Small Modular Power System for Clean Energy Generation

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ABSTRACT

The overall goal of this project is to design, develop and demonstrate a 50-kW modular gasification system for grid-connected combined heat and power using forest residue.

Building on the success of the previous 12.5-kW small modular biomass project, this new project will result in the development and demonstration of a 50-kW small modular biopower (SMB) system designed for a parallel connection to the local utility grid and capable of continuous operation. This project will support the goal of a commercially viable small modular biopower system.

A SMB system will be designed and developed and tested in a two-phase program. The first phase involves a one-year R&D program to design, fabricate, and factory test a 50-kW system. During second phase, this new first of its kind unit will be grid-connected, and field demonstrated in California for two years.

The SMB system shall be designed to meet or exceed The California Air Resources Board (CARB) emission standards, including nitrogen oxides, volatile organic compounds, and particulate matter, for a combined heat and power distributed generation system. The engine/generator set will be capable of operating 24 hours per day, 6 days per week.

This project supports the Public Interest Energy Research (PIER) program objectives of improving cost competitiveness of the biomass energy conversion technologies and reducing environmental risks and cost of electricity.

INTRODUCTION

The demand for electricity in California is growing faster than the generation 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 biomass residue that contributes to dangerous fire conditions. Biomass fueled, distributed 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 utilizing municipal solid waste instead of storing it in scarce landfills.

The recent, successful, California Energy Commission co-funded small modular biopower (SMB) technology demonstration project at Hoopa, California was a first step towards introducing SMB to the State of California. The primary goal of the project was to demonstrate technical and operational capability of a prototype SMB system. Secondary goals included determining the most appropriate power range for economic viability, and defining a path to successful commercialization of the product.

During 2002, the Hoopa Valley Indian Tribe operated a SMB system rated at 12.5-kW to provide power and heat to a greenhouse, which was used to support their sustainable forestry business at the Tsemeta Forest Regeneration Complex at Hoopa, California. The project successfully demonstrated that a prototype SMB system could use waste forest slash and thinnings to provide utility grade power to the complex. The project also provided heat to properly maintain seedling bed temperature. The SMB system was successfully connected to the PG&E grid.

The first prototype SMB system successfully met project objectives. However, further development of the prototype technology and extended on-site testing is needed to meet the demands of the market for distributed generation systems in California.

PROJECT GOALS

A larger new SMB project, co-funded by the California Energy Commission under the PIER program, builds on the success of the previous pilot project, and continues the development and advances of the previous energy Commission supported 12.5-kW SMB development program.

This new project will develop and demonstrate a 50-kWe biopower system capable of using a variety of California's biomass residues as an alternative to fossil-fuel-fired distributed generation power systems, and will provide greater choice for California consumers. This project will meet the 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 would otherwise be open-air burned (air quality), allowed to rot (increased greenhouse gas), or deposited in landfills (high cost). This project will help in 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 is also met by responding to customer demand for a fully automatic, environmentally certified, 50-kWe biopower system designed for continuous grid-tied operation in California.

PROJECT OBJECTIVES

The overall objective of this project is to design, develop and demonstrate a 50-kW modular gasification system for grid interconnection, and combined heat and power using forest residue and other biomass wastes. This project supports the PIER program objectives of improving cost competitiveness of the biomass energy conversion technologies and reducing environmental risks and costs of California's electricity.

The specific technical objectives are:

- Provide up to 50-kW_e and 80-kW_t power to the proposed on-site loads
- Provide 3-phase power in parallel with the grid in net metering mode to displace retail sales and achieve economic advantage for a distributed power system
- Operate with no more than one operator by achieving full automation of start-up, operation, monitoring, and shutdown
- Provide 50-kWe power with a turndown range of 10 to 1 using biomass residue as the renewable fuel source
- Operate SMB continuously 24 hours for six days
- 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:
  - — For the first twelve months of operation, the system will have 60% availability

— For the second twelve months, the system will have 80% availability
— At peak power of 50 kW, the SMB system shall meet or exceed CARB's emission standards (including nitrogen oxides, volatile organic compounds, and particulate matter) for a combined heat and power distributed generation system.

