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

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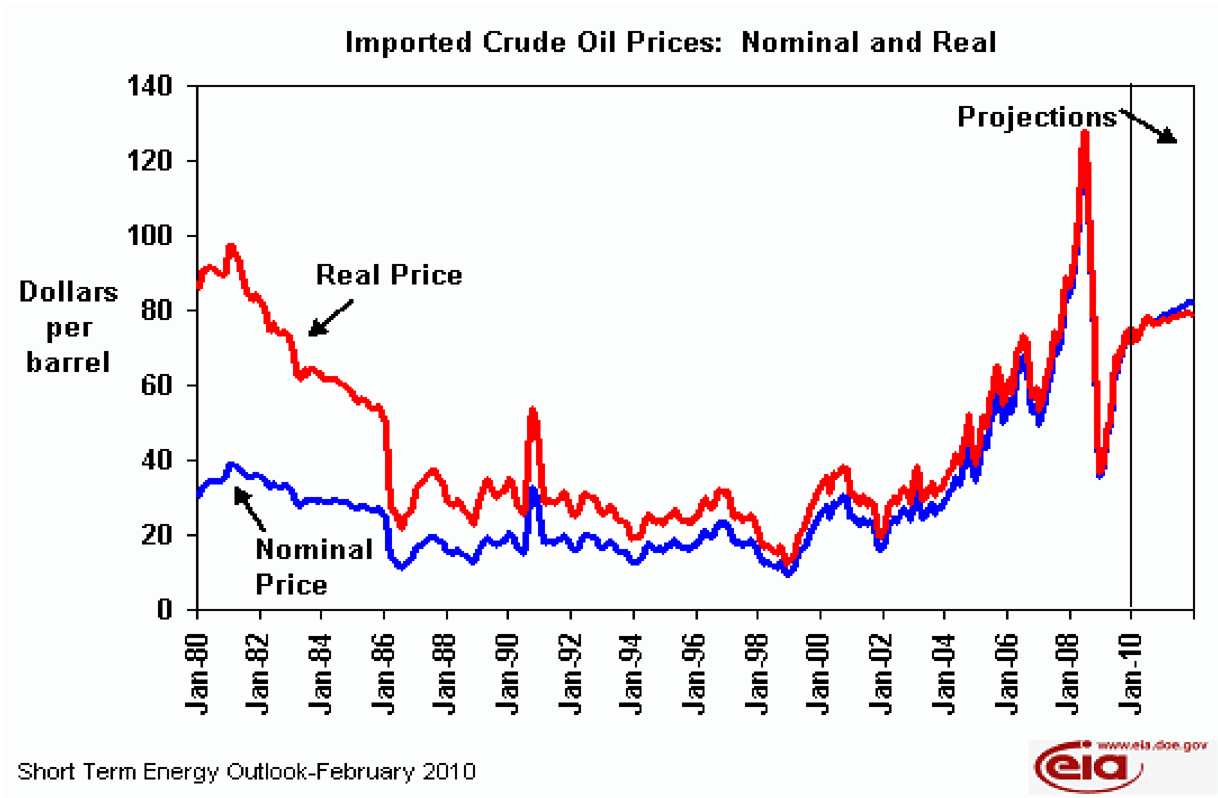
INTRODUCTION

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 2009a). The real price in 2009 dollars of crude oil 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 historical trends in nominal and real prices are illustrated in Figure 1.

The U.S. is the world's leading consumer of petroleum, using a total of 19.5 million barrels per day or 25 percent of total world petroleum consumption, but only produces 6.7 million barrels per day (U.S. Energy Information Administration 2009). 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 total domestic supply, leaving the U.S. vulnerable to price spikes and supply disruptions by countries exporting to the U.S. (U.S. Energy Information Administration 2009; Bureau of Transportation Statistics 2010). This dependence on foreign oil, as well as high domestic demand, has 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 U.S. Department of Energy (2009b) as a way 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



Source: Bureau of Transportation Statistics (2010).

