Energy Research and Development Division
FINAL PROJECT REPORT

Developing and Operating a Wood Gasification System for Commercial Greenhouses in Northern California

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This project is dedicated to the memory of Jane Turnbull, a guiding light who passed away in the fall of 2008. Her support, expertise, and dedication to energy related issues were sorely missed as the project strove to fulfill what began as her vision for using biomass for energy.

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.

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Developing and Operating a Wood Gasification System for Commercial Greenhouses in Northern California is the final report for the wood gasification project, PIR-07-001 conducted by Growpro Inc.]. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

Biomass, particularly waste wood from forest harvest operations, has the potential to provide electrical and thermal energy for commercial greenhouses. The use of waste wood has been hampered by a lack of appropriately sized equipment that can use wood as a fuel source. This project adapted existing wood gasification technology developed by Fluidyne Gasification New Zealand to autonomously provide heat and electrical energy for a commercial greenhouse operation in northern California. The adaptations to the gasifier included fuel drying and feeding, hearth geometry, gas cooling and filtering, and full automation of all functions. The project concurrently developed and implemented strategies for obtaining and processing the wood fuel and for utilizing the gas in a grid-connected combined heat and power genset (an electrical generator located close to the end user) in a greenhouse heating system.

Keywords: California Energy Commission, gasification, wood energy, biomass energy, producer gas, ceramic candle filter

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EXECUTIVE SUMMARY

Introduction

Growpro, a commercial tree seedling nursery in northern California wanted to evaluate the potential availability of large quantities of waste wood from logging operations in nearby forests. Researchers at the nursery decided that wood gasification was the best technology after evaluating a number of possible approaches to heating greenhouses with wood. Researchers contacted Fluidyne Gasification in New Zealand to discuss a gasification system. Growpro purchased two Fluidyne gasifiers in as-new condition that had been sold in the United States in the 1990s. Automation of the fuel feed and gas filtration functions needed to be accomplished before the gasifiers could be used for heating. A newly-formed research team applied for and received a grant from the Energy Commission to conduct this development work as well as additional research on fuel supply and availability.

Project Purpose

The overall goal of this project was automating and upgrading a simple, proven wood gasification system based on the Fluidyne Gasification NZ Pacific Class for use in greenhouse heating and electrical generation at a commercial tree seedling nursery in northern California. More specific goals included:

- Establishing a fuel production system to make gasifier fuel from forest biomass and to develop fuel specifications for that system.
- Demonstrating and validating a simple wood gasification system that could produce clean gas for 30-40 kilowatt (kW) power production and heating applications.
- Demonstrating and validating the automated fuel handing system, gasifier-engine genset for combined heat and power applications. Genset refers to an electrical generator located close to the end user.
- Utilizing the knowledge gained from this demonstration effort to facilitate successful commercialization of the integrated system.

The project had five specific technical performance objectives:

- Determining the production output and chip quality of the fuel production system incorporating an appropriate chipper. The objective for the target maximum sustained production rate was 40 cubic meters of chips per hour.
- Evaluating and validating the production of producer gas from the biomass gasification process. This objective required that sufficient gas could be produced to generate 30 kilowatt electrical (kWe) continuously without degradation of the engine or other equipment and that the gas would be usable in a spark ignition engine generator. It also required that the system would be capable of generating sufficient gas to provide 1.2 million British thermal units per hour (Btu/hr) to

heat greenhouses at the nursery when used exclusively for heating, or 800,000 Btu per hour in combined heat and power (CHP) mode.

- Evaluating and validating the technical specifications of the system, including gas composition and energy content, gasifier, engine, generator efficiencies and overall efficiencies.

- Evaluating the integrated system with a targeted capacity factor of 80 percent and availability of 90 percent.

- Evaluating the integrated system to determine whether it could meet the targeted emissions and applicable air standards of the Siskiyou County Air Pollution Control District.

In addition, the project had four specific economic objectives:

- The fuel cost of heat provided to the greenhouses would be less than $4.80 per million Btu.

- Annual fuel savings for heating from the system would be $45,000. This objective assumed six months of heating for 16 hours per day at 1.2 million Btu/hr at a propane price of $2.00 per gallon.

- Levelized cost of electricity generated at less than $0.10 per kilowatt hour (kWh) when the system was used in CHP mode.

- An installed capital cost of a commercial system resulting from this project of less than $50,000 per million Btu heat output, which would result in a simple payback period of about five years at current prices.

Project Results

Early in the project, the research team decided to build a larger Fluidyne Andes Class gasifier rather than update the two Pacific Class units. The single Andes unit had more potential gas output than the two Pacific units combined and incorporated advances in Fluidyne technology. The development of the Andes Class was accomplished through 15 versions of the gasifier and the accompanying fuel and gas handling systems. The team initially constructed a manually operated version with cyclones and a baghouse to test the gas cooling and filtration systems. Problems were encountered with this approach, including the need for low temperature and low humidity gas in the baghouse. The research team substituted a much more successful ceramic candle filter system to address these problems.

The research team purchased and tested a spiral screw chipper during the time the original Andes was being constructed. Testing proved that the chipper created chips that had ideal characteristics for gasification, including chunky physical dimensions and low content of fine particles. The chipper also allowed production of seven different sizes of chips using seven different blades available from the manufacturer.

The first generation of the automated fuel supply system was hydraulically driven with a ladder slide feed bin and fuel drying capabilities. This system worked, but problems with bin capacity led to substituting a drag chain bin that proved much more suitable for the application. The research team constructed a drag chain conveyor/dryer to dry the chips while they were being elevated for feeding into the gasifier airlocks to make the best use of this type of feed bin.

Researchers evaluated a series of possible gensets, and finally settled on a Rule 21 certified CHP genset with a good track record of installations in California. This genset was chosen primarily because it was hoped that the Energy Commission Rule 21 certification would greatly ease the grid interconnection process. Ultimately, this proved to be the case. The CHP genset was connected to the Pacificorp grid after an extended but not overly expensive process. Emissions testing of the genset was delayed because of difficulties with automating its operation on producer gas. This automation work was delayed until the gasifier development reached the point where there were only minimal variations in gas quality over time. At the time this report was written, the team was working with the genset manufacturer to accomplish software modifications to their operating system and hardware additions to the fuel mixing system.

The team constructed and tested a burner and heat exchanger that provided up to 1.3 million Btu/hr in one of Growpro's greenhouses. Basic emissions testing showed that the producer gas burned very clean, but additional burner development was needed to further reduce nitrogen oxide (NOx) emissions.

Developing a reliable system took longer than expected. The team constructed a data acquisition system to monitor all system functions that included an online gas analyzer for continuous monitoring of gas content. This monitoring coupled with hundreds of trial runs and equipment modification resulted in a system that made high quality producer gas suitable for use in engines and burners.

The project fully met three of its four goals and three of its five objectives. This project demonstrated that heating greenhouses with producer gas from a woodchip gasification system was both possible and economical. Generating electricity with the same system was also feasible, but the economics were not as compelling as for heating.

Researchers demonstrated a low cost fuel acquisition system consisting of processing wood from both timber harvest and fuel reduction operations that would otherwise have been burned onsite and transported to a chipping site. This system involved production of gasifier ready chips from both a specialized chipper purchased by the project and commonly available chippers used by chipping contractors. Fuel storage and initial drying have been shown to be much more economical if wood is held in log form until needed, then chipped on demand.

