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STOACHASTIC TECHNO-ECONOMIC ANALYSIS FOR AN INTEGRATED STRATEGY TO COPRODUCE JET FUEL RANGE ALKENES AND PENTANEDIOLS

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ABSTRACT

We evaluate the techno-economics of an integrated strategy to coproduce biofuels (Jet fuel range alkenes (JFA)) and biochemicals (pentanediols and pentane). Coproduction of biochemicals could improve the economics of biofuels production, and this study shows the feasibility of proposed strategy by stochastic analysis. Monte Carlo simulation is introduced for the stochastic analysis considering the uncertainty in major economic parameters of integrated strategy. The stochastic analysis obtains the distribution of minimum selling price of JFA. The integrated strategy considering uncertainties in key economic parameters has low minimum selling price of JFA ($2.86 and 3.17 per gallon of gasoline equivalent (GGE)), and the price is within the price range of biofuels ($2.90-4.82 per GGE).

Keywords: Biofuels, Biochemicals, Stochastic analysis, Monte Carlo simulation, Techno-economic feasibility

NONMENCLATURE

Abbreviations

P_L	Cumulative probability
GGE	Gallon of gasoline equivalent
JFA	Jet fuel range alkenes
MSP	Minimum selling price
PeD	Pentanediol
Std. Dev.	Standard deviation

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1. INTRODUCTION

Cellulosic biofuels is an attractive renewable fuels, because the raw material, lignocellulosic biomass, one of the most plentiful resource and there is no concern about carbon dioxide emission. However the problem in the use of biofuel is a high price due to high feedstock cost and technological immaturity [1, 2]. In addition, the recent drop in oil prices also opens up a price gap between biofuels and fossil fuels [3]. To overcome this bottleneck, a new approach to process economics through simultaneous production of valuable chemicals has been proposed [1, 4]. Recently, an integrated strategy coproducing jet fuel range alkenes (JFA) and pentanediols (1,2-pentanediol and 1,5-pentanediol; PeDs) from cellulose and hemicellulose fraction of lignocellulosic biomass is proposed, the fuel price assumed by deterministic techno-economic analysis is comparable to current biofuel price. Although the result of deterministic analysis shows that the integrated strategy is economic feasible, an uncertainty in these major economic parameters could lead uncertainty in the minimum selling price (MSP). An uncertainty analysis introducing Monte Carlo simulation can be used to assume more reliable production cost and MSP.

In this study, the stochastic analysis for the integrated strategy coproducing JFA and PeDs from lignocellulosic biomass is conducted to evaluate the techno-economic feasibility by using Monte Carlo simulation, and the results provide decision-maker with more reliable information on economic feasibility of the proposed strategy.

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2. METHODS

2.1 Integrated strategy coproducing JFA and PeDs

We obtained process data from previous study for development of integrated strategy coproducing JFA and PeDs from corn stover [5]. The process consisted of seven main steps (biomass handling, pretreatment, cellulose-to-JFA, hemicellulose-to-PeDs, boiler, wastewater treatment, storage). Corn stover is shredded and hydrolyzed through biomass handling and pretreatment, then the solid stream (containing cellulose and lignin) and aqueous stream (containing xylose) are sent to cellulose-to-JFA and hemicellulose-to-PeDs, respectively. Cellulose in solid stream is converted to JFA via four sub-steps of cellulose-to-JFA (levulinic acid production, gamma-valerolactone production, butene production, JFA production). Xylose in aqueous stream is converted to PeDs and pentane via four sub-steps of hemicellulose-to-PeDs (furfural production, furfuryl alcohol production, 1,2-pentanediol production, 1,5-pentanediol production). The integrated strategy produce fuels (115 tonnes per day of JFA) and chemicals (177 tonnes per day of PeDs and 26 tonnes per day of pentane) from 2,000 tonnes per day corn stover.

The energy requirements for integrated strategy are 131 MW of heating energy, 249 MW of cooling energy, and 2 MW of electricity when considering heat integration and on-site heat production by combustion of biomass residues (lignin and humin) obtained from integrated process.

