Thrust Area 3: Biomass (Bio gasification)

Combined Cooling, Heat, Power, and Biofuel from Biomass and Solid Waste

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Description: The goal of this project is to provide the underlying research and demonstration of a novel technology which would enable the economic utilization of dispersed biomass and solid waste resources to produce electric power, cooling, heat, and transportation fuels. This integrated gasification and power generation system combines University of Florida advances in high-temperature gasification, hydrogen generation and separation, and advanced gas turbine systems. Their integration is expected to result in significant improvements in the cost, emissions, feedstock flexibility, and water requirements, all in a relatively compact, modular plant system. This in turn will enable much greater utilization of renewable energy supplies, helping the development of a sustainable energy supply infrastructure.

Budget: $576,000
Universities: UF
External Collaborators: Siemens Power Generation, Florida Turbine Technologies, Energy Concepts Co., Nu-Power Technologies LLC, PlanetGreenSolutions Inc., LPP Combustion, LLC.

Progress Summary

The current project focus is in three areas: development of a system architecture and thermodynamic model, development of models and system-level experiments for the PoWER gas turbine unit, and exploration of the underlying science and demonstration of the high temperature steam gasification (HiTS) subsystem. These activities are structured in such a way as to allow stepwise research and development of the overall plant in outlying years.

The system architecture includes the full integration of waste heat and water produced in the gas turbine module with the gasification subsystem. This in turn allows efficiency gains, reducing the proportion of hydrogen utilized internally, and allows zero net usage of external water resources. A thermodynamic system model has been refined during the current year, and the architecture is suitable for inclusion of more complete subsystem models as their development continues. The PoWER and HiTS subsystem models have been further developed to include more detailed physics and, for the PoWER model, transient effects.

The PoWER system has been implemented as an experimental system in previous programs, and a demonstration-level plant is nearing completion. Early stage integration of the HiTS and PoWER subsystems includes operation of a Capstone C60 gas turbine engine on syngas from the developmental gasifier. Installation of the Capstone unit, including gas handling subsystem and load bank, has been accomplished. Some base test using Methane (CH_4) has been performed, and simulated syngas mixture test would be performed during this reporting period.

For HiTS, experiment using 15kW trailer gasification system was performed to enhance syngas quality so that we could supply the syngas to the microturbine ultimately. Conventional 4-cylinder engine was used instead of microturbine to check the validity at present. The engine output data was recorded via load bank, and syngas composition was analyzed via gas chromatograph. The results show that the overall efficiency from biomass to electricity is mostly near 25%, which is close to the efficiency when the gasoline or natural gas used. In addition to that, bench-scale steam gasification system was also being tested using hydrogen and oxygen combustion to supply high temperature in oxygen free condition.

The Membrane reactor to be used alongside with the steam gasifier is designed to operate at 900°C to carry out the WGS reaction using MIEC (Mixed Ionic Electronic Conductivity) properties and in situ removal of H2 which helps in shifting the equilibrium to the right thus facilitating more H2 production and conversion of CO.

On the simulation side, equilibrium model for the gasifier was developed to predict the syngas quality with respect to reactor temperature, pressure, feedstock and steam to biomass ratio. The results were compared to other literature values, which are very close to theirs. The model outcome will be compared to the experimental result consecutively. Also, kinetic model which considers time effect will be studied for accurate prediction in the future.

2011 Annual Report

I. Experimental Facility

Trailer scale gasification system consists of a gasifier, cleaning system and an engine generator set with a load bank. The down-draft gasifier with the capacity of handling about 10 kg of biomass per batch will introduce syngas to the engine after cooling and cleaning stages. Ford DSG-423 four cylinder IC engine was operated at 1800 rpm to generate electrical power through the generator and the load was recorded at the load bank.

