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Economic feasibility of tobacco leaves for biofuel production and high value squalene

RESEARCH ARTICLE

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Abstract

In this paper, we estimate the economic feasibility of biofuel production and high value squalene from tobacco-based biomass. Pro-forma stochastic financial statements were constructed and the feasibility of multi-year financial projects were evaluated. The results suggest the commercialization of biofuel production from tobacco is not economical in the short run, but may have a potential in the long run. The results also indicate the economic feasibility of high value squalene is viable under the certain conditions.

Keywords: biofuels, tobacco, squalene, project feasibility analysis, multi-year simulation models
JEL code: C15, Q13, Q16, Q42

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1. Introduction

In this article we investigate the economic and financial feasibility of biofuel and high value squalene production from tobacco leaves. Using a tobacco plant as a feedstock has been motivated by recent interest in investigating renewable fuel feedstocks. In 2004 the U.S. government terminated the federal tobacco quota program (Capehart, 2004). This safety net used a production control and price support system to guarantee farmers a minimum price at the beginning of the season. The termination of the program had a substantial impact on tobacco farmers. The 2012 Census of Agriculture found that the number of tobacco farms decreased by 82% from 56,977 in 2002 to 10,014 in 2012. Elimination of the safety net put tobacco farmers into an uncertain market with risky prices (USDA, 2012). In terms of acreage, the harvested area decreased by 30% from 2004 to 2016 (USDA, 2016). Alternative use of a tobacco plant, specifically for renewable fuel, has been discussed in the literature (Adrianov *et al.,* 2009; Giannelos, 2002; Usta, 2005; Usta *et al.,* 2011). Over the last few years, research institutions, such as Tyton BioEnergy Systems, Synthetic and Systems Biology Innovation Hub, NUP/UPNA-Public University of Navarre, the IdAB-Institute of Agrobiotechnology, and Lawrence Berkeley National Laboratory, have begun to engineer and modify the plant to use it as a fuel feedstock. The advances in the research show promising potential for tobacco growers, but these institutions have not addressed the key issue yet, whether tobacco farming as a feedstock is economically viable or not? This study contributes to the literature by developing a probabilistic financial model, based on the Monte Carlo simulation approach, to assess the economic feasibility of tobacco leaves as a renewable fuel feedstock. Currently, two main products can be produced from a tobacco plant if used as a feedstock, a finished motor fuel, and high value squalene oil. Both of these products are highly demanded, as outlined in the next two sub sections.

Tobacco as a renewable fuel

Rising energy costs and policies to reduce dependence on foreign energy supplies has dramatically increased the domestic production of plant-based fuels as an alternative fuel source. Fossil fuels are becoming scarce resources and their prices will again increase gradually. Moreover, the energy sector is one of the largest contributors to greenhouse gas emissions, and a contribution to climate change. Global demand for energy is expected to increase by at least 50% over the next 20 years, with this increase mainly driven by rapid population growth and industrial development in developing countries (Brackmort, 2012; Liu *et al.*, 2014). Alternatives to fossil fuels have been sought for decades. Biofuels have been considered one the most promising possibilities for solving the problem. The U.S. is searching for solutions through biofuels because these fuels are renewable, which means they can be constantly replenished and, in contrast to nonrenewable sources, won't eventually dwindle. Moreover, the United States is committed to increase the amount of biofuels it uses from 9 to 36 billion gallons by 2022 (Brackmort, 2012).

Currently, biofuels are produced from different types of biomass, including sugar-cane, corn, vegetable oil, algae, and wood, to name a few. Ethanol production is the major plant based-biofuel that has been used as an alternative fuel in the United States and Brazil. With the current available technology, virtually all ethanol is derived from corn in the United States. Because corn is also a food source, use of corn for ethanol production will affect consumers through food price increases. Considering a nonfood alternative for biofuel production is critical. Producing fuels and fuel-like precursors from farm-ready and non-food crops have been motivated by the U.S. Department of Energy as well. The tobacco plant is a potential source of renewable energy. In particular, tobacco leaves contain hydrocarbon molecules that can be converted into a fuel that can be used as a substitute for a petroleum fuel.[1] The tobacco leaves have at least four advantages in terms of biofuel production:

[1] The supply chain for tobacco-based renewable fuels is going to closely resemble to an existing supply chain for corn ethanol. The chain is composed of three main segments, tobacco biomass production and harvesting, squalene extraction, and refining to finished motor fuel. Tobacco production and harvesting will be similar to the conventional tobacco farming and the differences are outlined in the article. By-products, such as distiller's dried grains with solubles, will not be fed to animals but will be treated as residual stalks that are potential inputs for the pulp and paper industry.

1. Unlike other biofuels made from corn, soybean, and other crops, tobacco as a biofuel feedstock would not directly affect a major food source.
2. Tobacco generates multiple harvests per year and produces a large biomass.
3. Tobacco is amenable to genetic engineering, which means that in the long-run its leaves can store more hydrocarbon molecules than are currently present.
4. Tobacco cultivation has been widely known and it is grown in large tracts throughout the South and Eastern U.S., as well as more than 100 countries.

Tobacco as a high value squalene

The main hydrocarbon of interest contained in a tobacco leaf is squalene. Squalene is an isoprenoid compound structurally similar to beta-carotine and it is an intermediate metabolite in the synthesis of cholesterol. Squalene has clinical applications, mainly used as an adjunctive therapy in a variety of cancers (Kelly, 1999). Brito *et al.* (2011) also discuss the importance of squalene use in emulsion adjuvants. Squalene is also shown to have antioxidant, drug carrier, detoxifier, skin hydrating, and emollient characteristics (Kim and Karadeniz, 2012). Demand for squalene is high and according to Markets and Markets, a research firm, the squalene market is estimated to reach $211 million by 2021 and is projected to grow annually by 10.2% between 2016 and 2021 (Markets and Markets, 2016). Squalene extracted from the tobacco leaves does not have to be used for biofuel production and can be commercialized directly, given its clinical uses.

