Project 001(D) Alternative Jet Fuel Supply Chain Analysis

Pennsylvania State University

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Project Funding Level

FAA Funding: $200,000.
Matching: Penn State - $200,000
Total Funding: $400,000

Investigation Team

1.5.1 (Lead: Richard; supported by Zipp, Rials, and English) – Delineate the sustainability impacts associated with various feedstock choices (switchgrass, oilseeds and winter grasses) including land-use effects for the mid-Atlantic region, including the Chesapeake Bay watershed.

1.5.2 (Lead: Zipp, supported by Richard and Lewis) - Evaluate the supply chains associated with switchgrass, oilseeds and winter grasses for the mid-Atlantic region.

3.3.1 (Lead: Clifford; supported by Garcia-Perez) - Report on preprocessing requirements and refinery insertion points for various bio-oil and biomass feeds.

3.3.3 (Lead: Garcia-Perez, supported by Clifford) – Simulate satellite biomass-to-liquid processing (e.g. gasification/F-T catalysis, pyrolysis, hydrothermal liquefaction or vegetable oil processing)

7.1.4 (Lead: Richard, supported by Wolcott) - Updated Data Management Plan and Status Report

8.1.0 (Lead: Zipp, supported by Fowler, and Richard) - Analysis of ecosystem service valuation, law and policy drivers, and potential policy design of water quality improvements associated with perennial grasses and cover crops.

Project Overview

1.5.1 Delineate sustainability impacts associated with various feedstocks, including land use effects for mid-Atlantic region/Chesapeake Bay watershed. Includes subtasks addressing erosion and sediment delivery and water quality.

1.5.2 Evaluate the supply chains associated with switchgrass, oilseeds and winter grasses for the mid-Atlantic region.

3.3.1 Report on preprocessing requirements and refinery insertion points for various bio-oil and biomass feeds.

3.3.3 Simulate satellite biomass-to-liquid processing (e.g. gasification/F-T catalysis, pyrolysis, hydrothermal liquefaction or vegetable oil processing)

7.1.4 Updated Data Management Plan and Status Report

8.1.0 Analysis of ecosystem service valuation, law and policy drivers, and potential policy design of water quality improvements associated with perennial grasses and cover crops. Includes subtasks 8.1.1, a literature review, and 8.1.2, a report analyzing Chesapeake Bay opportunities as a co-product market opportunity.

Task #1.5:

- **1.5.1 Delineate Sustainability Impacts Associated with Various Feedstocks, Including Land Use Effects for Mid-Atlantic Region/Chesapeake Bay Watershed**
- **1.5.2 Evaluate the Supply Chains Associated with Switchgrass, Oilseeds and Winter Grasses for the Mid-Atlantic Region**

Penn State

Objective(s)

Evaluate the supply chains associated with switchgrass, oilseeds and winter grasses for the mid-Atlantic region.

Research Approach

Using the model developed in Task 8.1, we determined the price-supply curves to determine crop acreages at different price points. See Task 8.1 for a description of the returns to biomass needed to induce conversion.

Milestone(s)

Determined the returns needed to induce farmers to convert to switchgrass. This is the first step to estimate the price-supply curves.

Major Accomplishments

Economic model to motivate land use conversion has been developed and demonstrated at ASCENT and CAAFI meetings

Publications

N/A

Outreach Efforts

Economic model to motivate land use conversion has been demonstrated at CAAFI meetings.

Awards

N/A

Student Involvement
One graduate student is a major contributor to this project, drafting both the literature review, and the coding to estimate our model.

Plans for Next Period
Future work will couple these results on farmer adoption of switchgrass with a more accurate model of water quality benefits and use the value of these water quality benefits to offer optimal payments to farmers for these services.

References
See Task 8.1

Task #3.3:
- **3.3.1 Report On Preprocessing Requirements and Refinery Insertion Points for Various Bio-Oil and Biomass Feeds**
- **3.3.3 Simulate Satellite Biomass-to-Liquid Processing (e.g. Gasification/F-T Catalysis, Pyrolysis, Hydrothermal Liquefaction or Vegetable Oil Processing)**

Penn State and Washington State

Objective(s)
Evaluate commercial options for biofuel intermediates insertion into petroleum refineries for conversion to AJF.