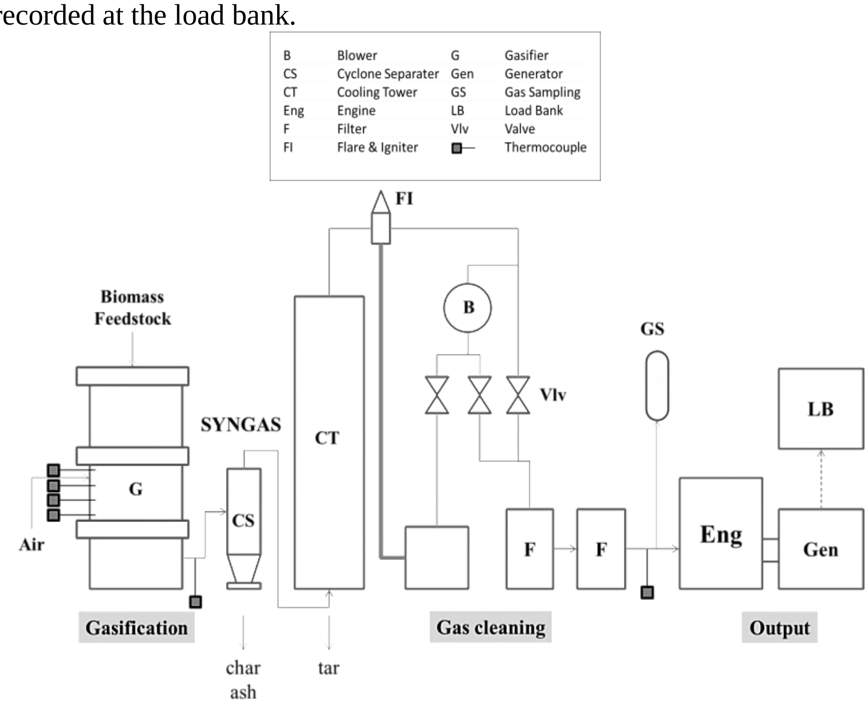

Figure 1: Schematic of experimental setup

II. Engine analysis

Energy consumption rates of the syngas could be calculated using measured syngas flow rate before it enters the engine. They were compared to the actual engine powers which were measured at the engine output using the generator and load bank to find engine efficiency. Before comparing the actual condition, stoichiometric air and fuel mass flow rates were calculated to check the equivalence ratio because if it is burned at the fuel-rich condition, excess syngas would not completely combusted. As it is found that all four syngas were combusted at fuel-lean condition, it is assumed there was enough air to burn all the syngas. Considering the efficiency using gasoline is around 30%, engine efficiencies using syngas from various feedstocks have quite reasonable values.

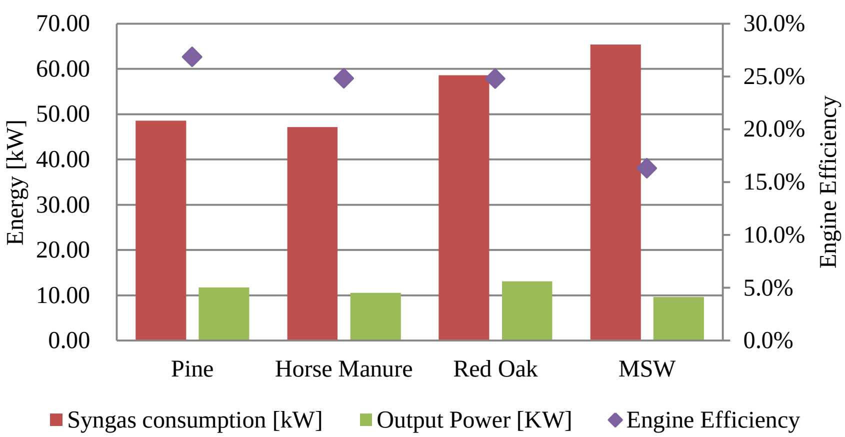

Figure 2: Engine efficiency (Energy input / Energy output)

III. Equilibrium Model

Biomass gasification is a series of chemical reactions to make synthetic gas which is useful form of energy. There are several types of biomass gasification models to predict gasification performance with given gasification condition such as temperature, pressure, feedstock, and oxidizing agent like air or steam. We have developed thermodynamic equilibrium model to predict the experiment result. Once we have feedstock chemical composition, amount of air and steam, temperature and pressure information, it is possible to determine the chemical composition and heating value of the syngas at the equilibrium state. These values could be compared to the actual experiment results.