Figure 1. Historical and Forecasted Real (2009 dollars) and Nominal U.S. Imported Crude Oil Prices, 1980-2010.

energy crops, forest resources, logging and mill residues, agricultural crop residues, and municipal waste (National Renewable Energy Laboratory 2007; U.S. Department of Energy 2009b). These fuels are projected to offer distinct advantages over starch-based ethanol and fossil fuels in that they have the potential to reduce net CO_2 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 U.S. Department of Energy (2006) established a goal that biomass-based energy will supply seven percent of the nation's power, 20 percent of its transportation fuels, and 55.3 million pounds of biobased products by 2030. The U.S. Department of Energy (2005) estimates that by using cellulosic biomass, a resource base of 1.3 billion dry tons can be attained with the potential to produce enough biofuels to meet one-third of the current demand for fuels in the transportation sector. The immature nature of the 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 production are one of the largest obstacles to the successful growth and development of the cellulosic biofuels industry and will impact the rate at which the industry grows (Hess, Wright, and Kenney 2007).

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). Feedstock logistics encompass all of the operations required to grow, harvest, transport, and store the feedstock and guarantee that a delivered 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 National Renewable Energy Laboratory (2007) of the U.S. Department of Energy has set a cost target goal to reduce the logistics cost component to $0.39 gallon in 2012. This objective is intended to make cellulosic ethanol cost competitive at a production cost of $1.07 per gallon. The 2012 goal is approximately equal to a 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 2009b; Epplin et al. 2007; Pacheco 2006).

Feedstock costs are dependent on a variety of factors such as 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 (acres planted per square mile) and energy yield per acre (gallons of biofuels that can be produced) of the selected feedstock must be adequate so that transportation and other logistics cost can be controlled (Fumasi, Richardson, and Outlaw 2008).

This paper examines the total and per ton cost to supply a hypothetical 30-million gallon conversion facility with high energy sorghum (HES), switchgrass (SG), and other alternatives (e.g., wood chips) for a 12-month period on a sustainable basis for the El Campo, Texas region. 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 because 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 the cost impacts for delivering a reliable supply of 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 cost and the capital, labor, and variable inputs required for the proposed biomass production system.

OBJECTIVES

This research addresses the financial and economic costs of supplying a hypothetical 30-million gallon cellulosic biomass conversion facility with alternative feedstocks for one year on a sustainable basis. A review of literature indicates these costs can account for a significant amount of the total production costs of cellulosic biofuels but must be contained for these biofuels to become competitive and significantly contribute to transportation fuel. This paper evaluates the financial and economic logistics costs by focusing on a set of specific objectives which include: (a) establishing production alternatives to produce HES and SG, (b) establishing harvesting, transporting, and storage options for biomass crops as well as options to purchase alternative feedstocks, and (c) incorporating all alternatives into a cost-minimizing analytical model. Applications of the model include sensitivity analyses to provide direction to research that can make the greatest impact in reducing costs and to determine those factors contributing most to the cost of cellulosic biofuels.

REVIEW OF LITERATURE

A review of selected literature is provided to address the various facets of this research. The literature review includes (a) federal and state policies, (b) the economic and financial feasibility of using biomass as an alternative energy source, and (c) the basic characteristics of HES and SG feedstocks and their production.

United States Federal Policies and Funding

Recent federal policy has the goal of decreasing the U.S. demand on foreign fuels as well as providing a clean-burning fuel to reduce greenhouse emissions. The major focus of these policies is on increasing the domestic production of advanced biofuels through research grants, private loan initiatives, biofuels marketing, demonstration projects, and producer incentives. Substantial portions of government-based funding and federal policies are focused on the science of converting plant material into fuels, with little interest directed toward the logistics of biomass production (Avant 2009).

The Energy Independence and Security Act of 2007 mandates that 36 billion gallons of renewable fuels be produced annually by 2022, with 16 billion gallons of the total being cellulosic biofuels (H.R. 6--110th Congress 2007). The Act also provides $25 million in annual funding to provide grants for biofuels research, development, demonstration, and commercial applications for states where the level of ethanol production is low. Title IX of the 2008 Farm Bill focuses on the development and sustainability of renewable energy sources, primarily energy derived from biomass or bio-based sources (H.R. 2419--110th Congress 2008). The 2008 Farm Bill also provides $1 billion in overall funding to support energy-related programs and to promote investments in new technologies and alternative feedstocks.