Research Approach
Using an extensive literature review, PSU identified and evaluated commercial biomass feedstocks and bio-based intermediates that could be inserted in a refinery or be converted to alternative jet fuel with minimal processing. The evaluation considered bio-based liquids at three insertion points: 1) “bio-crude” introduced at the front of the refinery for crude processing with petroleum, 2) refinery-ready liquids inserted after crude processing and utilizing conversion and/or finishing unit operations to upgrade the bio-based liquids into fuels, and 3) blend-ready fuels that are inserted during blending to upgrade low-value refinery streams, improve specifications, and take advantage of blending, storage and distribution capacity. Unit operations and process opportunities and constraints were assessed for a range of bio-based liquids relevant to alternative jet fuels.

Milestone(s)
Currently we are working on report focused on oxygen removal of bio-based fuels and intermediates.

Major Accomplishments
The accomplishments of this task (Task 3.3) will provide the project and stakeholders with a clearer understanding of the options, pros and cons of integrating bio-based feedstocks in a conventional petroleum refinery. Oxygen in biomass intermediates may discourage petroleum-refining facilities from pursuing the use of intermediates, so how to remove the oxygen is critical. We are working on a literature review of how to remove oxygen using conventional processes and catalysts as well as suggesting alternative catalysts.

Publications
A Technical Report was developed for discussion with Delta Airlines. We have written a publication on this material that will be submitted in the next couple of months.

Outreach Efforts
We are currently working on a publication to submit in late 2017 to the journal *Energy and Fuels*.

Awards
N/A

Student Involvement
N/A

Plans for Next Period
The literature review of how to remove oxygen using conventional processes and catalysts as well as alternative catalysts will be completed and submitted for publication.

References
See technical report.

Task #7.1.4: Updated Data Management Plan and Status Report
Penn State and Washington State and ORNL

Objective(s)
Update Data Management Plan and provide status report.

Research Approach
The primary goal of this task is to develop a common framework that facilitates transparent and open data access for supply chain model intercomparison and improvement, specifically targeting the needs and opportunities of the AJF sector. This effort requires coordination of all team members, many of whom have independent models and datasets, some of which are proprietary. The team developed a consensus approach to data use and model access and then established appropriate agreements and documentation.

Milestone(s)
This year we transitioned the data management plan to be administered by staff at Washington State University. The ASCENT01 data management system is being evaluated as a model for other ASCENT projects.

Major Accomplishments
PIs and students working on the project have reviewed signed the Data Use Agreement document and the Data Use Acknowledgement document, file naming conventions and meta data documentation have been developed, and over 2200 files have been uploaded into the system. Most of these files are journal articles, but 70 of the files are datasets that have been classified and logged in our Common Data needs document for internal data sharing and eventual public release.

Publications
None

Outreach Efforts
N/A

Awards
N/A

Student Involvement
N/A

Plans for Next Period

Continue to encourage participation, now under the auspices of Washington State University.

Task #8.1: Analysis of Ecosystem Service Valuation, Law and Policy Drivers, and Potential Policy Design of Water Quality Improvements Associated With Perennial Grasses and Cover Crops

Penn State

Objective(s)

Analysis of Ecosystem service valuation and policy design of water quality improvements associated with perennial grasses and cover crops. Includes subtasks 8.1.1 (Literature review) and 8.1.2 (Report analyzing Chesapeake Bay opportunities as a co-product market opportunity.

Research Approach

Drawing on scholarly literature, government reports, legislation and policy documents, we have investigated the legal and policy incentives for ecosystem services for the Chesapeake Bay region. To operationalize those policies in an economic farmer decision framework, we developed a land use conversion contract model following the general land conversion model by (Song, Zhao, & Swinton, 2011), while also incorporating subsidies in the form of payments for ecosystem services and incentive compatibility constraints. Specifically, we expanded the model by considering that the potential payoff for farmers who choose to initiate land use conversion and adopt biofuel crops consists of not only the monetary values of crop outputs, but also a one-time lump-sum payment and subsidies that are depended on the consequential environmental benefits. We also extended the model to offer targeted payments to farmers based on the predicted effectiveness of improving water quality benefits based on the farmer's location. Figure 1 provides an example of delivery factors that represent the proportion of nitrogen pollution in each area reaching the Chesapeake Bay (Environmental Protection Agency, 2010). We use this information to target payments for environmental services based on the benefits provided by planting switchgrass. For example, to reduce nitrogen concentrations in the Chesapeake Bay it will be more effective to reduce nitrogen in the red counties compared to the blue counties.