The research team constructed and successfully operated a new generation of Fluidyne Gasifiers, specifically the California Andes Class. This new Fluidyne system represented substantial performance and operational improvements over the original Pacific Class. Researchers demonstrated the use of the gas in engine driven gensets up to 43 kWe for approximately 500 hours. Only 40 of those hours were during operation of the grid-connected CHP unit due to unresolved fuel metering issues. The grid-connected genset was operated at up to 43 kWe on producer gas. Heating output of up to 1.3 million Btu/hr (gas only) was clearly demonstrated and the unit was able to heat a greenhouse for the commercial production of tree seedlings.

Automated fuel handling and removal of gasification byproducts was the most difficult aspect of the project. Researchers accumulated a total run time of approximately 1600 hours, including continuous and autonomous operation for 100 hours without a system failure. Researchers have demonstrated that a cogeneration plant can be operated simultaneously with a greenhouse heating system from the same gasifier.

Parts of the next generation of gasifiers have been constructed and tested. A path to commercialization has been established, and the ability of the system to gasify the smaller fuels required by the new system has been established.

The project achieved three of the five technical objectives and three of the four economic objectives. This project demonstrated that heating greenhouses with woodchip fired gasification was both possible and very economical. Generating electricity with the same system is also feasible, but the economics were not as compelling as for heating. However, it was possible to generate power for in-house consumption at a cost that was competitive with purchased power, particularly if the waste heat was recovered and used. The research team was unable to demonstrate sustained runtimes in excess of 500 hours (the maximum to date has been 100 hours) because debugging all of the systems in the much altered development machine took longer than expected. Researchers expect that long sustained runtimes may only be possible when the first commercial prototype is put into operation.

The research team purchased a spiral cone type chipper in 2008 after testing a range of chipper types. Chip production was estimated at 25 dry tons per hour, or about 120 cubic meters per hour with 300 horsepower diesel. The spiral cone chipper proved to be fast and highly efficient and was able to make a very clean, uniform chip from each of the three blade sizes researchers purchased with the unit. The main limitation was that the maximum log diameter is 11 inches. Researchers used the 1/160 blade which makes a chip 2.5 inches to 4 inches in length for most of the project testing.

The system was tested with the grid connected CHP genset at up to 43 kW along with an estimated 300,000 Btu/hr for greenhouse heating. Producer gas output of up to 160 standard cubic feet per minute (scfm) with a high heating value of 135-145 Btu per scfm giving about 1.3 million Btu/hr input was measured and burned to provide heat to a greenhouse. Additional waste heat of an unknown amount would also be available in a pure greenhouse heating application. The system could generate 43 kWe and provide 1.1

million Btu/hour of heat in CHP mode at full gas output, 300k Btu/hr from the CHP genset and 800k Btu/hr from burning the remainder of the gas.

The researchers purchased five gas continuous analyzers and logged the gas composition along with important temperatures, pressures, and system operations. The gas composition when gasifying the large chips was 20-22 percent carbon monoxide (CO), 15-16 percent hydrogen (H_2), an estimated 1.5 percent methane (CH_4), 10-12 percent carbon dioxide (CO_2), and less than 5 percent oxygen (O_2). This gave the producer gas a high heating value (HHV) of about 135-145 Btu/scfm. Researchers based the output calculations on 140 Btu/scfm. The gasifier to combustible gas efficiency based on 8000 Btu/dry pound for the fuel and 140 Btu/scfm for the producer gas was about 72 percent. Researchers gasified 147 lbs per hour at an output of 100 scfm or 1.167 million Btus of wood to produce 840,000 Btu/hr of burnable gas.

Researchers were unable to calculate engine and generator efficiencies due to reliability problems with the flow meter and insufficient continuous operation time. Efficiencies for greenhouse heating were around 50 percent, 70 percent for the gas making system and 70 percent for the burner/heat exchanger. Researchers anticipated substantial improvement in the overall efficiency of the heating system with the next generation of gasifiers and burners, which will make all of the waste heat available by being located in the greenhouse. Researchers also anticipated improvements to the greenhouse heat exchangers.

The system accumulated approximately 1600 hours of operation time during the course of the project. Autonomous sustained runs up to 100 hours were demonstrated. The loss of the chipper engine in the fall of 2011 as well as the continued inability to run the genset autonomously delayed planned sustained runs that would have enabled a better appraisal of system reliability.

The system easily met the applicable air standards of the Siskiyou County Air Pollution Control district because of its small size. A full analysis of the engine emissions was not conducted because of the lack of sustained generator runtime. The exhaust analysis of the test genset (with a catalytic converter but no mixture control) reported CO emissions of about eight parts per million (ppm) and NOx emissions of about 85 ppm at nine percent O_2.

Wood fuel purchased for use in 2013 cost $30 per green ton, including delivery to the nursery. This wood had a moisture content of 46 percent, giving a delivered cost of about $56 per dry ton. At approximately 16 per million Btu/dry ton, this resulted in a price of $3.50 per million Btu. Chipping added $6.00 per dry ton and drying with a gasifier would cost another $3.50 per ton, resulting in a total prepared fuel cost of $65.50 per ton. The prepared fuel cost was about $4.10 per million Btu. The delivered heat cost with the current system at 50 percent efficiency was $8.20 per million Btu. By comparison, propane at $2.00/ gallon had a fuel cost of $21.50 per million Btu and at 80 percent efficiency a delivered heat cost of $27.88 per million Btu. The cost of heat for the greenhouses heated by the wood gasification system was therefore $19.68 per million Btu less than the current propane heating system.

A gallon of propane yields about 75,000 Btus of heat at an average efficiency of 80 percent. A dry ton of wood yields about 8 million Btus of heat at an average efficiency of 50 percent. The nursery would use 3,456 million Btus assuming 180 days at 16 hours per day and 1.2 million output. This was about 46,000 gallons of propane or $92,000 dollars. The wood equivalent was 432 dry tons or $28.30. The annual fuel savings from a 1.2 million Btu/hr heat system was $63,700. The system would replace approximately 80,000 gallons of propane and save over $110,000 per year if it were expanded to provide all of the heating needs. Another advantage of wood heat was that the price should be much more stable over time, which allowed much better financial projections for the nursery operations.

The project was producing about 40 scfm of producer gas per dry pound of wood, which equaled 0.38 kWh per pound of wood using the Fluidyne engine tables. Thus, 2.7 pounds of wood per kilowatt at $0.028 per pound equaled a fuel cost of $0.0756 per kilowatt. This cost was offset by the value of the heat obtained as a byproduct. The CHP genset produced about 7,000 Btus of usable heat per kW of electricity generated. This heat was worth $26.88 per million Btu or about $0.18/kWh as a replacement for propane. The project approach will also generate revenue from the two percent char byproduct that was valued at about $0.50 per pound or $2.50 per cubic foot.

Estimates for operating, maintenance and capital cost yielded a levelized cost of electricity of about -$0.04/kWh based on the gasification energy cost calculator from the California Biomass Collaborative website. The negative cost was the result of the high value of the heat when replacing propane. The value of producer gas heat from a non-CHP system if the heat was valued at $8.10 per million Btu resulted in a levelized cost of electricity of about $0.15.