2.2 Deterministic techno-economic analysis

The deterministic techno-economic analysis was performed by using economic parameters and assumptions applied in the previous study (Table 1 and 2) [5]. Capital and operating costs were calculated based on the simulation model, and the MSP of JFA which equal total cost and revenue was determined by using discounted cash flow analysis. The MSP of JFA determined based on the JFA production and net manufacturing cost (difference between total cost and total revenue of PeDs and pentane) was expressed in the gallon of gasoline equivalent (GGE).

Table 1 Economic assumptions

Economic assumptions [a]		Unit
Cost year basis	2016	USD
Annual operating time	8,410	h
Equipment lifespan	30	y
Construction time	3	y
Loan terms	10	y
Depreciation period	7	y
Working capital	5.0	%*
Equity	40.0	%*
Loan interest	8.0	%
Nominal discount rate	10.0	%
Tax rate	35.0	%

[a] Taken from system-level study. [5]
* Percent of total capital investment

Table 2 Economic parameters

Economic parameters [a]		Unit
Corn stover price	84.7	$ per tonne
HCl price	285.7	$ per tonne
NaCl price	40.0	$ per tonne
2-sec-Butylphenol price	57.1	$ per tonne
H_2SO_4 price	46.6	$ per tonne
$Ca(OH)_2$ price	130.6	$ per tonne
H_2O price	0.2	$ per tonne
H_2 price	2,116.0	$ per tonne
1,2-Pentanediol price [b]	2,000.0	$ per tonne
1,5-Pentanediol price [c]	3,000.0	$ per tonne
Pentane price [d]	1,500.0	$ per tonne
Ru-Sn(1 : 4)/C catalyst price	359,500	$ per tonne
Ru/MnO_x catalyst price	346,800	$ per tonne
$Rh\text{-}MoO_x/SiO_2$ catalyst price [e]	794,740	$ per tonne
Electricity price	67.5	$ per MWh
Low pressure steam price	21.5	$ per MWh
Cooling water price	2.0	$ per MWh

[a] Taken from system-level study. [5]
[b-e] Taken from online market data.

2.3 Stochastic techno-economic analysis

Based on the results of deterministic analysis, we conducted stochastic analysis by using @Risk software which is a excel spreadsheet add-in software program from Palisades Corporation. The stochastic analysis was performed to estimate the distribution of MSP of JFA considering uncertainty in major economic two cost parameters which had large impacts on the MSP of JFA. Monte Carlo simulation with 10,000 iteration was performed to show probability distribution of the MSP of JFA. In each iteration, uncertain input variables were sampled from distributions of economic parameters assumed based on price data reported in literature.

3. RESULTS AND DISCUSSION

3.1 Deterministic evaluation

Total cost ($219.1 million per year) consists of annualized capital cost ($65.9 million per year) and operating cost ($153.3 million per year) (Table 3).

Annualized operating cost accounts for 70% of total cost, and it is 1.3 times larger than the annualized capital cost. Except for the annualized capital cost, the corn stover ($59.4 million per year; 27% of total cost) accounts for the largest portion of total cost, followed by catalyst cost ($27.2 million per year; 12% of total cost).

Table 3 Annualized costs of integrated strategy

	Annualized cost ($ million per year)	% of total cost
Capital cost	65.8	30%
Operating cost	153.3	70%
Corn stover	59.4	27%
Catalyst	27.2	12%
Utility	23.8	11%
H_2	20.0	9%
Other variable operating	9.3	4%
Fixed	13.6	6%
Total costs	219.1	100%

The total revenue of chemicals is $177.8 million per year that consists of 1,5-Pentanediol ($104.9 million per year), 1,2-Pentanediol ($38.7 million per year), and pentane ($12.0 million per year). In the integrated strategy, the MSP of JFA is $2.90 per GGE that is 12% lower than the average biofuel price ($3.29 per GGE [2]) from 2014 to 2016.

