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The Economic and Financial Implications of Supplying a Bioenergy Conversion Facility with Cellulosic Biomass Feedstocks

Will Allen McLaughlin, Ed Rister, Ronald D. Lacewell, Lawrence Falconer, William Rooney, Dean McCorkle, and Juerg Blumenthal

The production of fuels from renewable sources is an issue of growing importance as the United States (U.S.) investigates ways to improve energy security and gain independence from foreign oil. The U.S. is heavily dependent on oil, which supplies more than 40 percent of the nation's total energy demand and more than 99 percent of the fuel that is used in the transportation sector (U.S. Department of Energy 2009). The real price of crude oil in 2009 dollars has exhibited an upward trend over the past ten years, ranging from $13.71 per barrel in January 1999 to $127.73 per barrel in July 2008 (U.S. Energy Information Administration 2009).

The U.S. is the world's leading consumer of petroleum, using a total of 19.5 million barrels each day, or 25 percent of total world petroleum consumption, but it (i.e., the U.S.) only produces 6.7 million barrels per day (U.S. Energy Information Administration 2008). Since the U.S. is incapable of producing sufficient petroleum to meet its energy short falls, imports are important. The U.S. imports 12.92 million barrels of petroleum per day, or 60 percent of its total domestic use. This leaves the U.S. vulnerable to price spikes and supply disruptions by countries exporting to the U.S. (U.S. Energy Information Administration 2008; Bureau of Transportation Statistics 2010). This dependence on foreign oil and the high domestic demand have prompted both the federal government and private sector to explore alternative sources of energy that are sustainable and can be produced domestically.

Fuels produced from cellulosic biomass have been identified by the United States Department of Energy as a means to enhance the security of the U.S. energy supply and reduce the U.S. dependency on imported petroleum. Cellulosic biofuels such as ethanol, pyrolysis liquids, gasoline, and jet fuel can be produced from biomass resources using dedicated energy crops, forest resources, logging and mill residues agricultural crop residues, and municipal waste (National Renewable Energy Laboratory 2007; U.S. Department of Energy 2009). These fuels are projected to offer distinct advantages over starch-based ethanol and fossil fuels in that they have the potential to reduce net CO2 emissions to almost zero, they can be produced from a very diverse resource base, and their production generates economic benefits for rural communities through the creation of new jobs and new industries (Solomon, Barnes, and Halvorsen 2007; Knauf and Moniruzzaman 2004).

The Biomass Research and Development Technical Advisory Committee, a committee of volunteers from industry, academia, nonprofits, and local government formed to advise the Secretaries of Agriculture and Energy, established a goal that biomass-based energy will supply five percent of the nation's power, 20 percent of its transportation fuels, and 25 percent of its chemicals by 2030, approximating 30 percent of the nation's current petroleum consumption (U.S. Department of Energy 2003). A later estimate by the U.S. Department of Energy (2005) suggests that by using cellulosic biomass, a resource base of 1.3 billion dry tons of biomass feedstocks can be attained with the potential to produce enough biofuels to meet one-third of the current demand for fuels in the U.S. transportation sector. The immature nature of the U.S. cellulosic biofuels industry represents significant challenges, however, in that the industry lacks the infrastructure for the acquisition and logistics of cellulosic biomass. The logistics costs associated with cellulosic biomass are one of the largest obstacles to the successful

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growth and development of the cellulosic biofuels industry and will impact the rate at which the industry grows (Hess, Wright, and Kenney 2007).

Biomass feedstock production and logistics costs comprise 35 to 65 percent of the total production cost of cellulosic biofuels and largely impact the financial and economic competitiveness of these fuels (Fales, Hess, and Wilhelm 2007). Biomass feedstock logistics encompass all of the operations required to grow, harvest, transport, and store the biomass feedstock and guarantee that a delivered biomass feedstock meets the specifications of a conversion facility (Energy Efficiency and Renewable Energy 2008).

From a perceived biomass-based ethanol production cost of $2.25 per gallon in 2005, the United States Department of Energy's National Renewable Energy Laboratory has set a cost target goal to reduce the logistics cost to $0.39 per gallon in 2012. This objective is intended to assist in making cellulosic ethanol cost competitive at a production cost of $1.07 per gallon. The 2012 goal is approximately equal to a biomass feedstock cost of $35 per dry ton assuming an average conversion rate of 90 gallons of fuel per dry ton (U.S. Department of Energy, Office of Biomass Program 2009; Epplin et al. 2007; Pacheco 2006).

