7-2014

Techno-Economic Analysis (TEA) of Using a Destoner to Fractionate Distillers Dried Grains with Solubles (DDGS)

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Abstract

With the rapid development of the ethanol industry in recent years, various studies have examined distillers dried grains with solubles (DDGS), the main co-product from ethanol production. Previous studies have examined fractionating DDGS using sieves and aspirators. However, information about the cost effectiveness is lacking. The objective of this project was to determine techno-economics of DDGS fractionation using a destoner to separate nutrients. Mathematical models were built for conducting techno-economic analysis (TEA), which allowed for estimations of capital costs, annual operating costs, annual revenues, and net profits. The techno-economics of the base case ethanol plant were examined by adjusting material and market costs, and estimating fractionation efficiencies and fraction prices based on protein content. This study demonstrated the possibility of using a destoner to fractionate DDGS to produce higher economic returns.

Keywords

DDGS, SuperPro, destoner, fractionation, techno-economic modeling

Disciplines

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CSBE | SCGAB

An ASABE – CSBE/ASABE Joint Meeting Presentation

Paper Number: 141914327

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Written for presentation at the

2014 ASABE and CSBE/SCGAB Annual International Meeting

Sponsored by ASABE

Montreal, Quebec Canada

July 13 – 16, 2014

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With the rapid development of the ethanol industry in recent years, various studies have examined distillers dried grains with solubles (DDGS), the main co-product from ethanol production. Previous studies have examined fractionating DDGS using sieves and aspirators. However, information about the cost effectiveness is lacking. The objective of this project was to determine techno-economics of DDGS fractionation using a destoner to separate nutrients. Mathematical models were built for conducting techno-economic analysis (TEA), which allowed for estimations of capital costs, annual operating costs, annual revenues, and net profits. The techno-economics of the base case ethanol plant were examined by adjusting material and market costs, and estimating fractionation efficiencies and fraction prices based on protein content. This study demonstrated the possibility of using a destoner to fractionate DDGS to produce higher economic returns.

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Introduction

With increased demand for fossil fuels, the supply of ethanol as a fuel additive has been increasing, and the US ethanol industry has grown rapidly in recent years (Schnepf and Yacobucci, 2013). In 2013, 13.3 billion gallons of ethanol has been produced by nearly 200 operating plants, which is a little higher than the production of 2012. What's more, ethanol's share of the gasoline pool has been gradually important, which has risen from just 3% in 2005 to 10% today (RFA, 2014). During all the bio-ethanol plants, most of them have chosen dry grind processing, which treats corn with grinding and slurring, and then adds enzyme to transform starch into monosaccharide for yeast fermentation (Singh et al., 2001).

There are three products generated from corn-based fuel manufacturing: bioethanol, distillers dried grains with solubles (DDGS) (or other co-products), and carbon dioxide. In 2013, 37.8 million metric tons (mmt) of high-quality feed has been generated, which increased 2.3 million metric tons comparing to 2012 (RFA, 2014). Marketing of DDGS as an ingredient is directly related to sustainability of the dry grind plant, and sold with a varying market price (US$85–300/ton) (Liu, 2008). DDGS is composed largely of protein (25-35%), fiber (7-10%), and fat (3-14%) as a dry mix of particulate materials, which makes it possible as an ideal material for feed (Bhadra et al., 2009; Rosentrater and Muthukumarappan, 2006; Shurson and Alhamdi, 2008; Srinivasan et al, 2009; Zhang and Rosentrater, 2013a; Zhang and Rosentrater, 2013b). In 2013, 48% of DDGS has been used for reef battle; 31% of DDGS has been used for dairy cattle and 12% of DDGS has been used for swine (RFA, 2014). Due to various particle compositions, especially high protein and high fiber particles, an efficient method of separating DDGS into high protein and high fiber fractions could contribute extra economic benefit to the producers (RFA, 2012; Srinivasan et al., 2005). The high protein portion has greater value as a feed to animals (Belyea et al., 2004), while the high fiber fraction has more potential for corn fiber gum or as raw material for lignocellulose ethanol production (Singh et al., 2002; Rosentrater, 2007; Rosentrater and Krishnan, 2006; Srinivasan et al., 2005).

