Stochastic Techno-Economic Analysis of Alcohol-to-Jet Fuel Production

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PURDUE UNIVERSITY

INTRODUCTION

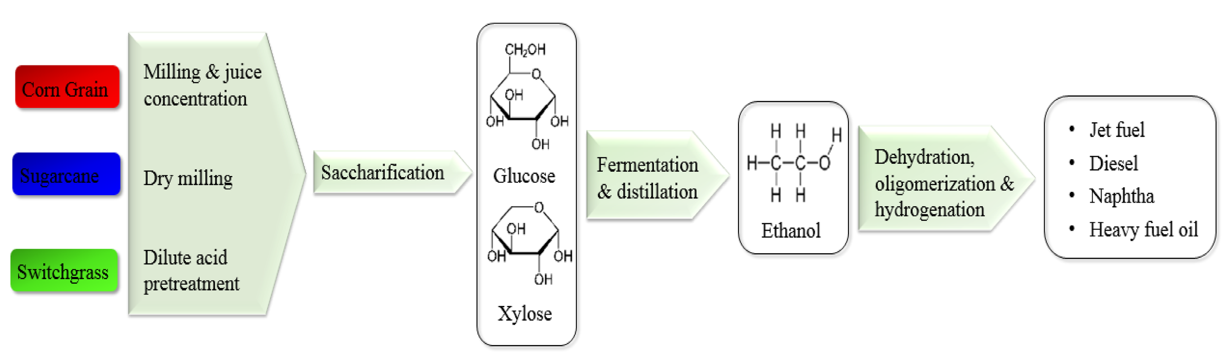
Background:

- Renewable aviation fuel is being used by over 20 airlines
- FAA goal is 1 bil. gal. of renewable. aviation fuel by 2018
- Requires energy dense, low O_2, hydro-carbon liquid fuels
- ATJ is one of the 4 major aviation biofuel technologies
- US Navy and ICAO are committed to renewable aviation fuels

Highlights:

- *Breakeven price distr. in addition to NPV and IRR*
- *Econometric linkages between technical conversion efficiency with all input and output levels*
- *Time-series price estimation based on historical prices*