Researchers were unable to establish concrete information about the capital cost of the equipment because the development phase took much longer than expected. However, researchers estimated that it should be feasible to sell a basic gasifier-based greenhouse heater for less than $100,000. The unit would consist of a chip blower with auger to receive dried chips from a walking floor van and blow them to the greenhouse gasifier, as well as a greenhouse gasifier burner with a one-hour fuel hopper with airlock, a gasification hearth, a ceramic candle filter, and a burner/heat exchanger all in one package. The cost of a stand-alone installation would exceed the targeted $50,000 per million Btu. However, since the chip blower/auger unit could be shared by several units, it is possible that the cost for multiple units at the same location would reach the targeted cost. The very favorable estimates of fuel savings would allow the project to meet the simple payback period of five years even if the cost of the units exceeded $100,000.

The results of this project clearly showed that wood gasification could be used to provide low cost heat in commercial greenhouses located in areas of California that have access to waste wood. It can also be used to provide electricity although at today's prices this is not as economically compelling as heat.

The project team made the following recommendations:

- Handle wood waste from forest management in log form with conventional equipment and store fuel in log form rather than in chip form.
- Carefully prepare specified fuel to ensure reliable operation.
- Optimize the gasifier configuration for the specified fuel.
- Use a ceramic filter for particulate removal for more operating flexibility.
- Keep the system above the dew point until after the filter system.
- Aggregate system components as much as possible to reduce cost and improve reliability.
- Use a real-time gas analyzer and frequent logging of a wide range of system parameters to optimize gas production.
- Use low cost programmable logic controllers (PLCs) as a cost-effective way of monitoring and controlling the gasification system.
- Use ordinary personal computers with low cost data acquisition and control software to view and log real-time data from a system.
- Test the system under all potential operating conditions, particularly those related to moisture and temperature.
- Test the system over long periods of time.
- Investigate any potential deviations in fuel characteristics.

Project Benefits

This project demonstrated that waste wood from forest harvest operations could potentially provide electrical and thermal energy for commercial greenhouses. Using biomass rather than fossil fuels to generate electricity reduces greenhouse gas emissions that cause climate change as well as other air emissions that cause air pollution and its adverse health and environmental effects.

CHAPTER 1: Project Tasks, Observations and Results

1.1 Task 2.1 - Fuels Reduction and Sustainability Evaluation

Growpro Inc. purchased approximately 1,200 green tons of forest biomass during the term of the Energy Commission project. When the gasification system demonstrated by the project is fully implemented, Growpro will use approximately 1,400 green tons or about 700 bone dry tons (bdt) per year for greenhouse heating, plus and estimated additional 700 bdt for electrical generation coupled with smaller scale facility heating and drying needs. Woody biomass is readily available in the immediate vicinity of the greenhouse facility. The fuel that was purchased from a 2012 fuel reduction project (forest management) required a haul of only about 8 miles.

Local sources of woody biomass include the Klamath National Forest, private timber companies (such as Fruit Growers Supply Company, Timber Products, Roseburg Resources, and others listed in Appendix A), and government sponsored fuel reduction projects, as well as smaller scale private forest management and fuel reduction activities. The total amount available varies from year to year, but estimates obtained from the two private timber companies and a forest contractor for fuel reduction indicate that there is in excess of 30,000 bdt annually available in the vicinity of the Scott Valley from those three sources alone.

The Klamath National Forest also prepared a spreadsheet (Appendix B) showing the potential for access to biomass resources in the western side of the forest near the Scott Valley. This spreadsheet shows that there are 77,000 acres of national forest land on less than 35 percent slopes and with ¼ miles of an at least minimally surfaced road that could provide up at least 77,000 (1 ton per acre) tons annually (Roger Simas, USFS, Klamath NF).

In September, 2010, the Klamath National Forest issued a comprehensive preliminary feasibility assessment for a proposed biomass facility in Yreka, California, about 20 miles from the facility.[1] The report includes detailed information about the availability and sustainability of biomass fuel within a 50 mile radius of Yreka. The summary shows that approximately 370,000 bdt of woody biomass could be sustainably obtained annually within this area at an average blended cost of $53.60/ bdt. This estimated value is only slightly less than the actual delivered cost before fuel preparation of $56.00/ bdt.

An adequate and sustainable biomass fuel supply is readily available in the vicinity of the Scott Valley at a very reasonable cost. Researchers have multiple potential sources and the harvest and delivery infrastructure is excellent.

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[1] Craig Hustwit, John Munsell, John Ignosh, Chad Bolding, "Preliminary Feasibility Assessment for the US Forest Service for a Proposed Biomass Facility in Yreka, California Klamath Site Final Report" < http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5247580.pdf>

1.2 Task 2.2 - Procure and Test Appropriate Chipper

The project evaluated chips from 3 basic types of chippers: drum chippers, disc chippers, and a spiral screw chipper. The only type of chipper that could produce the large chunk type of chip most appropriate for Fluidyne gasifiers was the spiral cone chipper. Researchers ordered and received a spiral cone chipper with the 3 sizes of spiral blades that make the largest chips. These blades are identified as 2/160, 1/104, and 1/160. Providing engine power for the chipper proved challenging, but was successfully accomplished. The project used a 300HP diesel engine that was obtained locally, and purchased a large 3:1 gear reduction unit. The unit was assembled in the team's facilities and tested. Subsequently (Fall 2011), the original engine was damaged beyond repair. The team is nearly finished with the re-powering of the chipper that will also make it mobile. Mobility will make the chipper fit better into the fuel handling system developed by the team. During the period of time that spiral cone chipper was non-operational, the team tested fuel from a large forestry whole tree disc chipper.

1.2.1 Testing the Spiral Cone Chipper

The chipper is simple: a single driven shaft with a blade. Logs are pulled in through a feed hopper and expelled through the top.

Figure 1: Chipper with In-Feed on the Right and Chip Spout at the Top

Figure 2: Chipper with the Lid Lifted Showing the Blade and the Two Expeller Fins on the Left Attached to a Flywheel, 1/104 (Medium) Blade

Figure 3: Additional Blade Sizes: Left- 2/160, Right-1/160

1.3 Task 2.3 - Develop Fuel Specification with Gasifier and Generator

The spiral cone chipper acquired for this project was purchased with 3 cutting blades of different pitches that produce 3 different sizes of chips. The purpose of the testing is to determine which size chip will be most appropriate for continuous operation of the gasifier. The testing included a physical characterization of the chips, and test burning and adjustment of the gasifier to optimize the gasification process.

1.3.1 Physical Characterization

The objective of these tests was to determine the average chip size produced by each of the 3 blades, and the moisture content of the chips from the variety of tree tops purchased for the project. Results of the testing are included in the test matrix below:

Table 1: Chip Test Results Using Three Blade Sizes

Laimet blade size	1/160	1/104	2/160
Chip 1 x t x w (in.)	3.7 x .4 x .5 to 5″	2.25 x .4 x .3 to 4″	1.7 x .25 x .25 to 4″
Moisture content			
Douglas fir	12%	9	10
Ponderosa pine	35	26	35
White fir	12	38	x
Incense cedar	24	21	x
Sugar pine	36	35	38

Notes:

1) For further description of chipper and blade visit www.laimet.com under chippers
2) Chip measurements are average length, thickness and width in inches. Because of how the chips are made in this chipper, the width is quite variable.
3) The tree tops came from a mixed conifer logging operation which is why researchers had 5 species to test.

