposed to solar and wind that are intermittent in nature
- Provides both electricity and heat, reaching efficiencies of nearly 80 percent
- Operates automatically, so a full-time operator is not needed
- Competitive against other distributed generators such as diesels, solar, and wind
- Producer gas can be used to fuel engines, burners, fuel cells, or chillers
• Clean and green
• Ideal for rural enterprise

Figure 71: 75-kW BioMax® Modular Biopower System

A typical system is priced in the range of $150,000 to $600,000, depending on the model and options.

One of the main reasons why the Department of Energy originally contracted with CPC was to exploit the benefits of standardized, small, modular systems for mass manufacturing. The potential for low cost manufacture through volume production techniques is significant.

Even at today’s low volumes, CPC’s systems are cost effective in areas having high energy prices (e.g., CA, NY, HI, or any of the European countries). With increased volumes, CPC expects the capital costs to decrease and competitiveness to further improve.

The largest markets for the BioMax® systems are in the following areas:

• Small industrial and commercial (displace energy using biomass residues)
• Diesel retro fit (displace diesel fuel in existing diesel engine/gensets)
• Research and Education (biofuels research instrument)
• Agro-processors (use process residues to displace heat and power)
• Military (dispose military waste, while displacing diesel fuel)
• Disaster Relief (use storm debris such as trees, branches and construction materials to make heat and power)
• Small enterprises (mainly in high poverty areas in developing countries, use local biomass to power small enterprise)

For further information on CPC’s products, go to http://gocpc.com and click the tab marked “Products”.

10.4 Evaluation Criteria

10.4.1 Community Preferences
CPC is eager to locate in a community committed to working with CPC to realize its potential. As a small company, that commitment translates primarily to up-front, tangible assistance that is extremely important in the startup of such an enterprise.

CPC is also interested in locating in a community with access to potential investors, partners, and collaborators.

Since CPC will be transferring new products to the manufacturing plant over time it is important that the new location be within a 1-2 hour drive of our headquarters in Littleton, CO.

10.4.2 Manufacturing Plant Requirements
Some of the key criteria, at which CPC is looking for the new manufacturing plant include:

• Accessible to CPC headquarters in Littleton, CO
• Very attractive financial incentives available with emphasis on the near-term
• Very attractive facility lease terms and conditions
• Facility size (~35,000 to ~50,000 SF) and amenable to U-shaped process flow for efficient assembly of systems
• Minimal improvements needed to get facility up and running
• Facility has all necessary utility services, loading docks, and heating systems
• Facility is easily serviced by common over-the-road carriers and FedEx or UPS
• Facility has space for outside storage of at least 10 BioMax® containers (40’ x 8’)
• Adequate Ceiling height of at least 25 feet
• Room to expand in the future
• Facility available within a reasonable timeframe
• Favorable work environment
• Availability of labor at reasonable cost
• Evidence of strong community support for the project
• Availability of potential local investors/partners/collaborators

CPC will design a very efficient layout for the product assembly. Figure 72 shows one concept, where the product will move from station to station along a track.

10.5 Manufacturing Details

Manufacturing of a BioMax® system will be accomplished as follows:

• Outside vendors who have the ability to machine and weld stainless steel will fabricate the gasifier, heat exchanger, and filter sub-assemblies
• Standard off-the shelf systems will be purchased in bulk primarily from wholesalers
• Assembly of the above components will be performed by CPC at our own assembly plant
• Testing will be performed by CPC to ensure product quality prior to shipment
• Therefore, CPC will be involved almost exclusively in assembly operations, which do not involve complex processes or equipment, or involve the use of hazardous materials.
• Simple jigs and fixtures will be used to speed up assembly operations.
• All painting operations will be done on by outside vendors to minimize the need for environmental permits.
CPC’s target investment cost for this first plant, assuming purchase of the facility, is $2,000,000. Given the extremely large number of vacant manufacturing facilities in the US and the number of states looking to attract “Green” industries, CPC is confident that it can meet this investment target.

10.6 Benefits To Community

CPC’s new manufacturing plant will have other positive impacts on the surrounding community. CPC expects at least 80 people to be working in the plant by the fifth year, and generating revenues of at least $60M.

A significant portion of the revenue is expected to be spent for procurement of such on items as component manufacturing, materials, services, insurance, etc. Depending on the number of qualified suppliers of goods and services, the plant could have a very positive impact on the community’s economy.