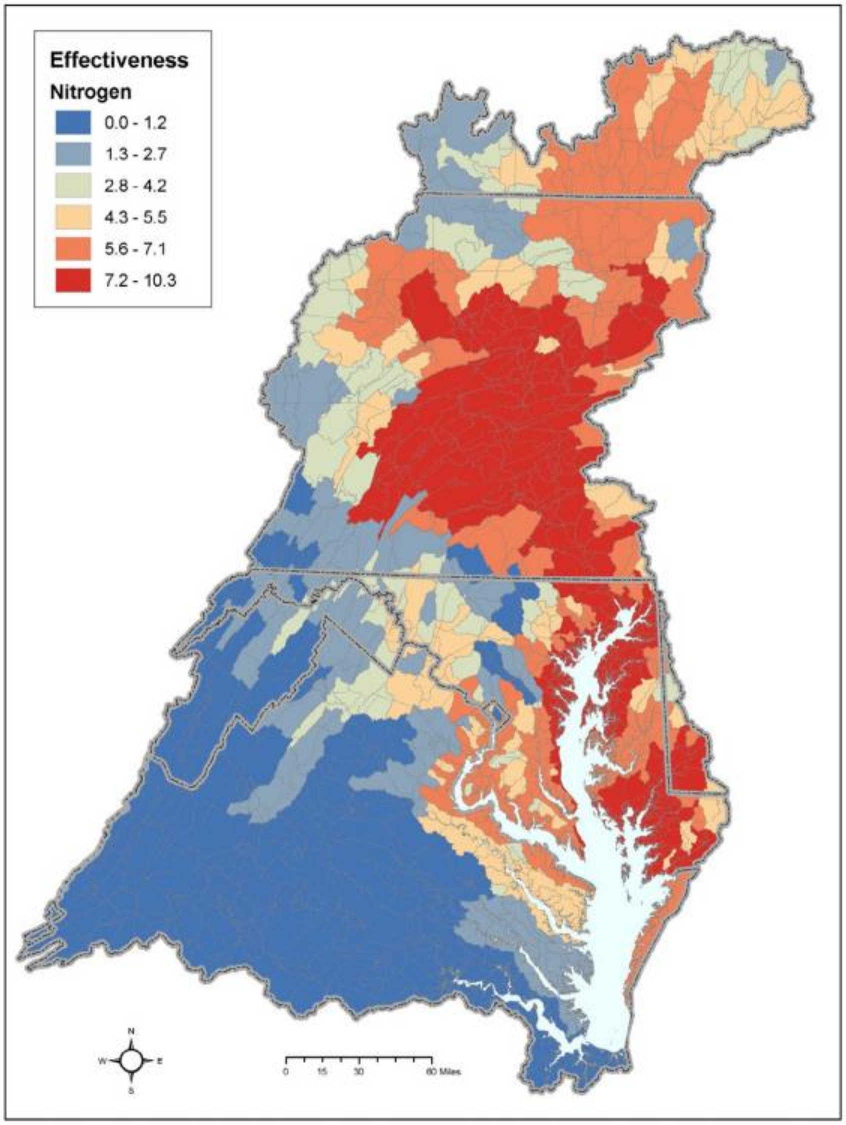

Figure 6-5. Relative effectiveness illustrated geographically by subbasins across the Chesapeake Bay watershed for nitrogen.

(Environmental Protection Agency, 2010)

The one-time lump-sum welfare transfer (denoted as T_{cs}) includes monetary compensation as well as technological assistance from government agencies to offset any fixed costs that farmers might incur if they convert their cropland from a corn-soybean rotation (denoted as *c*) to biofuel crops such as switchgrass (denoted as *s*). For simplicity, consider that $\{c,s\}$ is the only set of crop choices for a risk-neutral farmer with a unit of cropland, and any one-time land use conversion from *i* to *j* would incur a lump-sum cost $C_{ij}, i,j \in \{c,s\}$. Hence, it is necessary that $T_{cs} \geq C_{cs}$ holds for any conversion from c to s in order for farmers to participate. We compare a uniform payment to all farmers versus a targeted payment for the environmental services provided to the Chesapeake Bay (see Figure 1).

