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Field to Flight: A Techno-Economic Analysis of the Corn Stover to Aviation Biofuels Supply Chain

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Introduction

Importance of Aviation Biofuels

Aviation biofuels are important for three reasons: to reduce greenhouse gas (GHG) emissions, meet the Renewable Fuel Standard (RFS) for cellulosic biofuels, and improve U.S. energy security. Greenhouse gas emissions are a growing concern.

The United States Environmental Protection Agency reports that the transportation sector is responsible for 32% of the total CO_2 emissions from combustion of fossil fuels. In 2012, it contributed 27% of total US GHG emissions (U.S. Environmental Protection Agency). As a result, there has been a focus on producing biofuels for the transportation sector as a way to reduce GHG emissions. In 2011, jet fuel made up about 11% of the U.S. transportation sector's energy consumption (2013a). The U.S. Energy Information Administration (EIA) predicts that by 2040, it will increase to 13%.

The Energy Independence and Security Act (EISA) of 2007 set a target level of 16 billion gallons ethanol equivalent (9.8 billion gallons jet fuel equivalent) cellulosic biofuels by 2022 (Administration 2013). The U.S. consumes over 20 billion gallons of aviation fuel each year. With a blending ratio of aviation biofuel to petroleum fuel of 50%, the potential for aviation biofuels is over 10 billion gallons/year. The U.S. Energy Information Administration expects consumption to grow each year (2013a). Drop-in cellulosic biofuels are necessary to meet the requirements of the RFS. Drop-in fuels are second-generation biofuels that can be directly dropped into the fuel system. In addition, while there are other options available to render the ground transportation fleet greener (electric vehicles, compressed natural gas), the only option for aviation is biofuels. Theoretically, aviation biofuels could meet the entire RFS requirement for cellulosic biofuels.

Growth in aviation biofuels can also help improve U.S. energy security. Currently, the U.S. is highly dependent on oil imports. Aviation biofuels can allow for diversity in fuel supply.

Our Analysis

The feedstock we chose for the analysis presented here is corn stover, a cellulosic feedstock. Cellulosic feedstocks can come from dedicated energy crops such as miscanthus and switchgrass or from crop and forest residues. There is an abundance of corn stover available for harvest throughout the United States. Corn stover has advantages over other biomass feedstocks. Corn stover supports rather than competes with human food production (2013b). It is also a relatively inexpensive feedstock option. According to the National Academy of Sciences report, alfalfa, switchgrass, and miscanthus all have farm level prices exceeding corn stover (National Research Council 2011).

The conversion process used for the analysis is fast pyrolysis. It is preferred to the other options because it produces a higher yield of liquid (Jones 2009). Pyrolysis is also preferred in comparison to other conversion processes due to its lower cost (Anex et al. 2010). Fast pyrolysis produces bio-oil, which is then upgraded through hydroprocessing so it can be blended with gasoline and diesel fuels.

Policy Considerations

The cellulosic biofuel industry can be incentivized by government, but it is owned and operated by the private sector. Cellulosic biofuels have higher costs, which means there is higher risk for private investors, so incentives may be needed to entice private investors to invest. There are a wide array of possible policies that could be used to stimulate biofuels production. In the research reported here, we focused on two policies, which differ in the extent to which they help reduce uncertainty for private sector investors. These are a reverse auction and a capital subsidy.

In a reverse auction, a government prospective purchaser would request bids for a contract to supply aviation biofuels. Private investors would place bids on the price per gallon of fuel. The lowest unique bidder (thus the name reverse auction) wins the bid (Gaggero 2010). The government incurs a cost with a reverse auction. The production level and biofuel price are fixed, regardless of the oil price. Therefore, the government may win or lose depending on oil market price. No matter what oil price, the government (or other purchaser) must pay the contracted price per gallon of fuel.

We modeled the capital subsidy to have the same cost to government as the reverse auctions cases. There are many ways the capital subsidy could be implemented. The exact implementation method is not a critical factor in our analysis, as we are more interested in the degree of risk reduction compared with cost.

Financial Model

All of our analysis is done using a discounted cash flow model, initially with deterministic values, but for the bulk of the analysis incorporating risk in key uncertain data parameters. The base year for all data is 2011.