Figure 4: Examples of Chips Made the Spiral Cone Chipper with Various Blade Sizes

Note: In the lower right corner are chips made by a conventional disc chipper.

1.3.2 Results

The chipper performed as expected by producing chips of relatively uniform size and thickness with very little fine material as compared to other types of chippers. The quantity of fine material was reduced further by reducing the speed of the chipper from 1000 rpm to 500 rpm. The moisture content analysis showed considerable variation among species, even though all tops originated from trees harvested on the same few days in June. Douglas fir tops apparently dry out much faster than other species. This result was a reminder that any chip drying solution must respond to the worst possible case, not selective samples of available biomass material.

1.3.3 Gasifier Testing

In order to provide optimum gas production, the Fluidyne gasification process requires that hearth parameters be matched to fuel characteristics. This matching can only be accomplished by observing temperature and pressure trends while burning the selected fuel. Previous work by Doug Williams of Fluidyne NZ at Growpro demonstrated that all of the available softwood species can be used for fuel. Previous work demonstrated that the moisture content of the fuel must be below 20 percent. Therefore, the plan was to dry chips of each of the size to below 20 percent, then adjust the throat height and the depth to the grate within the gasifier. The adjustments were made based on the temperature and pressure dynamics while making gas, and observations of the cooled char bed. The twin objectives were to adjust the throat height so that oxidation takes place above the throat and reduction takes place in the throat and to adjust the depth of the char bed so that the maximum amount of gas is produced without either burning through the bed, or having high pressure drop due excessive bed depth.

The smallest chips (2/160) proved to be unsatisfactory in the gasifier as currently configured, due to excessive back pressure from a finely textured char bed. The chips do have the advantage of flowing well through the hearth.

The medium chip (1/104) was quite satisfactory. Both the throat and the grate were moved upward to accommodate the relatively small size of the char. Sustained and optimized gas making was achieved after 3 test cycles.

The large chip (1/160) also proved satisfactory. Parameters were adjusted downward slightly to accommodate the larger char, and sustained gas production was accomplished. Because of the somewhat lower energy required to produce this larger chip, it was initially chosen as the chip to use. However, during the subsequent 10-20 hours of operation, researchers experienced fuel feed problems which researchers attributed to the large, chunky fuel. The initial decision was made to use the medium chip. After a year of testing, and many modifications to the gasifier design, the team decided to change the fuel to the large chip. This larger fuel has resulted in a more stable gas output due to reduced potential for plugging of the hearth. The larger chip also requires less energy to produce.

The team demonstrated that chips made from any of the common western commercial conifer species using the spiral cone chipper with either of its largest two spiral blades can be used for fuel in the Fluidyne Andes gasifier when dried below 20 percent moisture.

1.4 Task 2.4 - Design and Procure Fuel Transport and Storage Systems

When the proposal for this project was originally developed, the team anticipated that specially developed transport and storage equipment would be required. However, during discussions with potential fuel suppliers it was determined that the anticipated fuel, treetop residue from logging operations could be transported with existing equipment, and storage would be best undertaken by leaving the logs in piles until needed.

The tree tops were processed by the logger to remove limbs, then transported by two existing methods. The first 120 tons were transported in 40 cubic yard roll-off bins by a local refuse company. These bins had the advantage that they were very easy to load, and could be emptied with no additional equipment. However, they were limited to 13 tons per load because of weight limitations on the truck. The remaining 1150 tons were transported on mule train truck and trailer log trucks. Because they were purchased in the fall, researchers were able to obtain the services of a logging shovel to unload them. The mule train trucks could haul up to 25 tons per load, but the additional cost of unloading, plus the additional distance of the haul, resulted in similar delivered costs.

Our original concept was to chip the logs as they were delivered, and store the chips. It became apparent very early in the fuel acquisition process, that it would be far more economical to store the logs on the ground, then chip them as needed. Storage of chips would have required a large (10,000 sq.ft.) paved, well-drained area that would have to be kept free of dirt, rocks, and pooled water. There was also the potential for spontaneous combustion. Below are some slides showing the preparation, loading and unloading of tree tops purchased for the project.

Figure 5: Preparation, Loading and Unloading of Tree Tops

Right: Truck arrives at landing . Delimbed tops are center left

Left: Bin was placed on ground for loading. This allowed the grapple operator to see into the bin and load faster.

Loading the bin: total loading time was 15 minutes. In the future, we hope to have a second bin on a trailer and bins may be left for the logging contractor to fill at his convenience.

The unloading was equally quick. Just open the doors and tip. They do spread a bit; about twice the log length.

Report Update: March 2012

The best method of moving woody biomass to the chipper has been determined to be using conventional log hauling equipment. This equipment is readily available in the area, and the operators are familiar with how to handle material in this way. Growpro Inc. purchased and equipped an excavator to unload log trucks as they arrive with the fuel.

Figure 6: Log Loader Equipped with Excavator to Unload Log Trucks

Figure 7: Log Loader with the Fuel Logs from a Fuel Reduction Project

These fuel logs are about 40 feet in length and all less than 11" in diameter. Researchers purchased approximately 560 green tons, which you see here in the pile. The log loader is an excavator equipped with a 35" grapple. These logs will be allowed do dry in this pile through the summer of 2012, at which time they will be less than 20 percent moisture, and will be chipped as needed to heat the greenhouses and generate electricity.

1.5 Task 2.5 - Acquire Fuel

The project has purchased approximately 1,200 green tons of fuel. Section Task 2.4 describes the log acquisition process. The cost of the fuel is within the range anticipated by the project team, and the quantity available far exceeds the need of project, Task 2.1.

1.6 Task 2.6 Design, Acquire, and Install Fuel Feed Equipment

The team designed and constructed and purchased components for the initial fuel feed system for the Andes gasifier consisting of a fuel storage feed bin/dryer bin, a conveyor to elevate the chips, and an airlock system. The fuel bin/dryer was based on a roll-off type bin that was modified to include a perforated drying floor and a hydraulically operated ladder-type fuel feed. The dryer floor was supplied with hot air from heat exchangers placed under the hearth in the exiting gas stream. The hydraulic fuel feed and a cross conveyor were automated with appropriate sensors, and coordinated to operate with a purchased 40 foot conveyor which moved the chips up to the airlock.

Figure 8: Original Fuel Feed/Dryer Bin and Conveyor

Figure 9: Gasifier with Linear Lock on Top and Rotating Gate Below

The airlock consisted of a purchased linear gate on top of the airlock chamber, and a site-built rotating gate at the bottom. A linear gate could not be used for the bottom lock because the contact between the pyrolysis gases and the chips in the lower position quickly caused a failure of the seal. The site built lower gate was based on a proven Fluidyne design with silicon tadpole seals which did not become sticky when in contact with pyrolysis gases. The airlock can be seen below with the linear gate at the top of the lock and the lever operating the lower gate further down.

This original airlock system is still in use, although the team is testing a rotary system that could improve reliability.

The original chip drying system worked satisfactorily, but the feed bin suffered from relatively low chip capacity, and an inability to fully empty the bin. The bin was eventually replaced with a drag chain bin (from a forage wagon). This change necessitated the construction of a new drag chain dryer and conveyor. The new dryer was provided with hot air from a pre-filter primary gas cooler developed in response to issues with the ceramic candle filter. This new system has become to be very reliable after a series of modifications to deal with problems as they cropped up.