The specific long-term economic/cost objectives for the 50-kW power system are as follows:

- capital cost of $1,750 per kW
- electricity cost of less than 10 cents per kWh
- heat cost less than $1.00 per therm.

The new designs for major components of the BioMax® are required to achieve a peak power rating of 50 kW with the capability of operating in parallel with the grid in net metering mode, 24 hours per day, for a continuous period of 6 days. Therefore, the components to be redesigned and upscaled include the gasifier, heat exchanger, gas filtering system, control system, feeder/dryer, genset, air/fuel management system, and grid intertie system, as described below:

- Redesign and upscale the BioMax® 12.5-kW gasifier to achieve a 50-kW peak power output on wood-gas.
- Redesign the heat exchangers to achieve necessary degree of cooling.
- Redesign the gas filtering system to achieve necessary level of gas cleaning for a 50 kW SMB.
- Redesign control system, air/fuel management, feeder/dryer, genset for a system capable of operating 24 hours/day, 6 days/week.
- Redesign grid intertie system to accommodate 50-kW peak power in accordance with the requirements of the local utility.
- Use CARB emissions standards as the design basis.

PROJECT DESIGN

The system called the BioMax® has been developed by Community Power Corporation of Littleton, Colorado with the support of the California Energy Commission, and is designed to convert woody biomass to heat and power. The system gasifier converts the biomass to producer gas, which is a mixture of fuel gases such as hydrogen, carbon monoxide and methane. The gas mixture is ignited in an internal combustion engine, and spins a generator to make utility grade electricity. Waste heat is captured in the form of hot water.

The 50-kW SMB system consists of three modules: the dryer/feeder module, gas production module, and the power production module.

Dryer/Feeder Module

Raw woodchips are conveyed from the long-term chip storage into a surge bin with a capacity of four cubic yards. The surge bin is positioned above a compact chip sorter, which can handle 200 lbs of woodchips per hour. The chips are metered into the chip sorter as required to meet system fuel demand. Drying air from the gas cooling heat exchanger will dry sorted chips in auger/dryer sections. Exhaust air will be filtered to remove particulates from the moisture-saturated air. Each auger/dryer section will function independently but works in series with other sections to meet the total drying requirements to dry fresh cut woodchips with a range of >50% moisture content to <15% moisture content, depending on wood resource and environmental conditions. The dryer sections will elevate dried wood chips into the gasifier.[1]

Gas Production Module

The gas production module components include a gasifier, gas heat exchanger, gas filter, and control system. These components are identified on the system diagram in Figure 1.

The fixed bed downdraft gasifier is a 20-inch diameter cylinder with thermocouples and pressure taps. Gasification air is injected into the gasifier. This 50-kW gasifier is designed for high char conversion through the introduction of secondary air. The producer gas includes hydrogen, carbon monoxide, and methane. The shell-and-tube heat exchanger is used to cool the producer gas stream from initial temperature of 800°C to a final temperature of about 100°C. The producer gas flows inside the tubes for easy cleaning during scheduled maintenance, while the cooling air flows through the shell side of the heat exchanger. The system has a multi-filter up flow baghouse design. A common trough joins the filters with an auger in the base to remove the char and filter fines. One of the filters is always off line for cake shedding.

