

Project Title: Generating Electricity with Biomass Fuels at Ethanol Plants

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Milestone Description: Eighth three-month reporting period

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Congressional District: Minnesota fifth (UofM Sponsored Projects Administration)

Minnesota fourth (UofM Bioproducts and Biosystems Engineering)

Executive Summary

- Updated project web site www.biomassCHPethanol.umn.edu with most recent results
- Completed economic analysis
- Presented three workshop meetings on “Profitable Use of Biomass at Ethanol Plants” in Mankato, MN; Norfolk, NE; and Des Moines, IA on February 19th, 20th, and 21st, respectively.
- Prepared final project report
- Communicated about project activities; carried out project management, accounting, and reporting functions.

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Generating Electricity with Biomass Fuels at Ethanol Plants (RD-56)

Milestone 8 – Summary Chapter for Final Report

Project Leaders

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Douglas G. Tiffany, Research Fellow, Applied Economics Department
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Executive Summary

Biomass can provide electricity and process heat at dry-grind ethanol plants to both reduce costs and improve the renewable energy balance for ethanol production. Ethanol co-products such as distillers dried grains with solubles (DDGS) or the solubles portion (syrup) can potentially be used for energy. Corn stover or corn cobs are also potential biomass energy sources for ethanol plants.

We evaluated nine fuel-technology combinations that take advantage of the available biomass fuels and the higher thermal efficiencies which can be captured with combined heat and power (CHP) at ethanol plants.

Conclusions of Project

- There is enough biomass (coproducts and/or stover/cobs) to provide power and heat at ethanol plants.
- Emissions (NO_x, SO_x, and chlorine) associated with using these biomass fuels need to be addressed.
- Biomass improves the renewable energy balance, which corresponds to reduced life-cycle greenhouse gas (GHG) emissions for ethanol production, ie lowers the carbon foot print.
- Technologies are for the most part “off the shelf”, although not all have been implemented with these specific biomass fuels.
- Applications involving process heat are most likely to be economically feasible.
- Combined heat and power (CHP) applications also are likely to be economically feasible.
- A mixture of syrup and stover or cobs provides the greatest potential for economic feasibility of the fuels studied (stover, DDGS, mixture of syrup and stover or cobs).
- A low carbon foot print incentive for ethanol encourages use of biomass fuels at the plant.
- Other factors that favor biomass over conventional natural gas fired plants include: higher natural gas prices, higher corn prices, lower ethanol prices, and lower DDGS prices.
- Electric power generated with biomass at ethanol plants is renewable and firm, which means it could contribute to the base load of the electric generation system.