The farmer's payoff is consisted of two components. First, the monetary values of crop *i* outputs in period *t* is denoted by $\pi_i(t)$ which follows a stochastic process with evolution of a general form (Song et al., 2011), as follows:

(1) $$d\pi_i(t) = \theta_i(\pi_i,t)dt + \sigma_i(\pi_i,t)d\varepsilon_i,\ i \in \{c,s\}$$

where the drift term $\theta_i(\pi_i,t)$and variance $\sigma_i(\pi_i,t)$ are observable nonrandom functions, and $d\varepsilon_i$ is the increment of a Wiener process[1] which assumes that farmers would be able to learn about and predict future returns in each new period based on information updated in previous period. The correlation coefficient between c and s is denoted as ρ, such that $\mathrm{E}[d\varepsilon_c d\varepsilon_s] = \rho dt$. Farmers' expected present value payoff from crop returns on land use *i* at period *t* is denoted $V^i\big(\pi_c(t),\pi_s(t)\big)$, which depends on the distribution of future returns of both land uses and farmers make decisions between keeping land use *i* or convert it into alternative j (Song et al., 2011), as:

(2) $$V^i\big(\pi_c(t),\pi_s(t)\big) = max\begin{Bmatrix}\pi_i(t)dt + e^{-rdt}EV^i[\pi_c(t+dt)\times\pi_s(t+dt)], \\ V^j\big(\pi_c(t),\pi_s(t)\big) - C_{ij}\end{Bmatrix}$$

Second, farmers who agree to convert land use from corn-soybean to switchgrass (thus a $c \to s$ process) can receive, by the end of each period *t* of this particular conversion process, a subsidy from government agencies based on the generated environmental values. Switchgrass and many other biofuels have the potential to provide a variety of environmental benefits such as soil nitrogen sequestration, water nutrient reduction, and biodiversity conservation. These benefits, although often not traded with market values, can be utilized by government agencies and regulators as a part of the efforts on environmental protection and ecosystem restoration. For simplicity, we denote the environmental performance level of land use alternative *i* as a stochastically continuous and twice differentiable function $\phi_i(e_t), i \in \{c,s\}$, such that:

$$\frac{d\phi_s(e_t)}{dt} > 0, \qquad \frac{d^2\phi_s(e_t)}{dt^2} \leq 0$$
$$\frac{d\phi_c(e_t)}{dt} \leq 0, \qquad \frac{d^2\phi_c(e_t)}{dt^2} \leq 0$$

This restriction allows us to differentiate the environmental performance of the two land uses so that switchgrass would generate increasing environmental benefits, while corn would generate limited (but not necessarily negative) environmental benefits.

Suppose that $\phi_i(e_t)$ is observable to government agencies at the end of period t, and a subsidy is paid to farmers based on the perceived environmental performance level. Without loss of generality, we define a subsidy rate, m, as a per unit compensation rate paid to farmers according to the perceived environmental performance level at the end of period t. Hence, the total subsidies paid to farmers in each possible land use scenario in period *t* are as follows:

(3-1) grow corn in period $t-1$, and convert land use to switchgrass in period t:

$$-C_{cs} + T_{cs} + m\phi_s(e_t) = m\phi_s(e_t), \text{ since } T_{cs} = C_{cs}$$

(3-2) grow switchgrass in period $t-1$ and period t:

$$m\phi_s(e_t)$$

(3-3) grow corn in period $t-1$ and period t:

$$m\phi_c(e_t)$$

[1] The Wiener pdf is $f_{W_t}(x) = \frac{1}{\sqrt{2\pi t}}\exp(-\frac{x^2}{2t})$, following normal distribution with zero mean and variance *t* at any fixed period *t*. The covariance between any *s* and *t* is $cov(W_s,W_t) = \min(s,t)$, and $corr(W_s,W_t) = \sqrt{\frac{\min(s,t)}{\max(s,t)}}$.

(3-4) grow switchgrass in period $t-1$, and convert land use to corn in period t:

$$-C_{sc} + m\phi_c(e_t)$$

Since we assume that $\phi_s(e_t)$ is increasing over time, it is necessary that the total subsidy paid to farmers of land use type s by government at the end of each period t is strictly higher than farmers of land use type c.