3.2 Stochastic evaluation

The deterministic analysis showed that corn stover and catalyst prices have large impacts on the MSP of JFA. The stochastic analysis was performed on the two scenario, each considering uncertainty in corn stover (scenario 1) and catalyst (scenario 2) prices. The uncertain input variables of two economic parameters obtained from price data reported in literature [6, 7] were used for the stochastic analysis. Stochastic MSP and cumulative density curve of MSP estimated using Monte Carlo simulation are shown in Fig. 1.

In the scenario 1 considering uncertainty of corn stover price, the range of MSP is $1.53-4.07 per GGE, and the mean and standard deviation (Std. Dev.) are $2.86 per GGE and $0.494 per GGE, respectively. The MSP distribution has little skewness, and the cumulative probability (PL) that the stochastic MSP will be lower than the average biofuel price is 78.5%. In the scenario 2 considering uncertainty of catalyst price, the range of MSP is US$ 2.71-4.50 per GGE, and the mean and Std. Dev. are $3.17 per GGE and $0.317 per GGE, respectively. The MSP distribution has a positive skewness, and PL is 69.2%. Compared to the scenario 1, the mean is shifted to right and the MSP distribution is narrowed and skewed to the left. This is due to the difference in distribution between input variables. This analysis showed that the MSP is within the price range of biofuel ($2.90-4.82 per GGE [2]), even if the key cost parameter is changed. Compared to the deterministic analysis, the stochastic analysis can provide probabilistic results on economic feasibility of the integrated strategy when the market conditions are varied. And it is also used as a reliable information for risk-averse investment. Although

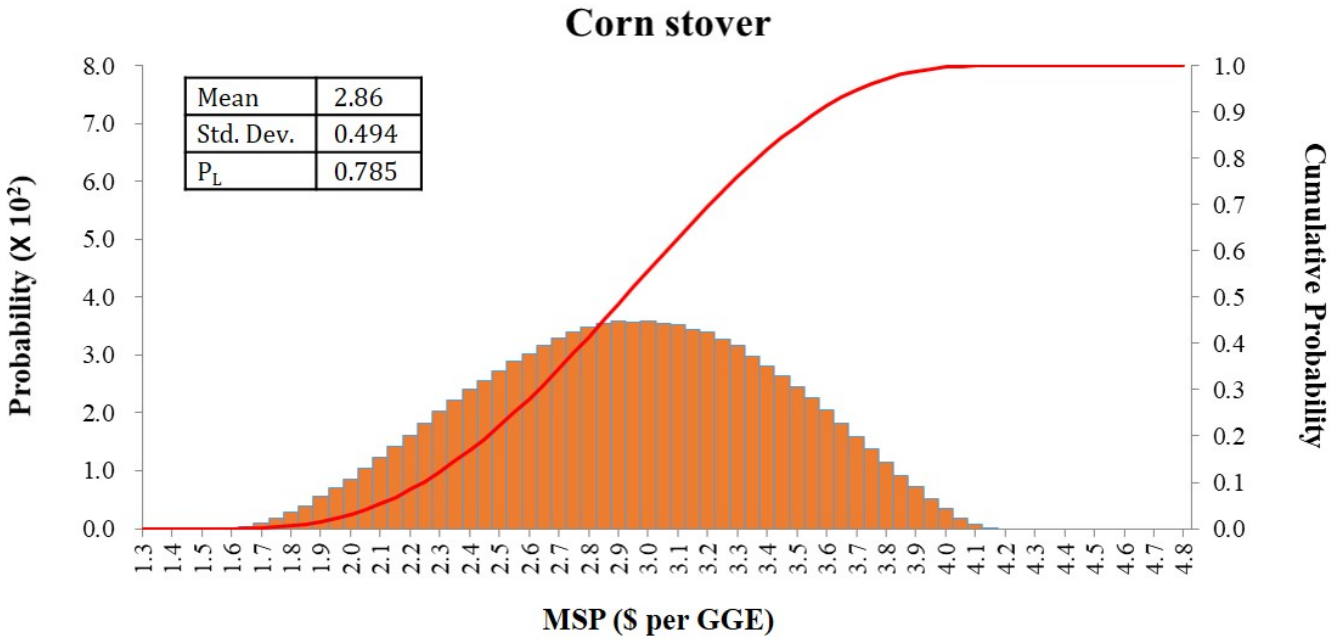

Fig. 1 Stochastic MSP and cumulative density curve of MSP for the scenario 1 (corn stover). The unit of the mean and the Std. Dev. is $ per GGE.