The U.S. Department of Energy (DOE) has provided $375 million ($125 million for each of three centers over five years) intended to enhance conversion technologies and accelerate basic research in the development of cellulosic ethanol and other biofuels (U.S. Department of Energy 2009a). The major focus of the centers is determining how to reengineer biological processes to develop new, more efficient techniques for converting cellulosic plant material into ethanol or other biofuels.

Economics of Energy Crop Production

Few studies have been conducted to date that include a detailed analysis of all the components, time constraints, labor, and investment and operating cost required to supply cellulosic biomass to a conversion facility on a commercial scale using HES, and SG. Research has been performed on many of the segments involved in the supply chain system, such as transportation logistics and production economics, but few have combined these processes into holistic analyses.

Much of the economic literature focuses on minimizing the costs associated with energy crop production because this is seen by many as a major hurdle towards the integration of energy crops into the supply system. A study conducted by Fumasi, Richardson, and Outlaw (2008) for the Beaumont, Texas, area focused on the interaction between various factors such as yield risk, technological expertise, and capital investment on the contract price needed to induce farmers to grow cellulosic feedstocks compared to other enterprises. In addition, the project considered how bio-density, fuel prices, and type of crop produced impact the transportation and harvesting cost. This study concluded harvesting and transportation costs accounted for 50 percent or more of the delivered feedstock costs, regardless of the type of crop produced.

Turhollow (1994) estimated the cost for 1989 and projected the cost for 2010 production circumstances to grow and supply a biorefinery with biomass for four different cropping strategies in the Midwest and Southern regions of the United States.[1] Turhollow's results indicate that energy crops must sell between \$48 and \$66 per dry ton in 1989 and between \$33 and \$48 per dry ton in 2010 to be competitive with corn from the Midwest and soybeans from the Southeast.[2] Harvesting, handling, storing, and transportation of the feedstock comprised approximately 40 percent of the total costs of production. The study also found that by applying "Just In Time" delivery and avoiding storage, costs could be reduced by \$7 to \$21 per dry ton (representing 21 to 44 percent of total costs). The impact of the current dramatic commodity price increases are sure to increase the cost for producing cellulosic feedstock and are not a part of this study.

High Energy Sorghum Characteristics and Production

Sorghum is a highly-productive annual grass that is well adapted to grow in hot, dry regions of the world. These plants are naturally drought tolerant and are very efficient users of water, requiring one-third to one-half less water than corn (Butler and Bean). Its drought

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[1] The study was performed in 1989 and current cost estimates were obtained for that year. Cost estimates for 2010 were projected based on changing production circumstances and technology (Turhollow 1994).

[2] The selling price for dedicated energy crops is reduced in 2010 based on the assumption that dedicated energy crops will have a higher biomass yield and machinery costs will be lower than in 1989 (Turhollow 1994).

tolerance reduces the risk of crop loss and maintains yield potential throughout the growing season (Rooney 2010). Sorghum can be classified as sweet sorghum, grain sorghum, or forage sorghum, depending on its genetic composition and intended end use. Texas AgriLife Research plant breeders have developed a new HES designed for biomass and energy production (Blumenthal et al. 2007).

HES are photoperiod-sensitive hybrids that combine the characteristics of grain and sweet sorghums (Monk, Miller, and McBee 1984) to create a plant specifically designed for biomass production. Avant (2009) indicates HES is capable of producing 15 to 20 dry tons/acre of biomass under favorable growing conditions, while Rooney (2010) and Blumenthal (2010) are more guarded in their projections, speculating yields of 10-12 dry tons/acre may be a more realistic expectation in the short run. Rooney (2010) realized yields of 10-11 dry tons/acre on non-irrigated research plots in the Brazos River bottomlands of Texas.

Switchgrass Characteristics and Production

SG is a perennial C4 grass native to North America that is characterized by high-yielding potential and a tolerance to water and nutrient deficits (McLaughlin, Samson, and Bransby 1996). SG is adaptable to many soil types and can be grown in areas that would not support the production of many other crops.