Objective of the study

The objective of the study is to estimate the economic feasibility of both biofuel production from tobacco leaves and high value squalene production. First, we analyze biofuel and squalene markets independently. Following, we discuss major requirements for tobacco-based biofuel production to become financially feasible. To achieve this objective, the sub-objectives are to:

1. Model the cost of tobacco production for biomass.
2. Estimate the cost of squalene extraction from the leaves.
3. Estimate the cost of squalene refining for the finished motor fuel.
4. Estimate the probability of profitable production of finished biofuels and high value squalene from tobacco biomass, and report pro-forma financial statements to analyze the overall economic feasibility of the two products.

2. Literature review

Research related to feedstock feasibility for biofuels literature is very broad, and extensive. Many feedstock alternatives have been studied from an economic standpoint, such as, algae, sweet sorghum, sugar cane, energy cane, switchgrass, corn starch, corn stover, to name a few (Monge *et al.*, 2014; Outlaw *et al.,* 2007; Palma *et al.*, 2011; Rezenede and Richardson, 2015; Richardson and Johnson, 2014, 2015; Richardson *et al.,* 2007a,b, 2010, 2014a,b). Comparing a tobacco-based feedstock feasibility with the feasibility studies of other feedstock materials are not applicable, as they depend on different production, price, yield, and, most importantly, technology assumptions.

Research related to biofuel and squalene production from tobacco feedstock is limited. Because the concept of using a tobacco plant as a feedstock is still in its infancy, the area of research is a new concept. At this time there does not exist a single study that addresses the economics of renewable fuel production from the tobacco plant or the production of high value squalene from tobacco leaves. Some studies have analyzed the chemical properties of producing biofuel from tobacco seeds (Giannelos, 2002; Usta, 2005; Usta *et al.,* 2011). Although these authors found that the seed oil can be used as a fuel for diesel engines, tobacco plants yield a modest amount of seeds, making a biofuel production unattractive from a financial standpoint. Adrianov *et al.* (2009) explored engineering approaches to enhance the oil content in tobacco leaves for biofuel production. Typical tobacco plant leaves contain 1.7 to 4% of oil on a dry weight basis. Tobacco plants were engineered and gene modification increased oil content to 6.8%. Adrianov *et al.* (2009) strengthen the argument that the tobacco plant can be genetically modified to produce more hydrocarbon molecules. They emphasize that because of its biomass potential and the possibilities of further metabolic engineering, tobacco represents an attractive and promising energy plant which could also serve as a model for utilization of other high-biomass plants for oil production. However, this hypothesis has not been verified from an economic standpoint.

All of these studies discuss the potential of the tobacco plant for being a next generation biofuel crop. However, none of these studies actually describe the economic feasibility of the feedstock to produce biofuels. The current study aims to bridge the gap and focus on economic feasibility. The study will be useful to investors or scientists looking for a new biofuel feedstock or new materials for squalene production.

3. Data and methodology

Economic feasibility studies including risk have proven to be a powerful tool in business valuation (Johnson *et al.*, 2016; Kwak and Ingall, 2007; Monge *et al.*, 2014; Outlaw *et al.*, 2007; Palma *et al.,* 2011; Rezende and Richardson, 2015; Richardson and Johnson, 2014; Richardson *et al.*, 2007a,b, 2014a,b). We employ a stochastic cash flow and net present value (NPV) approach for the analysis.[2] A stochastic NPV approach has been widely used as one of the main methodologies to define the overall viability of a risky project (Monge *et al.,* 2014; Outlaw *et al.*, 2007; Palma *et al.*, 2011; Richardson *et al.*, 2007a,b). NPV is also considered to be a simple and intuitive approach for lay investors (Monge *et al.,* 2014). Therefore, the NPV probability distribution estimated using a Monte Carlo simulation method, and the underlying probability distributions for stochastic variables (yields, input prices and output prices) will be used to conduct the feasibility studies for biofuel and squalene. The estimation of the underlying probability distribution for NPV is critical in the estimation of the probability of success, where economic success is defined as a positive NPV criteria.[3] Assumptions for estimating the probability distributions for the random variables (yields and prices) are discussed in the subsequent sections.

Tobacco biomass yield

Tobacco biomass yield and squalene production are critical stochastic variables for the two economic simulations. Tobacco for biofuel feedstock production requires more dense planting than traditional tobacco production for conventional use, so historical yield data cannot be used directly. Because there is no market for tobacco yield that requires dense planting, the yields for biomass tobacco were simulated using the GRKS distribution.[4] The assumed minimum, middle, and maximum yield values were obtained from the trials conducted by Mundell and Chambers (2011) at the Kentucky Research Institute. Their results indicated that tobacco yield ranged between 55,000 to 150,000 pounds per acre. Assuming 80% moisture content, this translates into approximately 11,000 to 30,000 pounds per acre on a dry matter basis. Given limited yield data is available, the GRKS distribution was used to simulate yield with a minimum of 55,000, middle of 90,000, and maximum of 150,000 pounds per acre. A 6% growth rate was incorporated each year to account for technological increases in yield over time. Using the inverse transform sampling method,[5] the tobacco yield is distributed as follows (the values are in thousands of pounds and the sign, '~', denotes a stochastic variable):

$$\widetilde{\text{Yield}}_{\text{tobacco}} \sim \text{GRKS}(55, 90, 150) \quad (1)$$

[2] A stochastic NPV approach has advantages when compared to conventional NPV methodology as the former allows us to combine the shapes of probability distributions for variables we cannot observe, such as: profits, costs, or prices so the decision maker can make better decisions.
[3] A positive NPV indicates that the internal rate of return exceeds the investors' discount rate. For the present study the discount rate is set at 7% as suggested by others (Richardson *et al*., 2007a; Palma *et al*., 2011; Monge *et al*., 2014).
[4] The GRKS is a parametric, two-piece normal distribution and has been used extensively for studying project feasibility analysis (Monge *et al*., 2014; Outlaw *et al*., 2007a,b; Palma *et al*., 2011; Richardson *et al*., 2007a,b). The GRKS is similar to the triangle distribution and has the same parameters: minimum, middle, and maximum values. However, it is different from the triangle distribution because it accounts for uncertainties that go below and above the assumed minimum and maximum values, respectively about 5% of the time.
[5] Inverse transform is a method for pseudo-random number sampling to generate sample numbers at random from any probability distribution given its cumulative distribution function.