For separating the various components of DDGS, numbers of methods have been tried to fractionate, including sieving, aspiration and other attempt (Liu, 2009; Srinivasan et al. 2009; Garcia and Rosentrater, 2008). All the methods mentioned thus far, however, are suboptimal in the efficiency and economy that are the hallmark of sustainable industrial production. A destoner is a simple and efficient machine to use air flow and shaking to separate, which can remove stones and soil from grains. In previous research, destoner fractionation has been proved as a somewhat efficient method to separate fractions of DDGS (Zhang and Rosentrater, 2013a). The convenience and inexpensive operations are the greatest advantages to using a destoner, which makes it appropriate for industrial production (Heiland and Kozempel, 1988). Most studies to fractionation of DDGS by destoner are done on a small scale, but no research has been done to study possibility and economic analysis in the industry scale (Zhang and Rosentrater, 2013a). As it is known, the feasibilities to experimental and industrial scales are completely different stories. Equipment costs, fluctuating prices of material and other process parameters may play an important role in the whole process, which is not necessary to be considered in experimental scales. For this reason, it is very important to predict accurately with various affected factors in industrial scale for detecting feasibility to fractionation of DDGS through a destoner.

Petrides (2011) mentioned that computer models can make such economical predictions more accurate with enough data of parameters and simulation. ASPEN PLUS (Aspen Technology, Inc., Burlington, MA) and SuperPro Designer (Intelligen, Inc., Scotch Plains, NJ) have been utilized as tools for cost analysis in the bio-ethanol industry (Hass et al, 2006; Kwiatkowski et al, 2006). This study used part of a TEA model (McAloon and Yee, 2011), which was a 40 million gallon dry-grind ethanol from corn to determine the economic feasibility of a DDGS fractionation system. The main objective of this research was to explore techno-economics of three different scales of using a destoner process to fractionate DDGS, and then to determine how effectively they can obtain revenue and profit.

Materials and methods

Computer Model

SuperPro Designer (Intelligen, Inc., Scotch Plains, NJ) is an industrial design software, which can facilitate modeling, evaluation and optimization of integrated processes in a wide range of industries (SuperPro Designer, 2014). In general, SuperPro can include a series of chemical component, equipment, mixture and resource databases. By defining flow rate, composition, physical and economic characteristics for each stream, this software can determine mass and economic balances for the individual unit operations and whole systems. This study used the USDA model (Wood et al, 2013), updated in 2013 for a 40 million gal/y ethanol plant. This studied assumed another two scales, which are 100 and 150 million gal/y ethanol plant. These models used operational 330 and 24 hours per day. The price of destoner was from Hebei Fengbafei Trade Co., Ltd (Hebei, China) (Table 1). After setting basic data into the model, SuperPro produced a variety of reports based on each simulation, and the design of the three scales are shown in Figure 1, Figure 2 and Figure 3.

Simulations

Simulations were run based on modifying how various scales of destoner were used. Two different variables were considered in this model:

1) Quantity of DDGS treated in one year (118,880 ton / year DDGS in a yearly 40 million gallon ethanol plant; 297,000 ton / year DDGS in a yearly 100 million gallon ethanol plant; 445,500 ton / year DDGS in a yearly 150 million gallon ethanol plant).
2) Prices of various DDGS fractions were determined by various protein percent (Original DDGS was $200 / ton; Medium protein DDGS was $214.45 / ton; High protein DDGS was $222.27 / ton). The equation for calculation is:

   Final DDGS price = Original DDGS price ($) + Protein percent over original DDGS (%) * $10 per percent ($ / %)

For the design of the model, the flow rate of DDGS and destoner capacity were the only limitations to model building. Because the destoner had a limited flow rate, the medium and larger scales process had to split DDGS into two flows to increase amounts of destoner capacities to fractionate DDGS. In this model, the price of DDGS was only judged by protein percentage, which is commonly used as a main factor for pricing of DDGS. According to our previous study, the protein in DDGS is about 29.03%; the medium protein DDGS is about 30.52%, and high protein DDGS is about 31.30% (Zhang and Rosentrater, 2013). Though the lighter protein part of DDGS has a lower protein, it was still higher than the lowest DDGS basic level, which means it has the same price as unfractionated DDGS. This study simulated original DDGS at $200 / ton and $10 change to every one percent point of protein increase, which resulted in medium protein DDGS of $214.45 / ton and high protein DDGS of $222.27 / ton (Wood et al, 2013).