Hence, the optimal land use decision problem in Equation (2), for value functions V^i and $V^j, i, j \in \{c, s\}$, must satisfy the following conditions along with the IC and IR constraints:

(4-1) $$LV^i(\pi_c(\mathrm{t}), \pi_s(\mathrm{t})) \geq 0, i, j \in \{c, s\}$$

where $LV^i(\pi_c(\mathrm{t}), \pi_s(\mathrm{t}))$ is the second order Taylor expansion of $V^i(\pi_c(\mathrm{t}), \pi_s(\mathrm{t}))$ by applying Ito's lemma, as:

$$LV^i(\pi_c(\mathrm{t}), \pi_s(\mathrm{t})) = \mathrm{r}V^i(\pi_c, \pi_s) - \pi_i(\mathrm{t}) - \sum_{p=c,s} \alpha_p(\pi_p, \mathrm{t}) \frac{\partial V^i}{\partial \pi_p} - \sum_{p=c,s} \frac{\sigma_p^2(\pi_p, \mathrm{t})}{2} \frac{\partial^2 V^i}{\partial \pi_p \partial \pi_p}$$

$$-\rho \sigma_c(\pi_c, \mathrm{t}) \sigma_s(\pi_s, \mathrm{t}) \frac{\partial^2 V^i}{\partial \pi_c \partial \pi_s}$$

(4-2) $$V^i(\pi_c, \pi_s) \geq V^j(\pi_c, \pi_s) - C_{ij}, i, j \in \{c, s\} \; and \; i \neq j$$

(4-3) Either (4-1) or (4-2) holds with strict equality.

Data

We collected the following data to estimate the supply of switchgrass by water quality benefits provided to the Chesapeake Bay. Through personal communication with Jeff Sweeney at the Chesapeake Bay Program Office of the Environmental Protection Agency, we obtained data on the effectiveness of reducing nitrogen in each county to Chesapeake Bay water quality goals (Figure 1). For this first step, we focused on nitrogen reduction but other water quality goals could be considered. For each of the effectiveness categories, we also needed data on corn yields, prices, and profits and potential switchgrass yields, prices, and profits. We also need the variance of these estimates. We obtained these data from personal communication with Laurence Eaton at the Oak Ridge National Lab (Daly, Halbleib, Hannaway, & Eaton, n.d.).

Parameter Calibration and Estimation

The model can be parameterized and solved by collocation using OSSOLVER (Fackler, 2008) and estimated with CompEcon package in Matlab (Miranda & Fackler, 2002). Value functions can be approximated using a linearized combination of a sequence of known basis functions, such as:

(5) $$\widetilde{V^i}(\pi_c, \pi_s) = \sum_{j_c=1}^{n_c} \sum_{j_s=1}^{n_s} c_{j_c j_s} \psi_{j_c j_s}(\pi_c, \pi_s)$$

where $c_{j_c j_s}$ is obtained when the decision optimality conditions are satisfied. The optimal decision rule is determined by solving and evaluating the approximated value functions at $\{c, s\}$ as well as the return minus the conversion costs, and based on the results the best payoffs from converting are then compared with the best payoffs from not converting (Fackler, 2008).

The empirical method involves solving the parameters in the return equation and calibrating parameters in the value functions. Return from land use is assumed to follow stochastic processes, with unknown parameters including the drift term θ_i, variance σ_i and correlation between the two alternatives ρ, which can be re-parameterized by linearization approximation. Two stochastic processes are often used. If return follows geometric Brownian motion (GBM), the analytical representation is as follows:

(6) $$d\pi_i = \theta_i \pi_i dt + \sigma_i \pi_i d\varepsilon_i, \; i \in \{c, s\}$$

Discrete approximation of the inter-temporal return difference gives:

(7) $$\ln \pi_{i,t} - \ln \pi_{i,t-1} = \left(\theta_i - \frac{\sigma_i^2}{2}\right) + \sigma_i \varepsilon_i,\ i \in \{c, s\}$$

Denote $\alpha_i = \theta_i - \frac{\sigma_i^2}{2}$, then α_i, σ_i and ρ can be estimated by maximum likelihood estimates.

