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Impact of feedstock diversification on the cost-effectiveness of biodiesel

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HIGHLIGHTS

- Chance constrained optimization model developed to evaluate biodiesel blends.
- Physical property derivation of technical constraints derived from fatty acid types.
- Uncertainty and variation in feedstocks managed through optimization formulation.
- Feedstock diversification reduces costs while maintaining fuel specifications.

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ABSTRACT

While biodiesel production and consumption for use in transportation has risen considerably over the last decade, its competitiveness in the marketplace is largely due to regulatory and fiscal support from governmental bodies, exceeding $25 billion in 2010 in the EU and US alone. The price of feedstocks represent 80–85% of the total biodiesel cost, and with over 350 different oil feedstocks available for blending, there is potential to optimize feedstock blends to reduce costs. This paper presents a chance-constrained optimization model that considers the technical constraints of conventional, first generation feedstocks, pricing trends, as well as the uncertainty and variation latent within these numbers. Further, the frequency with which a feedstock blend portfolio should be re-evaluated is considered through a case study. The model is then applied to a second case study for actual fuel constraint scenarios used in the EU and US. The results demonstrate the potential for substantial cost savings through targeted feedstock diversification, minimizing risks to producers from price fluctuations while still meeting technical fuel standards.

1. Introduction

Worldwide economic growth drives ever-increasing demand for energy across all economic sectors. For the transportation sector, this growth may translate into a rate of energy demand which nearly doubles by 2050 [1]. Meeting this demand securely and sustainably will require leveraging a range of solutions, including a shift to alternative and renewable fuels.

Despite controversies around its lifecycle greenhouse gas (GHG) emissions and potential contribution to increased food and feed prices [2–5], many believe that biodiesel will play an important role in the alternative fuel portfolio for transportation due to widespread policy goals. In fact, consumption of biodiesel has increased tremendously over recent years as a result of national energy policies worldwide [6]. In the US, domestic production and use of biodiesel rose from approximately 7.5 million liters in 2000 to 4 billion in 2011 [7–9]. Globally, demand is even greater. In the EU, biodiesel consumption has grown to over 10 billion liters [10], and the OECD-FAO projects global production to exceed 45 trillion liters by 2020 [11]. Unfortunately, this commitment to biodiesel comes at a cost. Currently, the production of biodiesel is more expensive than petrodiesel, and regulatory and fiscal governmental intervention is required to sustain the biodiesel market [12,13]. Steenblik [3] estimates that combined subsidies for biodiesel and bioethanol exceeded $25 billion in 2010 in the US and EU alone [3]. While the short-term goal of these policies is to meet national renewable energy targets, the long-term expectation is that the biodiesel industry will mature into a cost-competitive alternative to petrodiesel.

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Creating a self-sustaining biodiesel industry will require changes throughout the whole biodiesel supply chain: from feedstock cultivation to transport of feedstocks to biodiesel production through blending of these feedstocks [14]. Operational-level decision making at these production facilities, particularly the feedstock selection process for blending, appears to offer a significant opportunity to reduce production cost. For biodiesel produced by transesterification, feedstock costs represent between 80% and 85% of the total production cost [6,15,16]. In addition, the individual feedstocks on which biodiesel depend exhibit high price volatility, threatening the long-term financial stability of any producer [17]. Skillful selection of a portfolio of raw materials at the producer level can provide a powerful financial advantage and, as this paper will show, if that portfolio is diversified it can stabilize costs, reducing financial risk.

Realizing the goal of nimble, diverse feedstock selection is challenging, however, for several reasons, including: (1) the number of available feedstocks (at least 350 identified to-date) [18]; (2) the difficulty in mapping physical characteristics of the feedstocks to ultimate fuel performance; (3) the variation of feedstock properties (including prices) across time and location [18,19], and (4) national policies that limit access to otherwise technically and/or economically attractive feedstocks.

