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Techno-economic analysis of using corn stover to supply heat and power to a corn ethanol plant – Part 2: Cost of heat and power generation systems

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ABSTRACT

This paper presents a techno-economic analysis of corn stover fired process heating (PH) and the combined heat and power (CHP) generation systems for a typical corn ethanol plant (ethanol production capacity of 170 dam^3). Discounted cash flow method was used to estimate both the capital and operating costs of each system and compared with the existing natural gas fired heating system. Environmental impact assessment of using corn stover, coal and natural gas in the heat and/or power generation systems was also evaluated. Coal fired process heating (PH) system had the lowest annual operating cost due to the low fuel cost, but had the highest environmental and human toxicity impacts. The proposed combined heat and power (CHP) generation system required about 137 Gg of corn stover to generate 9.5 MW of electricity and 52.3 MW of process heat with an overall CHP efficiency of 83.3%. Stover fired CHP system would generate an annual savings of 3.6 M$ with an payback period of 6 y. Economics of the coal fired CHP system was very attractive compared to the stover fired CHP system due to lower fuel cost. But the greenhouse gas emissions per Mg of fuel for the coal fired CHP system was 32 times higher than that of stover fired CHP system. Corn stover fired heat and power generation system for a corn ethanol plant can improve the net energy balance and add environmental benefits to the corn to ethanol biorefinery.

1. Introduction

A typical corn ethanol plant (dry milling process) with 170 dam^3 of ethanol production capacity requires 5.6 MW of power and 52.3 MW of process heat annually [1]. The demand for heat to power ratio to the ethanol plant is about 9.4. At present, almost all of the ethanol producers use natural gas as a primary fuel to produce process heat and the electricity comes from power grids. Fluctuations in natural gas and electricity prices may impede the economics of corn ethanol production. Use of coal as a fuel to produce process heat may be economical, but coal has a negative impact on public acceptance of ethanol due to high environmental emissions [2,3]. Alternatively, biomass (corn stover) can supply process heat and/or power for the corn ethanol plant with minimal environmental impacts. Co-firing of biomass in the coal

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burner is also one of the options to promote biomass use and to mitigate environmental emissions [4]. Development of biomass based heat and/or power generation system has many advantages apart from reducing fossil fuel load during the life cycle of corn ethanol production. Biomass combustion technology is well developed and can operate at relatively high thermal efficiency.

Combined heat and power (CHP) or cogeneration systems produce both heat and power simultaneously from the same primary source of fuel. There are many kinds of CHP systems available for both heat and power production in the market [5]. Detailed reviews of different CHP technologies available in the market are reported in EDUCOGEN [6] and ONSITE SYCOM [7]. Table 1 shows the performance characteristics of different CHP technologies. Overall thermal efficiency of the CHP system varies from 70 to 80% compared to a power plant thermal efficiency of about 35%. Wahlund [8] reported a detailed overview of fourteen cogeneration plants in Sweden. The electrical capacity varies from 2 MW to 39 MW with the electrical efficiency of 20–30% and the systems configuration includes steam turbine with different combustion boilers (circulating fluidized bed, bubbling fluidized bed, grate-fired type). Environmental Protection Agency (EPA) promotes the use of combined heat and power (CHP) generation system for corn ethanol producers in the US, mainly because of increased fuel efficiency, additional cost savings from onsite production of heat and power and alternative fuels and reduced greenhouse gas emissions [9]. Steam turbine based CHP system has several advantages over other technologies especially for the corn ethanol plant. Fuel flexibility, plant availability throughout the year and high heat to power ratio of 3–10 kW kW^{-1} for the steam turbine based CHP system looks a very attractive option to the corn ethanol plant [6,9,10].

Morey et al. [11] proposed the use of DDG or corn stover for heat and electricity generation for the ethanol plants and found that there was a significant annual energy cost savings for the 150 dam^3 ethanol plant. However, there is a lack of information on the economic assessments of the steam turbine based CHP system using corn stover for the corn ethanol plant. Environmental emission of such a system is also essential to compare different technological options and to evaluate the environmental impacts. The main objectives of this study were to conduct a detailed techno-economic analysis of corn stover fired thermal systems to supply heat and/or power for a typical corn ethanol plant and to compare with coal alone and co-firing options. The paper also presented a cursory analysis of the environmental impact of biomass compared to that of natural gas and coal for an ethanol plant.

2. Methodology

Techno-economic assessment of supplying heat and/or power to the corn ethanol plant was conducted using corn stover as a primary fuel. We proposed two types of thermal systems to the corn ethanol plant: 1) process heat (PH) generation system and 2) combined heat and power (CHP) generation system. The fuel for these two systems can be biomass, coal or a combination of both. In the first system, the total heat demand for the plant is generated using biomass or coal fired thermal system and the electricity is supplied from power grid. The CHP system supplies both heat and power onsite for the ethanol plant. Techno-economic analysis of each thermal system was performed using RETScreen® International, a clean energy project analysis software tool developed by Natural Resources Canada [12]. RETScreen® International, a decision-support and capacity building tool that can be used to evaluate the energy production, life cycle costs and greenhouse gas emission reductions for various energy technologies. The software has the ability to choose user defined fuel options, power and heat generation systems and different operating conditions.

2.1. *Process heat (PH) generation system*

A biomass fired steam boiler system (Fig. 1) was proposed to replace the natural gas fired boiler system in the corn ethanol plant. The heating plant supplies the process heat demand of 52.3 MW constantly throughout the year (24/7). The power demand for the plant is supplied through the electrical grid. RETScreen® [12] has number of biomass boiler manufactures who can custom supply biomass boilers based on the required

Table 1 – Typical performance characteristics of different CHP technologies [6,9].

Parameters	Reciprocating engines		Steam turbine	Gas turbine
	Compression ignition	Spark ignition		
Typical capacity (MW)[a]	0.03–5	0.05–5	0.2–800	1–500
Electrical efficiency (%)[b]	27–45	22–40	15–38	22–36
Overall efficiency (%)[c]	70–80	70–80	80	70–75
Heat to power ratio	1–2	1–2	2–10	0.5–2
Fuel type	Diesel, fuel oil	Natural gas, biogas, propane	Any fuel	Natural gas, propane, oil
Unit availability (%)	90–95	92–97	100	90–98

a Capacity represents the total electrical output (MW) of the CHP system.
b Electrical Efficiency is a measure of amount of boiler fuel converted into electricity on the HHV of the fuel.
c Overall Efficiency is a ratio of total electricity and heat generated over the total fuel consumed in the boiler based on the HHV of the fuel.