Discounted cash flow analysis is used to find the net present value of a project in order to assess whether it will be successful or not. It has two steps, cost analysis and discounted cash flow analysis, which lead to calculating a minimum fuel selling price (MFSP). It is useful for comparing projects of different size (Towler 2013). A discounted cash flow rate of return (DCFROR) is the interest rate at which the net present value (NPV) equals zero. It measures the maximum rate a project can pay and still break even by the end of the project life (Sinnott 2005).

The data used in the analysis comes mainly from the Iowa State University studies by Wright et al. (2010) and Brown et al. (2013). We recreated their analysis using a discounted cash flow rate of return analysis in order to be certain that our data used in the economic analysis was accurate.

Using economic and technical assumptions, we found a minimum fuel selling price of $2.53 per gallon. Brown et al. (2013) found a fuel price of $2.57 per gallon when the internal rate of return is 10%. Therefore, we can be confident that our assumptions and results are an accurate recreation of Brown et al. (2013).

Technical Uncertainty

We modified assumptions and parameters in order to better reflect reality in the market. There are four variables that have a large impact on the non-risk adjusted breakeven fuel price. We researched feedstock cost, final fuel yield (bio-oil yield multiplied by fuel yield), hydrogen cost, and capital cost, which led us to new min, mode, and max values. The mean is a pert distribution. Our ranges are much more realistic based on current literature.

Using the mean of the new parameter values, we can calculate a new non-risk adjusted breakeven fuel price. The breakeven fuel price is substantially higher than the breakeven fuel price with the old parameter values from Brown. With all of the new parameters the fuel price is $3.33 per gallon. The increase in prices is primarily due to the increase in hydrogen cost and decrease in final fuel yield from the old (Brown) parameter values.

Figure 1 on page 3 provides a breakdown by major cost category of the breakeven fuel price. The breakdown of breakeven fuel price is provided for 4 different cases: 1) using all of Brown's assumptions, 2) the authors' assumptions and Brown's conversion rate, and 3) all of the authors' assumptions with conversion rate impact separated out, and 4) all of the authors' assumptions with the new conversion rate incorporated. The sum of all the parameters in each bar is the breakeven fuel price. Using Brown's conversion rate and the authors' assumptions versus Brown's assumptions had a substantial impact on the breakeven fuel price.

Final fuel yield also had a large impact on the breakeven fuel price. There is a decrease in final fuel yield from 25.83% biomass to 22.97% biomass or about 7 million gallons. Decreasing the fuel yield to 50.4 million gallons

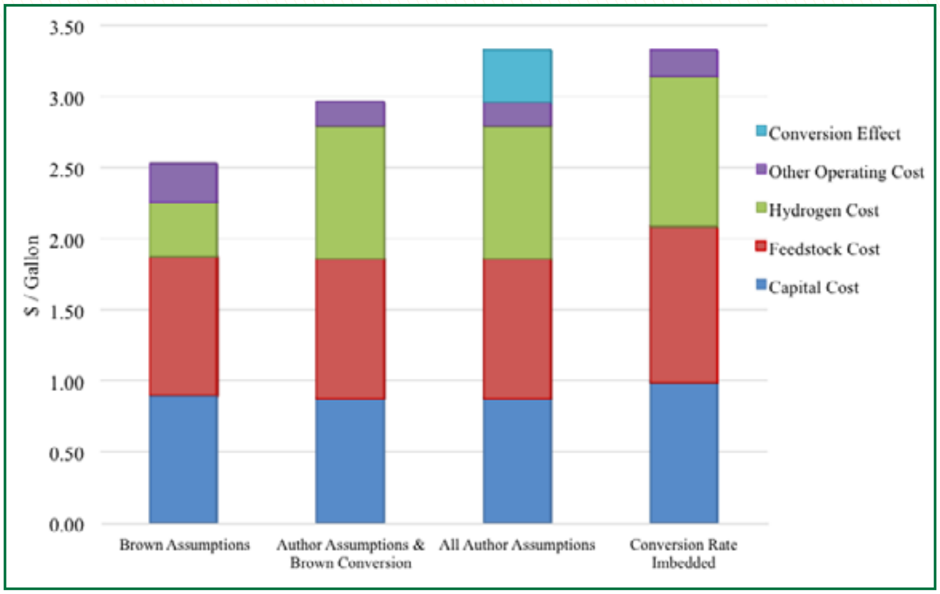

Figure 1. *Breakdown of Impact Each Parameter Has on Non-risk Adjusted Breakeven Fuel Prices ($/gallon)*

results in an increase in price by $0.37 per gallon from the second stacked bar to the third one.