The standard electrical power was $0.046 / kW-h, and labor cost was $23.66 / h, which is from the 2013 USDA model (Wood et al. 2013). Installation costs depend on various types of equipment, and storage cost depends on storage volume. For the cost of destoner, it depends on throughout, which is shown in Table 1. Loan interest was set at 7.0% per year. For model outputs, there are three important tables to consider, which included fixed capital estimate summary, process summary and profitability analysis. The fixed capital estimate summary consisted of by three parts total plant direct cost, total plant indirect cost and contractor's fee & contingency (Table 2). Annual operating cost consisted of raw materials, labor-dependent, facility-dependent and utilities (Table 3). Among profitability analysis, the unit production cost, unit production revenue, net profit and payback time were the most important results for this study (Table 4). All these three tables were combined in an executive summary (Table 5).

Results and Discussion

Capital Costs

Capital costs are independent of the level of output, which cost associated with the capital or investment expenditures on land, plant, equipment and inventors (CIEL, 2013). Direct fixed capital cost (TFC) was composed with total plant direct cost (TPDC), total plant direct cost (TPIC) and contractor's fee& contingency (CFC). Total plant direct cost was mainly affected by the total equipment purchase costs and maintenance cost for the individual process, which included equipment purchase cost, installation, process piping, instrumentation, insulation, electrical, buildings, yard improvement and auxiliary facilities. Annualized equipment and installation costs for all three scales, in $/year, are shown in Table 2. Based on cost evaluations of all scenarios, installation contributed to about 20% of equipment costs, while equipment contributed to the remaining 33%. In this model, TPIC was used for capital costs calculations for the whole plant, including of engineering and construction.

Annual Operating Costs

Annual operating costs of industry are composed with the operation of a device, component, equipment and facility in one calendar year (Nichols, 1933). In this model, the destoner process consisted of the expenses related to utilities, facilities, labor, and raw materials. Table 3 shows how each of these costs impacted annual operating costs as a whole for every scale. In every scenario, annual operating costs were largely impacted by raw materials costs, which had an average of 97% of annual operating costs. Only 3% of annual operating costs were decided by other categories.

Facility costs were composed of maintenance costs, insurance, local taxes and factory expenses, which accounted for about 1.20% of all scales. Labor costs were concluded based on the number of working hours needed per year, which were decided by the scale and equipment number. All scales were set by the same unit cost which was 23.66, nearly three times than Iowa lowest salary requirement. The total annual labor working time of small scales was 2,138 hours, which resulted in

$50, 595 for the labor cost. Medium and large scales keep the same size and structure of model, which resulted in labor cost were $ 783,278 per year.

In this study, the majority of the annual operating cost came from the raw materials. Raw material costs were determined by various DDGS with different percentages of protein. Original DDGS was set at $200 per ton and $10 to one percent point of protein change. Three scales were 118,880, 297,000 and 445, 550 ton, which based on the model of USDA (Wood et al, 2013). Annual costs for the three scales were $23,760,000, $59,400,000 and $89,100,000, which are shown in Table 3.

Due to the destoner process, utility costs in this study were mainly related to the costs of electricity, which standard power was set at $0.046 / kW-h. Comparing all three scales, utilities in the whole cost are always less than 0.3% and have little effective on costs, which only take $16,942, $41,231 and $61,847 for small, medium and large scales.

Annual Revenues

The destoner process produced three marketable products: low protein DDGS, medium protein DDGS and high protein DDGS. Due to low protein DDGS keeping the same price as raw materials, the annual revenue of the destoner process was only determined by medium protein DDGS and high protein DDGS. The market prices of initial DDGS were set as $200 / ton and medium and high protein DDGS calculated by the computer model based upon their protein concentration, which assumed that DDGS was 29.03% protein (Zhang and Rosentrater, 2013a). The market value of protein ($1.05/ kg) was determined based upon previous study and resulted in medium and high protein DDGS of $214.45 / and $222.27 / ton (Wood et al, 2013).