Figure 10: Storage Feed Bin Is On the Left, and the Dryer/Elevator/Feeder on the Right

1.7 Task 2.7 - Design, Acquire, and Install Gas Filtration Modifications

The development of a reliable gas filtration system involved the testing of a series of filter configurations. At the end of this extended process, a reliable filter system based on ceramic candles was implemented.

Figure 11: Andes Class with Cooler and Cyclones Ahead of a Baghouse to Filter the Gas

The initial tests of gas filtration systems had a cyclone feeding into a baghouse. The baghouse did not work well because the cyclone removed the coarser char particles that were need to keep the cake on the bags pervious to gas, and to allow the back pulse to remove the cake. The gas cooler shown in this photo also proved inadequate to cool the gas sufficiently to operate the baghouse over extended runs.

A higher efficiency gas cooler was constructed, and the cyclones were removed for the next version of the Andes.

Figure 12: Andes Class with High Efficiency Gas Cooler and Baghouse

The high efficiency cooler is just behind the wood post in the photo. In the foreground you can see an early version of the automation system. This cooling/filtering system worked, but the cooler lost efficiency over time because it was cooling unfiltered gas. The baghouse proved difficult to operate in the winter because the gas temperature remained below the dew point for too long during startup, a condition which plugged the filter.

Figure 13: Original Configuration of the Ceramic Candle Filter

The row of green backpulse valves is visible at the top of the filter housing in the center of the photo above.

After the difficulties with the baghouse, the team decided to construct a ceramic candle filter. The candles were purchased from a supplier in the United Kingdom and the filter was constructed from plans adapted to the gasifier application. This filter has 80 ceramic candles with filtering capability of less than 10 microns. The cake is removed from the candles periodically by a high pressure back pulse of producer gas. The candles operate at up to a recommended 350C but can tolerate up to ,1,000C and have an estimated operational lifetime of at least 5 years.

Early problems with cake removal led to the introduction of a hot gas cooler ahead of the filter designed to reduce the input temperature of the gas. This modification, made at the suggestion of the candle manufacturer, has resulted in successful accumulated operation of the filter of about 1,000 hours.

Figure 14: Brand New Candles Inside the Filter Before the First Use

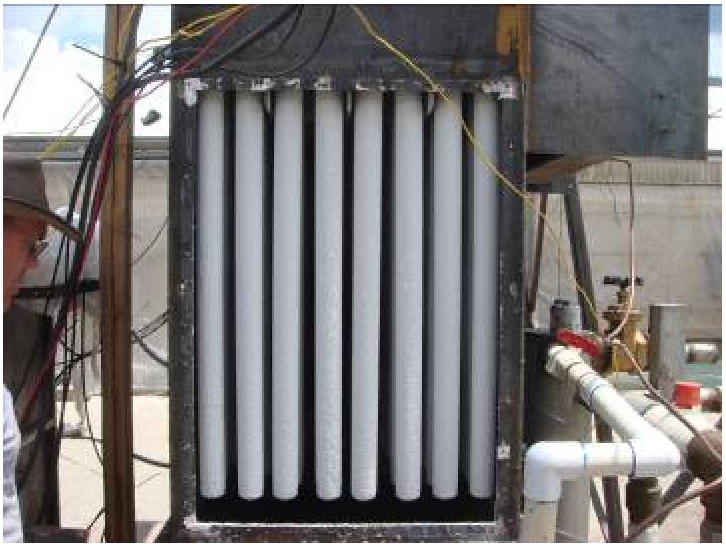


Figure 15: Final Filter/Cooler Configuration Added a Gas Cooler Ahead of the Filter, and Reconfigured the Downstream Cooler and Condenser

From right to left are the airlocks above the gasifier, the primary gas cooler behind the shroud, the ceramic candle filter, the air tube condenser, and the gas tube condenser. This is the current configuration of the coolers and filters. A commercial version is planned which will optimize the size of each element, and be designed into a much more compact unit.

1.8 Task 2.8 - Develop Process Automation

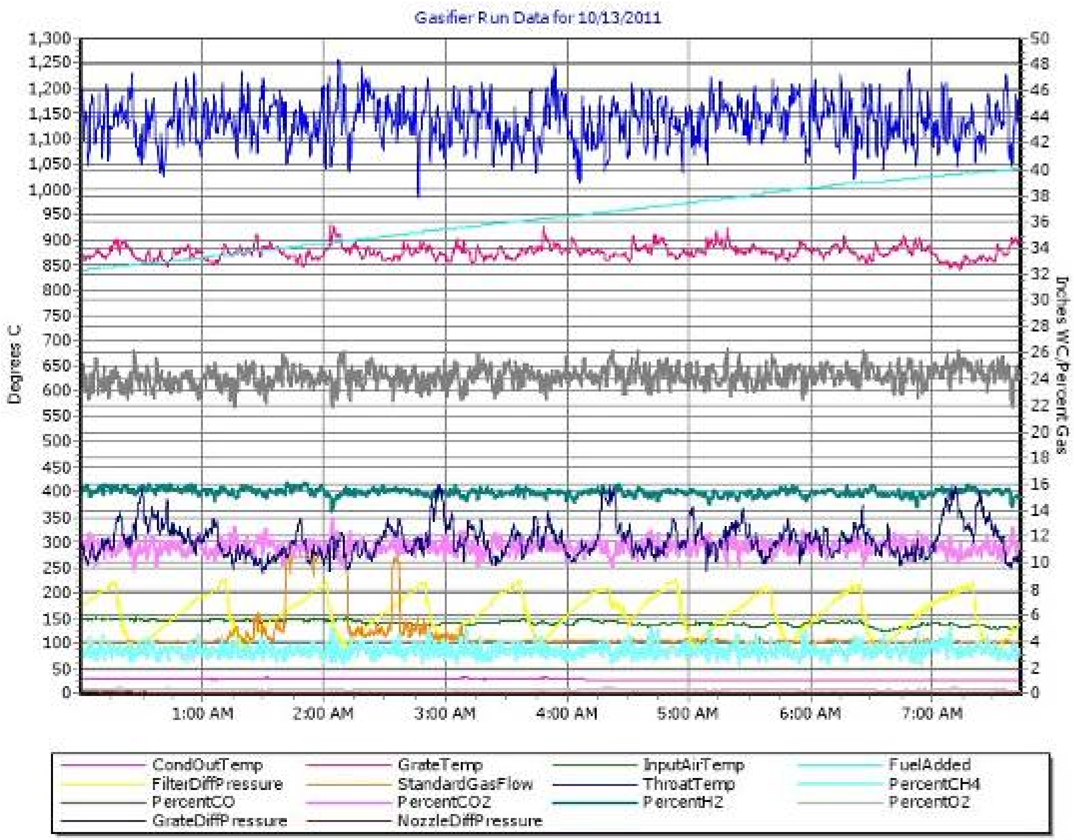
The team has successfully developed a functioning PLC-based control and data logging system for the Andes Class gasification system. The system is based on a PLC with 20 DC inputs, 16 AC output, 8 thermocouple input, 8 analog outputs and 8 analog inputs. The PLC monitors critical temperatures and pressures and controls the fuel feed system, the gas filtration system, the system output, and the burner. In the future it will operate the genset. The PLC reports data to a laptop PC running data acquisition and control software. The PC also receives gas composition data from a 5 gas continuous gas analyzer. The data are displayed in real time on the PC, plus the PC communicates with a central server that logs key parameters every 15 seconds, and makes the data available in real time for remote viewing via the internet.