Biomass feedstock costs are dependent on a variety of factors such as biomass feedstock variety, yield, location of the conversion facility relative to the field, and the harvest, collection, storage, and transportation systems used (Hess, Wright, and Kenney 2007). To minimize these costs, the variety of biomass selected must be both environmentally and economically sustainable within the conversion facility's operating region and the crop density (i.e., acres planted per square mile) and energy yield per acre (i.e., gallons of biofuels that can be produced) of the selected biomass feedstock must be adequate so that transportation and other logistics cost can be controlled (Fumasi, Richardson, and Outlaw 2008).

This research examines the total and per dry ton cost to supply a hypothetical 30-million gallon conversion facility with high-energy sorghum (HES) and switchgrass (SG) for a 12-month period on a sustainable basis. The cost analysis covers the biomass supply chain up to the point of the biomass being in storage at the processing plant site; i.e., no costs of the ethanol conversion process are incorporated into the estimated costs. HES and SG were selected for analysis due to their ability to produce large amounts of dry weight biomass per acre, their relatively low input usage, and the fact that the climate found in the southeastern U.S. is well suited for the production of these crops (Fumasi, Richardson, and Outlaw 2008; Mitchell, Vogel, and Sarath 2008). Alternatives in production practices and other factors are considered in sensitivity analyses to gain insight on their cost impacts to deliver a reliable supply of biomass feedstock to the conversion facility, assuming these biorefineries must operate 365 days a year to be cost competitive (Avant 2009; Rooney 2010). A bi-weekly linear programming model was developed and applied to determine the supply-chain costs and the capital, labor, and variable inputs required for the proposed biomass production system.

There are several prior studies related to costs to supply cellulosic biomass feedstock for conversion to fuel. This analysis takes a dramatically-more-detailed view of more real-life challenges such as trafficable days, machinery and labor constraints, and seasonal harvested biomass feedstock yield relationships, balancing costs against timing and need for an imbedded insurance capability. The serious misconceptions and underestimates of costs based on a simplistic approach of extrapolating from crop enterprise budgets are clearly exposed in this report.

Addressing the land requirement suggests the need for more than 110,535 acres of HES (in a three-year rotation) and approximate 37,225 acres of SG to supply the 30-million gallon conversion facility year-round, and the

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approximate 40,000 acres of insurance SG acreage, adding up to a total of 187,760 acres required to support the conversion facility. This indicates a substantial commitment of land to meet the demand for a bioenergy processing plant.

The baseline scenario for this analysis provides a best estimate benchmark with which to make comparisons. Investments and associated ownership costs are summarized in Table 1. The total requisite initial investment is estimated to be $118.3 million while the annual ownership costs (including insurance, property taxes, and fixed repairs) expressed on an annual basis are estimated to be $14.9 million (calculated on an annuity equivalent basis). Purchasing machinery is the most significant cost associated with capital investments, accounting for 56 percent of the total $118.3 million (Table 1); note that land is assumed to be leased from landowners, reducing the initial requisite capital investment. This investment analysis suggests a cost of $37.41 per ton of biomass or $0.49 per gallon of ethanol just to cover the investment. That is, these estimates represent investment costs only -- no operation costs are included.

Table 1. Summary of a Baseline Scenario Required Capital Investments for HES and SG, Hypothetical Middle Gulf Coast, Edna-Ganado, Texas Area Corporate Biomass Feedstock Farming Entity Supplying 30-Million Gallon Cellulosic Conversion Facility, 2010.

Item [a]	Full Capital Investment Cost	Amortized Investment Cost	Annual Cost per Acre of Biomass feedstock[b]	Annual Cost per Ton of Biomass feedstock[c]	Annual Cost per Gallon of Fuel[d]	% of Total Annual Capital Costs
Headquarters	$5,579,279	$988,015	$13.34	$2.47	$0.0329	7%
Purchased Machinery	$46,913,459	$8,298,523	$112.04	$20.75	$0.2766	56%
Irrigation	$24,852,075	$2,068,376	$27.92	$5.17	$0.0689	14%
SG Custom Establishment	$23,036,147	$1,694,634	$22.88	$4.24	$0.0565	11%
Storage	$17,868,336	$1,869,809	$25.24	$4.67	$0.0623	13%
Total	$118,249,295	$14,919,357	$201.42	$37.31	$0.4973	100%