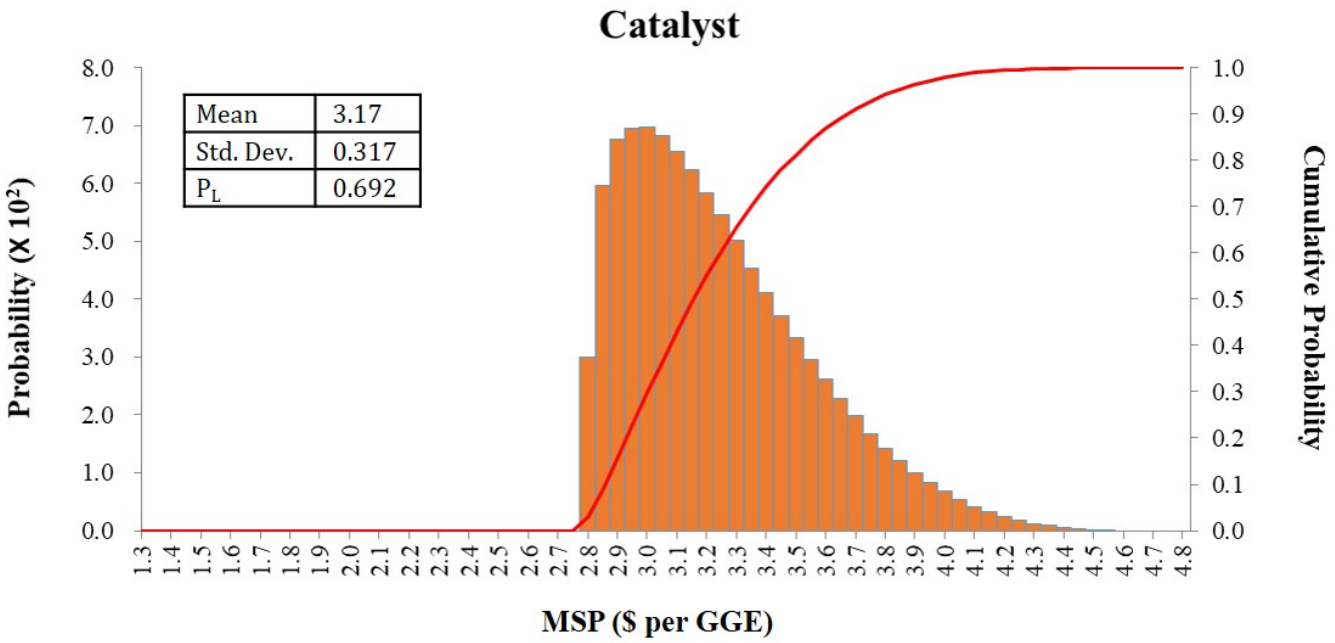

Fig. 2 Stochastic MSP and cumulative density curve of MSP for the scenario 2 (catalyst). The unit of the mean and the Std. Dev. is $ per GGE.

this study only considered the price uncertainties, we will consider the technical uncertainties such as conversion and selectivity of the catalytic reactions provide more reliable information to the decision makers.

4. CONCLUSIONS

This study evaluated the economic feasibility of integrated strategy coproducing biofuels (JFA) and chemicals (PeDs and pentane) based on the large-scale simulation model. Through the deterministic analysis, total cost of integrated strategy ($219.1 million per year) and MSP of JFA ($3.29 per GGE) were estimated. Corn stover (27% of total cost) and catalyst (12% of total cost) costs had large impact on the MSP of JFA. Stochastic analysis considering uncertainty in the two major parameters showed that even though uncertainty of cost parameters was considered, MSP of JFA ($1.53-4.50 per GGE) was within the price range of biofuel ($2.90-4.82 per GGE). As a further study, we will perform stochastic analysis for other parameters.

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