In addition, there will be many new opportunities, within the host community, for companies to complete component manufacturing, materials distribution, miscellaneous services, building maintenance, etc. It is difficult to estimate the potential impact this outside work will have, but the cumulative value of these opportunities over the period could approach $100,000,000.
Incremental tax revenues can be expected for our host city and surrounding communities, not only from the manufacturing plant, but also because of revenues and profits generated for outside suppliers of goods and services.

CPC’s systems are unique in the world, and a successful launch of commercial manufacturing could accrue positive press from news agencies around the world. States that have been strong supporters of renewable energies are expected to frequently mention the host community in many of the articles about the State’s dedication to renewable sources.

Finally, CPC has been a good corporate citizen at our Littleton operation, and it expects to continue that role in the new location.

10.7 Notification of Intent to Submit a Proposal

Interested candidates are requested to fill out the attached Notice of Intent to Propose and submit it to Art Lilley at artsolar@aol.com.

10.7.1 Proposal Requirements

Please submit proposals responding to the following:

- Description of the proposing organization
- Description of candidate community and benefits to CPC of locating there
- Description of candidate site(s). Provide supporting data such as pictures, data, maps, etc.
- Describe how site(s) match up with each of the Manufacturing Plant Requirements listed herein
- Summarize financial incentives available to Community Power Corporation. Break down by the timing of availability with emphasis on those in the near-term.
- Provide a milestone plan and schedule of what is required by Community Power Corporation, if it decided to accept the proposal
- Outline any special terms and conditions, obligations or requirements that would be imposed in return for the proposed package of incentives

Feel free to include any other information that you believe will be important to CPC’s location decision.

10.7.1.1 Deadline

Please submit final proposals by email to artsolar@aol.com, within 30 days of receipt of this document.
10.7.2 Evaluation Criteria
The proposals will be evaluated by CPC using the following scoring criteria:

- Near-term financial incentives: 30 percent
- How well facility meets manufacturing requirements: 25 percent
- Favorable terms and conditions: 20 percent
- Plan and schedule: 15 percent
- Long-range financial incentives: 10 percent

10.7.3 Contact For Questions
For answers to questions please contact Art Lilley at artsolar@aol.com, (724)348-6386. He will respond quickly with requested information.
CHAPTER 11: Conclusions And Recommendations

11.1 Conclusions

This project demonstrated the ability of the BioMax® 50 biomass gasification system to achieve reliable, unattended operation around the clock for extended periods of time. Monthly availabilities of up to 98 percent were achieved, although during the second year, the average monthly availability averaged about 80 percent. Other than obtaining permission to grid connect, all other goals of this project were met. This project demonstrated the technical viability of the BioMax® concept.

The BioMax® technology has vast commercialization potential, due to the widespread availability of biomass residues and wastes, the increasingly high costs of fossil fuels, and the public’s awareness of the need for carbon-neutral alternative-energy sources, e.g., biomass.

11.2 Recommendations

It is recommended that:

- the BioMax® 50 system at Dixon Ridge Farms be encouraged to continue to generate needed data on reliability and maintenance;
- the rules and regulations to encourage distributed power generation be specifically expanded to include power generated from biomass;
- a prototype Biomass Energy Services Company (BESCO) be encouraged in the vicinity of Dixon Ridge Farms to take advantage of the automated reliability that would allow one employee to simultaneously operate several BioMax® systems;
- Larger BioMax® systems be deployed by the BESCO, e.g., BioMax® 100.

11.3 Benefit To California

11.3.1 Realized

The benefit of this project, demonstrating the gasification of biomass in a small, automated, modular system, has been to place the State of California on the cutting edge of this successful renewal-energy technology. This project has confirmed California’s leadership in advanced-state-of-the-art renewable energy that is carbon neutral, displacing the use of fossil fuels while disposing of waste biomass.

11.3.2 Potential

The potential exists for California to continue this leadership in the widespread application of distributed power generation from agricultural and silvicultural biomass residues, including with waste-heat recovery for useful purposes.
To achieve this beneficial impact on the economy of California requires the removal of institutional barriers that discourage its widespread deployment, such as have been provided for solar and other specific renewable energy sources. In particular, it is difficult to connect electrical power generated from biomass to the grid operated by certain utility companies in California. Biomass is stored solar energy, so it should give the same preferential treatment now given to solar energy.