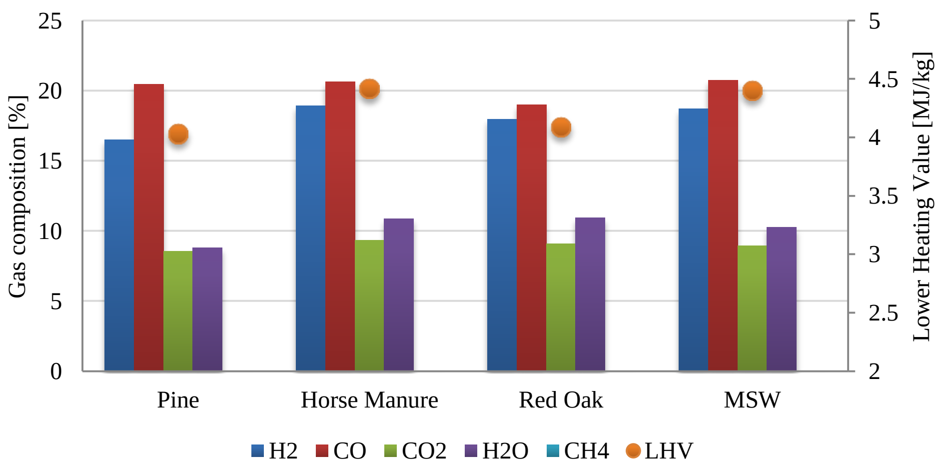

Figure 3: Equilibrium model prediction for the syngas composition and the lower heating value

IV. Steam gasification

Bench-scale high temperature gasification system was developed to check the steam gasification feasibility with municipal solid waste (MSW) and farm biomass waste. This system involves a thermal-chemical process that employs super-critical high-temperature steam to break down the feedstock to pure hydrogen-rich gaseous bio-fuels. Since the gasification agent is steam, the entire process is free of air and oxygen that traditionally produces air pollution effluents from incineration. The combustion of the hydrogen provides not only the steam as a product of the combustion but also provides an extremely high temperature, oxygen free environment for gasification. In addition part of the carbon monoxide produced may undergo a water shift reaction with the steam and produce additional hydrogen. Part of the hydrogen produced by the gasification is recycled back to the torch to maintain the gasification temperatures.