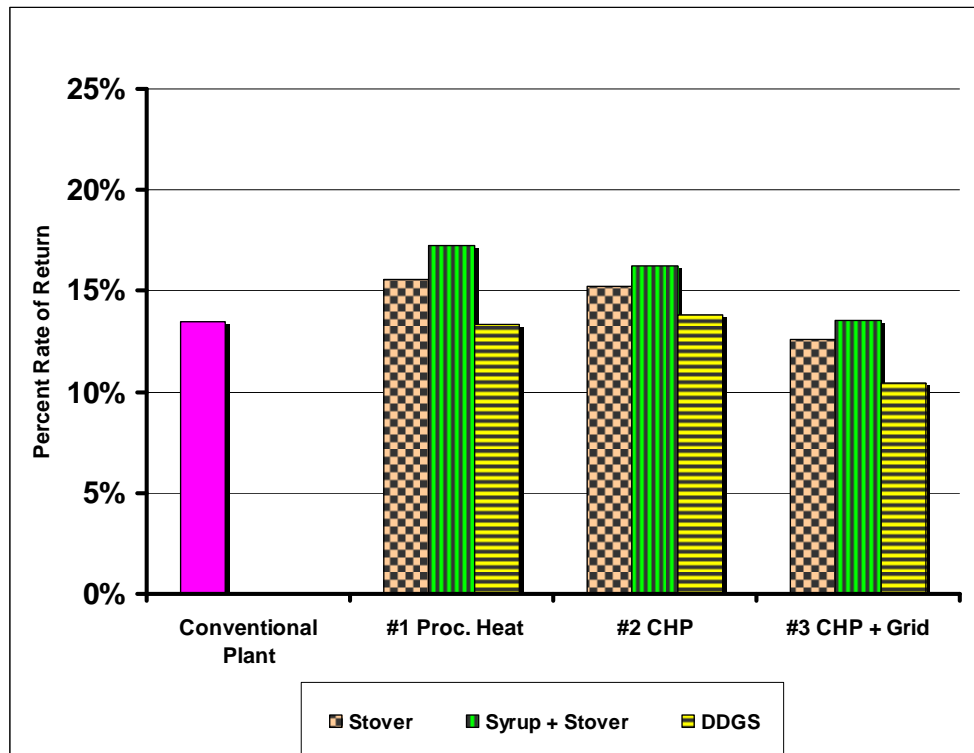
Technical and Policy Recommendations

- Incentives that pay more for low-carbon footprint ethanol, ie ethanol that has a greater green house gas (GHG) reduction potential are needed. The incentives should progressively pay more for greater life-cycle GHG reductions.
- Renewable electricity incentives are needed to make generating electricity to send to the grid economically attractive.

Benefits of Project

- We have evaluated a range of technical and economic issues related to using biomass to generate electricity and process heat at ethanol plants and made that information available to all interested parties – ethanol plants, engineering firms, electric utilities, bankers/lenders, environmental regulators, and legislators and public policy officials. The information is available at www.biomassCHPethanol.umn.edu.
- A workshop entitled “Profitable Use of Biomass at Ethanol Plants” was presented at three locations (Mankato, MN; Norfolk, NE; Des Moines, IA) in February 2008. Approximately 140 people attended and evaluations of the workshops were very strong at all locations. The response to the question “Would you recommend this to others interested in this topic?” was 100% yes for all three locations.
- We have identified systems that generate renewable electricity that potentially are economically feasible under current conditions.
- Using biomass to generate electricity in conjunction with producing biofuels (ethanol) improves the thermodynamic and economic efficiency of the overall process and results in substantial amounts of both renewable biofuel and renewable electricity.
- The biomass technologies such as combustion/gasification, combined heat and power, and handling systems for biomass materials such as corn stover that we are proposing for corn dry-grind ethanol plants also will be essential components of cellulosic ethanol plants. Thus, the results of the project help to lay some of the important ground work for generating renewable electricity in conjunction with producing the next generation of biofuels.

Rates of return for 190 million liter (50 million gallon) ethanol per year capacities for nine biomass fuel/technology combinations compared to a conventional plant. More details are presented in Chapter/Task 16 – Economic Analysis.



Overview of Project

Energy, particularly natural gas for process heat, is one of the major costs in operating an ethanol plant. Although the energy balance for producing ethanol is positive, ethanol conversion (distillation, evaporation, drying) at either dry mill or wet mill plants requires the largest amount of energy in the overall process. Under current technology for ethanol conversion, the process heat is usually supplied by natural gas and the electricity is generated with coal or natural gas. Biomass can provide electricity and process heat at dry-grind ethanol plants to both reduce costs and improve the renewable energy balance for ethanol production. Ethanol co-products such as distillers dried grains with solubles (DDGS) or the solubles portion (syrup) can potentially be used for energy. Corn stover or corn cobs are also potential biomass energy sources for ethanol plants.

We collected co-product samples at five cooperating dry-grind ethanol plants for fuel analysis. Feed streams included distillers dried grains with solubles (DDGS) – 4 plants, distillers dried grains (DDG) – 1 plant, distillers wet grains (DWG) – 5 plants, and syrup – 5 plants. We also obtained a corn stover sample for analysis. We determined moisture, ash, sulfur, chlorine, nitrogen, carbon, hydrogen, and oxygen contents of the fuels as well as heating value and ash fusion values. We used these results along with information from the literature for similar biomass fuels in our modeling and analysis.