The benefit to California would be the large amount of additional distributed electrical power generation added to the existing grid, without the cost and permitting delays of additional power transmission lines or large power generation facilities. These distributed power sources also add reliability to the grid. In addition, the disposal of a large amount of biomass residues would be accomplished, reducing amount of material being landfilled, burned (accidentally or otherwise), or being left to rot in the field.
APPENDIX A:
Example of Article Written by a Visitor to Dixon Ridge Farms

(Written and disseminated by a visiting scientist, Liz Hamilton, who published the article in the Australian Central Highlands Agribusiness Forum.)

Established in 1979 by the Lester family, Dixon Ridge Farms, are a vertically integrated farming operation that raise, grow, pick, hull, dry, shell, sort, store, package and sell organic walnuts. Each year they process around 685,000 kg of walnut meats which results in 910,000 kg of walnut shells that need to be disposed of.

Although current energy prices have dropped considerably during 2009, fuel prices in California soared during 2008, with propane gas prices tripling to an all-time high of $2.15/gallon. Concern about future fuel costs, as well as the environmental benefits of renewable power, has driven Dixon Ridge Farms to look into complete energy self-sufficiency. In 2007, the Lester’s set a goal of being energy self-sufficient by the year 2012, while being carbon-neutral or negative. Another part of that goal is to make sure that this energy comes from non-food sources.

Russ Lester and his family were already selling their walnut shells to a biomass power plant for which they received between $10-20/ton, so they were familiar with the concept of using biomass as a renewable energy source.

In 2007, the Lester’s began working with the Community Power Company (CPC) of Colorado. CPC secured a cost-shared California Energy Commission grant to place one of their BioMax® 50 downdraft gasifier systems at Dixon Ridge Farms to convert their walnut shells into electricity or heat.

CPC’s gasifier converts walnut shells to a low Btu combustible fuel gas. The gasifier is also capable of converting other biomass feedstocks including woodchips and tree prunings. Project Manager, Brad Roberts reckons that a large number of agricultural residues in California such as olive pits, grape marc and almond shells would also be well suited to gasification.

The BioMax 50 gasifier produces enough syngas to fuel a generator outputting 50 KW of utility-grade electricity from around 45 kg of shells/hour. The combustible gas is then used in an engine generator to produce electricity, or combusted to produce heat for the Lesters’ walnut drying system. The electricity is used to power a 1115 metre$^2$ freezer that previously cost them $4-5,000/month to operate.
Previously, the Dixon Ridge Farm at Winters used about 34,000 litres of propane/week to fuel 6 heaters during the month-long walnut drying season. Now they use producer gas from the gasifier to displace 30 percent of the propane used in their heaters.

“We estimate that the walnut shells that we would normally sell for $20/ton are worth $150/ton when gasified and used to offset our onsite heat and electricity costs” said Russ Lester.

Brad Roberts believes that, having now clocked over 11,000 hours of operating time as of October 2009, including one endurance run where the system operated for 732 hours out of 745 hrs (>98 percent of the time), the BioMax® 50 has the highest availability record of any small modular gasification plant in the world. The plant is normally shutdown every two weeks for scheduled maintenance. New units being designed by CPC will have additional self-cleaning features to reduce the need for operator intervention.

The biochar, a by-product from the gasification process which is 47 percent carbon, is produced at the rate of around one 55 gallon drum every 2 days. This is being added to compost and incorporated into the organic farming system. Russ and his daughter Jenny have been working on the carbon aspect of the project with UC Davis associate professor Johan Six, of the plant sciences department. Initial studies indicate that the half-life of the carbon in the biochar in the soil exceeds 1000 years. Other possible benefits of the biochar are the retention of soil nitrogen and water. These and other benefits will be the subject of future research.

The Lester’s BioMax® 50, is a prototype which is tied in with various energy and agricultural research projects at University of California Davis, as well as providing valuable information back to CPC. Brad monitors the gasifiers performance, collects research data, performs CPC-designed experiments, and trouble shoots when necessary. He feels that the average mechanically minded person would be able to run the system which is getting easier to do as improvements are incorporated through his activities.

The Lester’s said the biggest hurdles to energy self-sufficiency at Dixon Ridge Farms have been regulatory. Due to outdated regulations, modular biopower from biomass is not allowed to be grid interconnected on their solar net meter, even though it is recognized as a good renewable technology by the utility and the State of California.

For more information visit: www.gocpc.com or www.dixonridgefarms.com