Applied Energy 230 (2018) 330–343

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

# Financial viability of biofuel and biochar production from forest biomass in the face of market price volatility and uncertainty

Robert M. Campbell[a,b,*], Nathaniel M. Anderson[b], Daren E. Daugaard[c], Helen T. Naughton[a]

[a] University of Montana, Economics, Liberal Arts Room 407, 32 Campus Dr., Missoula, MT 59812, USA
[b] U.S. Forest Service, Rocky Mountain Research Station, 800 East Beckwith, Missoula, MT 59801, USA
[c] Burning Oak Energy, LLC, Rolla, MO 65401, USA

## HIGHLIGHTS

- Uncertainty in market prices drives financial outcomes.
- Monte Carlo simulation allows uncertainty to be quantified.
- Biochar-only production offers a potentially profitable venture.
- Biofuel-biochar coproduction requires RINs to achieve financial success.

## ARTICLE INFO

*Keywords:*
Financial analysis
Techno-economic analysis
Biofuel
Biochar
Pyrolysis

## ABSTRACT

A comparative techno-economic analysis of two different thermochemical biomass conversion pathways was conducted to examine the effects of fuel price and other variables on project financial performance. Monte Carlo simulation was used to quantify the effects of uncertainty and volatility of ten critical variables: biofuel, biochar and feedstock prices, discount rate, capital investment, labor cost, loan terms, feedstock drying, and biofuel and biochar conversion rates. Market prices for biofuel and biochar have the largest impact on net present value (NPV) of any variable considered, due in part to the high levels of uncertainty associated with future prices of both. Across the ranges of input values for these variables in simulation analysis, hearth-based pyrolysis biochar production had the highest likelihood of profitability with a mean NPV of $41.5 million and only 20% of outcomes resulting in a net loss, while 68% of outcomes for auger-based biochar-biofuel coproduction represented a financial loss, including a mean NPV of -$24.2 million. However, when additional revenue from Renewable Identification Numbers (RINs) credits generated by biofuel production is considered, financial outcomes of biochar-biofuel coproduction improve to 50% likelihood of experiencing a net loss. Findings of the very strong impact of market prices on financial outcomes, relative to other important technical and economic variables, can inform effective targeting of future renewable energy policy, as well as the design of future techno-economic analyses, which do not currently focus on the effect of market prices on profitability.

## 1. Introduction

### 1.1. Background

Today the Earth's climate is widely acknowledged to be changing as a result of anthropogenic greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (IPCC), one of the essential actions in mitigating the effects of climate change is offsetting a substantial portion of fossil fuel consumption with renewable energy sources [1]. In order to reduce fossil fuel emissions, governments around world have implemented policies that encourage the transition from fossil fuels to renewable fuels through the use of both market-based mechanisms and command-and-control approaches.

In the United States of America (U.S.), the Energy Independence and Security act of 2007 aimed to increase energy security and reduce greenhouse gas emissions. As part of this legislation, the Renewable Fuel Standard established by the Energy Policy Act of 2005 was expanded, setting renewable blending targets for transportation fuels that increase each year to an annual target of 36 billion ($36 \times 10^9$) gallons (gal) (136.3 billion liters [L]) by 2022 [2]. Compliance with the

* Corresponding author at: University of Montana, Economics, Liberal Arts Room 407, 32 Campus Dr., Missoula, MT 59812, USA.
*E-mail address:* robert3.campbell@umontana.edu (R.M. Campbell).

https://doi.org/10.1016/j.apenergy.2018.08.085
Received 28 June 2018; Received in revised form 10 August 2018; Accepted 16 August 2018
0306-2619/ © 2018 Elsevier Ltd. All rights reserved.

mandate is tracked through the use of Renewable Identification Numbers (RINs), which are generated by the production of renewable biofuel and act as credits that can be bought and sold by obligated parties. According to the U.S. Energy Information Administration (EIA), despite the financial incentive provided to producers by RINs and other mechanisms such as tax credits and loan guarantees, the targets for non-corn cellulosic biofuels have never been met [3,4].

Woody biomass from forests is one source of feedstock that can be used to produce cellulosic biofuel and help meet fuel blending targets. According to a study by the U.S. Department of Energy (DOE), biomass residues from forest management have the potential to provide between 16.2 and 18.9 million (M) dry tonnes (equivalent to 1000 kg and abbreviated *t* unless otherwise noted) of biomass per year for energy [5]. However, there are technical and logistical challenges associated with the production of biofuel from forest biomass that can reduce financial viability. Volatility in market prices for fossil-based transportation fuels can make investments in biofuel production risky and this volatility has likely contributed to the gap between cellulosic biofuel targets and growth in the capacity of the industry, particularly during periods of sustained low prices. Government policy incentives can offer various strategies to improve the financial viability of biofuel production through the use of mechanisms like carbon credits, renewable energy credits, capital subsidies, and reverse auctions to provide price stability. Some previous studies have found production costs of liquid biofuels from forest biomass to be too high to compete with fossil fuels without considering policy incentives [6].