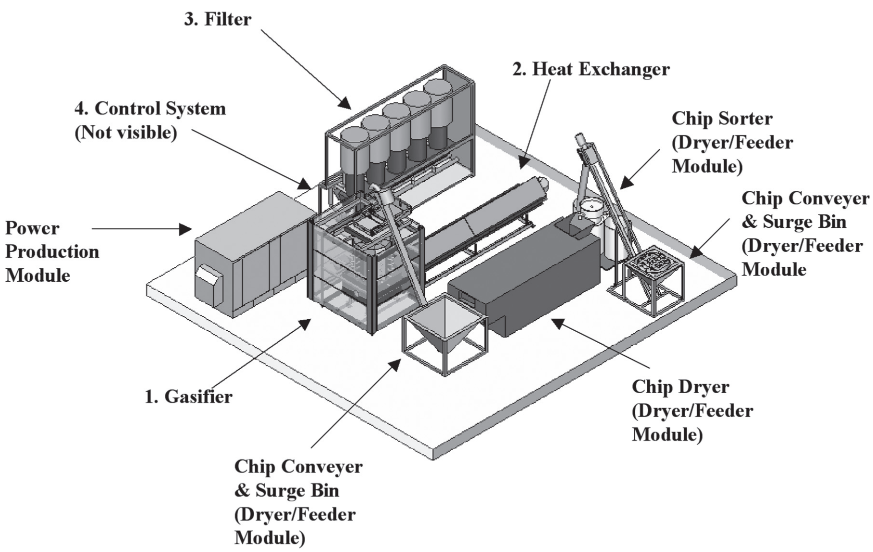

Figure 1. System Diagram

Power Production Module

For the 50-kW design, a large block GM 8.1L Vortec engine for power production is used. The Vortec is a conventional spark ignition, commercial block engine configured for operation on gaseous fuels. However, compression ratio on the Vortec engine is increased from 9:1 up to 14:1 by installing high compression pistons to boost engine efficiency. A shaft mounted 50-kW, 3-phase, generator is added to the engine platform. Various commercial engine controls are added, including ignition advance control, throttle management and output power conditioning.

An engine coolant/exhaust heat exchanger is added to the exhaust to remove heat. Additional heat from the engine exhaust will greatly increase efficiency in CHP mode. The engine-generator set will provide required combined heat and power.

The prototype components of the gas production module for BioMax50® have been designed, fabricated and tested. The system is ready for long term testing.

A test plan was developed to clearly document performance and identify problems with the SMB modules and system. The shop testing of each of the three modules and the complete 50-kW SMB system has been completed (see Figure 2). A 144-hour test run was performed to simulate the six-day continuous operation objective. System measurements, taken under loads and conditions prescribed in the test plan include gas energy content, char and ash production data, stability of gasifier, electrical efficiency, combined heat and power efficiency, effects of fuel moisture content, specific gasification rate, superficial gas velocities, power output, emissions, and other pertinent performance parameters.

ENGINE EXHAUST EMISSIONS ASSESSMENT

Emissions from Biomax 50® were measured in terms of the California regulations for Distributed Power Generation 2003 standards (CA DPG 2003). Emission measurements were made for oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), sulfur dioxide (SO_2), oxygen (O_2), and carbon dioxide (CO_2). The average measured emission rates were compared to the CA DPG 2003 values for both combined heat and power and the electrical output only. The units were pounds per megawatt-hour (lb/MWh).[2]

The emission results are summarized in Table 1.

Table 1. Emission Summary

	NO_x (lb/MWh)	CO (lb/MWh)	VOC (lb/MWh)
Weighted Test Average	0.39	4.47	0.03
CA DPG 2003 Standard (Electrical Only)	0.50	6	1
CA DPG 2003 Standard (CHP)	0.70	6	1

PROJECT SITE AND DEMONSTRATION

This 50-kW SMB system was scheduled for installation at the Siskiyou Opportunity Center, Mount Shasta. However, the technical requirement for 24-hour testing could not be met at this site. Selection of a new host site is being finalized. The project will be installed and a