Data display and logging includes the following:

- Temperature
    - Input air
    - Hearth (intermittent due to melting of thermocouples)
    - Gas leaving the reduction zone
    - Gas entering the filter
    - Gas leaving the cooler/condensers
    - Air temp
- Pressure
    - Drop across the nozzles
    - Drop across the hearth
    - Drop across the filter
    - Total system pressure (vacuum) upstream of blower
    - System pressure downstream of blower
- Flow
    - Flow of gas exiting the gasifier(vortex meter has proved to be unreliable due to sensitivity to RF noise.
    - Flow of input air (periodic implementation)
- Gas composition(percent by volume)
    - CO, H_2, CO_2, O_2(leak detection), other hydrocarbons (as CH_4)
- Operations
    - Fuel drops
    - Fuel weight (implemented earlier, but not currently operational)
    - Blower frequency setpoint
    - Condensate removal (yet to be implemented)

The continuous logging has proven to be an invaluable tool for troubleshooting, and optimizing system parameters.

Table 2: Eight Hour Sample of Some of the Logged Parameters



The upper trace is the temperature of the hearth, the next trace down is the temperature of the gas exiting the reduction zone (with the faint fuel drop trace passing through). The third and fourth traces are CO percent and H2 percent. The fifth trace is the pressure drop across the hearth with the CO2 within it.

The PLC provides controls for the following operations:

System output via control of blower frequency

- Fuel feeding
  - The system monitors fuel hopper level sensors. When fuel is needed it shuts the lower airlock gate, opens the upper gate, advances the feeder/dryer conveyor the correct amount, closes the upper gas and drops the lower gas to dump fuel into the fuel hopper. The PLC also monitors the fuel level in the

conveyor, and provides additional fuel as needed from the fuel storage/feed bin.

- Gas filtration
  - The system monitors the pressure drop across the filter. When it reaches a preset point, an in-house designed microprocessor controlled board turns on the pressure pump, and sequences the back pulsing of the 10 banks of filter elements.
- Burner operation
  - The PLC provides startup purging and ignition for the greenhouse burner, and monitors the flame via a thermocouple. The burner is provided with continuous spark ignition.
- The PLC provides for out-of parameter system shutdown. Shutdown parameters will include out of fuel, hearth gas over/under temperature (such as would result from char bed failure, or fuel feed failure), gas filter over/under pressure, full char and condensate containers, burner failure, and genset failure. Currently only the gas filter, hearth temperature, and out of fuel parameters are implemented.

The real time display of operating parameters and gas quality proved to be an invaluable tool for optimizing the performance of the gasifier.

1.9 Task 2.9 - Install and Commission Gasifiers, Generator, and Heating Equipment

The installation and commission of the gasification system has been an ongoing effort over the entire time of the project as system testing led to system modification. The pictures below show the sequence of major modifications.

Figure 16: Brand New Andes, August 2008 with Fluidyne Pacific Class System on Left

The hearth was commissioned and tested without automation or filtering.

Figure 17: Andes Class in the Fall 2008 with first gas filtration method installed, a cyclone with a bag house filter

Figure 18: January 2009 Andes Class Gasifier with Automated Fuel Feed, a Modified Gas Cooler, a Gas Condenser, and a Bag House Filter

Figure 19: August 2009 Andes Class Gasifier with Fully Automated Fuel Feeding and Drying, and Bag House Filter Replaced with Ceramic Candle Filter

Note the green test genset. The grid-connected genset was still awaiting approvals.

Figure 20: December 2010 the Current Layout

The drag chain bin on the right has replaced the inefficient feeder dryer bin. The red dryer/elevator/feeder conveyor has replaced the dryer bin and the longer gray conveyor. The hearth, filter and condenser coolers have been rearranged and consolidated. A new primary cooler has been added ahead of the ceramic filter to improve the filter performance.

Figure 21: Greenhouse burner with a capacity of 1.3mm Btu/hour

The burner and greenhouse heat exchanger have been installed in a production greenhouse at Growpro. The burner has proven to be very reliable over a wide range of outputs. The heater is capable of replacing the 5 propane unit heaters in the greenhouse. During the 2012 spring heating season, the team plans to operate the heater each night to gain experience with it and the rest of the system.

Each of these new versions has been commissioned with participation by all key team members. Doug Williams came from New Zealand approximately two times a year, and participated daily in the extended testing of the hearth via a live computer video link. Tom Miles was on site for the commissioning of major modifications, and participated in the testing via a live data feed from the server. The accumulation of data and experience during the commissioning and testing phase, particularly the real time gas composition from the analyzer, greatly increased the team's understanding of how the Fluidyne Hearth behaves. This testing and modification has resulted in a gasifier that reliably produces a high quality producer gas.

1.10 Task 2.10 - Purchase of Rule 21 Generation Equipment, Air Quality Testing and Equipment Modification

The team purchased and installed a rule 21 CHP genset. An interconnection with PacifiCorp is in place. The project goal of developing solid emissions data from both the genset and the greenhouse burners has only been partially met.

Figure 22: Control Panel and CHP Plumbing of the Rule 21 CHP Genset

Figure 23: Engine Compartment of the Rule 21 CHP Genset

The CHP genset was purchased in 2008, the first year of the project, but the interconnection agreement was not complete until February 2010. The interconnection personnel at PacifiCorp generally did their best to keep the project moving. After considerable misunderstanding of the nature of the Rule 21 equipment that the project was proposing to interconnect, PacifiCorp eventually allowed the equipment to be connected with no modification. PacifiCorp demanded a deposit of approximately $12,800 but refunded all but the eventual cost of about $4,100. One of the interesting aspects of the interconnection was that PacifiCorp used the change to shift all of the equipment costs (such as the meter and the CTs) and all of the maintenance cost for this equipment to Growpro Inc.

The purchased Rule 21 CHP genset should prove to be a good test bed for using producer gas to generate electricity, but the team has experienced unanticipated difficulties adapting it to the requirements of producer gas. Approximately 40 hours of manual operation on producer gas with electrical generation up to 43kw have demonstrated the possibilities, but the goal of continuous, automatic operation has eluded us. Researchers have been unable to gain the cooperation a key supplier of mixing and metering equipment to adapt the genset controls to produce gas. The genset manufacturer has offered to make software changes to their system to allow testing on producer gas, but this work has not yet been accomplished. The team feels that the system will eventually be able to run autonomously on producer gas and supply enough electricity for the needs of the nursery with any surplus going to the grid. This work will continue with a goal of making this a reality by the summer of 2012.

The team purchased an exhaust gas analyzer for emissions testing. The limited data collected to date shows engine emissions from the test genset to be CO –8ppm and NOx –85ppm at 9 percent O2 with a catalytic converter but no mixture control. The CHP grid connected genset, which includes a highly sophisticated emissions control system does not yet have enough run hours on producer gas to do proper testing. Researchers anticipate being able to complete this work in the summer of 2012.

Emissions testing of the greenhouse burner shows CO at 0ppm and NOx at 39 PPM with 9 percent excess air. Work continues on the burner to further reduce the NOx levels and to determine emissions over a wider range of outputs. The burner output is currently limited by the need to improve the efficiency of the heat exchanger.

