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Project Summary

Waste Combustion System Analysis

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This report presents the results of a study of biomass combustion alternatives. The objective was to evaluate the thermal performance and costs of available and developing biomass systems. The characteristics of available biomass fuels were reviewed and the performance parameters of alternate power generating systems were evaluated using a thermodynamic model. The results were compared with available information on commercially available equipment. Capital and operating costs were also estimated. The selection of an optimum biomass combustion system depends on the available fuel and the specific application. A case study of an ethanol plant was conducted to illustrate the key considerations.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Biomass is available in large quantities and offers several benefits compared to conventional fossil fuels including:

- Reduced CO_2 emissions (which mitigates global warming)
- Reduced pollutant emissions, particularly SO_2
- Reduced dependence on fossil fuels

In addition, some forms of biomass are available as waste materials at low or no cost compared to fossil fuels. This offers the potential to achieve the benefits listed above at a net cost savings.

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Biomass Fuels

Biomass fuels include waste materials from agricultural operations, urban and industrial wastes, and materials grown specifically for their fuel value. These fuels consist of three major components: dry cellulose, ash, and moisture. Dry cellulose, the combustible portion of the material, is essentially the same for all types of biomass. It can be represented by the chemical formula $CH_{1.44}O_{0.68}$ with a higher heating value of 8,555 Btu/lb* (standard deviation of 4.4% for 50 samples).

The water and ash contents of biomass can vary greatly, and these parameters can impact the design and operation

* 1 Btu/lb = 2.324 kJ/kg

of the combustion system. High moisture content fuels may require auxiliary fuel for flame stabilization. The mineral matter in the biomass can cause ash deposition problems and corrosion of turbine blades in gas turbine applications.

The pollution emission potential for biomass fuels varies. In general, biomass contains low sulfur levels so that the SO_2 emission potential is low compared to most fossil fuels. The average SO_2 emission potential for 50 fuels was 0.55 lb/10^6 Btu.* The NO_x emission potential varies substantially. While the low heating value of biomass minimizes thermal NO_x, some biomass fuels contain substantial amounts of bound nitrogen. A substantial fraction of that bound nitrogen can be converted to NO_x, particularly if the fuel is gasified and fired in a gas turbine combustor without heat removal (which is the preferred approach based on thermodynamics). The highest fuel nitrogen content for the fuels evaluated in this study was 14.34 lb/10^6 Btu. If conversion of this nitrogen to NO_x was limited to 10%, NO_x emissions would still be 1.4 lb/10^6 Btu.

Biomass Combustion Systems

The two major methods of using biomass for power production are direct firing in a boiler to produce steam for a Rankine cycle and using it in a Brayton cycle (gas turbine) with or without heat recovery from the turbine exhaust. The gas turbine configuration has many alternate arrangements such as integrated gasification and addition of a steam bottoming cycle. The thermodynamic performance of several cycles was evaluated over a range of design parameters and with alternate biomass fuel characteristics. The performance achievable by currently available technology, along with typical costs, is summarized in Table 1.

Biomass fuel characteristics affect these cycles differently. For boiler combustion systems, fuel moisture is a thermodynamic detriment. The latent heat of the fuel moisture is not recovered, resulting in a direct reduction in boiler efficiency. However, in gas turbine systems, the fuel moisture can actually increase thermodynamic efficiency since the water is effectively processed through a Rankine cycle. This benefit is only achieved if the moisture is vaporized in the combustion system at pressure without heat removal. Direct firing pulverized biomass in a gas turbine combustion burner is one way to achieve this. Another way is to gasify the biomass under pressure, remove particulates and alkali in a hot cleanup system and then fire the clean gas in the gas turbine combustor. At present, this approach to improving performance is limited by two factors: (1) the moisture content of the biomass must be less than about 20% for satisfactory gasifier operation and to produce a combustible gas with sufficient heating value for gas turbine combustor operation, and (2) a high temperature cleanup system has not been developed.

The STIG cycle involves direct injection of steam generated in a heat recovery steam generator. This improves efficiency in a manner analogous to the moisture content of the fuel. Taken to the limit of maximum steam injection, the STIG cycle offers substantial efficiency improvement. However, current aero-derivative gas turbines cannot handle the large turbine mass flows which result. This limits the STIG cycle to moderate steam injection rates.

Ethanol Plant Case Study

Ethanol production uses sugarcane as a feedstock and produces bagasse as a waste material. Substantial electrical power and heat are required to operate the plant. A conventional approach would involve electrical power from a utility (generated by firing a fossil fuel) and heat generated on site by fossil fuel combustion in a boiler. The potential for combustion of the bagasse to supplant the electrical power and/or the heat requirements was evaluated. In the lost optimized case, net CO_2 reductions of 50,000 lb/hr* were achieved. In addition, each case evaluated exhibited a simple pay back of less than 2.5 years.

Recommendations

The gas-turbine-based systems offer the greatest potential for efficient use of biomass. Among these, systems which fire the biomass under pressure are attractive since the fuel moisture content is a benefit. Development of the following should fully exploit this concept:

1. A gasifier capable of processing high moisture biomass
2. A combustor capable of firing low-heating-value gas without auxiliary fuel

The thermodynamic performance of the STIG cycle can be improved by injecting greater amounts of water. However, the water injection rate is limited by the gas turbine design. It may be possible to modify the gas turbine design to handle increased water injection.

NO_x control is a key issue, particularly for biomass fuels with high nitrogen content. Combustion modification has the potential to reduce No_x emissions without large cost or performance penalties. It may apply to gas-turbine-based systems with integrated gasifiers.

* 1 lb/10^6 Btu = 435 ng/J

* 1 lb/hr = 0.0454 kg/hr

Table 1. Performance of Current Technology

System	Heat Rate, Btu/k Whr [a]	Cost, $/kW
Simple Cycle Gas Turbine Pressurized Gasification Hot-Gas Cleanup	10,092	1,415
Simple Cycle Gas Turbine Pressurized Gasification Cold-Gas Cleanup	11,910	1,320
Combined Cycle Atmospheric Gasification Cold-Gas Cleanup	11,200	1,962
Combined Cycle Pressurized Gasification Cold-Gas Cleanup	8,944	1,552
STIG [b] Cycle Pressurized Gasification Cold-Gas Cleanup	9,667	1,457
STIG Cycle Atmospheric Gasification Cold-Gas Cleanup	12,350	1,246
Combined Cycle + Process Steam Pressurized Gasification Hot-Gas Cleanup	10,100	2,237
Combined Cycle + Process Steam Pressurized Gasification Cold-Gas Cleanup	11,918	2,086
Stoker Boiler 30 MW	11,046	2,200

[a] 1 Btu/kWhr = 1054 J/k Whr
[b] STIG = steam injected gas turbine cycle

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The complete report, entitled "Waste Combustion System Analysis," (Order No. PB92-125418/AS; Cost: $26.00, subject to change) will be available only from:
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