[a] The Baseline Scenario includes the production, harvest, transportation, and storage of only HES and SG biomass feedstock, SG land grown for insurance, and both full- and part-time labor. HES refers to High-Energy Sorghum and SG refers to Switchgrass.
[b] Biomass feedstock refers to harvested HES and SG. Cost per acre was determined by dividing total costs by the summed total of HES and SG acres harvested, i.e., explicitly not including SG acreage grown for insurance.
[c] Cost per dry ton was determined by dividing total costs by the total dry tons required annually by the conversion facility (400,000 dry tons).
[d] Cost per gallon was determined assuming a conversion rate of 75 gallons of fuel per dry ton of feedstock (Avant 2009).

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Operating costs for the baseline scenario as presented in Table 2 suggest a cost of $96.71 per ton of biomass or $1.29 per gallon of ethanol, not including investment or processing. The major operating cost items were field operations and labor. Consideration of the total costs (i.e., investment plus operating) to deliver biomass to a bioenergy processing plant suggests approximately $134 per ton or $1.79 per gallon. With the more realistic evaluation of actual production across growing/harvest periods represented in this study, the average yields of biomass crops were much lower than the assumed maximum due to harvesting at non optimum times.

Table 2. Summary of Baseline Scenario Annual Operating Cost for HES and SG, Hypothetical Middle Gulf Coast, Edna-Ganado, Texas Area Corporate Biomass Feedstock Farming Entity Supplying 30-Million Gallon Cellulosic Conversion Facility, 2010.

Item [a]	Total Annual Cost	Annual Cost per Acre[b]	Annual Cost per Ton of Feedstock[c]	Annual Cost per Gallon of Fuel[d]	% of Total Annual Capital Costs
Borrow Operating Money	$962,278	$12.99	$2.41	$0.0321	2.49%
Land	$3,656,150	$49.36	$9.14	$0.1219	9.45%
Labor	$8,862,136	$119.65	$22.16	$0.2954	23.91%
Irrigation	$3,438,341	$46.42	$8.60	$0.1146	8.89%
HES Field Operations	$11,741,985	$158.53	$29.35	$0.3914	30.35%
SG Field Operations	$3,395,417	$45.84	$8.49	$0.1132	8.78%
Transportation	$2,608,612	$35.22	$6.52	$0.0870	6.74%
Transfer Tractor Hours[e]	$141,072	$1.90	$0.35	$0.0047	0.36%
Overhead Management	$3,876,855	$52.34	$9.69	$0.1292	10.02%
Total	$38,682,845	$522.25	$96.71	$1.2894	100.0%

[a] The Baseline Scenario includes the production, harvest, transportation, and storage of only HES and SG feedstock, SG land grown for insurance, and both full- and part-time labor. HES refers to High-Energy Sorghum and SG refers to Switchgrass.
[b] Feedstock refers to harvested HES and SG. Cost per acre was determined by dividing total costs by the summed total of HES and SG acres harvested, i.e., explicitly not including SG acreage grown for insurance.
[c] Cost per dry ton was determined by dividing total costs by the total dry tons required annually by the conversion facility (400,000 dry tons).
[d] Cost per gallon was determined assuming a conversion rate of 75 gallons of fuel per dry ton of feedstock (Avant 2009).
[e] Operating costs for Transfer Tractor Hours was determined by subtracting the operating costs per acre for Tractor Size 2 (152hp) from the operating costs per acre for Tractor Size 1 (225 hp) and the operating costs per acre for Tractor Size 3 (110hp) from the operating costs per acre for Tractor Size 2 (152hp). This method allows the excess Tractor Size 1 (225hp) hours to be transferred to field operations which require Tractor Size 2 (152Hp) and the excess Tractor Size 2 (152hp) hours to be transferred to field operations that require Tractor Size 3 (110hp) and capture the costs associated with operating a larger horse-power machine.

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The estimates in Table 2 represent a projection with the accompanying set of assumptions. A total of 41 alternative scenarios were evaluated and compared to this base case. These scenarios included alternative yield for HES and for SG; production of only HES and then only SG; and alternative modifications to capital costs, operating costs, discount rate, labor availability, storage deterioration, and trafficable days, all intended to represent possible occurrences other than those specified in the base case. The cost (operating and annual investment charge) per ton of biomass delivered to a processing plant ranged from $85 to $262. The best case scenario, using very optimistic assumptions, gave an estimated cost of $85 per ton or $1.13per gallon. Overall, the range for the most part was from $110 to $140 per ton, i.e., $1.47 to $1.87 per gallon. To review details of the model and assumptions, see McLaughlin (2011).