The costs associated with SG production include three major components: (1) establishment, (2) reseeding, and (3) annual management. A reliable and commonly recommended planting date for SG is three weeks before or after the maize (i.e., corn) planting date using conventional or no-till practices (Mitchell, Vogel, and Sarath 2008). SG stands may take three or more years to become fully established and it remains productive for about 10 years. The most favorable time to harvest SG is two to three weeks after a killing frost as this promotes nutrient recycling for winter storage. Delaying the SG harvest until the following spring to allow for "Just In Time" delivery can result in a dry matter loss of 20 to 30 percent, but further promotes nutrient recycling and reduces the ash content of the biomass (Blade Energy Crops 2009).

RESEARCH PARADIGM

The research paradigm used is a hypothetical corporate farm located in the El Campo, Texas, region. Centralized corporate management handles all production, harvesting, transport, and pre-biorefinery processing storage operations for HES and SG. This operation is separate from the bioenergy conversion facility and relies on a contract with the conversion facility for the purchase of the biomass feedstocks. Therefore, individual farmers are not responsible for growing, harvesting, or transporting the energy crops from the field to storage or to the conversion facility; instead, the corporation hires labor to operate its machinery and equipment and to perform field and delivery operations.

Land is cash leased at a rate that provides an incentive to landowners to switch their land from other production practices (mainly pasture or abandoned rice land in this region) to energy crops. It is presumed a cash lease rate substantial enough to move land from rice or row crop production to energy crops is not financially or economically feasible, given current HES production yield and harvesting technology (Raun 2010; Popp 2010). HES land is in a rotation with other crops, or left fallow, or used as pasture following harvest to allow for nutrient replacement. During years HES is not grown, the land is subleased to area producers by the corporation to allow for a maximum revenue stream. A rotation pattern of one year of HES followed by two years of fallow/pasture is used for this analysis.

Machinery used for the production of energy crops is either purchased or leased on a short-term basis (e.g., similar to contemporary leasing of combines for rice and/or other grain harvesting). A fleet of machinery that moves across the Southern U.S. and could be leased on a short-term basis would significantly reduce the capital cost for energy crop production, but no such system is currently in place. HES is assumed to be green chopped and either delivered to storage (located at/near the conversion facility) or delivered directly to the conversion facility "Just In Time."[3] SG land is not rotated with other crops, but rather it is a perennial crop and hence is continuously "farmed" and harvested (once per year) after establishment. SG is used to supplement the conversion facility's feedstock needs during periods of no or low HES production. SG is left in the field until it is needed by the conversion plant and then is delivered "Just In Time." Alternative feedstocks (e.g., wood chips) to HES and SG are also considered in sensitivity analyses as a source to supplement the conversion facility's feedstock needs. The availability and cost of most alternative feedstocks inhibits their use as an economically-viable alternative to produced crops. These alternatives are used to provide a cushion in periods when HES and SG production is low to assure the cellulosic conversion plants needs are met during each period.

METHODOLOGY

The logistics costs associated with supplying a bioenergy conversion plant with feedstock is the basic issue addressed in this research. For the purpose of this research, "logistics" is interpreted as all of the operations required to grow, harvest, and transport the feedstock from the

[3] "Just in time" delivery should be interpreted to mean that the exact amount of feedstock required by the conversion facility to meet periodic requirements is delivered to the conversion facility and no excess feedstock is transferred from period to period. Although SG, purchased transported alternative feedstock, and purchased delivered alternative feedstock are theoretically used supplemental to HES and delivered "just in time", these feedstocks could possibly be stored and transferred from period to period if desired by adjusting the user specified right-hand side constraints of the analytical model.

production area to the conversion facility, including any intermediate and final on-site storage as well as guarantee the delivered feedstock meets the specifications of the conversion facility.

To achieve the aforementioned objectives, a linear programming model was developed and applied to integrate capital budgeting, annualized costs, and crop enterprise budgeting. This provided an integrated optimization analysis of the production, harvesting, hauling, and storage of alternative feedstocks, given available time constraints. Capital budgeting and enterprise budgeting provide life-cycle cost information for use in the linear programming model.

Capital Budgeting

The appropriate method for evaluating a capital project is to apply economic and financial procedures toward identifying life-cycle costs for capital investments. Capital Budgeting involves the analysis of investment projects by evaluating the net cash flows generated by investments over their entire economic life (Penson and Lins 1980). To analyze each project, it is necessary to know (a) the initial cost of the investment, (b) the annual net cash revenues/expenses realized, (c) the expected life of the investment, (d) the salvage value, and (e) the discount rate to be used.

