Final Report

Xcel Renewable Development Fund Project (RD-56)

Generating Electricity with Biomass Fuels at Ethanol Plants

Chapter/Task 17 – Special Scenarios

This chapter outlines several special scenarios, which all focus on using the syrup since alternatives involving the syrup had the most favorable rates of return in the economic analysis (Chapter/Task 16). The scenarios include syrup and corn cobs in place of corn stover, partial use of biomass (syrup) along with natural gas, and a preliminary evaluation of electricity generation with integrated gasification combined cycle technology using syrup and corn cobs as fuel. It was primarily prepared by project participants at the University of Minnesota.

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RD56: Generating Electricity With Biomass Fuels at Ethanol Plants
Report for Task 17, "Special Scenarios"

Background of the Task

This chapter outlines several special scenarios, all of which focus on using the syrup since alternatives involving the syrup had the most favorable rates of return in the economic analysis (Chapter/Task 16). The scenarios include syrup with corn cobs in place of corn stover, partial use of biomass (syrup) along with natural gas, and a preliminary evaluation of electricity generation with integrated gasification combined cycle technology using syrup and corn cobs as fuel.

Corn cobs are part of the corn residue, but most cobs would not be captured in conventional corn stover harvest. They make up approximately 18% of the total biomass that could be available in the corn stover. They can be collected in the process of harvesting the corn, rather than in a subsequent step such as with the corn stover. When combined with the syrup, there is enough energy in the cobs to provide process heat and electricity to process the ethanol made from the corresponding corn grain produced on an acre of land. Corn cobs have physical characteristics that might allow them to be utilized without as much processing, for example densification, as corn stover. They also have lower ash content than corn stover.

Another special scenario is to use a combination of syrup and natural gas to provide process heat at ethanol plants. One plant, Corn Plus in Winnebago, MN, is already doing this. Although this alternative does not reduce fossil energy use as much as the full biomass options or provide for renewable electricity generation, it may be a bridge strategy for some plants because is takes advantage of the biomass source at the plant without having to supplement it with a biomass source external to the plant, for example corn stover or corn cobs. In addition, the quality and value of the DDG, resulting from removal of the syrup, may be enhanced.

Integrated gasification combined cycle (IGCC) systems produce greater levels of electricity for the same amount of biomass fuel used and process heat supplied at ethanol plants. The greater levels of electricity production with this technology will provide increased revenue for ethanol plants and may justify a larger low-carbon fuel premium for the ethanol produced.

Syrup-Corn Cobs

We modeled the technical performance of the syrup-corn cob alternative. Since the cobs are quite similar to the corn stover in terms of composition, the performance was approximately the same. Because of the lower ash content slightly less fuel was used and ash produced. Since cobs and stover are so similar, there was no change in the capital or operating cost assumptions. Thus, we did not perform a separate economic analysis. The results for the syrup-corn stover case should apply with the possibility that the delivered cost of corn cobs may be less than corn stover leading to somewhat higher rates of return. The effect of biomass fuel (stover or cobs) costs on rates of return are illustrated in the sensitivity results in Chapter/Task 16.

Syrup-Natural Gas

We modeled the technical performance of the syrup-natural gas alternative. We modeled only the process heat and combined heat and power cases, since all of the available syrup was consumed in those cases. We did not model a syrup-natural gas scenario producing CHP and sales of electricity to the grid because generating more electricity to send to the grid would require supplying more natural gas without using any additional biomass. Thus the extra electricity generated would not have any renewable component.

The fluidized bed combustion system is basically unchanged with the syrup-natural gas alternative, since the natural gas needs to be added either in the bed or prior to the bed in order to sustain combustion of the syrup, which is over 65% moisture. Most of the fuel nitrogen, sulfur, and chlorine from the syrup-corn stover or syrup-corn cob cases is in the syrup so substituting natural gas for the stover or cob portion does not significantly reduce the need for emissions control technology. There was no change in the steam tube dryer that was used.

The primary changes in capital costs involved the fuel handling equipment. There was only one type of biomass fuel (syrup) used, compared to the two types in the syrup-stover or syrup-cobs cases. The reduction in fuel handling equipment costs reduced the overall capital cost estimates for the 50 million gallon per year plants to $137,263,000 from $139,998,000 for process heat and to $154,473,000 from $157,535,000 for combined heat and power. The overall capital cost estimates for the 100 million gallon per year plants were reduced to $222,984,000 from $227,427,000 for process heat and to $250,942,000 from $255,916,000 for combined heat and power.