Squalene yield

Extraction volume of squalene can be estimated with a high degrees of precision after its content is determined because squalene is a non-volatile compound. As mentioned previously, Adrianov *et al.* (2009) was able to increase the oil content in the tobacco plant up to 7% in a short time span, so a high squalene content in the long run is a realistic assumption. Currently, tobacco contains about 2-4% of squalene on a dry matter basis, and, as previously mentioned, several research institutions aim to achieve as high as 20% yield content per dry matter. The information was verified as well through personal communication with tobacco researchers at Synthetic and Systems Biology Innovation Hub (Synthetic and Systems Biology Innovation Hub, personal communication, April 2015).

We used two different approaches for squalene production. For the tobacco biofuel market, squalene content was assumed to be 20% on a dry matter basis. For the high value squalene market, three cases were considered. The first case uses a conservative approach and assumes that current squalene content is 2% per dry matter, experiences modest growth over time and reaches 20% in 8 years and stays the same thereafter. The second scenario assumes that squalene grows moderately faster and reaches 20% in 6 years and stays the same thereafter. The third scenario analyzes an aggressive growth and assumes that squalene content will reach 20% per dry matter in 5 years. Squalene growth assumptions, used in the three scenarios, are modest given that scientists expect to reach 20% goal in the short period of time (Synthetic and Systems Biology Innovation Hub, April 2015, personal communication). Changes in squalene content will mainly affect the cost of refining. Production and extraction costs will basically remain unchanged, because expenses are heavily dependent on the biomass production.

Diesel, gasoline, and squalene prices

Diesel and gasoline values were simulated to incorporate risk for final products. Although there are many ways to simulate fuel prices, a Markov process was shown to accurately project prices, as well as providing dynamic information about the market (Aleksandrov *et al.*, 2013; Gonzales *et al.*, 2005; Mostafei *et al.*, 2011). In a Markov process, only the present value of a variable is relevant for predicting its value in the future. Following the basic generalized Wiener process as outlined in Hull (2006), the prices of gasoline and diesel are simulated as follows:

$$\ln P_{t+1} - \ln P_t = \sigma\varepsilon(\Delta t)^{1/2} \tag{2}$$

where, lnP_t is a natural logarithm of the gasoline or diesel price observed in period t; σ is the annualized variance of diesel or gasoline price obtained from past observations; Δt is a small change in period time t; and ε is a correlated standard normal deviate obtained by multiplying a factored correlation matrix between gasoline and diesel prices by a vector of standard normal deviates. Taking $lnPt$ to the right hand and exponentiating both sides, the stochastic process follows as:

$$P_{t+1} = P_t \exp^{\sigma\varepsilon\sqrt{\Delta t}} \tag{3}$$

The simulated prices are path dependent, where:

$$P_{t+2} = E(P_{t+1}) \exp^{\sigma\varepsilon\sqrt{\Delta t}} \tag{4}$$

Simulating the squalene prices is more challenging because a long history of data is not available, compared to fuel prices. Traditionally, shark livers are processed to obtain squalene, which has increased shark hunting. The extraction of squalene from vegetable sources has been motivated by environmental concerns, surrounding shark hunting (Markets and Markets, 2016). Not until recently, Amyris, Inc. (Emeryville, CA, USA) has started selling commercial quantities of squalene derived from crushed sugarcane. Currently, squalene sells for $ 30 per liter, which translates into $ 114 per gallon (Ciriminna *et al.,* 2014). However, determining the market value of squalene in the future is highly uncertain. The GRKS distribution was used to simulate squalene prices given the limited information available. Similar to squalene yield scenarios, three cases were considered for simulating the prices as well. In the first, the minimum, middle, and maximum values were chosen to be $ 92, 100, and 114 per gallon, respectively.

$$\widetilde{Price}_{squalene} \sim GRKS(92, 100, 114) \quad (5)$$

Note, that the first scenario uses a conservative approach. In particular, we used a current market price ($ 114 per gallon) to be the maximum value in the distribution. The second and third scenarios are even more conservative, and they incorporate price decay functions to account for possible supply growth from plant based squalene and environmental regulations regarding squalene production from sharks. In particular, the second scenario assumes that squalene value will decline gradually, on average, by 5% per year over the next 10 years. The third scenario is the most pessimistic, and assumes that squalene value, on average, declines by 10% per year over the next 10 years.

Tobacco production cost

The values used in the production budget are based on projected input prices and recommended production practices suggested by the Virginia Cooperative Extension (2012) and North Carolina State University Cooperative Extension (2012). The information provided by the guidelines was adapted according to the production characteristics associated with more dense planting for biomass production, rather than for human use. The variable production costs are composed of two types of costs; pre-harvest costs and harvest costs. Additionally, production also includes fixed costs. The detailed costs are based on a machine harvest method and incorporate multiple harvests per year.

Pre-harvest costs are typically cash expenses that must be paid annually to produce a crop of tobacco prior to harvest. Examples of pre-harvest variable costs include: plants, fertilizer, chemicals, machinery fuel and repairs, hired labor, machinery fuel, machinery repairs and maintenance, interest on the sum of cash costs for the time from planting to harvest, and labor expenses. These expenses appear also in the harvest variable costs section. The guidance on expenses related to machinery and labor were obtained from extension budgets and were adjusted according to the production sizes discussed in a subsequent section.