PATHWAY DESCRIPTION



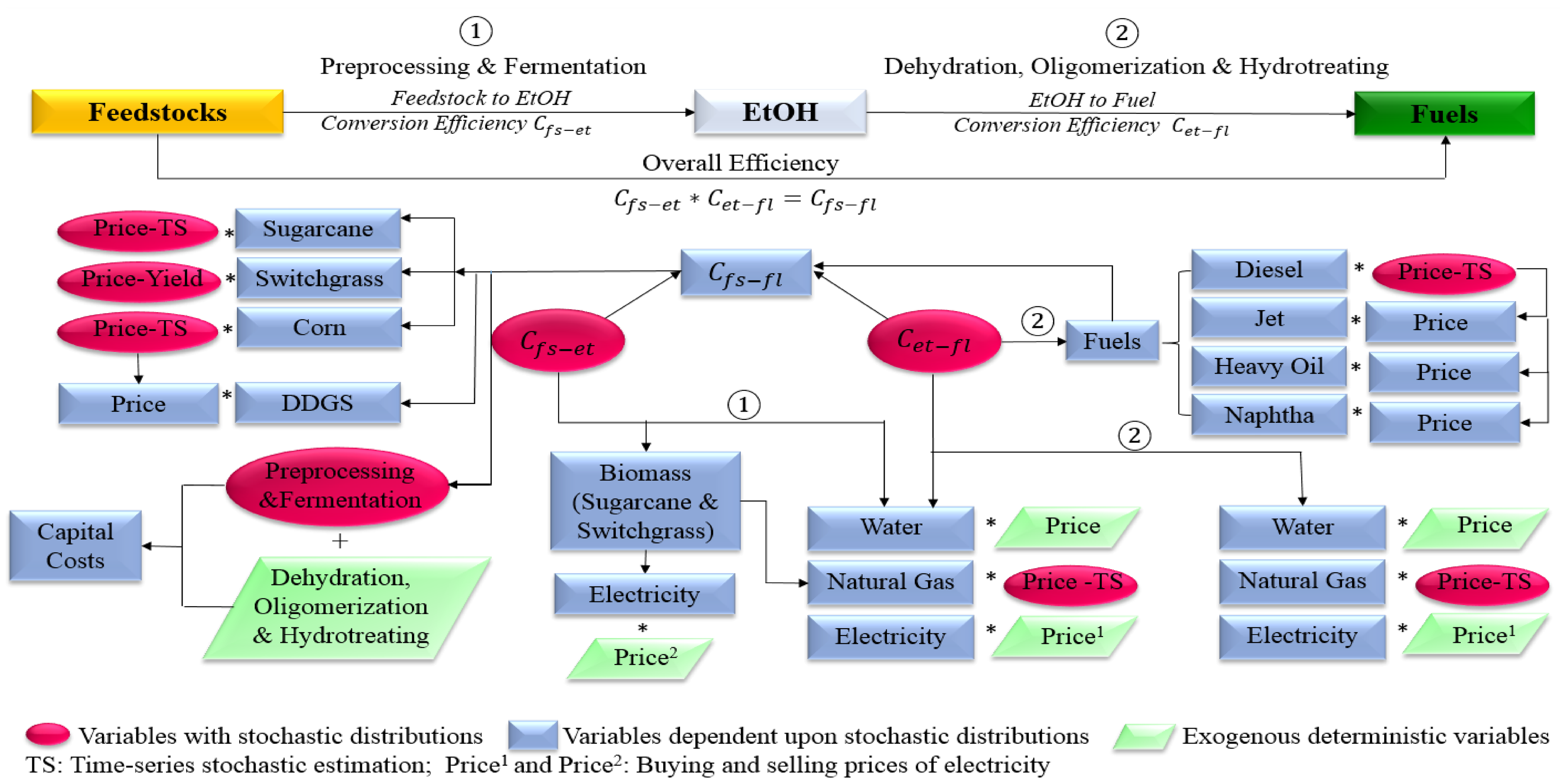
- The subject of this analysis is a subset of ATJ technologies that includes sugars derived from ***sugarcane, corn grain or switchgrass,*** followed by fermentation to an ethanol platform molecule. These feedstocks are selected to represent the *present and future* of renewable fuel production*: corn grain and sugarcane are commonly used for the production of ethanol in the US and Brazil, respectively, and herbaceous lignocellulosic crops, such as switchgrass, can be used for the production of second-generation renewable fuels such as cellulosic ethanol.*
- ATJ derived from ***corn grain*** results in the co-production of ***distillers dried grains and solubles (DDGS). Bagasse*** produced after juice extraction from ***sugarcane***, and ***biomass residues*** generated after sugar extraction and fermentation from ***switchgrass***, can be co-fired to meet the utility requirements of the biorefinery, and *excess electricity can be exported to the grid* (Staples et al., 2014).

OBJECTIVE

- The point of departure for this research is previous analysis by Staples et al. (2014) on renewable middle distillate production via fermentation and advanced fermentation technologies. We extend this work by considering future price projections and introducing technical uncertainties in ATJ production, thereby developing a deeper and more comprehensive understanding of the ATJ pathway.

METHODOLOGY

Model Overview



Technical Uncertainty

- Electricity, water and heat are demanded in ATJ production.
- The feedstock-to-ethanol process includes preprocessing, saccharification, and fermentation steps[Eq. (1) or (2)].
- The ethanol-to-fuel process consists of separation and postprocessing [Eq.(3)].

$$input = \beta_0 + \beta_1 C_{fs-et} + \beta_2 C_{et-fl} + \beta_3 C_{fs-et} C_{et-fl} \quad (1)$$

$$input = \beta_0 + \beta_1 C_{fs-et} + \beta_2 C_{et-fl} + \beta_3 C_{fs-et}^2 C_{et-fl} \quad (2)$$