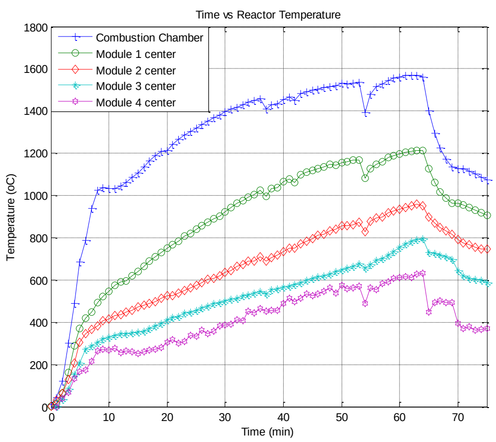

Figure 4: Reactor temperature with respect to time

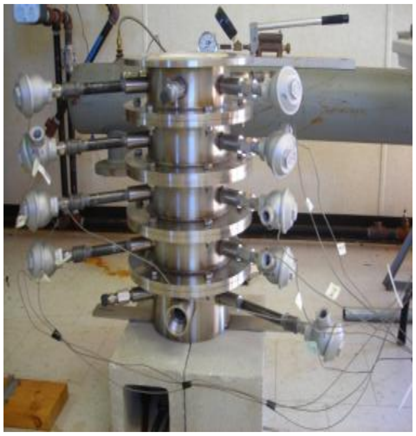

Figure 5: Bench-scale gasification system

V. Enhancing H_2 Yield Using SCZE Membranes

Syngas mixtures containing mostly H_2 and CO are typically generated at elevated temperatures via the conversion of biomass through steam gasification. The water-gas shift (WGS) reaction converts CO into CO_2 and provides additional H_2. To enhance H_2 yield further SCZE Membranes are being developed with the system in Fig 6.

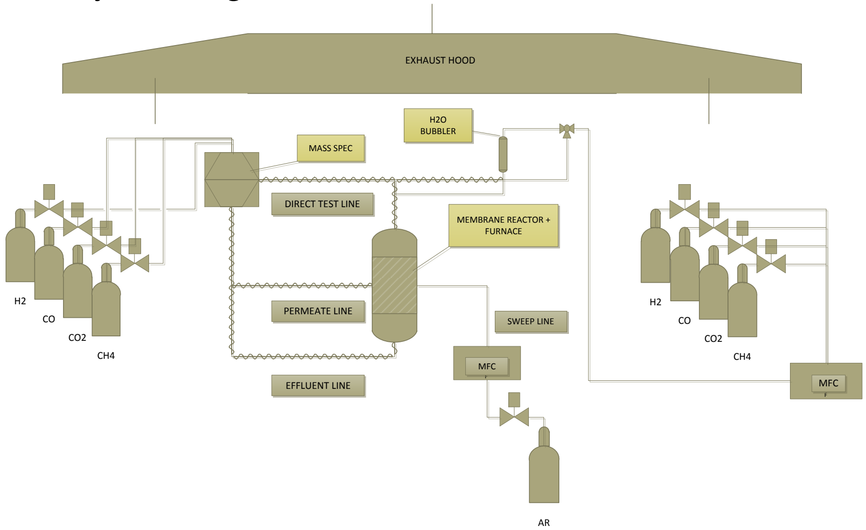

Figure 6: Experimental setup for H2 separation membrane

VI. Flameless Combustion Experiments and Modeling

The Power, Water Extraction, and Refrigeration (PoWER) system is the energy conversion subsystem to be eventually integrated with the steam gasification plant described above. One important feature of the PoWER system is that the combustion environment features high diluent concentrations, resulting in significantly reduced flame temperature. This in turn produces a flame characterized by very low soot production, highly-uniform temperature field, and low flame luminosity, so that the regime is termed flameless combustion. The low flame temperature reduces NOx without complex dry low-NOx technology; the low soot formation helps to reduce CO emissions. Overall, the primary regulated pollutants – NOx, particulates, unburned hydrocarbons, and CO – are simultaneously reduced to levels well below the current state of the art. At the same time, fuel flexibility is enhanced, making this system ideal for coupling to a biomass/MSW gasifier with a wide range of syngas compositions. This in turn makes the economics more attractive, as a single system is expected to be applicable in multiple applications with minimal or no modification.

Current activities have focused on coupling the output fuel stream of the gasifier to a modified, conventional microturbine in order to characterize the suitability of the various syngas variants for gas turbine operation. The gas turbine system is based on a Capstone C60™ microturbine (60kW) and multiple fuel sources, including methane, syngas, and a LPP Combustion, LLC gasified fuel skid, shown in Figure 7. The controls allow automatic, rapid switching between two gasified fuel paths, gasified liquid fuel (LPP) and biomass fuel. For test runs using stored syngas or other low-pressure fuel, we integrated a Copeland™ gas booster into the system. A Merlin Simplex portable load bank with 200 kW capacity is used to dissipate the electrical power as well as to control the engine output. As a parallel activity, integrated system modeling, PoWER(turbine), absorption refrigeration, and HiTS (gasifier), is continuing.