Table 4 shows the effect that each of these products has on the revenue of the plant. The revenues in the small scale are 2.178 million dollars per year for high protein DDGS, 10.289 million dollars per year for medium protein DDGS, and 12.15 million dollars per year for low protein DDGS, which totally gets 24.618 million dollars per year. With scales increasing, the total revenues also have an evidently increase, which got 61.544 million dollars in medium scale and 92.316 million dollars in large scale. Through the low protein has the largest number of total revenue, the system still judged the high protein DDGS as main revenue in all three scales. The possible reason was that high protein DDGS has a higher unit revenue rate, which was determined by protein percent. At the same production of three products, high protein DDGS can contribute extra 12.14% revenue than the low protein DDGS. Figure 4 shows how each product affects the overall annual revenue of the plant. According to Figure 4, it clearly shows that same scale contribute similar percent of total revenues, which was less affected by model scale and only decided by destoner separation rates for protein in DDGS.

Profits

Gross profits can be seen in Table 5, which shows capital cost, operating cost, revenue, and profit in million dollars per year. In addition, unit production cost and unit production revenue are shown in Table 5. Undoubtedly, large scale had the largest gross profit 1.228 million dollars per year, which was due to the large production scale. However, small scale had the highest efficient gross profit, and had the smallest unit production cost (2.49 $/kg) of all three scales. The possible reason for this condition is that the small scale process was the most simplified design with the least amount of destoner and other accessory equipment, which contributed a larger cost in total equipment cost. But for unit production revenue, it was easily found that all scales don’t have an evident change. The reason for this condition was that unit production revenue is determined by unit revenue of every product, which was set with the same data in all scales. After considering taxes and interest, three scales in return on investment are 11.08%, 7.32% and 9.03%, which represents payback time of 9.03 years, 13.67 years and 11.08 years. In general, all scales of payback time are positive, which means they may be valuable projects to invest in. However, payback time of all scales was still too long for investors, who are always interested in investing with higher efficient profit and less payback time. Increasing destoner efficiency and decreasing the equipment costs may become a better solution to increase unit profit and decrease payback time. Another factor is oil content. In this study, this model just calculated the change of protein, which determines DDGS prices in most agricultural trade markets. But in recent years, oil extraction has become very popular at plants, and can improve the value of co-products in corn based ethanol production. In 2012, the price of oil from a bio- refinery reached $1.173 per kg in 2012, which is approximately two times more than the price of 0.520 dollars per kg in 2005 (Index Mundi, 2012). A destoner also has an ability to concentrate oil in the DDGS (Zhang and Rosentrater, 2013a). Among all of the above, increasing unit profits and decreasing payback time have a possible feasibility, so using destoner to fractionate DDGS at an industrial scale may be realistic.

Conclusions

In order to perform economic calculations for new fractionation systems, SuperPro Designer was used for techno-economic modeling. The process of using destoner to fractionate distillers dried grains with solubles (DDGS) resulted in three types of DDGS, which provide additional revenue to the ethanol plant. Through the simulated scenarios, it can be concluded that destoner fractionation has a potential to play a vital role in increasing the market value of DDGS. The fractionation systems incorporated in this study increased the capital costs associated with the facility, but did not greatly affect the overall annual operating costs. The addition of fractionation, such as high protein DDGS, added revenue and improved the profits of the plant. The overall profits of a destoner process in all scales are positive, but the net profit was still very low. In the future, increasing destoner efficiency and decreasing equipment costs should be examined so that fractionation can be better utilized in the industry. What’s more, oil extraction to produce high and medium protein DDGS could also be considered.

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Table 1: Data for various destoner capacities (Hebei Fengbafei Trade Co., Ltd, China)

Model	Power(kW)	Price($)	Capacity (t/h)	Capacity (t/day)
FBF40	0.5	2000	2	48
FBF50	0.5	12000	5	120
FBF63	0.5	15000	6	144
FBF80	0.5	22000	8	192
FBF100	0.5	28000	10	240
FBF125	0.5	42000	14	336
FBF150	0.74	45000	15	360
FBF175	0.74	65000	21	504
FBF250	0.74	85000	27	648

Table 2. Fixed capital estimate summary (2013 prices in $)

