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Long term planning and hedging for a lignocellulosic biorefinery in a carbon constrained world

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ABSTRACT

While bioethanol has become a promising candidate for replacing fossil based transportation fuels, its economic feasibility still eludes industry investors. In particular, uncertainties exist in both production processes and associated markets. Hence, it is critical to develop process technology and strategize the operation and hedging decisions that improve financial viability. This paper considers long-term production scheduling under the impact of carbon tax constraints and ethanol spot price uncertainty, as well as risk management via ethanol swap contracts. More specifically, a framework consisting of a two-stage stochastic program and a two-factor time series model is presented to determine the weekly production rate and swap portfolios to maximize the process profit under spot price uncertainty.

1. Introduction

Fuel production from biomass feedstock is hindered by uncertainties in process technology, logistics and market development. Non-food feedstocks such as corn stover and perennial grasses have the most potential to be adopted in future generation biofuel facilities. A recent report from Larsen et al. [1] suggests although the process is developed, and the products are on the market, further policy and market research are still imperative to ensure the construction of commercial plants. Therefore, both optimal conversion process design and financial risk management are essential to develop a commercially viable industry.

A typical biochemical conversion lignocellulosic biorefinery includes feedstock storage and handling, pretreatment, saccharification and fermentation, ethanol, water and solid recovery as well as waste water treatment. Several alternative technologies are available for each step. Therefore, an optimal design of the process is achieved by choosing an effective technology for each step based on a specific objective. To date, researchers have proposed different optimal process configurations under diverse objectives.

For example, Martín and Grossmann [2,3] have proposed energy-optimized biorefinery conceptual models via hydrolysis and gasification of switchgrass. They postulate a superstructure that contains multiple candidate technologies in each conversion step, and formulate a mixed integer nonlinear program to solve for the optimal configuration after considering both heat and water integration. El-Halwagi et al. [4] have established a biorefinery optimization model based on economic and safety constraints. In addition to the economic factors, risk metrics are used in the decision-making problem of selection, location, and sizing of a biorefinery. Santibañez-Aguilar et al. [5] have proposed a biorefinery optimization model based on economic and environmental constraints. The economic objective considers the availability of bioresources, processing limits, and the demand of the product, while the environmental objective uses eco-indicator-99 to measure the total environmental impact. In their later study, Santibañez-Aguilar et al. [6] have formulated an optimization model for design and plan sustainable biorefinery supply chains that considers economic, environmental and social objectives. The social objective is measured as the jobs generated by the supply chains' implementation. Huang et al. [7] have analyzed five biomass species and tested different plant sizes to determine the optimal process efficiency and economical performance. Results show that aspen wood has the largest ethanol production rate, and switchgrass can generate the most amount of excess electricity. Furthermore, the optimal plant production size locates between 2000 and 4000 dry Mg per day. Grisi et al. [8] have considered the optimal short-term scheduling strategy of a biorefinery, which aims to maximizing the hourly plant economic profit.

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The formulated mixed integer linear programming model takes into account production costs, products price, and energy demand. Lythcke-Jørgensen and Haglind [9] have integrated lignocellulosic ethanol production into a heat and power plant with the goal of minimizing ethanol production cost. The results suggest that the ethanol production cost rises continuously as the processing capacity increases, and the average yearly exergy efficiency decreases with increasing ethanol production capacity.

As a result of developing markets for energy products, biorefineries are exposed to exogenous price risk. Thus, effective management of the financial risk arising from price fluctuations is a major concern in the industry. To date, several researchers have investigated this topic [10–17].

In the pioneering work by Barbaro and Bagajewicz [10], a two-stage programming methodology has been proposed and different risk measures such as downside risk, value-at-risk (VaR) and conditional value-at-risk (cVaR) are suggested. In some later studies, financial tools such as forward contracts and futures are incorporated to hedge the risk. For example, the work by Park et al. [11] considers the financial risk management of a refinery via diversifying suppliers and futures contracts. In the work of Yun et al. [12], the authors implement futures contracts to hedge against the fluctuating price pattern for raw materials and create a model for multi-product biorefinery to enhance the process profitability. Recently, researchers also develop other methodologies to address the challenge in price risk. For example, Calfa and Grossmann [13] develop an optimization framework to address both contract selection and price optimization with different price models. A deterministic optimization is implemented first, and then followed by a stochastic counterpart that considers demand and raw material price uncertainty. In their later study of the optimal procurement process in an oil refinery [14], financial derivatives and production flexibility strategies have been introduced in their one stage stochastic program framework. The work of Cheng and Anderson [17] creates a sequential stochastic program model to determine the short-term production commitment and hedging decisions for a lignocellulosic biorefinery. The environmental constraints are considered by imposing tiered carbon tax constraints. Cheali et al. [16] explore the effect of market price uncertainty on the design of optimal biorefinery configuration through developing a computer-aided decision support tool. Geraili and Romagnoli [15] add downside risk measure to their previous decision framework (Geraili et al. [18]) to control the price uncertainty. Such choice leads to a multiobjective optimization.