Integrated Gasification Combined Cycle

A special case of IGCC technology was evaluated on a basic level because it has the capability to produce increased amounts of renewable electricity with the co-product fuel that is available. A simplified diagram of the power generation system for this case is shown in Figure 1.

In this arrangement biomass fuel is gasified and combusted in a twin fluidized bed process to produce synthesis gas. The synthesis gas passes through a gas cooler which generates some process steam. The gas is then cleaned, compressed and combusted in a gas turbine. The hot combustion products from the gas turbine and the fluidized bed combustor are used to provide heat to the steam generator. The assumptions made for steam generation are the same as in all previous cases.

Superheated steam at 482° C (900° F) and 6,300 kPa (900 psig) exits the steam generator and is piped to a backpressure steam turbine losing 5° C (9° F) along the way. The turbine specifications are the same as those used in the CHP cases. After desuperheating, process steam is then supplied at 446 kPa (50 psig) to the ethanol process, the ethanol co-product dryer, and the gasifier fuel dryer. The gasifer fuel is a mixture of syrup and corn cobs. Because the gasification process requires fuel moisture contents less than about 20%, the syrup and corn cobs are mixed and then dried before gasification.

The model for IGCC is preliminary. It includes heat and power estimates and fuel use, but does not yet model emissions control and gas clean up technology. Since we did not model all elements of the system, we did not develop capital cost estimates or perform an economic analysis.