Standard Capital Budgeting – Net Present Value (NPV) analysis is used in this research along with the calculation of life-cycle annuity equivalent values (e.g., Rister et al. 2009) to determine the economic feasibility of biomass feedstock production. Standard NPV analysis allows for comparison of uneven flows of money among alternative investments. Annuity equivalent calculations extend the standard NPV analysis to allow comparisons of projects with different economic lives (Rister et al. 2009; Sturdivant et al. 2008; Rogers 2008; Boyer 2008).

Enterprise Budgeting

Enterprise budgets allow managers to compare costs and returns of alternative crop or livestock activities and evaluate the technology, resources, and management practices used for each option. An enterprise is an unit of economic organization specifically designed for business use. The primary purpose of enterprise budgets is to estimate the costs, returns, and profit per unit for each enterprise (Kay, Edwards, and Duffy 2003). This provides a valuable planning tool for business managers and provides a way to estimate the profitability of different enterprises and management strategies. The crop enterprise budgets are the building blocks for annual activities in the linear programming model.

Linear Programming

Linear programming (LP) is a quantitative research technique that minimizes or maximizes an objective function by allocating scarce resources across multiple alternatives in the most-economically manner possible (Beneke and Winterboer 1973). LP models provide an effective tool for analyzing a variety of economic decisions such as crop selection, transportation, budgeting, and firm-level management problems, as well as facilitate an unbiased analysis of the problem, subject to resource availability; for a more extensive literature review, refer to McLaughlin (2011).

There are three fundamental elements that comprise a LP model. The first element is the objective function which, when optimized (either profit-maximizing or cost-minimizing in the most fundamental LP models), selects the optimal solution from a universal set of possible solutions. The decision variables comprise the second component. Decision variables indicate the unknown quantity of each respective decision activity available to optimize the solution. The final elements of a LP model are the constraints. The constraints are restricting in that they specify the amount of each resource that is available or the upper limit of the resource and can also specify the minimums and maximums for specific activities as well as establish relationships among decision variable activities (Parker 1985; McCarl and Spreen 2003). Several examples of previous research utilizing LP are discussed in McLaughlin (2011) to establish the basis for the approach used in developing Sorghasauras© (McLaughlin 2011), the LP model used in this research.

Methodology Summary

The collective use of linear programming, capital budgeting, annuity equivalent values, and enterprise budgeting represent a dependable method to evaluate a complex set of alternatives and goals. The linear programming model developed in this research project is a robust, multiple-period model capable of evaluating a cost-minimizing production program with a variety of alternative feedstocks and production alternatives (e.g., planting and harvesting dates) available. The model is applied to the El Campo, Texas, area, but it is flexible enough in its design to be applied to other regions. This is accomplished by adapting the data used in the model to reflect the production practices, technology, and resources used in a specific region.

BASELINE RESULTS

A two-phase analytical process is followed: (a) a baseline scenario is defined and analyzed where there are both HES and SG feedstocks, providing a benchmark for subsequent comparison purposes; and (b) several sensitivity analyses are investigated, focusing on various logistical features and associated critical data. These analytical results are compared to those for the baseline scenario with consideration for (1) results changing in the anticipated direction, and (2) magnitude of changes signifying relative importance of the respective factors or variables.

The cost estimates and capital requirements are derived from the previously-introduced methodology, the Sorghasauras© model application, and the primary and secondary data provided for the base scenario analysis. The results discussed cover the base analysis of HES and SG and are used as a benchmark for comparison to results from subsequent sensitivity scenarios. Due to many factors of uncertainty, there is no one single best solution, but rather a suite of solutions that provide insight both on cost per dry ton of feedstock and those parameters that have the greatest impact on this cost.