$$input = \gamma_0 + \gamma_1 C_{et-fl} + \gamma_2 C_{et-fl}^2 \quad (3)$$

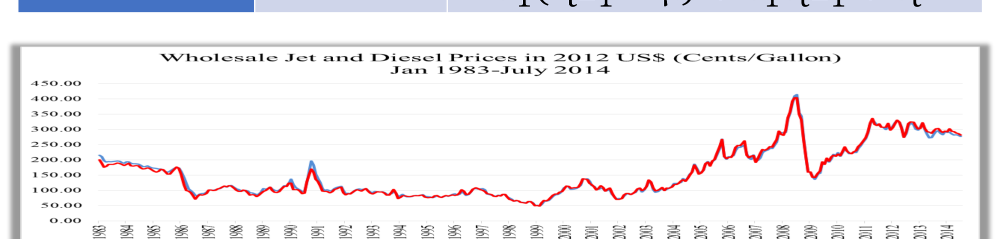
		Min	Mode	Max	Mean
Feedstock to EtOH (kg feedstock per kg EtOH)	Corn Grain	3.29	3.56	3.90	3.57
	Sugarcane	11.38	13.19	14.38	13.09
	Switchgrass	4.00	4.82	8.22	5.25
EtOH to Fuel (kg EtOH per MJ Fuel)	Corn Grain Sugarcane Swtichgrass	0.03	0.04	0.07	0.04

Price Uncertainty

Time-Series Estimation

We can use time-series estimation to project future prices of commodities with mature markets to capture the uniqueness of the motion process of each product market based on historical prices. All prices are truncated at 0.75 of their min historical prices to avoid negative extremes

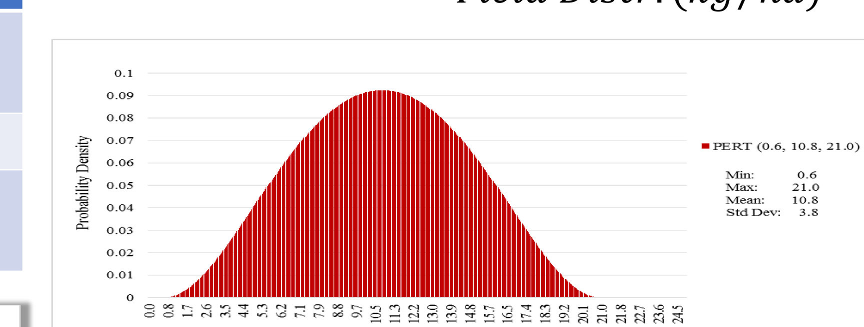
Prices	TS Model	Equation Forms
Corn Grain Sugarcane	MA2	$P_t = \mu + b_1\varepsilon_{t-1} + b_2\varepsilon_{t-2} + \varepsilon_t$
Natural Gas	MA1	$P_t = \mu + b_1\varepsilon_{t-1} + \varepsilon_t$
Diesel	ARMA11	$P_t - \mu = a_1(P_{t-1} - \mu) + b_1\varepsilon_{t-1} + \varepsilon_t$



Contract-based Price Estimation Indexed by Yield for Switchgrass

Yield	Units	Mean	Std Dev	Coefficient of Variation
Upland	1000kg/ha	8.70	4.20	0.483
Lowland	1000kg/ha	12.90	5.90	0.457
Mean	**1000kg/ha**	**10.80**	**5.08**	**0.470**