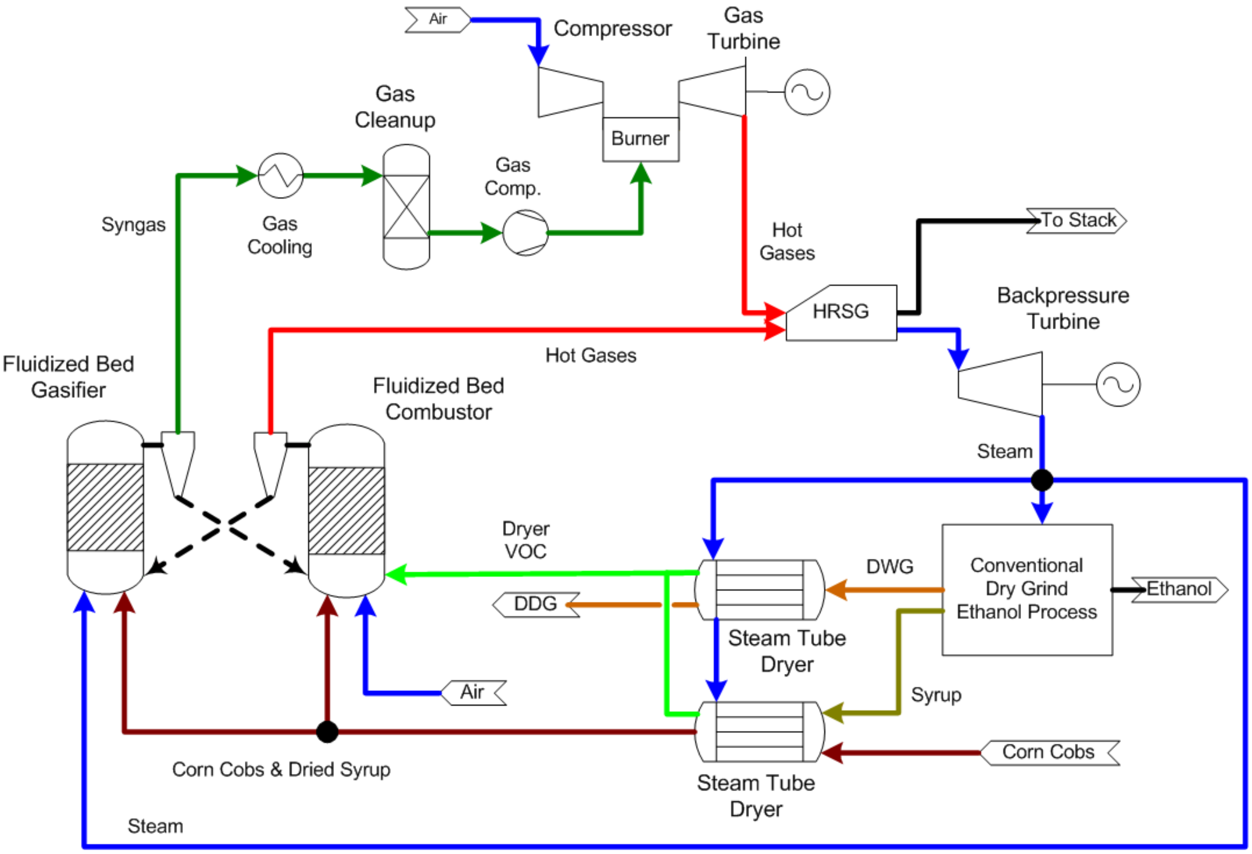

Figure 1. Integrated gasification combined cycle diagram

Results for the Special Scenarios

Table 1 presents some important performance results for the three special scenarios. Results for syrup and corn cob combustion are very similar to the results for syrup and corn stover combustion presented in Chapter/Task 16. The performance results for syrup and natural gas combustion are similar to the syrup and corn cob combustion results for the first two cases. The third case was not simulated because all of the required additional fuel to generate electricity for the grid would be natural gas. The syrup and corn stover integrated gasification combined cycle (IGCC) modeling results show the potential for increased generation and generation efficiency for this technology. This technology bundle appears to warrant further analysis.

Emissions after application of control technology for NO_x, SO_2, and HCL are shown in Figures 1 through 3, respectively. Syrup and corn cobs combustion and syrup and natural gas combustion are compared to the three primary fuels of Chapter/Task 16 (corn stover combustion, syrup and corn stover combustion, and DDGS gasification. Emissions for all three cases involving combustion of syrup with another fuel, either corn stover, corn cobs or natural gas, were similar. Most of the fuel nitrogen, sulfur, and chlorine is in the syrup component; therefore emission results are similar for all three cases.

Table 1. System performance results for a 190 million liters (50 million gallons) per year dry-grind ethanol plant.[1]

	Biomass Fuel Use [2] (Wet Basis) ton/day	Fuel Energy Input Rate $\mathrm{MW_{th}}$	Power Generated (Gross) $\mathrm{MW_e}$	Power To Grid (Net)[3] $\mathrm{MW_e}$	Power Generation Efficiency	System Thermal Efficiency[4]
Syrup & Corn Cob Combustion						
Process Heat Only	711	64	0	-5.7	-	62.4%
CHP	777	75	8.8	2.8	11.7%	64.5%
CHP & Elec. to Grid	951	104	16.0	9.6	15.4%	53.0%
Syrup & Natural Gas Combustion						
Process Heat Only	561	63	0	-5.8	-	62.8%
CHP	561	74	8.8	2.7	11.8%	64.9%
Syrup & Corn Cob Integrated Gasification Combined Cycle (IGCC)						
CHP & Elec. to Grid	984	109	30.3	21.6	27.7%	71.0%

[1] All energy and power values in this table are based on the fuel Higher Heating Value (HHV).

[2] Moisture contents: Corn cobs – 13%; Syrup – 66.8%; Syrup and corn cob combustion – 55%, 52%, 45% for levels 1, 2, 3, respectively; Syrup and corn cob IGCC – 44%.

[3] Negative values refer to power purchased from the grid by the ethanol facility.

[4] Efficiency of converting fuel energy into other useful forms of energy (process heat and electricity).