1.11 Task 2.11 - Performance Evaluation of the Gasifier-Engine System

The team intended to do the planned testing the performance of the gasification system during the Fall of 2011, after all of the associated systems were stable and operating properly. Unfortunately, the engine powering the spiral screw chipper failed while Doug Williams was in California for the testing (and also the commissioning of the next generation gasifier developed by the team). There were also indications that the continuous gas analyzer had calibration issues that needed to be addressed by the manufacturer. The performance evaluations of the system are now scheduled for Spring, 2012. Researchers plan to develop curves showing the performance of the gasifier over the full range of possible outputs in each of the following areas:

- Fuel conversion efficiency

  Examine fuel consumption and related gas quantity and quality to determine the optimal and minimum/maximum outputs for the Andes class gasifier.

- Filter performance

  Evaluate the pressure drop across the filter, and the backpulse frequency to determine the minimum number of filter candles needed for any given output. This information will be used to optimize the filtration for the next generation of systems.

- Gas quality including HHV, tar and particulate content.

  Evaluate the influence of output on gas quality to determine the range of acceptable outputs, and to determine the potential heat and electrical generation of the system.

- Mass balance

  Validate the gas quality and quantity data

The gas making efficiency of the Andes hearth has been determined although there is a need to carefully examine efficiency over a wide range of outputs. At a gas output of 100 scfm and 140 Btu/scf (from gas analyzer data and Rob Williams HHV spreadsheet), the Andes hearth made about 840.000 Btu/ hour as clean gas using 147 dry lbs per hour of fuel. This gives a gas conversion of 41 scf per pound of wood or 2.57 cubic meters per kilogram. Assuming an average fuel energy content of 8,000 Btu/dry pound, the conversion efficiency is about 72 percent.

Analysis of the performance of the ceramic candle filter suggests that the filter can probably be downsized and still perform adequately at the anticipated system gas outputs. Examination of engine components after approximately 200 hours of operation shows no accumulation of particulates (or tar). Additional run time will allow confirmation that the filter will be satisfactory for long term operation of engines.

Obtaining accurate data on fuel consumption has been challenging. The first system used was automatic weighing of each fuel drop. This system suffered from poor reliability. The second system tried was to first determine the average weight of a programmed fuel drop by making several hundred weighed drops, then calculate the fuel used over a time period from the number of drops. The efficiency data above is based on this method of calculating fuel consumption. The team is currently implementing a method of weighing the fuel feed bin which will result in more accurate estimates of fuel consumption over extended run times.

1.12 Task 2.12 - Technology Transfer Activities

The team has undertaken a variety of technology transfer activities. Regular updates on the progress of the progress have been posted on the Fluidyne website (www.fluidynenz.250x.com). These updates include both photos and discussion by Doug Williams. Doug Williams has discussed certain aspects of the project on the gasification list which can be seen at: http://lists.bioenergylists.org/pipermail/gasification_lists.bioenergylists.org

Tom Miles has attended and presented at many public forums where information about the project was part of the presentations.

Tom Jopson has attended the meetings of a local biomass collaborative and presented information about the project. He has also discussed the possibilities of gasification for heating and electrical generation in Lebanon, where he does consulting work in reforestation.

The project site in Etna, California is open to visitors. A diverse range of visitors have been to this site including local ranchers and loggers, foresters from several timber companies, academic personnel from UC Davis, UC Berkeley, and Oregon State University, USFS personnel from the local ranger district and the Forest and Regional offices, resource classes from the College of the Siskiyous, a forest landowner from New Zealand, and members of a local biomass group interested in developing uses for waste biomass in the local area.

The team has discussed the technology with several tech companies with potential uses for the technology. Most recently researchers discussed gasification with a consultant in North Carolina working on a project to gasify pelleted military waste. He supplied us with some sample pellets for testing. Researchers had discussions about gasification with a company in the San Francisco Bay area with plans to use gas as a feedstock for organisms producing lipids for liquid fuel.

Similar activities will continue in the future, particularly the regular progress updates on the Fluidyne website.

1.13 Task 2.13 - Production Readiness Plan

The team has fabricated in-house most of the elements of the Fluidyne gasification system. This was necessary because most of the commercially available products that could potentially be useful are designed for applications with much higher capacities than this gasification system, and are therefore far too costly. A good example of this is commercially available chip handling equipment. The team has remained committed to developing a gasification product that is accessible to users at sensible price without subsidies. In house construction has the advantage that components can be designed to match the application, but have the disadvantage that they must be produced and not just purchased.

Several potential methods of producing components of the system have been investigated. Options include firms that use customer supplied drawings to cut out kits of parts for assembly by others, firms that will use the same techniques, but will also provide assembly work, and firms that will contract to provide finished units. All three types of production are readily available in larger metropolitan areas such as San Francisco and Portland. Visits to some of these firms show that they will provide quotes for production based on CAD drawings.

Production of this Fluidyne gasification system will be relatively easy once a commitment has been made to a final design. The final design awaits additional sustained runtime that could longer term problems in some of the components, and further testing of fuel handling methods to reduce the cost and bulk of the currently employed methods.

CHAPTER 2:
Conclusions and Recommendations

The results of this project clearly show that wood gasification can be used to provide low cost heat in commercial greenhouses located in areas of California that have access to waste wood. It can also be used to provide electricity although at today's prices this is not as economically compelling as heat.

The Fluidyne gasification system has been proven to be robust and capable of reliably making producer gas with a very low level of undesirable contaminants over long periods of time. Full automation of these gasification systems is challenging because cost and space constraints limit the availability of off-the-shelf components. The project team had to design and build virtually all of the major automation components including the fuel feeder, the gas coolers and filter, the char and condensate removal equipment, the producer gas burner and heat exchanger, and the system automation system.

Based on the results of this project, the team makes the following recommendations:

- Fuel
    - Handle wood waste from forest management in log form with conventional equipment.
    - Store fuel in log form rather than in chip form
    - Carefully prepare specified fuel as this is essential for reliable operation.
- Gasification
    - Optimize gasifier configuration for specified fuel
    - Use a ceramic filter for particulate removal for more operating flexibility
    - Keep system above the dew point until after the filter system
    - Aggregate system components as much as possible to reduce cost, and improve reliability
    - Use a real-time gas analyzer and frequent logging of a wide range of system parameters to optimize gas production
- Automation
    - Use low cost programmable logic controllers (PLC's) as a cost effective way of monitoring and controlling a gasification system
    - Use ordinary personal computers with low cost data acquisition and control software to view and log real-time data from a system
- Testing
    - Test the system under all potential operating conditions, particularly those related to moisture and temperature
    - Test the system over long periods of time
    - Investigate any potential deviations in fuel characteristics