$$Switchgrass\ Cost = \frac{Farmer\ Payment\ (\$/ha)}{Yield\ Distr.(kg/ha)}$$



$$Pr\_DDGS_t = -0.016 + 0.956 * Pr\_Corn_t$$

$$Jet_t = 0.004 + 0.988 Diesel_t \quad R^2 = 0.996$$

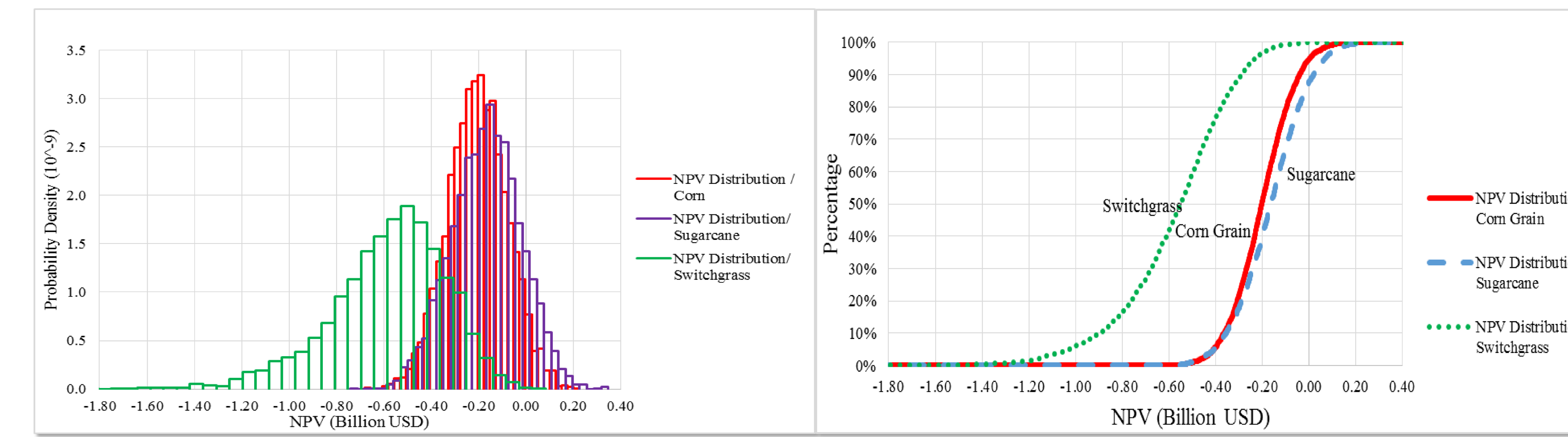
$$P_{other} = P_{oth\_Base} / P_{Diesel\_Base} * P_{Diesel\_Distr.}$$

Breakeven Price Distributions

We run the standard Monte Carlo simulation and to save all the simulated values and plug them back in the model to calculate the breakeven price for each iteration using the Excel Goal Seek function (NPV=0). The breakeven prices are then fit to an appropriate standard distribution. ***This distribution then can be used to determine the probability for any breakeven price.***

RESULTS

Net Present Value (NPV) Distributions



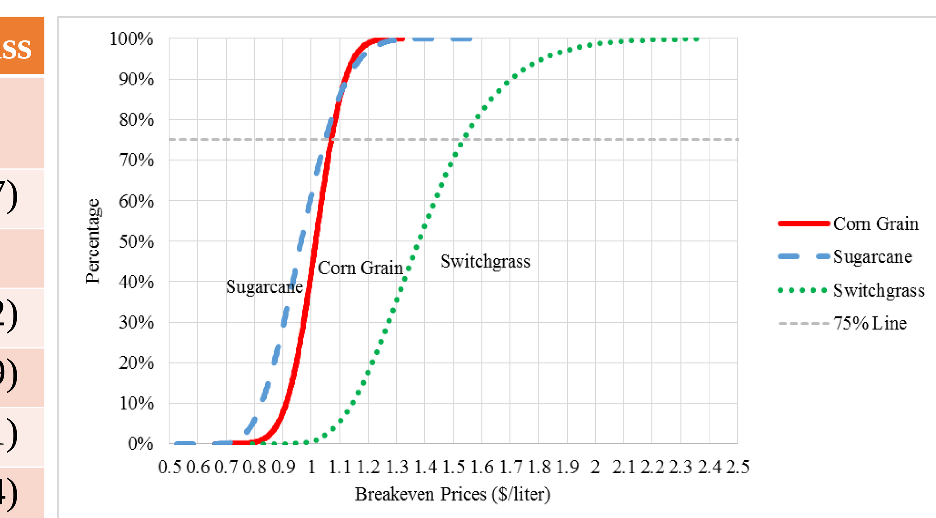
Sugarcane FSD Corn Grain FSD Switchgrass
Prob. Loss > 85% for all three pathways!

Investment Incentives are Needed!