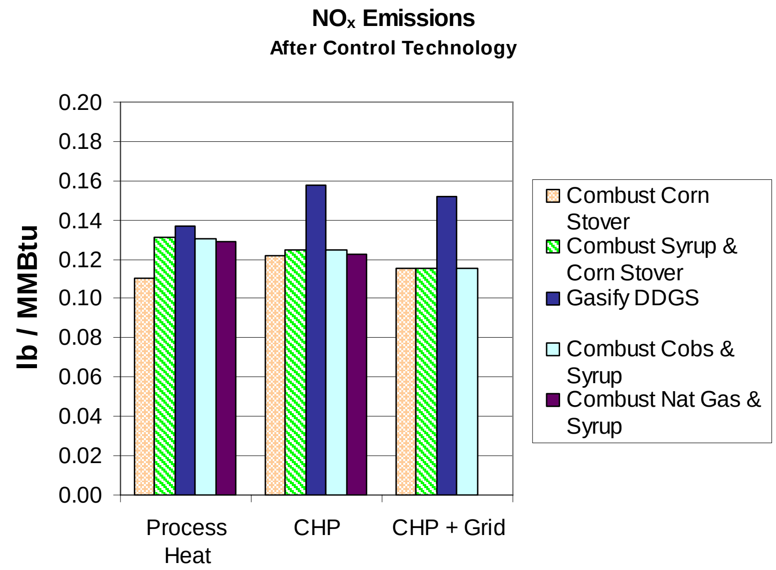

Figure 1. $\mathrm{NO_x}$ emissions after control technology.

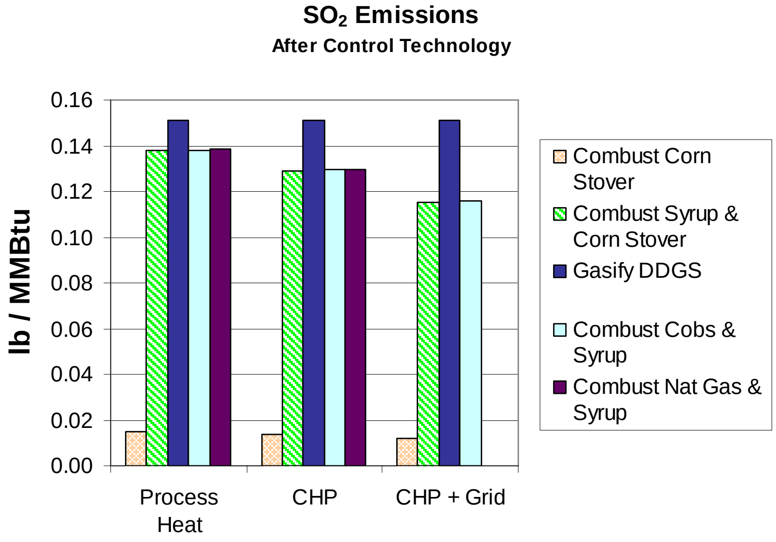

Figure 2. SO_2 emissions after control technology.

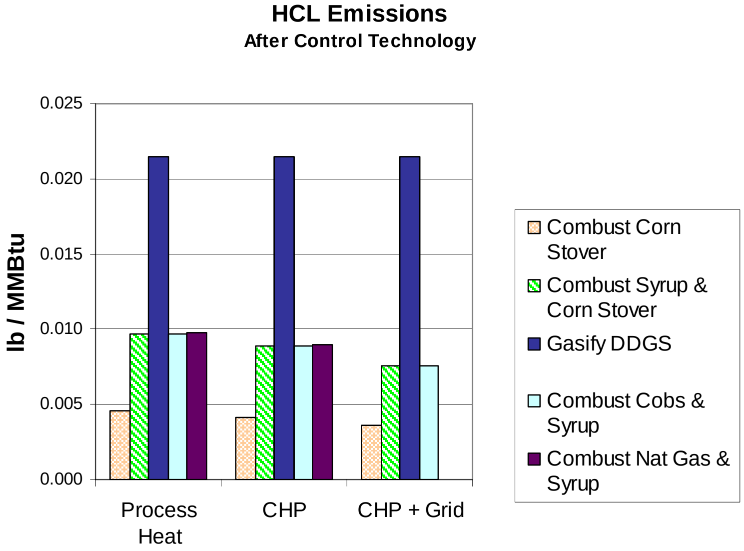

Figure 3. HCL emissions after control technology.

The renewable energy ratio for the three special scenarios and the three primary fuels are compared in Figure 4. Syrup and corn cob combustion has the same renewable energy ratio as syrup and corn cob combustion at all levels. The renewable energy ratio for syrup and natural gas is less than the case with syrup and either corn stover or corn cobs because more fossil fuel is being used. However, the renewable energy ratio is higher than the conventional case. The renewable energy ratio for syrup and corn cobs IGCC is greater than 5, reflecting the greater levels of renewable electricity being produced.