Several earlier researchers have focused on finding the ethanol threshold prices of entering and exiting the business for a corn biorefinery under policy and supply-side price uncertainty [19–24]. Schmit et al. [19] have determined the ethanol gross margin for different scales of corn ethanol plants under increasing price volatility. They further concluded that the ethanol margin variability delays the new plant investment and exiting of operating plants. In their later study [20], the recent US renewable energy policy change is investigated and their impact on the development of corn biorefinery is quantitatively measured. This line of inquiry concluded that the existence of these policies has ensured the survival of the plants, and narrowed the distance between optimal entry and exit curves. The work of Kirby and Davison [21] uses Monte Carlo methods to assess the value of a corn ethanol facilty under a real options framework, showing that even a modest increase in correlation between gasoline and corn prices would singificantly devalue the plant. Based on the Kirby and Davison [21] work, Maxwell and Davison [22] determine the managerial decision for a corn biorefinery to switch between operating and suspending the plant. They also demonstrate that increasing correlation between corn and ethanol prices is detrimental to the biorefineries, and without government subsidy, the plant is still profitable but embraces larger risk. Maxwell and Davison [23] generalize to develop a quantitative framework to model and interpret regulatory changes during the life of a corn biorefinery, and arrive at the conclusions that the policy uncertainty may impact the plant's profitability either way depending on the subsidy level. And since the operator is risk averse, it is always optimal to switch off the plant before policy changes. Finally, Li et al. [24] evaluate whether it is a good time to invest in cellulosic biorefinery in Iowa, and find out that it is profitable yet non-optimal to invest in pyrolysis-based biorefinery and the gain from waiting exceeds the costs of delaying the investment project.

The findings of these papers suggest that the financial feasibility of biofuel production is subject to financial and policy risk, thus management of the risk becomes essential for the industry sustainability. However, each of these studies uses financial derivatives to *value* the project, not as an operational strategy for risk management. This approach fails to reflect the current practice of fuel trading industries. Interviews with biorefinery operators have shown long-term production and risk management strategies are more favorable compared to the short-term ones. As for the financial instruments used in risk management, swaps have gained substantial popularity in the last decade for long term risk management [25]. Therefore, it is essential to quantitatively model the use of swap contracts in long term risk management for biorefinery industry.

Moreover, in most of the biorefinery process models, the environmental concerns, such as greenhouse gas (GHG) emission, are overlooked. According to Boldrin and Astrup [26], although a biorefinery is generally recognized as a tax credit earning facility thanks to its greenhouse gas emission reduction, this is not universally true due to the choice of calculation criteria in implementing life cycle analysis. As a result, it is necessary to consider the production strategy under a stringent carbon tax policy. Finally, unlike an ordinary oil refinery where the price uncertainty mainly arises from the supply side, the fair price of the feedstock of the second generation biorefinery is still in the exploration stage, therefore, no solid market has been formed to effectively manage the potential price uncertainty (Larson et al. [27]). However, the price volatility for the final product can be a major concern.

The only existing literature that explicitly considers the effect of environmental policy on the production and risk management strategy is the work in Cheng and Anderson [17]. However, the framework of Cheng and Anderson [17] considers a short-term decision horizon, allowing simpler time series models and risk management tools. Therefore the current study contributes to the state of the art in the following directions:

- Related previous work such as Cheng and Anderson [17] or Ji et al. [14] assumes that the spot price follows Geometric Brownian Motion (GBM), which is appropriate for short time horizons. Under a long-term horizon, the use of GBM to represent the underlying product price is no longer acceptable. The inherent drift in this type of model would result in more conservative production and hedging decisions for the biorefinery operator, thus leading to a suboptimal profit level. Therefore, for the longer term model developed here, a more realistic model is required. Specifically, a sophisticated two-factor model is applied based on Schwartz and Smith [28] to simulate the ethanol spot price and the fixed rate (formally introduced in Section 3.3) pricing of the swap contract.
- Previous research on the use of financial derivatives for risk management in this industry has focused on simple forward contracts. However, forward contracts are not frequently used in the commodity derivative industry, so this work extends the existing literature by considering the use of swap contracts for hedging.