Drying the tobacco biomass is a major post-harvest cost. Moisture content of the feedstock can be anywhere from 70-80% depending on field and weather conditions. The maximum optimal moisture content for harvest was assumed to be 80%.

Fixed costs are expenses that result from the ownership of land, equipment and buildings. Examples of these costs include depreciation, property taxes, interest, and insurance. Detailed information on fixed expenses were incorporated in the model. For illustration, the adjusted mean production costs based on 90,000 pounds of green biomass per acre are presented in Supplementary Table S1.

For input prices that have limited historical data (i.e. herbicides, fungicides), we employed a GRKS distribution to simulate those costs. For input prices that have relatively large history of data (i.e. fertilizer prices), we employed a multivariate empirical distribution (MVE) proposed by Richardson *et al.* (2000). A MVE is a non-parametric distribution and accounts for inter-temporal (across time) and intra-temporal (across variables) correlation among the random variables.

Squalene extraction and refining costs

We employed a supercritical fluid extraction (SFE) method to calculate the cost of squalene extraction from the tobacco biomass. The literature suggests that SFE is a proven method of extraction (Anderson, 2011; Bhattacharjee and Singhal, 2003; Bhattacharjee *et al.,* 2012; Cathpole *et al.,* 1997; Mercer *et al.,* 1999;

Reverchon, 1997; Rizvi *et al.,* 1986; Vazquez *et al.,* 2007). Detailed information for the cost of extraction, squalene recovery, and the cost of an SFE plant was obtained through personal communication with Cybertech Engineering. Supplementary Table S2 summarizes the required inputs and deterministic total cost of squalene extraction per acre.

Squalene is too heavy to be used directly in gasoline because it has 30 carbon atoms in its backbone. Tracy *et al.* (2011) describe squalene as a promising potential precursor to high-octane gasoline because the carbon backbone is branched. The authors describe that branched hydrocarbons are known to have octane numbers superior to linear molecules. The authors also show that catalytic cracking is a natural route to generate gasoline from squalene. Their results indicated that the gasoline obtained from squalene has high octane numbers. In particular, the research octane (RON) and motor octane numbers (MON) were 96.5 and 84.6, respectively. The result meets the required minimums of 91 RON and 82 MON for gasoline.

Cost of refining is calculated by breaking down the total cost of a gallon of gasoline to obtain the fraction of refining from the total cost. The cost of gasoline is broken down into four components: crude oil, refining cost plus profits, distribution and marketing cost, and taxes. Crude oil margin is the difference between the monthly averages of the composite refinery acquisition cost, which is basically the average price of crude oil paid by oil refineries. Refining cost and profits is the difference between the monthly average spot price of gasoline after it exits the refinery and the average price of crude oil purchased by refineries. Distribution and marketing costs and profits are the difference between the average retail price of gasoline as computed from U.S. Energy Information Administration's (EIA) weekly survey and the sum of the other two components. The fourth component is taxes, which is a monthly national average of federal and state taxes applied to gasoline and diesel. According to EIA, the cost breakdown of gasoline and diesel as of May, 2016 are represented in Supplementary Table S3.

Based on the information provided in Supplementary Table S3, the approximate cost of refining can be estimated accounting for the fraction of diesel and gasoline that could be refined from squalene. Following Tracy *et al.* (2011), Hillen *et al.* (1982) and Banerjee *et al.* (2002), the refined squalene is assumed to yield 65% gasoline and 35% diesel. This leads to an estimated cost of refining to be approximately \$ 0.46 per gallon.[6]

Financial statements

The simulated random variables for yields and prices were used to construct the stochastic pro-forma financial simulation model to simulate a 10-year time horizon. Tobacco is cultivated primarily on small and medium-sized farms. The most common size of a tobacco farm is from 4 to 12 acres (Huntrods, 2012; USDA, 2006). Therefore, we constructed the financial statements for a 5 acre hypothetical farm in Barren county, Kentucky. Stochastic input and output variables were simulated according to the aforementioned distributional assumptions. Several key output variables (KOV) were calculated to assess the overall financial and economic feasibility of producing biofuels from squalene from tobacco. Through Monte Carlo simulation, the model estimates a probability distribution for each of the KOVs such as, present value of ending net worth, net cash income, net cash flow, net worth, and NPV. The distributions of these KOVs have been used for analyzing the feasibility of alternative feedstocks for renewable fuels (Monge *et al.,* 2014; Outlaw *et al.,* 2007; Richardson and Johnson, 2014; Richardson *et al.,* 2007a, 2014a,b). To estimate the distributions for the KOVs, the model must include variables in an income statement, a cash flow statement, and a balance sheet. The NPV is calculated as follows:

$$NPV = -(\text{BeginningNetWorth}) + \sum_{t=1}^{10} \left(\frac{\widetilde{\text{Dividends}}_t}{(1+r)^t} \right) + \left(\frac{\text{Ending}\widetilde{\text{NetWorth}}}{(1+r)^{10}} \right) \quad (6)$$

[6] The fuels once refined are equivalent to gasoline and diesel, and they can enter the current fuel pipeline without modification.

Equation 6 is calculated by adding the present value of ending net worth and total discounted dividends, and subtracting the beginning net worth. Annual dividends (farmer withdrawals) are calculated as a fraction of the beginning net worth and, as a bonus, from positive annual net cash income (NCI). If the value of NPV is greater than zero, the business is considered an economic success (Palma *et al.,* 2011; Richardson *et al.,* 2012).

To calculate the beginning net worth, the summation of the initial assets is required. The main assets are tobacco drying equipment, the SFE plant, and the harvesting machinery. It was assumed that a share of the initial capital needed to operate the business is financed. The loan share was assumed to be 60% for all the equipment, as suggested by Richardson *et al.* (2012), yielding a beginning liability (details discussed in the balance sheet section). The beginning liability is subtracted from the initial asset value, and any initial cash reserves are added, to yield beginning net worth.