Recognizing these complexities surrounding optimal feedstock selection at the producer level, this paper will (a) describe a basic model by which producers can identify the best feedstocks for given market context; (b) explore whether the optimal blend changes across market contexts, and (c) characterize the potential economic value of adopting various approaches to risk mitigation through batch planning. The work contributes to the understanding of how feedstock diversification can help control costs while maintaining fuel quality, and under what contexts the benefit of diversification is most valuable. To accomplish these goals, a composition-based physical property prediction model has been developed for four key properties. Furthermore, a chance-constrained (CC) optimization method, which explicitly considers the inherent uncertainty present in feedstock properties (or quality) using performance-based constraints, has been implemented for a few cases to find the minimum-cost blend portfolio for a given market context. Only conventional vegetable oils commonly used for biodiesel production have been studied in the scope of the work.[1] While case-based work focusing on four properties and select feedstocks is limited in its generalizability, this demonstration provides evidence that CC optimization in biodiesel blending models can identify production strategies that lower average cost and that hedge against price volatility for producers.

1.1. Challenges in feedstock selection for biodiesel

Others have recognized that feedstock diversification may be an important issue for the biodiesel industry. For example, in an effort to control financial risks emerging from fluctuations in feedstock prices, some US producers have converted their facilities to multi feedstock use systems, especially after the price of soybean oil rose faster than diesel prices between 2007 and 2008 [7]. Furthermore, the US Department of Agriculture started to fund research on feedstock diversification. However, to date, there has been little quantitative research done on the potential cost implications of diversification strategies.

Meanwhile, identifying the optimal blend of raw materials to make a final product is not a new topic and has been explored for decades in many industries [20,21] including the petroleum industry [22–24]. Methods have also been developed to explicitly consider uncertainty and integrate it into complex optimization problems [25]. To date, these models have limited treatment of biodiesel or employed performance-based specifications for biodiesel beyond empirical measurements of blends [26,27]. A recent article explored blends of biodiesel–ethanol–diesel fuels to identify valuable additives as well as demonstrate profit improvements for firms using these blends through use of waste feedstocks [28]. Batch planning decisions in the biodiesel industry have primarily been based on fixed recipes derived from producer experience [18] and therefore previous work has extrapolated fuel prediction rules from this empirical work. The work presented here aims to derive these properties from building blocks of the feedstocks and then explicitly manage their uncertainty through chance constrained blending models.

Producers face two key challenges related to selecting appropriate feedstocks. These are (1) compliance with regionally-specific technical specifications and policy requirements, often not met by a single feedstock and thereby requiring blending of multiple feedstocks, and (2) uncertainty in feedstock properties coupled with price volatility. Helping operators make decisions about diversification requires an approach capable of dealing with these challenges through a tool that is capable of designing multi-feedstock blends and predicting the final fuel properties prior to blending. This capability can enable producers to modify the batch composition over time as prices fluctuate and thereby obtain cost-effective and technically compliant biodiesel capable of competing with petrodiesel.

Because feedstock cost is estimated to be a major part of the production cost [15,16,26,29,30], cost reduction opportunities are strongly dependent on the feedstock prices. These prices not only differ from each other across feedstocks, but also fluctuate to a significant extent over time. Fig. 1a shows some of these prices between January 2003 and June 2011, deflated by the FAO vegetable oil price index. When the relative prices among feedstocks shift based on the market conditions, a producer might need to modify the feedstock proportions used in the batch to remain profitable. As can be seen from Fig. 1b, the correlations among deflated feedstock prices are either fairly weak and positive, or relatively strong and negative. Given that lack of strong positive correlations, the price behavior suggests that maintaining a diversified blend portfolio could be helpful to hedge against unexpected price changes in the market [31]. The ability to quickly adjust the blend portfolio in response to dynamics such as price fluctuations and availability in the market could bring substantial value to biodiesel producers.

2. Methods

2.1. Physical property prediction model

The physical characteristics of feedstocks typically used in a biodiesel batch differ from one another and these differences impact the characteristics of the final fuel. In most cases, a single feedstock is not able to meet all the technical specifications. These specifications also vary by region, for example, the EU has a higher *oxidative stability* standard compared to the US, and also enforces a maximum *iodine value* constraint that limits the use of soybean typically imported from the Americas.

Here we describe the development of the physical property prediction model to address the challenge of complying with four technical specifications. These four specifications were chosen

[1] Feedstocks considered in this paper provide more than 80% of today's global biodiesel production and this trend is not likely to change soon. The authors acknowledge the applicability of the methods developed here on the 2nd and 3rd generation raw materials including biodiesel derived from waste-cooking oil. However further data is needed to properly apply the model on these raw materials.