We evaluated the following technology alternatives:

- Current technology - natural gas for process heat and electricity from coal or natural gas
- Biomass (DDGS, cornstover or combination) to provide process heat (PH) only by combustion or gasification.
- Biomass (DDGS, cornstover or combination) to provide process heat and plant electricity (CHP) - waste heat from electric generation at temperatures sufficient to produce process steam.
- Biomass (DDGS, cornstover or combination) to provide process heat, plant electricity, and electricity to grid (CHPG) - amount based on using all waste heat for process steam.

Based on our analysis of the fuel characteristics and a preliminary review of the available conversion technologies, we settled on the following nine combinations of fuel-conversion technology groupings.

We selected corn stover as one fuel choice and determined that the best alternative for this fuel is combustion in a fluidized bed. We expect to receive corn stover in a 12 to 15% moisture content range. In our analysis we assumed that the corn stover would be delivered in a densified form (briquettes or pellets) at 30 to 35 lbs/ft³. We evaluated performance for ethanol plants using process heat, CHP, and CHPG for the corn stover combustion alternative.

A combination of syrup and corn stover was selected as another fuel choice. The syrup portion of the co-product appears to be less valuable than the DDG portion and many dry-grind ethanol plants indicate it causes problems in the drying process. The syrup is approximately 65% moisture content, which is too wet to sustain combustion and it does not contain enough energy

even if dried to meet the plant needs for process heat. Adding enough corn stover to the syrup to meet the plant process energy needs brings the moisture content of the mixture to around 55%, which is low enough to sustain combustion in a fluidized bed. Additional stover is added to provide sufficient energy for the CHP and CHPG alternatives. The resulting moisture contents are approximately 50% and 45%, respectively. We evaluated performance for ethanol plants using process heat, CHP, and CHPG for the syrup-corn stover combustion alternative.

DDGS were the other fuel choice. The fuel analysis indicated relative low ash fusion temperatures for this material, so we determined that the best alternative for this fuel was gasification followed by ash separation and then combustion. The lower temperatures and a reducing rather than oxidizing environment in the gasification system provided a better option than combustion for dealing with the low ash fusion temperatures. The DDGS moisture content is 10 to 13 %. We evaluated performance for ethanol plants using process heat, CHP, and CHPG for the DDGS gasification-combustion alternative.

The analysis was performed using Aspen Plus process simulation software. An Aspen Plus model of the dry-grind ethanol process was obtained from the USDA Agricultural Research Service and was used as the basis for the energy conversion system models that followed. This model contains a feature that allows it to be scaled to different annual ethanol outputs. For the purposes of this study all cases were set to produce 50 million gallons per year of denatured ethanol.

The primary components of the process such as fermentation, distillation, and evaporation were not changed. Only those components impacted by using biomass fuel were modified. They included steam generation (biomass combustion or gasification), air emissions control, thermal oxidation, and co-product drying. Several variations of steam turbine power cycles were used for the cases involving electricity generation. Process data from several ethanol plants participating in the project were also taken into account in the modeling process. Several sensitivity analyses were performed on each simulation to ensure good performance.

Model results include fuel use, fuel energy input rate, power generated, power generation efficiency, and system thermal efficiency. Air emissions (NO_x , SO_x , chlorine) after application of control technologies also are predicted.

The Aspen Plus model estimates important material and energy flows which allowed us to specify the capacities of the required capital equipment. Using these capacities, we worked with a consulting engineering firm to specify equipment to meet these requirements. The consulting engineering firm then estimated equipment costs using data from previous projects and by soliciting bids from potential vendors for some items. Cost estimates are categorized according to new equipment and the equipment that would be replaced (avoided cost) compared to a conventional dry-grind plant. We focused on the net change in equipment cost required to construct a dry grind ethanol plant to use biomass rather than natural gas and purchased electricity as energy sources. We developed capital cost estimates for plant capacities of 50 and 100 million gallons per year.

Changes in operating costs using biomass including increased labor as well as potential ethanol price premiums as a result of low-carbon fuel standards were also included in the economic analysis.