APPENDIX A:
Custom BAMF Market Assessment Report

Custom BAMF Market Assessment Report

Industrial Wood Residue Proximity Analysis

Distance <= 50 Miles

Potential Source / Contact Info	Est. Total Wood Residue (green tons/year)	Est. Total Energy (Million BTUs/Year)	Est. Total Power (MWe)	Distance (miles)	Rank
Custom Assessment for Klamath (1)					
Roseburg Forest Products Co P O Box 680 Weed, CA 96094-0680 Phone: 530-938-2721	20,930	56,511	1.89	32.39	1
Timber Products Co L P P O Box 766 Yreka, CA 96097-0766 Phone: 530-842-2310	15,080	40,716	1.36	5.47	2
Chuck L Logging Inc 6527 Big Springs Rd Montague, CA 96064-9105 Phone: 530-459-1138	5,850	15,795	0.53	19.77	3
Shasta Forest Products Inc P O Box 777 Yreka, CA 96097-0777 Phone: 530-842-2787	3,900	10,530	0.35	5.42	4
Sanders Preston Timber Falling 9509 N Old Stage Rd Weed, CA 96094-9516 Phone: 530-938-4120	3,900	10,530	0.35	31.75	5
Sawyer Wood Products Inc 299 Rogue River Pkwy Talent, OR 97540-8621 Phone: 541-535-3606	2,600	7,020	0.23	43.45	6
Dave Richardson Trucking 8817 Lwer Litle Shasta Rd Montague, CA 96064-9699 Phone: 530-459-5088	2,340	6,318	0.21	17.36	7
Naturalyards LLC P O Box 3180 Ashland, OR 97520-0306 Phone: 541-488-0838	1,430	3,861	0.13	34.48	8
Vanderlip Logging Company Inc 150 Lowe Rd Ashland, OR 97520-9618 Phone: 541-488-1756	1,300	3,510	0.12	41.54	9
Mark Crawford Logging Inc P O Box 720 Seiad Valley, CA 96086-0720 Phone: 530-496-3272	1,300	3,510	0.12	46.11	10
Jim Johnson Logging 4500 Scott Valley Rd Etna, CA 96027-9537 Phone: 530-467-3956	1,040	2,808	0.09	28.12	11
Morlog Corp 1257 Siskiyou Blvd 1149 Ashland, OR 97520-2241 Phone: 541-840-6490	1,040	2,808	0.09	37.45	12

June 16, 2010

DOE does not research, maintain, verify, or certify the location data presented herein and makes no warranty as to the accuracy of the data or its fitness for any particular purpose.

Page 1 of 3

Potential Source / Contact Info	Est. Total Wood Residue (green tons/year)	Est. Total Energy (Million BTUs/Year)	Est. Total Power (MWe)	Distance (miles)	Rank
Buk-N-Run Timber Falling LLC P O Box 1001 Fort Jones, CA 96032-1001 Phone: 530-468-5803	910	2,457	0.08	4.42	13
Edgewood Logging 2134 Stewart Springs Rd Weed, CA 96094-9537 Phone: 530-938-2692	910	2,457	0.08	30.43	14
Robert Gilmore Shop 267 Callahan Etna, CA 96027 Phone: 530-467-5651	780	2,106	0.07	32.30	15
Ken Dysert Logging P O Box 493 Fort Jones, CA 96032-0493 Phone: 530-468-2999	650	1,755	0.06	26.78	16
Fallon Logging LLC 255 Timberlake Dr Ashland, OR 97520-9085 Phone: 541-482-1470	650	1,755	0.06	34.69	17
Shasta Brown Inc 511 S Old Stage Rd Mount Shasta, CA 96067-9743 Phone: 530-926-4010	650	1,755	0.06	41.44	18
Farmer Logging P O Box 368 Talent, OR 97540-0368 Phone: 541-535-6026	650	1,755	0.06	44.24	19
Shasta Forest Products Inc P O Box 777 Yreka, CA 96097-0777 Phone: 530-842-2785	520	1,404	0.05	5.65	20
Jim Eller Trucking 5505 Shamrock Rd Yreka, CA 96097-9719 Phone: 530-842-5894	520	1,404	0.05	9.22	21
Quartz Valley Cutterz 13605 Quartz Valley Rd Fort Jones, CA 96032-9714 Phone: 530-468-5632	520	1,404	0.05	31.15	22
Hanscom & King Logging Inc 147 N Pioneer St Ashland, OR 97520-1823 Phone: 541-482-3221	520	1,404	0.05	38.80	23
Smiley Brothers Logging LLC 600 Balsam Ln Etna, CA 96027-9514 Phone: 530-467-3144	390	1,053	0.04	28.41	24
Frenzel Company 9344 Mt Ashland Ski Rd Ashland, OR 97520-9793 Phone: 541-482-3522	390	1,053	0.04	28.73	25
McEwen Logging P O Box 248 Etna, CA 96027-0248 Phone: 530-598-1453	390	1,053	0.04	31.83	26

Potential Source / Contact Info	Est. Total Wood Residue (green tons/year)	Est. Total Energy (Million BTUs/Year)	Est. Total Power (MWe)	Distance (miles)	Rank
Siskiyou Forest Products 190 Boles St Weed, CA 96094-2518 Phone: 530-938-2771	390	1,053	0.04	32.08	27
Double Bit Logging 910 Sawyers Bar Rd Etna, CA 96027-9410 Phone: 530-467-5341	390	1,053	0.04	32.87	28
Spencer Logging Co LLC 5401 N Old Stage Rd Mount Shasta, CA 96067-9137 Phone: 530-926-2164	390	1,053	0.04	35.87	29
Darrah Logging Inc P O Box 236 Mount Shasta, CA 96067-0236 Phone: 530-926-1706	390	1,053	0.04	35.93	30
30 Sources	**70,720** tons	**190,944** MMBTU	**6.39** MWe		

APPENDIX B:
Potential Biomass Availability, Western Klamath National Forest

Biomass Overview Westside Klamath (February 2006)

Scheduled Harvest Regulation Class 2 Acres Within 1/4 mile of Road Maintenance Level Class

	Road Levels 3,4,5						Road Level 2					
District	Partial Retention		General Forest		Recreational Rivers		Partial retention		General Forest		Recreational Rivers	
	0-35%	35-45%	0-35%	35-45%	0-35%	35-45%	0-35%	35-45%	0-35%	35-45%	0-35%	35-45%
Oak Knoll	1,817	775	1,397	814	138	114	5,859	2,369	6,243	3,352	117	101
Happy Camp	5,619	3,126	4,338	2,162	384	302	8,076	6,118	7,485	4,234	219	200
Salmon River	3,248	2,268	252	242	256	162	5,602	4,264	1,538	1,765	387	241
Scott River	3,005	2,076	738	593	187	136	8,614	4,580	3,238	2,592	76	82
Sub Totals	13,689	8,245	6,725	3,811	965	714	28,151	17,331	18,504	11,943	799	624
Ukonom	2,210	839	1,211	765	188	131	1,299	675	2,142	1,179	21	5
Totals	15,899	9,084	7,936	4,576	1,153	845	29,450	18,006	20,646	13,122	820	629

Acreage Summary

	Road Levels 3,4,5		Road Level 2		TOTALS	
District	TOTALS Road Levels 3,4,5	TOTALS Road Level 3,4,5	TOTALS Road Level 2	TOTALS Road Level 2	TOTALS All Road Levels	TOTALS All Road Levels
	0-35%	35-45%	0-35%	35-45%	0-35%	35-45%
Oak Knoll	3,352	1,703	12,219	5,822	15,571	7,525
Happy Camp	10,341	5,590	15,780	10,552	26,121	16,142
Salmon River	3,756	2,672	7,527	6,270	11,283	8,942
Scott River	3,930	2,805	11,928	7,254	15,858	10,059
Sub Totals	21,379	12,770	47,454	29,898	68,833	42,668
Ukonom	3,609	1,735	3,462	1,859	7,071	3,594
Totals	24,988	14,505	50,916	31,757	75,904	46,262