If the returns follow mean reversion (MR), the analytical representation is as follows:

(8) $$d\pi_i = \theta_i(\tilde{\pi}_i - \pi_i)dt + \sigma_i \pi_i d\varepsilon_i,\ i \in \{c, s\}$$

where $\tilde{\pi}_i$ is the historically observed average return of land use *i*, and θ_i here measures speed of reversion. Discrete approximation of the inter-temporal return difference gives:

(9) $$\frac{\pi_{i,t} - \pi_{i,t-1}}{\pi_{i,t-1}} = \theta_i\left(\tilde{\pi}_i - \pi_{i,t-1}\right) + \sigma_i \varepsilon_i$$
$$= \theta_i \tilde{\pi}_i - \theta_i \pi_{i,t-1} + \sigma_i \varepsilon_i, \qquad i \in \{c, s\}$$

Denote $\beta_{1i} = \theta_i \tilde{\pi}_i$, $\beta_{2i} = -\theta_i$, , then β_{1i}, β_{2i}, σ_i and ρ can be estimated.

Parameters

Table 1: Parameter estimates

Parameter	Seg0-1	Seg1-2	Seg2-3	Seg3-4	Seg4-5	Seg>5
alpha_c	0.086	0.080	0.081	0.079	0.079	0.068
sigma_c	0.181	0.160	0.176	0.193	0.159	0.147
alpha_s	-0.006	-0.005	-0.006	-0.008	0.000	-0.009
sigma_s	0.086	0.078	0.086	0.101	0.063	0.060
rho_t	0.671	0.655	0.646	0.722	0.609	0.451

Table 2: The net present value (NPV) of corn and switchgrass returns by nitrogen reduction bins.

Weighted Base Year NPV(2012 in $2016)	Seg(0-1)	Seg(1-2)	Seg(2-3)	Seg(3-4)	Seg(4-5)	Seg(>5)
Corn	$ 368.54	$ 572.46	$ 306.01	$ 508.77	$ 523.18	$ 284.32
Switchgrass	$ 113.22	$ 183.69	$ 136.62	$ 156.42	$ 171.10	$ 84.55

Preliminary Results

The preliminary results[2] are presented as conversion boundaries. If a farmer is growing corn-soybeans they will convert to growing switchgrass when annual returns to switchgrass are above the line b^{CS}. If a farmer is growing switchgrass they will convert to growing corn-soybeans when annual returns to corn-soybeans are greater than the line b^{SC}. Because of uncertainty, risk, and the option value (the value of continuing the current use and having the option of converting crops in the future when it is more profitable to do so) the annual returns to switchgrass have to be higher than the net present value (b^{CS}_{NPV}) of the annual returns to switchgrass to induce conversion.

[2] These results are preliminary so please do not cite.