Income statement

Among the three financial statements required for the analysis, estimating the pro-forma income statement is the first step. The revenues are the product of stochastic diesel and gasoline prices, and stochastic fuel production. The revenue for high-value squalene production is estimated from stochastic squalene production and stochastic squalene price. Additionally, we incorporated the revenues generated from lignocellulose feedstock which is a residual of the biomass after oil has been extracted. Tobacco residuals (tobacco stalks) are referred to be promising materials for pulp and paper industry (Shakhes *et al.,* 2011). We assume that the selling price of the feedstock will average $ 35 per dry short ton (McAloon *et al.,* 2000). Revenues generated from the tobacco stalks does not have a significant impact on the analysis.

The expenses are composed of pre-harvest and harvest expenses, tobacco drying expenses, squalene extraction cost, land rent, total operating expenses, and the interest expenses. The interest expenses consist of the interest from the original loan, the interest on the operating loan, and the interest on any cash flow deficit from the previous year. The operating loan is meant to cover a portion of production, operating, and fixed expenses. The portion of fixed operating expenses covered annually was obtained from Richardson *et al.* (2012). NCI equals total revenue minus total cash expenses.

$$\widetilde{NCI}_t = \widetilde{Revenue}_t - \widetilde{Expenses}_t \tag{7}$$

Cash flow statement

The main KOV in the pro forma cash flow statement is ending cash (EC). EC is the difference between cash inflows and outflows.

$$\widetilde{\text{Ending Cash}}_t = \widetilde{\text{Cash Inflows}}_t - \widetilde{\text{Cash Outflows}}_t \tag{8}$$

Cash inflows are the summation of NCI from the income statement, beginning cash, and interest earned on positive cash reserves from the previous year.

$$\widetilde{\text{Cash Inflows}}_t = \widetilde{\text{Beginning Cash}}_t + \widetilde{NCI}_t + \widetilde{\text{Interest Earned}}_t \tag{9}$$

Cash outflows are the summation of principal payments on the original loan, the fully paid deficit loan from the previous year's cash flow deficit, if any, dividends, and income tax. If NCI is positive, we assume that the owner receives a dividend equal to 5% of net cash income.

$$\widetilde{\text{Cash Outflows}}_t = \text{Principal Payments}_t + \widetilde{\text{Deficit Loan}}_{t-1} + \widetilde{\text{Dividend}}_t + \widetilde{\text{Income Tax}}_t \tag{10}$$

Income taxes are estimated using the internal revenue system corporate income tax schedule. The taxable income is estimated by subtracting the annual depreciation from NCI plus interest earned. If the difference is positive, income taxes must be paid, otherwise it is zero.

Balance sheet

Annual net worth comes from the pro-forma balance sheet and is the difference between of the stochastic value of assets and liabilities. The annual value of assets equals cash reserves plus the value of plant equipment and land. Total capital assets (beginning net worth) for the process unit are $ 850,000 and, as mentioned previously, will be financed with 40% equity and 60% debt at a 7% interest rate over a 10 year period. The initial capital investment in assets includes SFE plant, machinery harvester, and the drying equipment. Annual EC reserves are conditional on positive EC coming from the cash flow statement.

The annual value of liabilities is calculated by summing total deficit loans and the equity loan balance.

$$\widetilde{\text{Liabilities}}_t = \text{Original}\ \widetilde{\text{Loan}}_t + \text{Deficit}\ \widetilde{\text{Loan}}_t \tag{11}$$

The deficit loan is acquired to cover negative EC and, condition on the next year's EC, is fully paid in one year.

$$\text{Deficit}\ \widetilde{\text{Loan}}_t = \begin{cases} |\text{Ending}\ \widetilde{\text{Cash}}_t|, & \text{Ending}\ \widetilde{\text{Cash}}_t < 0 \\ 0, & \text{Ending}\ \widetilde{\text{Cash}}_t > 0 \end{cases} \tag{12}$$

The equity loan balance is the remaining balance in a given year after paying the principal and interest from the previous year.

$$\text{Original}\ \widetilde{\text{Loan}}_t = \begin{cases} \text{Original}\ \widetilde{\text{Loan}}_{t-1} - \text{Loan Principal}_t, & t > 0 \\ \text{Total Investment} \times \text{Fraction Financed}, & t = 0 \end{cases} \tag{13}$$

4. Results and discussion

Economic feasibility of biofuel production

Diesel, gasoline, squalene, biomass yield and the production costs were simulated with their distributional assumptions each year of the 10-year horizon. The model was simulated for 500 iterations to generate sufficient observations to estimate reliable distribution for the KOVs.[7] Stochastic pro-forma financial statements were constructed and summary statistics of the KOVs for biofuel production from tobacco are presented in Table 1. Results indicate that the potential production of biofuel from tobacco is uneconomical, even if the average squalene yield is 20% per dry matter. The summary statistics shown in Table 1 indicate the average net cash income, (averaged across 10 years), is negative for every iteration, given the minimum and the maximum values are $ -108,000 and -97,000, respectively. The average EC (averaged across 10 years) is also negative, and the range of the distribution is between $ -810,000 and -761,000. Large cash outflows are mainly caused by the increasing short term debt generated due to negative EC balance observed in previous years. As a result of increasing carry-over debt, the liabilities exceed the assets, yielding negative ending net worth by terminal year. The range of average ending net worth in the last year is between $434,000 and -385,000. The average NPV is highly negative, yielding a zero probability of economic success.

[7] The sampling procedure was the Latin hypercube, which allows for more complete simulation over the uniform (0,1) distribution space, so a smaller number of iterations is necessary when compared to the less efficient Monte Carlo sampling procedure.

Table 1. Summary statistics of the key output variables obtained from pro-forma financial statements for tobacco biofuel market.