Overview of High Energy Sorghum and Switchgrass Results

The total annual preliminary estimated cost to supply a 30-million gallon conversion facility with HES is $53.75 million, i.e., $1.79 per gallon of fuel produced (Table 1)[4]. These are preliminary estimates and subject to adjustment as the model is refined. A total of 313,255 dry tons of HES is produced on 36,950 acres while a total of 100,000 dry tons of SG is produced on 37,213 acres, to meet the annual feedstock requirements of the conversion facility. Thus, the total amount of feedstock produced is 413,255 dry tons on 74,163 acres.

The average HES and SG harvested yields equate to 8.48 dry tons per acre and 2.69 dry tons per acre, respectively. Certainly average yield is less than potential, since planting (for HES) and harvesting (for both HES and SG) occur over several months at less than optimum timing. Dividing the total annual cost by the total acres and the total tons produced results in an annual per acre cost of $725 and a per dry ton delivered and stored feedstock cost of $130. Assuming a fuel conversion rate of 75 gallons per dry ton (Avant 2009) and a 30-million gallon conversion facility size, total delivered feedstock costs is $1.79 per gallon of fuel produced.[5] To

[4] Assuming 75 gallons of fuel per ton of feedstock (Avant 2009).

[5] Cost per gallon of fuel was determined by dividing total annual cost by 30 million gallons, since a 30-million gallon per year conversion facility is assumed.

Table 1. Base Scenario of HES and SG Annual Total Cost by Major Segment, Hypothetical El Campo, Texas, Area Corporate Farming Operation, 2010.

	Total Cost (in thousands)	Cost per dry-ton[a]	Cost per Acre[b]	Cost per Gallon of Fuel[c]	Percentage of Total Cost
Headquarters	$ 995	$ 2.49	$ 8.71	$0.03	1.85%
HES Production Land	2,125	5.31	18.61	0.07	3.95%
SG Land	1,537	3.84	13.47	0.05	2.86%
Purchased Machinery	8,319	20.80	72.87	0.28	15.48%
Labor	8,830	22.07	77.34	0.29	16.43%
Irrigation	5,518	3.80	48.34	0.18	10.27%
HES Field Operations	11,833	29.58	104.78	0.39	22.01%
Transport HES	2,238	5.60	19.61	0.07	4.16%
SG Establishment	4,003	10.01	35.07	0.13	7.45%
SG Field Operations	3,461	8.65	30.32	0.12	6.44%
Transport SG	353	0.88	3.09	0.01	0.66%
Storage	665	1.66	5.82	0.02	1.24%
Overhead Management	3,877	9.69	33.96	0.13	7.21%
Totals	$53,754	$134.39	$471.98	$1.79	100.00%

[a] Number of tons of HES and SG
[b] Number of acres of HES and SG
[c] Number of gallons per ton

test the robustness of the model and assumptions, several sensitivity scenarios are currently being evaluated with results forthcoming.

LIMITATIONS

There are significant challenges facing the integration of biomass feedstocks into a cost-competitive supply system for mobile fuels. The absence of an infrastructure capable of producing enough biomass feedstocks to supply an economically-viable conversion facility is one major challenge facing the biofuels industry. To obtain a stable supply of feedstock, conversion facilities could engage in: (a) contracting with individual growers, (b) using a cooperative arrangement to contract with a group of growers, (c) arrange long-term land leases such as Conservation Reserve Program leases, and/or (d) purchase crop land (Epplin et al. 2007). The production of dedicated energy crops must be equally or more profitable than conventional crops for any of these options to be viable and to induce farmers into producing dedicated energy crops (Walsh 1994).

Loss of quantity and quality of biomass during storage is another challenge facing the biofuels industry. Storage is a necessary component of the feedstock supply system because biomass feedstocks have a narrow harvest window in most regions compared to the year-round need of the conversion facility (Hess, Wright, and Kenney 2007). Another hurdle in minimizing the cost to supply a biomass conversion facility with HES is the high moisture content of the harvested crop. HES harvested for silage with no field drying time has a moisture content ranging from 60 to 75 percent, depending on the season and growth stage (Rooney 2010). Also, a majority of the land ideal for crop production is already used to produce food and fiber crops for animal and human consumption. Acquiring this land for the production of biomass feedstocks will require significant cost that can potentially be cost prohibitive. Thus, it is expected marginal land will have to be used to produce biomass feedstocks, which will reduce the yield potential and increase the production cost of biomass feedstocks.

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