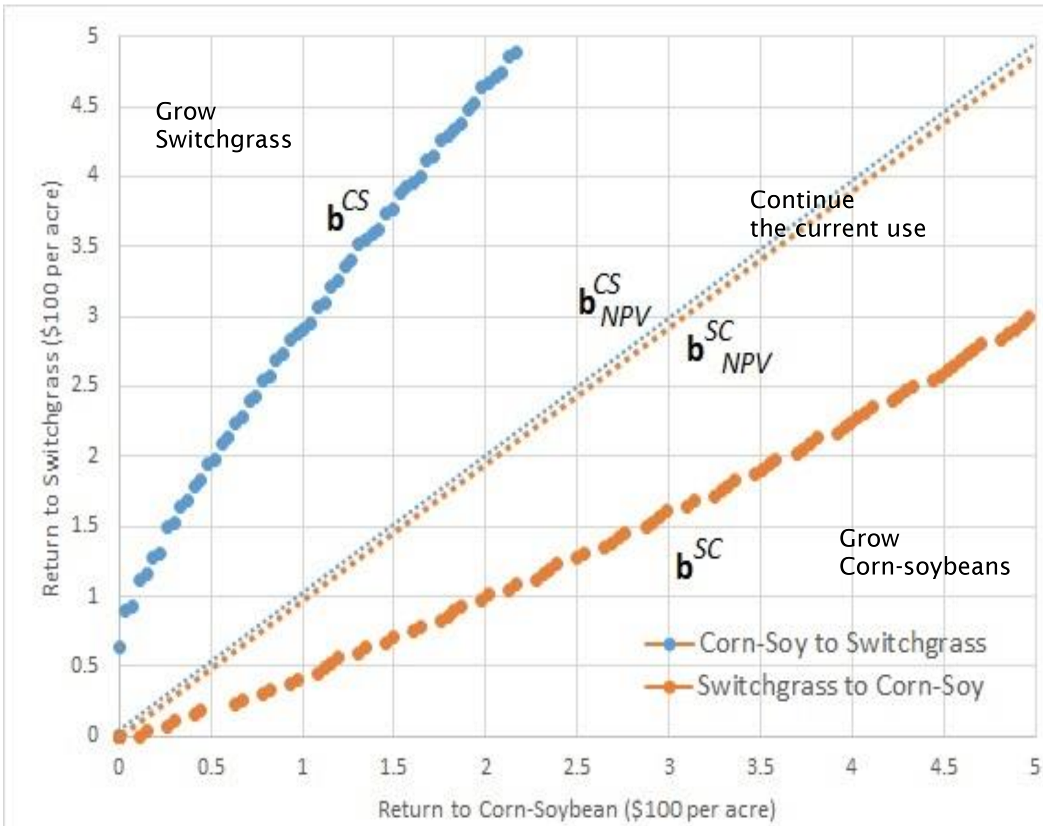

Figure 1: Replicate of the baseline model in (Song et al., 2011)

First, we replicated the baseline model in (Song et al., 2011). The optimality condition for conversion decisions are solved using Compecon toolbox (Miranda & Fackler, 2002) in MATLAB. The nodal points for the state variables (returns to corn-soybean and switchgrass, respectively) are evenly scattered over a revenue interval [0, 5] in hundred dollars ($100) in $1982. The output diagram shows the two boundaries in solid lines for conversions from corn-soybean to switchgrass (b^{cs}) and from switchgrass to corn-soybean (b^{sc}).