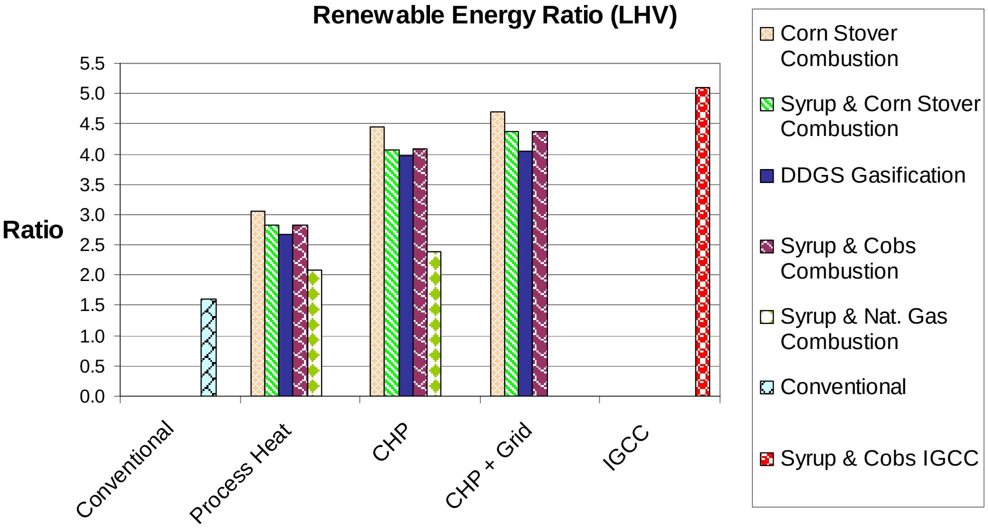

Figure 4. Renewable energy ratio (LHV).

Economic Analysis of Syrup and Natural Gas Combustion

Baseline rates of return for syrup and natural gas are compared to the other alternatives for 50-million and 100-million gallon per year capacities in Figures 5 and 6, respectively. At baseline conditions rates of return are lower for the syrup and natural gas alternatives than for the corresponding syrup and stover alternatives as well as for the conventional plants for both capacities. Because most of the increased capital costs to combust biomass are incurred for the syrup-natural gas alternatives, but the natural gas savings are not as great, this alternative has lower rates of return than both the conventional natural gas system and the syrup-stover alternatives.

Sensitivity results for rates of return for 50 million gallon per year plants are shown in Table 2. In all of the cases evaluated the rates of return for syrup and natural gas were lower than the corresponding syrup and corn stover alternative. It appears that the only scenario where syrup and natural gas might provide a higher rate of return than both the conventional natural gas system and the syrup-stover system would be for process heat under conditions of fairly high natural gas (e.g. $13/decatherm) and very high stover prices (e.g. on the order of $240/ton). This might correspond to a case where stover was not available for some reason. Thus, based on our analysis it appears that the best choice when using syrup would be to design for a system that uses biomass (corn stover or corn cobs) rather than natural gas as the other fuel in the mix.