Fuel Price Uncertainty

We used two jet fuel price projections to capture uncertainty on the expected return on investment. The two jet fuel price projections used are 1) a stochastic fuel price with no trend and 2) a stochastic fuel price that increases over time at a rate of the EIA jet fuel price projections. We use an initial fuel price of $3.03 per gallon, which is an average of the wholesale/resale price for jet fuel and diesel by refiners. The price is in real terms.

There are two main types of stochastic processes used for forecasting oil prices: Brownian motion and mean reversion. There are advantages and disadvantages to both forecasting methods. The key factor in determining which process to use is the speed of mean reversion. Researchers agree that if mean reversion is fast, then a mean reversion process is preferred. On the other hand, if mean reversion is slow, then Brownian motion is not a bad option for forecasting oil prices (Pindyck 1999, Postali and Picchetti 2006). Literature showed that mean reversion is slow. Therefore we use geometric Brownian motion (GBM).

In order to calculate the projected prices for our project we use an equation similar to the traditional geometric Brownian motion equation. After calculating the projected prices we regressed diesel price on jet fuel wholesale prices from 2004 to 2013. Using the intercept and slope we found an equation for diesel price. We assume that 50% of the fuel produced is jet fuel and 50% is diesel. By taking the average price of jet fuel and diesel each year, we get a combined price.

Results

We ran results on three cases with a deterministic price and stochastic cases for the reverse auction and capital subsidy policy cases. For each stochastic case we ran results using both fuel price projections.

For the reverse auction and capital subsidy, we did the original analysis both assuming firms bid with a 50% probability of loss and also at 25% probability of loss. In reality, it is highly unlikely that firms would be willing to bid at the 50% level due to the high risk. As a result, we only present the 25% level comparison of the two policies.

Base Case

The base case is deterministic with all of the variables fixed at mean values over the life of the project. Feedstock cost, final fuel yield, hydrogen cost, and capital cost are fixed at their mean values. Fuel price is fixed at $3.03/gallon. This is the average of the wholesale/resale price for jet fuel and diesel by refiners. Three discounted measures of project worth are calculated: net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (B/C). The economic analysis is before financing and taxes, while the financial analysis is after financing and taxes. We report the results with all of the variables fixed as stated above, and then find the breakeven fuel price for the financial analysis.

All three discounted measures of project worth have different criteria for accepting a project. A project is accepted when the net present value is greater than zero. For the internal rate of return (IRR), the IRR must be greater than the discount rate. Benefit-cost ratio (B/C) is the ratio of discounted benefits to discounted costs. A project is accepted when the B/C is greater than one. For the deterministic results, none of the discounted measures of project worth meet the criterion. This demonstrates the reality that without government intervention, investors would not be likely to find the plants attractive.

We found the breakeven fuel price with all of the variables fixed. The breakeven fuel price is the price at which a plant is neither running at a loss nor profit. We found the breakeven fuel price for the financial analysis instead of the economic since it is more realistic, accounting for financing and taxes. The results on the right in Table 1 are with the breakeven fuel price. Using the goal seek tool in excel, when NPV equals zero, the breakeven fuel price was $3.33/gallon.

Results Under Uncertainty

Next, we incorporate uncertainty in input variables and translate that to uncertainty in the results. The Palisade Corporation software @Risk was used to determine the risk of investment in aviation biofuels for the stochastic cases. Monte Carlo analysis is used to predict the uncertainty in NPV. By using a Pert distribution for the four technical variables stated previously, uncertainty is incorporated into the spreadsheet. We assume once a random draw is taken for any of the uncertain technical variables it remains constant over time. As a result, the values for the technical variables do not change from year to year for each random draw. On the other hand, there is no correlation among our four technical variables. They are assumed to be independent of each other. The stochastic case was run with both of the jet fuel price projections stated in the fuel price uncertainty section. The initial fuel price for each projection was $3.03/gallon. A breakeven fuel price was found for each projection. Results were reported for both prices. The mean, standard deviation, and probability of loss are reported in the tables.

The results for the first case where fuel price is steady are reported in Table 1. The results shown in the top of Table 1 were found using a steady stochastic fuel price of $3.03/gallon. The mean, standard deviation, and probability of loss are reported for the NPV, IRR, and B/C. The mean NPV's are negative, with the financial analysis being less negative than the economic analysis. The standard deviation and probability of loss are less in the financial analysis than in the economic. This is seen throughout all of the results. The nominal discount rate of 12.75% is equivalent to a real rate of 10% with our assumed inflation rate of 2.5%.