Figure 7: Micro-turbine test system

Integrated system modeling, gasification and PoWER system parts, is being simulated by using MATLAB® and C++. The system modeling architecture is shown in Figure 8. Three subsystem simulation programs are coupled to form the integrated plant model: turbocharger and microturbine system, vapor absorption refrigeration system (VARS), and HiTS.

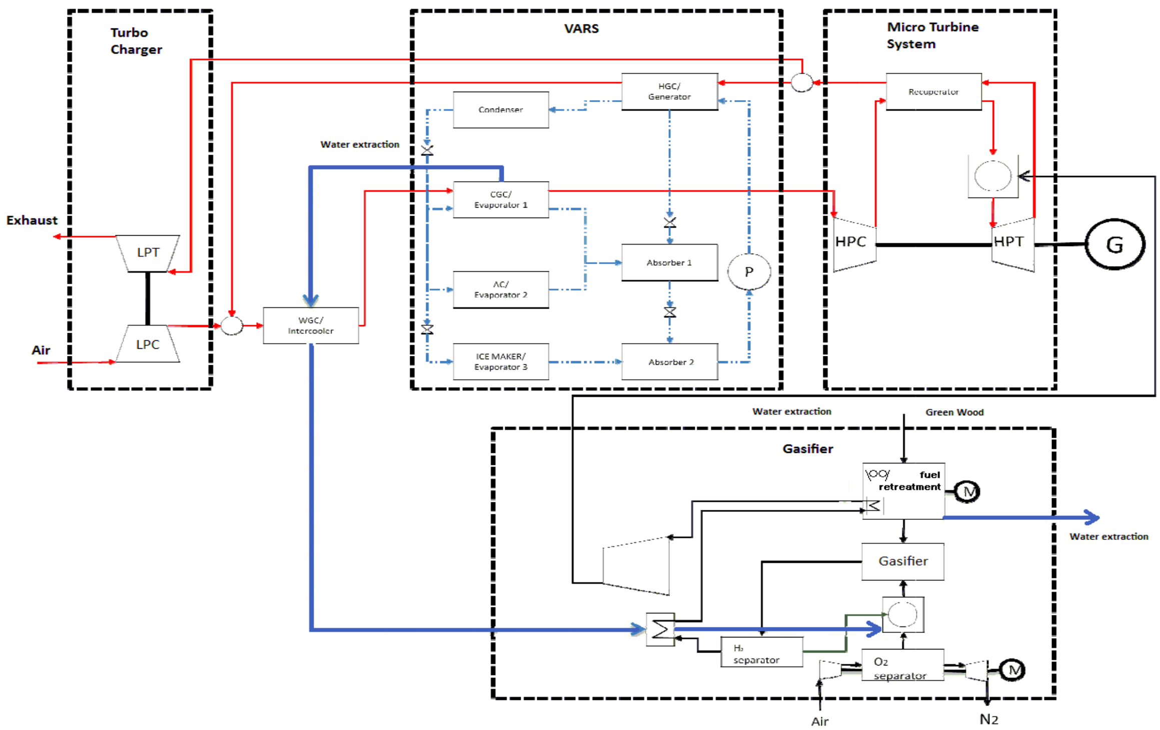

Figure 8: Integrated system modeling concept diagram

In the Gasifier simulation part, from biomass content, biomass flow rate, reactor design temperatures, component efficiencies and PoWER system water extraction are input data. Predicted temperatures, pressures and flow rates, energy flows, and syngas flow, temperature and compositions will be obtained as output data. Model chemical kinetics of the reactions in the gasifier have so far been made using an equilibrium assumption; the highly non-linear set of equations is solved by using MAPLE.

The modeling developments are steps along the path towards an integrated overall system simulation code. Such a code will allow determination of optimal flow path configuration to enable capture of waste heat and minimization of energy destruction, as well a parametric optimization for design purposes. The model is to be validated via interim experiments described above, so that the full plant design can be accomplished with confidence.