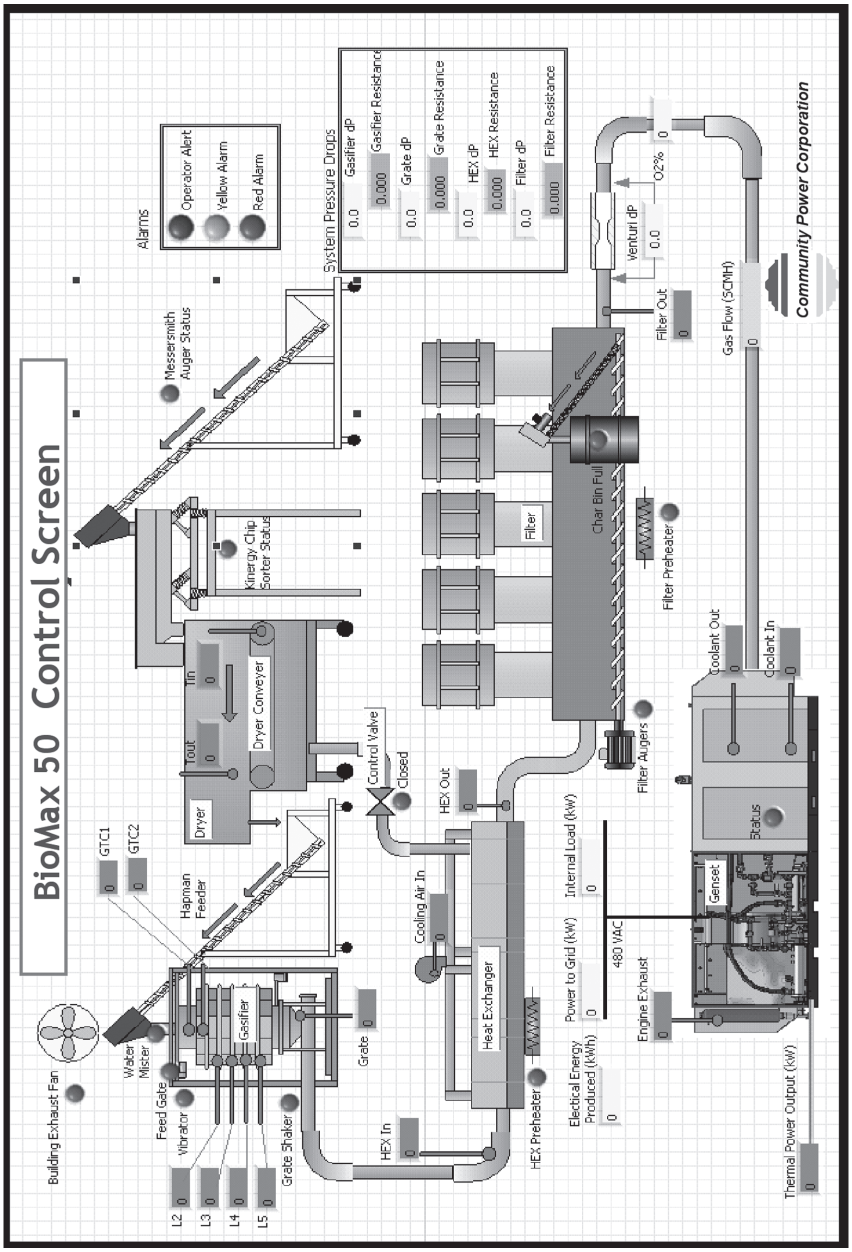

Figure 2. 50-kW SMB Modules and System

two-year demonstration will be started before the end of 2006.

Footnotes

1. Monthly and Quarterly Progress Reports.
2. Test Report, Biomax 50 Engine Exhaust Emissions Assessment, TRC, May 22, 2006.

ABOUT THE AUTHOR

Prab S. Sethi, P.E., is a Project Manager at the California Energy Commission, Sacramento. He has supervised research, development and demonstration of a large number of projects, including strategic value analysis for renewable technologies, ultra low NO_x burner systems, advanced Kalina combined cycle demonstration power plant, field testing of thermo chemical reactor/pulse combustor and fluidized bed gasifier system, advanced gas absorption heat pumps, compact vacuum insulation for freezers and refrigerators, thermal/photovoltaic concentrator/receiver, and solar double-effect absorption chiller systems. In addition, he has served as a member of the Technical Evaluation Committee to review and rank proposals submitted to the California Energy Commission for research, development and demonstration co-funding.

Previously, Mr. Prab has worked more than 15 years in supervisory and project management positions with Bechtel Corporation in Los Angeles and Phoenix, and with Sargent & Lundy Engineers in Chicago for design, project management, contract administration, licensing, construction, and system testing of power plants, petro-chemical and industrial plants. Mr. Prab has an MBA Honors degree from University of Chicago, and a Master's Degree in Mechanical Engineering from University of Wisconsin, Madison. He may be contacted at psethi@energy.state.ca.us.