	Average net cash income	Average ending cash	Average ending net worth	Net present value
Mean	-103,528	-784,492	-409,171	-862,987
Standard deviation	2,070	9,541	9,541	9,590
Coefficient of variation	-2.00	-1.22	-2.33	-1.11
Minimum	-108,821	-810,153	-434,832	-887,506
Maximum	-97,982	-761,147	-385,826	-837,297

The primary reason behind the unfavorable economic results is low prices for diesel and gasoline compared to the production and oil extraction costs of biomass.[8] Given NPV is negative, the model was solved to estimate the per unit subsidies on diesel and gasoline that would make NPV zero. The subsidies, on average, are $ 15/gallon for diesel and $ 25/gallon for gasoline. Thus, it is not likely that renewable fuels from tobacco will be economically viable, at least in the short run.

Economic feasibility of high value squalene market

Nine scenarios were analyzed to reflect assumptions about potential yield increases and price decreases that will occur if the supply of squalene increases. The scenarios are summarized in Table 2. The summary statistics for selected KOVs for the high value squalene market are presented in Table 3. The average NCI is positive for all nine scenarios. Probability of a positive average NCI is 100% for all scenarios except SC8P10, which has a 99% chance of a positive NCI, and the mean value is much lower when compared to other scenarios. This result is not surprising given that SC8P10 assumes a modest growth of squalene content per dry matter and a sharp decline in squalene price over time.

Comparing average NCI across squalene improvement rates for a given price decrease of 5% (SC8P5, SC6P5, SC5P5) shows that increasing the technological advances will significantly improve the economic viability as average NCI increases from $ 66,000, to $ 112,000, to $ 133,000, as the time to reach 20% squalene is reduced from 8 to 5 years, respectively. However, one must not ignore the price effect of increased supply, as evidenced by scenarios SC6P10, SC6P5, SC6P0, where average NCI increases from $ 66,000, to $ 112,000, to $ 169,000, respectively, as price decline rates are smaller and smaller. Judging the project feasibility solely on the average NCI is unrealistic as it does not capture the actual cash on hand a farmer will have left after paying the dividends, the principal payments, and the carry over debt payments (if any) over time.

[8] The average sale price for gasoline was $ 2.27/gallon and for diesel it was $ 2.32/gallon.

Table 2. Construction of nine scenarios for analyzing the feasibility of high value squalene market.

Scenario	Name	Squalene content	Price response
1	SC8P10	20% in 8 years	-10%/year
2	SC8P5	20% in 8 years	-5%/year
3	SC8P0	20% in 8 years	-0%/year
4	SC6P10	20% in 6 years	-10%/year
5	SC6P5	20% in 6 years	-5%/year
6	SC6P0	20% in 6 years	-0%/year
7	SC5P10	20% in 5 years	-10%/year
8	SC5P5	20% in 5 years	-5%/year
9	SC5P0	20% in 5 years	-0%/year

Table 3. Summary statistics of key output variables for nine scenarios for high value squalene market.[1]

	SC8P10	SC8P5	SC8P0	SC6P10	SC6P5	SC6P0	SC5P10	SC5P5	SC5P0
Average net cash income									
mean	26,245	66,480	117,554	66,028	112,425	169,854	86,639	133,356	192,694
st.dev	9,859	13,389	17,819	12,817	15,754	20,759	13,350	16,673	22,009
CV	38	20	15	19	14	12	15	13	11
min	-1,542	31,127	69,506	27,478	67,583	113,822	43,737	85,821	132,963
max	61,485	115,136	182,065	109,193	168,541	245,541	132,554	194,848	275,245
P (NCI>0)	99.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Average EC									
mean	-282,757	-187,801	-89,349	-117,930	-16,000	93,751	-14,778	88,406	202,632
st.dev	36,762	40,780	44,446	46,352	48,745	53,625	50,712	53,490	59,606
CV	-13	-22	-50	-39	-305	57	-343	61	29
min	-396,389	-324,803	-245,163	-270,661	-185,489	-94,732	-185,497	-98,582	-5,349
max	-181,946	-76,275	33,796	5,089	116,622	244,440	120,900	238,441	376,363
P (EC>0)	0.0%	0.0%	2.1%	0.2%	37.7%	95.2%	39.6%	93.9%	99.8%
Present value of ending net worth									
mean	1,416	145,434	298,022	158,174	304,456	468,325	236,333	380,757	547,983
st.dev	39,469	44,123	51,951	45,342	48,094	59,044	45,738	50,024	62,097
CV	2,787	30	17	29	16	13	19	13	11
min	-112,097	11,491	146,841	6,662	142,612	296,064	71,421	207,263	361,037
max	104,890	259,434	434,837	275,118	432,262	638,368	358,722	521,164	725,839
P (PENW>0)	51.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
P (PENW>BNW)	0.0%	0.0%	2.6%	0.0%	1.6%	86.8%	0.0%	31.4%	99.0%

[1] NCI = net cash income; EC = ending cash; PENW = present value of ending net worth; BNW = beginning net worth.

The average EC is negative for all scenarios except for SC6P0, SC5P5, and SC5P0. The results show that the average EC is highly responsive to both number of years it takes to reach 20% squalene content on a dry matter basis, and on the squalene price. Comparing average EC across squalene growth rates for a given price decrease of 5%, the probability of obtaining positive EC increases from 0 to 94% (SC8P5, SC6P5, SC5P5). On the other hand, assuming 20% squalene is achieved in 6 years, and comparing across squalene price decline rates, the probability of positive EC increases from 0.2 to 95% (SC6P10, SC6P5, SC6P0).

The third part of Table 3 summarizes the present value of ending net worth (PENW) for the nine scenarios. The average PENW is marginally positive for SC8P10, and significantly positive for the other eight scenarios. PENW is highly responsive to both, squalene content per dry matter and squalene price. In particular, assuming a 20% squalene content per dry matter is reached in 8 years, the probability of a positive PENW increases from 51 to 100% as the average squalene price drops from 10 to 0% per year (SC8P10, SC8P5, SC8P0). Similarly, the probability of a positive PENW is 100% as long as the 20% squalene content per dry matter is reached in 5, 6, or 8 years, holding the average price drop fixed at 5% per year (SC8P5, SC6P5, SC5P5). The results also indicate the probability of PENW being greater than the beginning net worth (BNW) is less than 40% for all scenarios besides SC6P0 and SC5P0. The probability of PENW being greater or equal than the BNW is 86 and 99% for SC6P0 and SC5P0, respectively.