We found the breakeven fuel price for when there is no trend in the fuel price. For a steady stochastic fuel price, the breakeven fuel price was $3.33/gallon. The results are in the bottom of Table 1. The biggest difference between the top and bottom is the probability of loss. With a fuel price of $3.03/gallon, the probability of loss for NPV hovers around 70%, while with a fuel price of $3.33/gallon it hovers around 50%.

There can be errors in IRR when stochastic simulations are run. Table 1 has IRR's for both the economic and financial analysis which contain errors. As a result the IRR will be inconsistent with the NPV and B/C.

The results for the second case where the stochastic fuel price is increasing at a rate derived from DOE projections are shown in Table 2 on page 5. The initial fuel price was $3.03/gallon, increasing to a price of $3.83/gallon in the last year of the plant life for the left side of Table 2. In comparison to the top of Table 1, mean NPV become positive, standard deviation is larger, and the probability of loss decreases substantially. An initial fuel price of $3.03/gallon results in a probability of loss of 49.7% for the financial analysis. There is a decrease of about 15% from using a steady stochastic fuel price of $3.03/gallon versus one that increases over the plant life.

Table 1. *Stochastic Results with Steady Stochastic Fuel Price*

	Economic			*Financial*		
	NPV	*IRR (nominal)*	*B/C*	*NPV*	*IRR (nominal)*	*B/C*
Mean	($141,776,821)	6.7%	0.89	($84,935,001)	10.3%	0.92
Standard Deviation	$259,469,857	7.8%	0.21	$215,099,088	10.2%	0.18
Probability of Loss	72.4%			66.8%		
Mean	($39,445,311)	9.1%	0.97	$102,484	13.8%	1.00
Standard Deviation	$258,015,067	7.7%	0.21	$213,936,040	10.3%	0.18
Probability of Loss	57.8%			51.9%		

[a]**Note:** (1) Nominal Discount Rate Used for NPV was 12.75% (2) IRR calculation had errors in the stochastic calculation (3) Negative prices in the stochastic simulation were ruled out.

Table 2. Stochastic Financial Results with Increasing Stochastic Fuel Price

	Initial Fuel Price of $3.03			*Initial Breakeven Fuel Price of $3.01*		
	NPV	IRR (nominal)	B/C	NPV	IRR (nominal)	B/C
Mean	$5,131,645	13.3%	1.00	$280,938	13.1%	1.00
Standard Deviation	$225,888,369	10.1%	0.19	$226,554,954	10.2%	0.19
Probability of Loss	49.7%			52.1%		

[a]**Note:** (1) Nominal Discount Rate Used for NPV was 12.75% (2) IRR calculation had errors in the stochastic calculation (3) Negative prices in the stochastic simulation were ruled out.

The initial breakeven fuel price for the financial case when fuel price is increasing is $3.01/gallon. The fuel price increases over the plant life to a price of $3.83/gallon. In comparison to using an initial fuel price of $3.03/gallon, the mean and standard deviation of the NPV on the right side of Table 2 remain about the same. The probability of loss is relatively similar to the one in the bottom of Table 1, where fuel price was the breakeven fuel price when prices were steady, because they both are reporting results for the breakeven fuel price.

Introducing uncertainty into the spreadsheet allows us to determine the risk involved in investment. Without any policies, we see the results shown in Tables 1 and 2. Even though the mean NPV becomes positive with the increasing price case, the probability of loss is around 50%. This is still a large probability of loss. Private investors would be discouraged from making an investment. As a result, some policy intervention may be needed to reduce the probability of loss.

Reverse Auction

Two main cases were conducted for the reverse auction. They are 1) a stochastic fuel price with no trend where producers bid a breakeven fuel price at 25% probability of loss with no policy and 2) a stochastic fuel price that increases over time where producers bid a breakeven fuel price at 25% probability of loss with no policy.

Within these cases, four contract lengths were analyzed – 0, 5, 10, and 15 years. We wanted to evaluate the impacts longer contract lengths can have on the probability of loss and also show illustrative bid prices for each contract length. The contract quantity used was 21 million gallons for the initial year and 42 million gallons per year for the rest of contract term. Once again we focus on the financial analysis because it is more realistic than the economic.