CONCLUSIONS

In conclusion, this research provides an intense comprehensive analysis of the holistic farm production-harvesting-transporting-pre-refinery storage supply chain paradigm which represents the totality of important issues affecting the conversion facility front-gate costs of delivered biomass feedstocks. The analysis dramatically extends beyond the complexity of most studies on costs of supplying biomass by developing a detailed model of activities, constraints, and goals. Several conclusions are apparent in reviewing and comparing the results from the baseline and several sensitivity scenarios. This section is intended to provide some generic conclusions not often recognized in other cellulosic-based biomass feedstock studies.

- The biomass feedstocks cost estimates derived in this research vary substantially (and tend to be higher) from those previously estimated for corn, forest residue, municipal solid waste, HES, and SG. Such results either arise because the biomass feedstock sources and associated supply logistics economics are less favorable in the targeted Middle Gulf Coast, Edna-Ganado, Texas study area and/or the methods for calculating costs are more comprehensive in this research, identifying aspects of the logistics costs not accurately captured in the cited literature. Typically, a crop enterprise budget is extrapolated for the cost estimates, ignoring issues of timing, yield reductions from non-optimal planting/harvesting, and major logistical constraints that all contribute to higher costs.

- Cost minimization optimization that recognizes tradeoffs in capital investments versus operating costs (i.e., input substitution) is a valid and insightful approach to investigating the economics of the holistic production-harvesting-transportation-storage supply chain system.

- Inclusion of the effects of trafficable field days and the opportunity to schedule/restrict production and related operations within model-user-designated time periods affords identification of issues perhaps otherwise overlooked or represented as insignificant in importance in other studies.
- Maximum-expected yields are not realized on average across all biomass acreage due to harvested yield tradeoffs associated with timing of planting and related field operations as well as post-harvesting transportation subject to availability of machinery and equipment resources.

- Maintenance of additional storage inventory and upkeep of additional biomass feedstock production acreage to protect (insure) against delays in deliveries, or lower than expected harvest yields, is costly.

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- Attempts to supply the conversion facility solely with regionally-grown HES biomass feedstocks is expensive compared to supplying the conversion facility with only SG biomass feedstocks, reflecting the substantial costs associated with intense field operations, harvesting, and transport.

- Beyond-the-farm gate costs account for more than 35 percent of the total-delivered costs while production and harvest of the biomass feedstock represent just under 65 percent of the costs, not including any conversion costs.

- Using only part-time labor (as opposed to mostly full-time labor) lowered delivered biomass feedstock costs by 10.8 percent (by $14.53 per dry ton).

- The level of assumed (actual) trafficable days can significantly affect the results in terms of dollar per dry ton delivered costs for biomass feedstocks – however, in all scenarios, costs remained above $100 per dry ton.

- Consideration of smaller farm sizes in the magnitude of 2,500 acres as opposed to the baseline scenario's assumed large-scale corporate farming entity resulted in almost doubling the per dry ton delivered biomass feedstock costs (to $261.52, i.e., an increase of 95.1 percent). This estimate assumes that each farm must purchase all needed machinery in integer units, suggesting that for an existing farm already having its machinery the costs may be less.

- Targeting specified production regions for development of a cellulosic-based biofuel conversion facility sets boundaries on biomass production/sourcing opportunities as well as opportunity costs related to existing enterprises. As supported by Fewell, Bergtold, and Williams (2011), the inclusion of incentive payments to landowners to entice the conversion of what is now pasture land to biomass production is an explicit consideration in this thesis research.

- There are uncertainties regarding feasible production yields in localized areas.

- There exists limited infrastructure for this scale of operation in the targeted Middle Gulf Coast, Edna-Ganado, Texas area. This suggests major pressure on local road systems at the peak of HES harvesting; the analysis assumed no field storage, i.e., all biomass was transported in bulk form to the processing plant within hours of being harvested.

- The relative conversion efficiencies of alternative biomass feedstocks are deserving of additional research, particularly in regard to the extent to which such efficiencies may affect the production-level decision choice of biomass feedstocks in the context of a holistic supply chain such as that used in this this research.

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