Combining all of the information from the three pro-forma financial statements is necessary to determine the probability of economic success. The probabilities of obtaining a positive NPV across the 9 scenarios are presented in Table 4. The results indicate both the squalene growth rate and the price decline rate are critical components in the analysis. In particular, assuming the squalene content reaches 20% in 8 years, the probabilities of obtaining positive NPVs improve from 0 to 81% as price reductions go from 10 to 0%. However, if average squalene price drops, on average, by 10% per year, the maximum probability of economic

Table 4. Probabilities of obtaining a positive net present value for nine scenarios for the high value squalene market.

Price decline rate	Squalene content per dry matter		
	20% in 8 years	20% in 6 years	20% in 5 years
10%/year	0%	2%	40%
5%/year	1%	86%	99%
0%/year	81%	100%	100%

success is 40%, given that 20% squalene content per dry matter is achieved in 5 years. Two scenarios have 100% probabilities of economic success. These scenarios require 20% squalene content per dry matter to be achieved either in 5 years or in 6 years, and assumes that the average squalene price remains unchanged over the 10-year time horizon.

In addition to looking at the average NPV values, it is important to look at the NPV distribution to assess the risk component for different scenarios. Figure 1 shows the cumulative distribution functions estimated from the simulation results to contrast the feasibility probabilities of the three scenarios using the NPV. In particular, Figure 1 shows the impacts of yearly price decline rates assuming that 20% squalene content can be achieved in 5 years (SC5P10, SC5P5, SC5P0). The probabilities of the project not being feasible (NPV<0) can be identified in the graph where the sigmoidal curves intercept the vertical axis. Therefore, the probabilities of the project being feasible (NPV>0) are estimated by subtracting the intercept from one.

As shown in Figure 1, assuming squalene price, on average, remains unchanged, the probability of the project being feasible is 100% (SC5P0). Even if the average squalene price declines by 10% per year, there is still a 40% chance of obtaining a positive NPV, as long as 20% squalene content is achieved in five years (SC5P10). As mentioned previously, the squalene market growth rate is projected to be greater than 10% per year, meaning that the annual price decline of 10% is perhaps too conservative. The most realistic scenario among the three is SC5P5, assuming that squalene price, on average, declines by 5% per year and 20% squalene content can be achieved in 5 years (SC5P5). The probability of obtaining a positive NPV under this scenario is 99%, showing a promising potential for tobacco growers in the future.

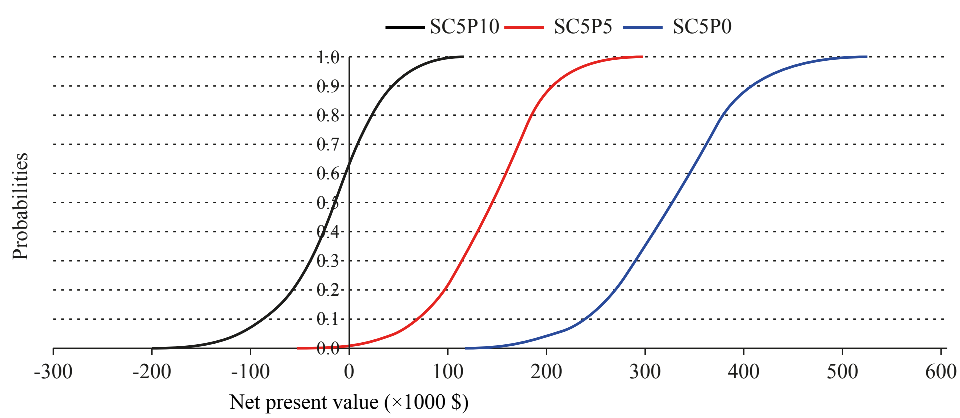

Figure 1. Cumulative distribution function approximation of the net present value for high value squalene market by altering price decline rates and assuming 20% squalene content can be achieved in 5 years.

Economic feasibility of biofuel production with sensitivity analyses

The previous two sections analyzed financial and economic feasibilities of a tobacco-based biofuel and squalene production independently. As discussed above, under current available technologies, producing and marketing only biofuel from the biomass is not profitable. The purpose of this section is to discuss the requirements for tobacco-based biofuel to become economically feasible. The process requires a significant portion of the biomass to be commercialized towards high value squalene market. In other words, part of the squalene extracted is refined and sold as a fuel, and the remaining portion is marketed as a high value product. As previously stated, the business is considered an economic success if the value of NPV is greater than zero. However, as outlined by Monge *et al.* (2014) 'an investor might adopt a more stringent criteria to consider a technology feasible by avoiding the chances of a negative NPV as much as possible'. Richardson *et al.* (2012) and Monge *et al.* (2014) follow the criteria that a business is considered an 'economic success' if the chances of a positive NPV are 95% or higher. Under this criteria, we conducted sensitivity analyses on multiple parameters to assess their impacts on the probability of economic success. In particular, we performed sensitivity analyses on the different fractions of squalene and fuel marketed, as well as the implications of capital and operating expenses reductions on the technologies' feasibility chances.

We maintained all the main aforementioned assumptions. The details of the assumptions are as follows: tobacco leaves contain 20% squalene yield per dry matter, the biomass yield is distributed as presented in Equation 1, gasoline and diesel prices follow a distribution from Equation 3, and the squalene price is distributed as outlined in Equation 5. With regard to the portion of squalene refined and commercialized as fuel, two cases were considered. In case one, 70% of the squalene is refined and sold as a fuel and the remaining 30% is marketed as a high value product. In case two, the portions were assigned as 75-25% for fuel and squalene, respectively. Commercializing more than 75% squalene for the fuel market is not profitable.