The first case is a reverse auction with a stochastic fuel price with no trend. Both the market price and the reverse auction price are steady over the plant life. Note that the 0 contract years case reverts to the previous case with no contract since the previous price regime is always in force. Therefore, when the contract length is 0 years, the fuel price reverts to the market price of $3.03/gallon. As a result, we see small or negative NPV's because the market price is not large enough to compensate for the costs. The market fuel price has stochasticity in it for all cases, while the reverse auction fuel price does not.

For all of the reverse auction cases we reported the mean, standard deviation, and probability of loss for the NPV. The first case is a reverse auction with a stochastic fuel price with no trend where producers bid a breakeven fuel price with 25% probability of loss. The reverse auction fuel price is the breakeven fuel price when producers bid with a 25% probability of loss when there is no contract. For this case, the reverse auction fuel price is $3.88/gallon. The results would all show similar trends at other probability of loss thresholds.

Table 3 on page 6 reports the financial results for a steady fuel price case when producers bid with 25% probability of loss. The mean NPV increases, becoming positive when the contract length increases to 10 years. Standard deviation decreases as the contract length increases. Last, the probability of loss decreases as the contract length increases. This is what we expected to happen. We see that the NPV mean becomes positive. As a result, we see a decrease in probability of loss. Probability of loss is 66.8% with no contract, and decreases to 23.3% with a 15-year contract. This is an over 40% decrease in probability of loss, which is substantial.

The second case is a reverse auction with an increasing stochastic fuel price. The market price and reverse auction price increase over the plant life. The results are in Table 3. The initial market fuel price is $3.03/gallon and increases to $3.83/gallon. The reverse auction fuel price when producers bid with a 25% probability of loss and there is no contract

Table 3. *Reverse Auction Results Where Producers Bid with 25% Probability of Loss with No Contract*

Financial						
	Steady Stochastic Fuel Price			*Increasing Stochastic Fuel Price*		
Length of Contract	Mean	Standard Deviation	Probability of Loss	Mean	Standard Deviation	Probability of Loss
0	($84,935,001)	$215,099,088	66.8%	$5,131,645	$225,888,369	49.7%
5	($3,076,598)	$180,494,175	52.7%	$54,654,207	$193,509,692	40.5%
10	$54,621,882	$144,923,926	37.2%	$92,101,790	$155,469,318	28.7%
15	$90,429,608	$121,718,449	23.3%	$116,683,443	$130,158,226	18.4%

Table 4. *Comparison of Reverse Auction and Capital Subsidy Financial Analysis Results When Fuel Price Is Stochastically Steady and Producers Bid with 25% Probability of Loss with No Contract*

	Reverse Auction				*Capital Subsidy*			
Length of Contract	*Mean*	*Standard Deviation*	*CV*	*Probability of Loss*	*Mean*	*Standard Deviation*	*CV*	*Probability of Loss*
5	($3,076,598)	$180,494,175	(58.7)	52.7%	($3,074,025)	$212,123,478	(69.0)	52.0%
10	$54,621,882	$144,923,926	2.7	37.2%	$54,629,464	$212,123,478	3.9	41.3%
15	$90,429,608	$121,718,449	1.3	23.3%	$90,458,790	$212,123,478	2.3	34.8%

is $3.53/gallon increasing to $4.46/gallon in the last year of the plant life. The results are similar to when fuel price is steady. The mean NPV increases as the contract length increases. Standard deviation and probability of loss decrease as the contract length increases, which is what we expect. The probability of loss decreases to less than 20% with a 15-year contract.

Overall we see that when producers bid at 25% probability of loss with no contract, the standard deviation and probability of loss decreases as the contract length increases. The mean NPV increases considerably. This is a result of the larger fuel prices bid when producers have a lower probability of loss. In addition, we also see that when the fuel price is stochastically increasing versus being steady, there are lower probabilities of loss.

Comparison of Reverse Auction to Capital Subsidy

Reverse auction and capital subsidy have different effects. In order to see how the effects of a reverse auction and capital subsidy differ, we did a comparison of all four cases. We focused on the financial results for each policy, reporting the mean, standard deviation, and probability of loss for NPV for contract lengths of 5, 10, and 15 years.