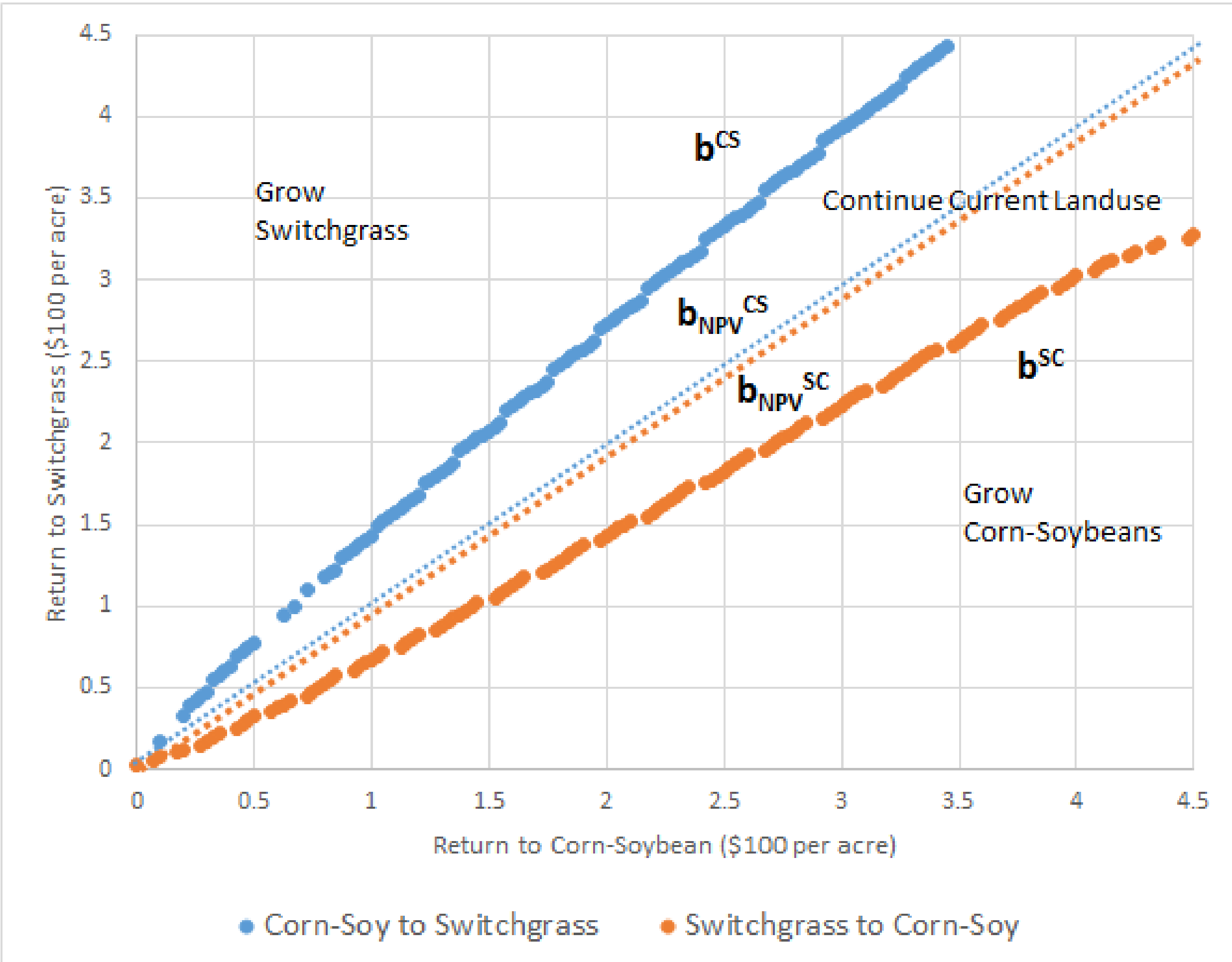

Figure 2: Subsidy to Switchgrass: $100 per acre from (Woodbury et al., n.d.)

In this modification, we applied a subsidy of $100 per acre to farmers if the crops are converted from corn-soybean to switchgrass.

Converting all units to 2016$, without a government subsidy if farmers can earn $230/acre per year with a corn-soybean rotation and $337/acre per year with switchgrass, then they will not convert to switchgrass unless they can earn more than $512/acre per year. Uncertainty, risk, and the option value to convert in the future increase the minimum return from switchgrass needed to induce farmers to convert to switchgrass. With a $100/acre per year payment for ecosystem services (PES) subsidy, farmers would only need $399/acre per year returns to convert their land to switchgrass. Therefore, farmers do need more than the real annual returns to incentivize them to grow switchgrass but a $100/acre subsidy for ecosystem services reduces the uncertainty and risk and therefore reduces the returns need to convert by more than $100/acre.

Table 3: Estimated total switchgrass acreage, nitrogen (N) reduction, and the percent of the Pennsylvania (PA) nitrogen (N) reduction goals

Time period	Outcome	No PES	Uniform Payment	Targeted Payment Aggregated
10 Years	Switchgrass (acre)	3877.41	7575.53	18911.00
	N Reduction (tons)*	69.79	136.36	340.40
	% PA N Goal**	0.49%	0.96%	2.39%
20 Years	Switchgrass (acre)	4502.17	6547.34	20178.00
	N Reduction (tons)*	81.04	117.85	363.2
	Pct. of PA N Goal**	0.57%	0.83%	2.55%
30 Years	Switchgrass (acre)	3751.34	5956.20	16753.00
	N Reduction (tons)*	67.52	107.21	301.55
	% PA N Goal**	0.47%	0.75%	2.12%

*Woodbury et al (2017) suggests that switchgrass can generate nitrogen reduction of 18kg/acre per year on fertilized agricultural land.
**According to the PA government, its goal is to reduce nitrogen by 31.4 million pounds (14242.8 tons) by 2025. (Hunter-Davenport, Brady, & Shader, 2016)

Milestone(s)
A draft of a review of the ecosystem benefits of perennial grasses and winter cover crops (water quality improvements, soil improvements, and biodiversity improvements) has been started. A manuscript to estimate the effects of payments for ecosystem services (PES) subsidies on the willingness to convert to biomass is under preparation. A white paper summarizing the legal and policy incentives for ecosystem services for the Chesapeake Bay Region has been finalized.

Major Accomplishments
N/A

Publications
A formal publication on the legal and policy incentives for the Chesapeake Bay Region is underway.

Outreach Efforts
N/A

Awards
N/A

Student Involvement
One graduate student is a major contributor to this project, drafting both the literature review, and the coding to estimate our model.

Plans for Next Period
Continue to work on a publication on the relationship between payments for ecosystem services (PES) and willingness to convert to biomass. Work to complete a national survey of current and proposed state and federal programs, and other legal and policy incentives, which monetize ecosystem services,

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