Rates of return for each alternative were calculated and compared. Although plants using biomass have higher capital costs, they may offer increased economic resiliency to changes in some of the key operating variables. Results showed favorable rates of return on investment for biomass alternatives compared to conventional plants using natural gas and purchased electricity over a range of conditions. The mixture of corn stover and syrup provided the highest rates of return in general. Factors favoring biomass included a higher premium for low carbon footprint ethanol, higher natural gas prices, lower DDGS prices, lower ethanol prices, and higher corn prices.

A website www.biomassCHPethanol.umn.edu was established for the project. Information was posted on the website as it became available. Drafts of individual tasks/chapters were posted on the website as they became available.

Project results were presented at various meetings. A workshop entitled “Profitable Use of Biomass at Ethanol Plants” was presented at three locations (Mankato, MN; Norfolk, NE; Des Moines, IA) in February 2008. Evaluations of the workshops were very strong at all locations. The response to the question “Would you recommend this to others interested in this topic?” was 100% yes for all three locations.

Summary and Conclusions of Project

- We evaluated nine fuel-technology combinations that take advantage of the available biomass fuels and the higher thermal efficiencies which can be captured with combined heat and power (CHP) at ethanol plants.
- There is enough biomass (coproducts and/or stover/cobs) to provide power and heat at ethanol plants.
- Emissions (NO_x, SO_x, and chlorine) associated with using these biomass fuels need to be addressed.
- Biomass improves the renewable energy balance, which corresponds to reduced life-cycle greenhouse gas (GHG) emissions for ethanol production.
- Technologies are for the most part “off the shelf”, although not all have been implemented with these specific biomass fuels.
- Applications involving process heat are most likely to be economically feasible.
- Combined heat and power (CHP) applications also are likely to be feasible.
- A mixture of syrup and stover or cobs provides the greatest potential for economic feasibility of the fuels studied (stover, DDGS, mixture of syrup and stover or cobs).
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- Other factors that favor biomass over conventional natural gas fired plants include: higher natural gas prices, higher corn prices, lower ethanol prices, and lower DDGS prices.
- Electric power generated with biomass at ethanol plants is renewable and firm, which means it could contribute to the base load of the electric generation system.

Technical and Policy Recommendations

- Incentives that pay more for low-carbon footprint ethanol, ie ethanol that has a greater green house gas (GHG) reduction potential are needed. The incentives should progressively pay more for greater life-cycle GHG reductions.
- Renewable electricity incentives are needed to make generating electricity to send to the grid economically attractive.

Summary of Outreach Activities – web, workshops, presentations, and papers

The project web site is www.biomassCHPEthanol.umn.edu .

A workshop entitled “Profitable Use of Biomass at Ethanol Plants” was presented at three locations (Mankato, MN; Norfolk, NE; Des Moines, IA) in February 2008. Evaluations of the workshops were very strong at all locations. The response to the question “Would you recommend this to others interested in this topic?” was 100% yes for all three locations.

Presentations

“Using Biomass to Enhance Dry-Grind Ethanol Profits” presented by Doug Tiffany at the Fuel Ethanol Workshop, June 21, 2006.

“Economics of Biomass Gasification/Combustion at Fuel Ethanol Plants” presented by Doug Tiffany at the Fifth International Starch Technology Conference held June 3-6, 2007 in Champaign-Urbana, IL. The conference focused on energy issues in starch related industries including ethanol plants.

“Utilization of Biomass for Electrical Generation: Technical and Policy Considerations” presented by Doug Tiffany for the University of Minnesota Electrical Engineering Seminar series at the following utilities: to a total audience of around 270, primarily in August, at the following locations: Great River Energy, Elk River, MN; Xcel Energy, Minneapolis, MN; Minnesota Power, Duluth, MN; Ottertail Power, Fergus Falls, MN; Alliant Energy, Dubuque, IA; Dairyland Power, La Crosse, WI; Southern Minnesota Municipal Power Agency, Rochester, MN. The four-hour presentation was made to total of approximately 270 people at the six locations in August 2007.

“Use of Distillers By-Products & Corn Stover as Fuels for Ethanol Plants” presented by Doug Tiffany at a Farm Foundation meeting on February 12, 2008 in Atlanta, GA.