The comparison of capital subsidy and reverse auction policy cases reveals quite a bit about the way the two policies function. The results when producers bid with a 25% probability of loss and fuel price is steady are shown in Table 4. In effect, the capital subsidy shifts the mean NPV to the right by the amount of the subsidy. However, it has no effect on the variance of NPV. The reverse auction also shifts the NPV to the right somewhat, but at the same time has a very large impact on variance, with standard deviation of NPV being much smaller. Thus, it is clear that the reverse auction is much more effective in reducing risk for private sector investors than is the capital subsidy. The probability of loss is also lower in all cases for a reverse auction, decreasing by almost 40% to about 23% when there is a 15-year contract. When the variances are as high as we see here, the probability of loss is not as good an indicator as the coefficient of variation (standard deviation/mean). In all cases, the coefficient of variation is much lower for the reverse auction cases.

When fuel price is stochastically increasing and producers bid with 25% probability of loss, we see the results in Table 5 on page 7. The impact when fuel price is increasing versus steady is seen in both policies. For the reverse auction, the mean NPV's are higher and the probability of loss is lower than in Table 4. In Table 5, the probability of loss, standard deviation, and coefficients of variation are lower in all instances for the reverse auction case. Therefore, the reverse auction reduces risk for private investors more than a capital subsidy.

An alternative way to compare reverse auction with capital subsidy is to compare the bid price at which producers

Table 5. *Comparison of Reverse Auction and Capital Subsidy Financial Analysis Results When Fuel Price Is Stochastically Increasing and Producers Bid with 25% Probability of Loss with No Contract*

	Reverse Auction				*Capital Subsidy*			
Length of Contract	*Mean*	*Standard Deviation*	*CV*	*Probability of Loss*	*Mean*	*Standard Deviation*	*CV*	*Probability of Loss*
5	$54,654,207	$193,509,692	3.5	40.5%	$54,653,703	$226,202,141	4.1	42.2%
10	$92,101,790	$155,469,318	1.7	28.7%	$92,100,794	$226,202,141	2.5	35.7%
15	$116,683,443	$130,158,226	1.1	18.4%	$116,686,406	$226,202,141	1.9	31.1%

Table 6. *Comparison of Bid Prices When Fuel Price Is Stochastically Steady and Producers Bid at 25% Probability of Loss with Policies*

Length of Contract	*Reverse Auction ($/ gallon)*	*Capital Subsidy ($/ gallon)*
5	5.21	5.44
10	4.16	4.44
15	3.85	4.15

can achieve 25% probability of loss with a policy. Table 6 presents the results for the steady price case. The bid prices for capital subsidy are the bid prices of reverse auction at which the capital subsidy case achieves 25% probability of loss, and the two policies have the same cost to government. When the probability of loss with polices is fixed, the bid prices for both cases decreases as the length of contract increases. The bid price reached $3.85 per gallon with a 15-year reverse auction contract. As the contract length increases and bid price decreases, the expected IRR and IRR standard deviation decrease (not shown). Thus, these results illustrate a risk-return trade-off. Fixing the probability of loss at 25%, the bid prices with capital subsidy case are much higher than the prices under reverse auction. This also indicates that reverse auction is more efficient in reducing risk for private investors. In addition, the bid price differences are also increasing with contract length, which indicates that the risk could be reduced more by reverse auction with longer contracts compared with capital subsidy. We also did the same analysis for the increasing price case, and the results show similar trends.

Conclusions

The aviation biofuel industry at present presents a high risk for private investors. There is uncertainty in future fuel price, feedstock availability and cost, process yields and costs, environmental impact, and government policy. Our analysis looked at the production of aviation biofuel from corn stover using the fast pyrolysis process. Currently, the risk is high for private investors. One way to reduce this risk is through government intervention.

Government intervention can be done in the form of a wide range of policies. We looked at two policies in our results: reverse auction and capital subsidy. We also ran a carbon tax, but found that it was not as effective at reducing risk. This is due to the carbon tax not being large enough to change behavior.

The two major factors that contributed to lower probabilities of loss were (1) a stochastic fuel price increasing at DOE projections, and (2) longer contract lengths. Reverse auction and capital subsidy both had large impact on probability of loss and coefficient of variation.

The reverse auction reduced risk more than capital subsidy at the same cost to the government. Implementation of this policy likely would be done by the government. The government would put up a contract for a certain quantity of aviation biofuels to be produced each year for a certain contract length. The plant builders would place bids on the government's contract. This bidding process is a means of effectively creating a competitively based subsidy for aviation biofuels. That is why it turns out to be more efficient. However, there may be difficulties in securing adequate competition for new processes such as pyrolysis based aviation biofuels. Reverse auctions have worked well for known technologies, but they may not function as well for new and unproven technologies. It may be useful to test the procedure with relatively small plants.

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