Table 5 shows the benefits of capital and operating expense reductions on the technologies' feasibility chances under the two cases discussed above. Cost reductions of 25% are considered possible in the short term, whereas 50% cost reductions are considered more long-term scenarios (Monge *et al.*, 2014). There are several cases under which the biofuel commercialization from a tobacco biomass is economically feasible (Table 5). Under all of the assumptions considered for the analyses, the project would become economically successful by reducing either the operating or capital expenses by 25 and 50%, respectively or possibly less. In particular, reducing both operating and capital expenses by 25% yields 99% probability of economic success, when considered 70-30% case for fuel and squalene, respectively. Reduction of capital expenses has much bigger impact on the chance of economic success when compared to reductions of operating expenses. When 75% of extracted squalene is refined and sold as a biofuel, economic success can only be obtained if capital expenses are reduced by 50% and operating expenses are reduced by at least 25%. Therefore, under these circumstances, biofuel production from tobacco biomass may have a potential in the long run.

Table 5. Probabilities (in %) of obtaining a positive net present value by reducing the capital and operating expenses (CAPEX and OPEX) by different percentages, joint market.

OPEX reduction (%)	**70% fuel – 30% squalene CAPEX reduction (%)**			**75% fuel – 25% squalene CAPEX reduction (%)**		
	0	**25**	**50**	**0**	**25**	**50**
0	0	13	100	0	0	62
25	0	99	100	0	0	100
50	54	100	100	0	95	100

5. Conclusions

The tobacco industry has been declining over the last several years. The removal of government support programs accelerated the reduction of tobacco farms and harvested acreage by over 82 and 30%, respectively. The objective of the study was to estimate the economic and financial feasibility of biofuel production and high value squalene production from tobacco plant leaves. Stochastic simulations were conducted to estimate the probability of profitable production of finished fuels and high value squalene from tobacco plant leaves. The biomass yield and squalene price were considered critical variables for these simulations. Stochastic pro-forma financial statements were simulated for a 10 year time horizon and NPV was calculated to assess overall feasibility of the project.

The results showed that if the only output produced from the biomass is used to produce a finished motor fuel, the project is not economically viable, at least under current available technologies. Even with the strongest assumptions of 20% squalene per dry matter and an average yield with a 6% annual growth rate, the economic success of renewable fuel production from tobacco plant leaves is not economical. The average net cash income, the average EC, and the average ending net worth were negative for the 10-year time horizon. Probability of economic success, i.e. Prob.(NPV>0), was zero, meaning that use of tobacco leaves to only produce biofuel is not economically attractive, under the assumptions made in this study.

Given the clinical applications of high value squalene, the hydrocarbon does not have to be refined for a fuel production. Nine scenarios were analyzed to assess the economic feasibility of producing high value squalene from tobacco leaves. Considering the project is economically feasible if the probability of obtaining a positive NPV is at least 95%, three scenarios out of nine yield favorable economic outcomes (SC5P5, SC5P0, SC6P0). The results showed that if the average squalene price remains unchanged, over the next 10 years, and squalene content reaches 20% per dry matter either in 5 or in 6 years (SC5P0, SC6P0), the project is economically feasible. Moreover, if squalene value drops by 5% per year, on average, and squalene content per dry matter reaches 20% in 5 years (SC5P5), the probability of economic success is about 99%. However, if squalene value drops, on average, by 10% per year, or the squalene content reaches 20% per dry mater in 8 years, the project is not economically feasible.

It has been demonstrated that tobacco-based renewable fuel production can become economically viable by improving certain agronomic and technological factors without any government support. In particular, if biofuel production is the main target, some portion of squalene should still be marketed as a high value product. Even under these circumstances, economic feasibility can only be achieved under certain conditions, requiring reductions of capital and operating expenses by at least 25%.

The results are relevant to potential investors who are considering tobacco as an alternative feedstock, and to farmers. We demonstrate that, under the assumptions made in the study, using tobacco as a biofuel feedstock, regardless of its high biomass potential, is still in its early stages and requires further technological and agronomic improvements before commercialization. Future research should focus on new insights regarding yield and biomass improvements, including analyses of squalene market with an updated price information, and reducing cost of processing.

6. Limitations of the study

Although the empirical framework of the analysis provided useful implications, those results, however, suffer from important limitations that must be acknowledged and discussed.

First, the study was based on lab experiments and bench scale extraction information with extrapolations of the processes to scale. Even though data are limited and assumptions must be made, studies such as this are necessary to evaluate alternative feedstocks, and to estimate how conditions will have to change to gain profitability and adoption.

Second, the study did not incorporate any possible governmental incentives. For example, possible renewable identification number credit and the second generation biofuel producer tax credit could be incorporated into the study. The RIN credit is a price mechanism that ensures the compliance of the renewable fuel standard by obligated parties (i.e. refiners, importers and blenders) and directly translates into a price premium for biofuel producers. To the best of authors' knowledge, currently there are no renewable identification number prices published specifically for tobacco biofuel as of May, 2016.

Third, we assumed a just in time delivery system and ignored any storage costs associated with either biofuel or squalene production. We also assumed that the SFE-plant was built just before the first year of operations.

Fourth, we assumed that squalene from the biomass is extracted using a SFE process, and the cost associated with this type of extraction was simulated in the study. Different research laboratories, as mentioned in the article, use their own extraction technologies. Some of these technologies are patented and the companies do not disclose any detailed information regarding the cost of extraction or the capital costs. Hence, their values maybe higher or lower than the values used in this study.

Supplementary material

Supplementary material can be found online at https://doi.org/10.22434/IFAMR2015.0179.

Table S1. Deterministic costs of tobacco production based on average yield of 90,000 pounds of green biomass per acre.
Table S2. Cost breakdown of squalene extraction based on average yield of 90,000 pounds of green biomass per acre.
Table S3. Cost breakdown of gasoline and diesel as of May 2016.

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