Total Plant Direct Cost (TPDC) (physical cost)	Small Scale [(a)]	Medium Scale [(b)]	Large Scale [(c)]
1. Equipment Purchase Cost	195,000	522,000	785,000
2. Installation	286,000	710,000	1,093,000
3. Process Piping	68,000	183,000	275,000
4. Instrumentation	78,000	209,000	314,000
5. Insulation	6,000	16,000	24,000
6. Electrical	20,000	52,000	78,000
7. Buildings	88,000	235,000	353,000
8. Yard Improvement	29,000	78,000	118,000
9. Auxiliary Facilities	78,000	209,000	314,000
TPDC	849,000	2,212,000	3,354,000
Total Plant Indirect Cost (TPIC)			
10. Engineering	212,000	553,000	838,000
11. Construction	297,000	774,000	1,174,000
TPIC	509,000	1,327,000	2,012,000
Total Plant Cost (TPC = TPDC+TPIC)			
TPC	1,358,000	3,540,000	5,366,000
Contractor's Fee & Contingency (CFC)			
12. Contractor's Fee	68,000	177,000	268,000
13. Contingency	136,000	354,000	537,000
CFC = 12+13	204,000	531,000	805,000
Direct Fixed Capital Cost (DFC = TPC+CFC)			
DFC	1,562,000	4,071,000	6,171,000

(a) The model can treat 118,880 ton DDGS per year, which is from a 40 million gallon corn based ethanol plant.
(b) The model can treat 297,000 ton DDGS per year, which is from a 100 million gallon corn based ethanol plant.
(c) The model can treat 445,500 ton DDGS per year, which is from a 150 million gallon corn based ethanol plant.

Table 3. Process summary of annual operating cost (2013 prices)

Process Summary	**Small scale ($)** [(a)]	**Medium Scale ($)**[(b)]	**Large Scale ($)**[(c)]
Labor Cost			
Unit Cost ($/h)	23.66	23.66	23.66
Annual Amount	2,138	33,106	33,106
Annual Cost	50,595	783,278	783,278
Materials Cost			
Unit Cost ($/ ton)	200	200	200
Annual Amount (ton)	118,800	297,000	445,500
Annual Cost	23,760,000	59,400,000	89,100,000
Utilities Cost			0
Unit Cost ($/ kW-h)	0.046	0.046	0.046
Annual Amount (kW-h)	361,680	904,200	1,356,300
Annual Cost	16,492	41,231	61,847
Annual Operating Cost			
Raw Materials	23,760,000 (98.34%)	59,400,000 (97.38%)	89,100,000 (97.82%)
Labor-Dependent	51,000 (0.21%)	783,000 (1.28%)	783,000 (0.86%)
Facility-Dependent	289,000 (1.20%)	754,000 (1.24%)	1,143,000 (1.25%)
Utilities	16,000 (0.26%)	41,000 (0.10%)	62,000 (0.07%)
TOTAL	24,161,000 (100%)	60,999,000 (100%)	91,088,000 (100.00%)

(a) The model can treat 118,880 ton DDGS per year, which is from a 40 million gallon corn based ethanol plant.
(b) The model can treat 297,000 ton DDGS per year, which is from a 100 million gallon corn based ethanol plant.
(c) The model can treat 445,500 ton DDGS per year, which is from a 150 million gallon corn based ethanol plant.

Table 4. Profitability analysis of using a destoner to fractionate DDGS (2013 Prices)

