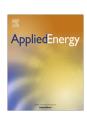
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Financial sustainability for a lignocellulosic biorefinery under carbon constraints and price downside risk



Lingfeng Cheng a,b, C. Lindsay Anderson a,*

- ^a Department of Biological and Environmental Engineering, Cornell University, United States
- ^b Department of Chemical and Biomolecular Engineering, Cornell University, United States

HIGHLIGHTS

- Stochastic program determines production, risk management strategy for biorefinery.
- Scheduled production commitment decreases as tiered carbon tax rate increases.
- Risk averse producers prefer the forward contract as a mode of product sales.
- Time varying forward prices and inventory enable producers to increase profits.
- Inventory is beneficial to producers, below the threshold for inventory costs.

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ABSTRACT

The development of an environmentally sustainable and financially viable replacement for fossil fuels continues to elude industry investors even though the benefits of replacing them is undisputed. Biofuels are among the promising replacements for fossil fuels. However, the development and production process for bio-based fuels creates uncertainty for industry investors. In order to increase process profitability, financial tools can be implemented with current technology. This paper proposes the use of forward contracts to mitigate risk, and it also considers the impact of carbon tax constraints and price uncertainty. Specifically, a stochastic optimization approach is implemented to develop strategies, which increases the net present value (NPV) of a production facility through determination of an optimal production schedule, as well as the creation of a portfolio of forward contracts to reduce product price risk. Results of numerical case studies show that if the policymaker is risk averse, production is higher in the early planning period rather than the later period. This paper also investigates the ability to maintain inventory in order to create additional financial benefit.

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1. Introduction

Production of fuel from biomass feedstock faces uncertainty in technology, logistics and market development, thus creating challenges for the industry investor [1]. Non-food feedstocks such as corn stover and perennial grasses have the most potential to be adopted in the future generation of biofuel facilities. In order to develop a viable biofuels industry, it is necessary to overcome challenges in process technology, and to determine optimal platform design. In addition, the financial viability of the process are sufficiently unstable that investment in the industry will require

succinct understanding of market dynamics, and careful management of financial risks. Financial derivatives, such as forward and swap contracts are widely used in the energy industry to hedge against the price downside risk [2]. Moreover, the price of biofuel based energy products does not take into account the cost of greenhouse gas emissions resulting from their production [3]. National governments can play a role in accomplishing a deduction of greenhouse gas emission by imposing carbon emission tax [4], thereby increasing the production cost of a biorefinery. According to [5], 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. As a result, it is necessary to consider the production schedule under stringent carbon tax policy.

The main purpose of this study is to determine an optimal production schedule and ethanol forward contract strategy for a

^{*} Corresponding author.

E-mail address: landerson@cornell.edu (C.L. Anderson).

Nomenclature Sets totalC total amount of organic compound discharged to water chemical components biogas total amount of biogas generated for electricity generaoperating unit unit carbon tax price regions genCH₄ total amount of CH₄ generated r total amount of CO2 generated l ethanol spot price scenario index genCO₂ month index genNO_v total amount of NO_x generated q feedstock used prod the amount of ethanol produced **Parameters** GHG total amount of Greenhouse gas produced M_i molecular weight of chemical component i Energy balance variables: Φ_i composition of chemical component i in feedstock energy needed to heat the operating unit i Q_{h_i} T_i required temperature in operating unit j Q_{c_j} energy produced from operating unit j heat capacity of chemical component i Cp_i energy produced from cooling the final product Q_{fc} price of chemical component i Price: Utility variables: enthalpy of chemical component i H_i HP high pressure steam required for heating Purindex_i purchasing cost index for operating unit j LΡ low pressure steam required for heating installing cost multiplier for operating unit j CW cold water required for cooling base price for operating unit i electricity total amount of electricity generated ratio, upper bound ratio of greenhouse gas emission for Resteam total steam generated gion r $unit_r$ Cost variables: unit carbon tax price for Region r sales revenue earned from ethanol and surplus electricity FOC_r process fixed operating cost corresponding to Region rVOC variable operating cost lower bound of the feedstock's hourly availability fs **FCC** fixed capital cost сар production capacity of the process WC working capital Boil boiler efficiency IC equipment installing cost Turbo turbo generator efficiency PC equipment purchasing cost electricity surplus ratio TDC total direct capital tax tax rate TIC total indirect capital IRR internal return rate ΝI annual net income for the plant time process lifetime NPV net present value user defined lower bound for NPV K Second stage variables forward contract price for month q F_q Continuous variables $P_{l,q}$ ethanol spot price for month q and scenario lethanol historical mean spot price production level for month q $P_{ethanol}$ the amount of ethanol sold in forward market for month unit inventory cost w_a cost S lower bound for ethanol spot price of the future month the amount of ethanol sold in spot market for month q c_q S upper bound for ethanol spot price of the future month inventory levels for month q $carbon_tax_{l,q}$ carbon tax collected for month q and scenario l Variables revenue, quarterly revenue for scenario l First stage variables quarterly net income for scenario *l* NI_1 Binary variables NPV_1 net present value for each scenario indicator variable, carbon emissions in Region r α value at risk Continuous variables an auxiliary variable defined in cVaR constraint z_l Mass balance variables: flow of chemical component i to operating unit j $f_{i,i}$

biochemical lignocellulosic biorefinery, in order to maximize its net present value under an acceptable level of risk. Throughout this study, the process model developed in [6] is used. In addition, the forward contracts are assumed to be readily available between the biorefinery and its counter-party. The forward contracts' strike prices are determined empirically through historical spot price average. The contract pricing problem is not addressed in this paper, but is discussed in the future work.

The paper is organized as follows. Section 2 provides a literature review of lignocellulosic biorefinery process optimization, the study on environmental and financial analysis of a lignocellulosic biorefinery, and the work on risk management in energy industry. Section 3 includes the description of the process parameters and assumptions, the formulation of the optimization model, and the solution procedure. The results are discussed in Section 4. Finally, in Section 5 the conclusions are drawn.

2. Literature review

2.1. Integrated lignocellulosic biorefinery process optimization

A typical lignocellulosic biorefinery includes feedstock storage and handling, pretreatment, saccarification and fermentation, product, water, and solid recovery, as well as waste water treatment [7]. For each step, several alternative technologies are available. A complete design of a biorefinery process model is achieved by choosing one technology for each of these steps while understanding the implications of each selection for the overall system performance. To date, researchers have proposed various methodologies to optimize the production process under specific objectives.

For example, Zondervan et al. [8] have established a biorefinery optimization model for a multi-product system. They consider a production network of 72 processing steps that can be used to pro-

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