Papers

Morey, R.V., D.G. Tiffany, and D.L. Hatfield. 2006. Biomass for electricity and process heat at ethanol plants. *Applied Engineering in Agriculture* 22(5): 723-728.

Morey, R.V., D.L. Hatfield, R. Sears, and D.G. Tiffany. 2006. Characterization of feed streams and emissions from biomass gasification/combustion at fuel ethanol plants. ASABE Meeting Paper No. 064180. ASABE St. Joseph, MI 49085.

Tiffany, D.G. and R.V. Morey. 2007. Economics of biomass gasification/combustion at fuel ethanol plants. Proceedings of the Fifth International Starch Technology Conference, Champaign-Urbana, IL. June 3-6.

De Kam, M.J., R.V. Morey, and D.G. Tiffany. 2007. Integrating biomass to produce heat and power at ethanol plants. ASABE Paper No. 076232. St. Joseph, Mich. ASABE.

Tiffany, D.G., R.V. Morey, and M.J. De Kam. 2007. Economics of biomass gasification/combustion at fuel ethanol plants. ASABE Paper No. 076233. St. Joseph, Mich. ASABE.

Tiffany, D.G., R.V. Morey, and M.J. De Kam. 2008. Use of distillers by-products & corn stover as fuels for ethanol plants. Farm Foundation Meeting, Atlanta, GA, February 12.

Outline of Individual Chapters/Tasks (Chapters/Tasks included as appendices or attachments)

Chapter/Task 1 – Applicable Biomass Co-Product Streams

This chapter provides an overview of potential biomass co-product streams (DDGS, syrup, DWG) available at ethanol plants or near plants (corn stover).

Chapter/Task 2 – Analysis of Biomass Co-Product Streams

This chapter describes the sampling and analysis procedures and provides fuel analysis results for dry-grind ethanol plant co-product streams as well as corn stover.

Chapter/Task 3 – Combustion Options

This chapter provides an overview of potential combustion and gasification systems that could be considered for supplying energy to an ethanol plant.

Chapter/Task 4 – Fuel Processing Options

This chapter describes requirements and potential methods for processing co-products to a form suitable for combustion.

Chapter/Task 5 & 6 – Combustion and Emission Modeling Results

This chapter describes a computational fluid dynamics approach to modeling fluidized bed combustion and predicted emissions for the ethanol co-products and corn stover as fuels.

Chapter/Task 7 – Evaluations Relative to Standards

This chapter provides an analysis of environmental regulations that may arise from the use of alternative biomass fuels at dry-grind corn ethanol production facilities.

Chapter/Task 8 – Evaluation of Control Technologies

This chapter describes potential technologies that can be used to control emissions such as NO_x, SO₂, and particulates that arise from biomass fuel combustion.

Chapter/Task 9 – Ash Characterization and Evaluation

This chapter describes characteristics and potential uses of ash that arises from the combustion of ethanol co-products as fuels.

Chapter/Task 10 – Capital and Operating Cost Estimates

This chapter describes the development of estimated capital costs that are required for the example systems defined in Chapter/Task 14 and the additional operating costs associated with using these biomass systems.

Chapter/Task 11 – Electricity Producing Options

This chapter outlines potential systems for producing electricity at ethanol plants.

Chapter/Task 12 – Compatibility with Existing Plant Combustion Systems

This chapter outlines potential advantages as well as disadvantages of incorporating biomass energy generation in existing plants.

Chapter/Task 13 – Electric Generation Considerations

This chapter outlines the opportunities and challenges of generating electricity and selling it to the grid.

Chapter/Task 14 – Technology Options and Integration with Dry-Grind Ethanol Plants

This chapter develops a model for integrating biomass energy conversion with conventional dry-grind ethanol plants. It describes in detail nine biomass fuel-technology combinations.

Chapter/Task 15 – Spreadsheet Architecture

This chapter describes development of the architecture of the spreadsheet used to conduct the economic analysis of Chapter/Task 16.

Chapter/Task 16 – Economic Analysis

This chapter presents results of an economic analysis comparing the nine biomass fuel-technology combinations to each other and to a conventional plant using natural gas and purchased electricity.

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.