Beyond government policies, the co-production of multiple revenue-generating products is one strategy biofuel producers can employ to improve the likelihood of financial success. Biofuel can be produced simultaneously with other products, such as chemicals and biochar, which is a solid carbon-rich charcoal used in a variety of applications, especially to improve soils for plant growth [7]. The few previous studies that have analyzed the financial viability of biofuel-biochar coproduction have found biofuel production to be most financially viable when biochar is considered as a revenue-generating coproduct. A study of methanol and biochar coproduction with two-stage pyrolysis or gasification processing of forest biomass found that, while gasification could produce methanol at prices competitive with fossil fuels without considering biochar revenue, pyrolysis production required the biochar coproduct to sell for between $220 and $280 per tonne to break-even [8]. Brown et al. [9] analyzed the profitability of two different pyrolysis production pathways using corn stover feedstock: a lower-capital slow pyrolysis system producing biochar and pyrolysis gas, and a higher-capital fast pyrolysis system producing biochar and bio-oil. Profitability for both pathways was found to be sensitive to feedstock prices, fuel selling prices, and the ability to earn carbon offset credits for the biochar [9].

Financial evaluation of emerging energy technologies is often conducted using techno-economic analysis, which is a modeling process that combines one or more measures of project financial performance, typically a benefit-cost analysis, with a detailed technical specification of the technology being evaluated [10,11]. These types of analyses, including the Shabangu et al. [8] and Brown et al. [9] studies of biofuel-biochar coproduction, have commonly relied on static inputs and have produced deterministic outcomes for financial metrics like net present value (NPV). This approach is most appropriate when important variables are known and consistent or accurately predictable over time, but when input variables are subject to uncertainty and volatility, as in the case of market prices for biofuel and biochar, it can produce overly simplistic estimates of project performance without quantification of uncertainty or risk [12].

Some recent techno-economic analyses have employed Monte Carlo simulation to incorporate input variable uncertainty into their estimates of financial outcomes and to quantify the sensitivity of these outcomes to changes in specific variables. Using a simulation approach, Petter and Tyner [12] found that uncertainty in product selling price was a main contributor of risk to investors in biofuel production facilities [12]. This finding may have been overlooked without the use of Monte Carlo methods, as they noted that previous studies of the same facilities that used deterministic sensitivity analysis instead found technical uncertainties associated with product yield and biomass feedstock cost to be the most influential variables in determining financial outcomes. Zhao et al. [10] estimated probability density distributions for both NPV and break-even price for eight different biofuel production pathways and also found that product market prices had the strongest effect on financial outcomes. In a different study, Zhao et al. [13] estimated break-even price distributions for cellulosic biofuel production using both programming and mathematical methods. They found break-even price to be most sensitive to technical uncertainty associated with feedstock cost and fuel yield. Yao et al. [14] accounted for technical uncertainty in alcohol-to-jet biofuel production to produce distributions of break-even price and found significant profitability impacts from technical uncertainty in fuel conversion rates and revenues generated from conversion by-products. No previous studies have used Monte Carlo simulation to analyze biofuel-biochar coproduction and the considerable uncertainty associated with future biochar markets and prices.

This study uses techno-economic analysis to compare two different pyrolysis production technologies using forest biomass feedstock. The purpose is to identify the factors that have the strongest effect on financial success to inform decision making that leads to efficient investment and effective operation of commercial facilities. The goal is to facilitate increased renewable biofuel and bioproduct production. The study improves on previous research in several important ways. It uses Monte Carlo simulation to account for uncertainty and volatility in key technical and financial variables associated with biofuel and biochar coproduction via pyrolysis. To our knowledge, no previous published study has accomplished this. Furthermore, rather than using a simple normal distribution based on a percentage range applied to a base case value, the distributions of these variables are established based on market transaction evidence and data collected from the operation of pilot scale facilities, with special emphasis on documentation of biofuel and biochar pricing.

Two biomass conversion pathways are evaluated. The first technology requires higher capital investment and can be used to produce both cellulosic biofuel and biochar, or biochar only, depending on market conditions. The second technology is a less costly investment, but only produces biochar with no liquid fuel option. Because of the substantial uncertainty associated with future biofuel and biochar prices, we hypothesize that the market prices for the goods produced will be the most impactful variables in the financial success of biofuel-biochar coproduction. Based on findings by previous studies and the experience of the authors with pilot scale systems, we also hypothesize that biofuel production will not be financially viable without considering biochar as a revenue-generating coproduct.

This section proceeds with a summary of the conversion pathways and their products, followed by a thorough review of available information about potential markets and prices for biochar to contextualize the potentially lucrative, but highly uncertain future status of biochar production. In the Methods section, technical descriptions of the two pyrolysis technologies considered in this study are provided and the methods used for financial evaluation are presented. Then, results of the analysis are presented and their implications for investment in and operation of biofuels facilities are discussed. Finally, the main conclusions are summarized with an emphasis on technology investment and management of coproduction operations.

### 1.2. Biomass conversion using pyrolysis

Biomass can be transformed into energy and products using biological conversion, including fermentation and digestion [15], or thermochemical conversion, including combustion, gasification [16],

Download English Version:

https://daneshyari.com/en/article/10131314

Download Persian Version:

https://daneshyari.com/article/10131314

Daneshyari.com