Breakeven Price Distributions

Feedstocks	Corn	Sugarcane	Switchgrass
Distribution	Normal	BetaGeneral	Gamma
Minimum	$-\infty$	0.64 (2.42)	0.84 (3.17)
Maximum	∞	1.56 (5.91)	∞
Mean	1.01 (3.84)	0.97 (3.68)	1.41 (5.32)
Mode	1.01 (3.84)	0.95 (3.59)	1.32 (4.99)
Median	1.01 (3.84)	0.96 (3.65)	1.38 (5.21)
Std Dev	0.08 (0.31)	0.12 (0.44)	0.22 (0.84)
1%	0.83 (3.13)	0.74 (2.81)	1.02 (3.85)
5%	0.88 (3.34)	0.79 (3.00)	1.10 (4.15)
15%	0.93 (3.53)	0.85 (3.21)	1.18 (4.48)
25%	0.96 (3.64)	0.89 (3.36)	1.24 (4.71)
50%	*1.01 (3.84)*	*0.96 (3.65)*	*1.38 (5.21)*
75%	*1.07 (4.05)*	*1.05 (3.97)*	*1.53 (5.81)*
95%	1.15 (4.35)	1.17 (4.44)	1.81 (6.87)
99%	1.20 (4.56)	1.25 (4.75)	1.25 (7.75)

Notes: Values within the parentheses is measured in \$/liter and values outside the parentheses are measured in \$/gallon.

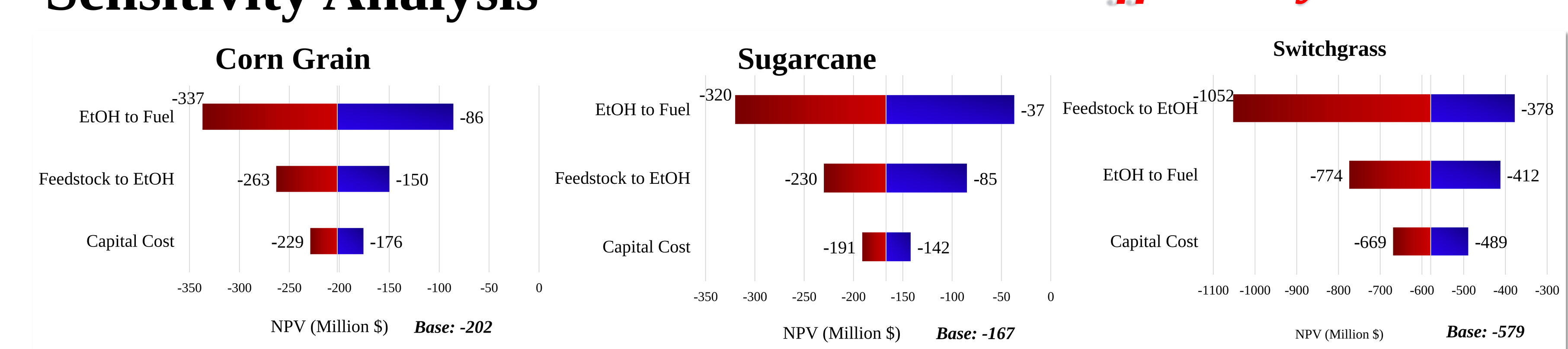


Switchgrass FSD Corn Grain SSD Sugarcane

It means that sugarcane ATJ has higher probability to have lower prices. CDFs of corn grain and sugarcane ATJs intersect at the 90% probability level. This is because DDGS prices increase with corn grain prices, which generates additional revenues when corn grain prices are high.

Sensitivity Analysis

Technical Efficiency Matters!



CONCLUSIONS

- We have assessed breakeven prices and NPV of ATJ biofuel production from three feedstocks using stochastic techno-economic analysis, accounting for ***technical and economic uncertainty in all major inputs and outputs.***
- We find that the variation of revenues from by-products can impact ***profitability***, and that ***technical uncertainty*** is critical in determining the economic performance of the ATJ fuel pathway.
- From a policy-perspective, ***risk profiles*** *such* as those developed in this analysis can also be used to assess the impact of alternative policies such as loan guarantees, tax credits, crop insurance, end user off-take agreements, reverse auction based on off-take contract and capital subsidy on reducing project risk (Tyner & Van Fossen, 2014).