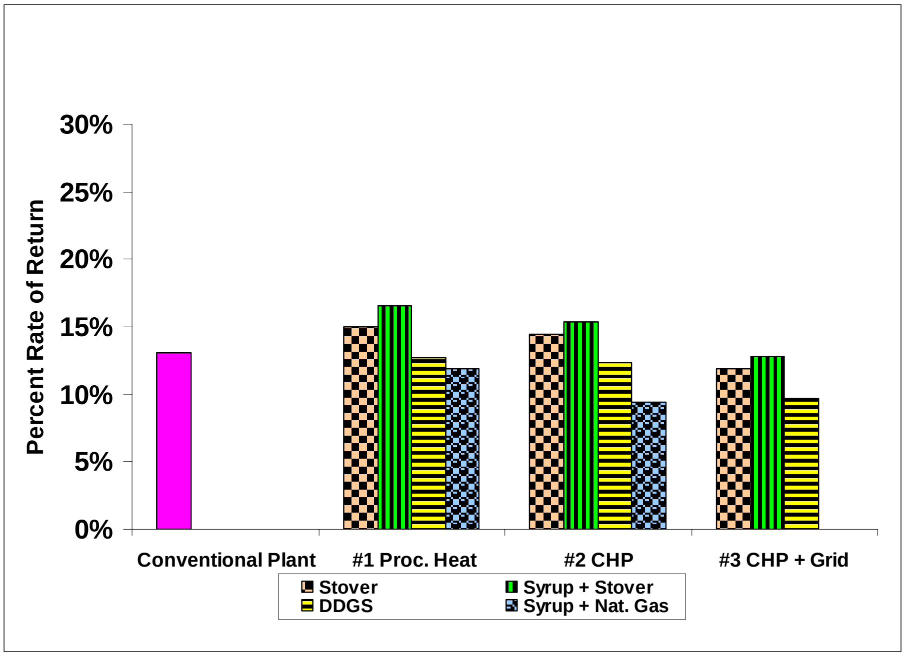

Figure 5. Baseline rates of return for 50 million gallon per year capacities.

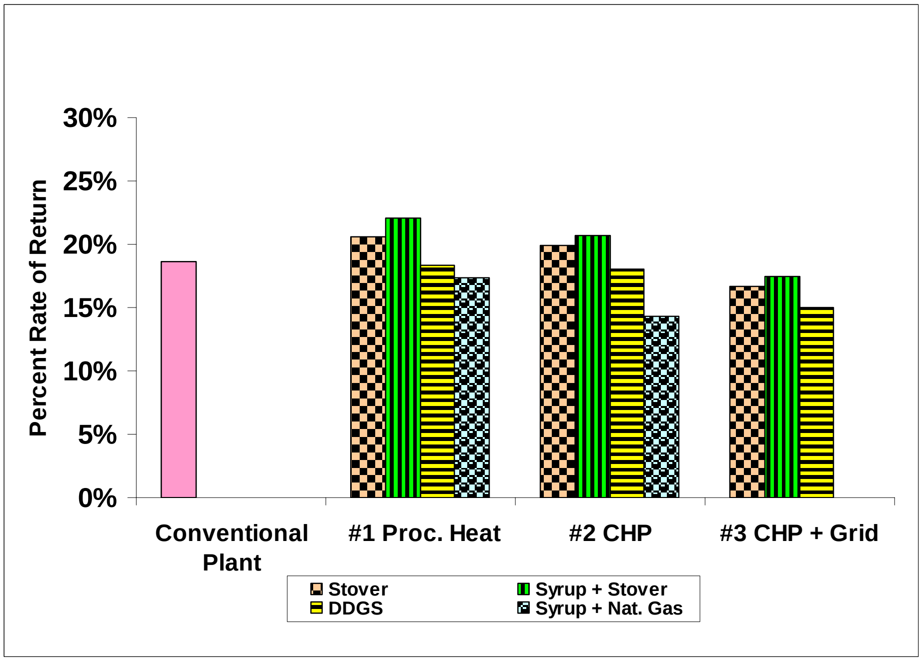

Figure 6. Baseline rates of return for 100 million gallon per year capacities.

Table 2. Sensitivity of rates of return on investment to changes in key economic parameters for 50 million gallon per year capacties.

Economic Parameters	**Convent. Plant Nat. gas Electric**	**Process Heat**		**CHP**	
		Syrup & Stover	**Syrup & Nat. Gas**	**Syrup & Stover**	**Syrup & Nat. Gas**
Baseline case	13.1%	16.6%	11.9%	15.4%	9.4%
Natural gas: 10 to $13/decatherm	7.7%	16.6%	10.4%	15.4%	7.5%
Natural gas: 10 to $7/decatherm	18.4%	16.6%	13.4%	15.4%	11.4%
DDGS: $145 to $174/ton	18.1%	18.4%	14.3%	17.4%	11.5
DDGS: $145 to $116/ton	8.0%	14.2%	9.6%	13.3%	7.3%
Corn stover price: $80 to $100/ton	13.1%	15.8%	11.9%	14.4%	9.4%
Corn stover price: $80 to $60/ton	13.1%	17.3%	11.9%	16.3%	9.4%
Electricity sale price: 6¢ to 10¢/kWh	13.1%	16.6%	11.9%	15.9%	10.0%
Low carbon premium: 20¢ to 27¢/gal.	13.1%	18.9%	13.4%	17.7%	10.6%
Natural gas: $10 to $13/dekatherm DDGS: $145 to $116/ton	2.7%	14.2%	8.1%	13.3%	5.4%