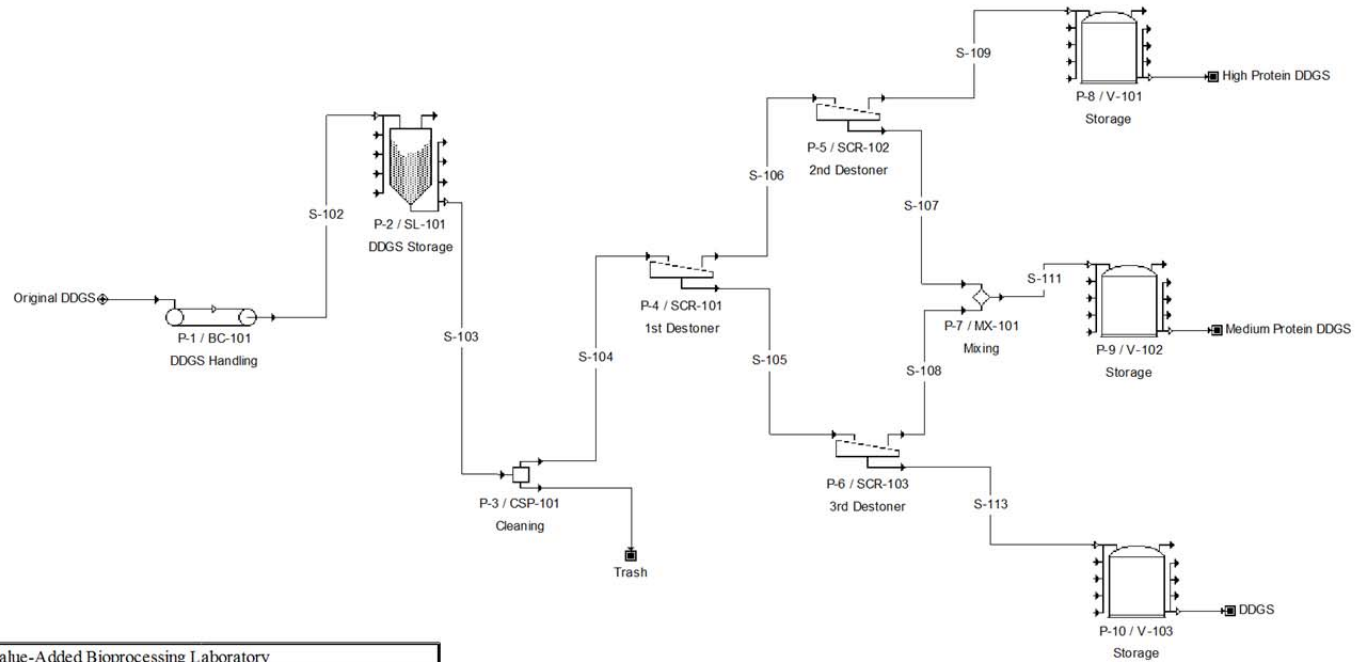
	Small Scale [a]	Small Scale [b]	Small Scale [c]
Direct Fixed Capital	1,562,000 $	4,071,000 $	6,171,000 $
Working Capital	2,170,000 $	5,477,000 $	8,177,000 $
Startup Cost	78,000 $	204,000 $	309,000 $
Total Investment	3,810,000 $	9,751,000 $	14,656,000 $
Investment Charged to Project	3,810,000 $	9,751,000 $	14,656,000 $
Revenue Rates			
High Protein DDGS (Main Revenue)	9,711 MT /y	24,279 MT /y	36,418 MT /y
Medium Protein DDGS (Revenue)	47,980 MT /y	119,951 MT /y	179,927 MT /y
Low Protein DDGS (Revenue)	60,752 MT /y	151,879 MT /y	227,819 MT /y
Revenue Price			
High Protein DDGS (Main Revenue)	224.27 $/MT	224.27 $/MT	224.27 $/MT
Medium Protein DDGS (Revenue)	214.45 $/MT	214.45 $/MT	214.45 $/MT
Low Protein DDGS (Revenue)	200.00 $/MT	200.00 $/MT	200.00 $/MT
Revenues			
High Protein DDGS (Main Revenue)	2,178,000 $/y	5,445,000 $/y	8,167,000 $/y
Medium Protein DDGS (Revenue)	10,289,000 $/y	25,723,000 $/y	38,585,000 $/y
Low Protein DDGS (Revenue)	12,150,000 $/y	30,376,000 $/y	45,564,000 $/y
Total Revenues	24,618,000 $/y	61,544,000 $/y	92,316,000 $/y
Annual Operating Cost (AOC)			
AOC	24,161,000 $/y	60,999,000 $/y	91,088,000 $/y
Unit Production Cost /Revenue			
Unit Production Cost	2.49 $/kg	2.51 $/kg	2.50 $/kg
Unit Production Revenue	2.53 $/kg	2.53 $/kg	2.53 $/kg
Gross Profit (J-K)	456,000 $/y	545,000 $/y	1,228,000 $/y
Taxes (40%)	182,000 $/y	218,000 $/y	491,000 $/y
Net Profit	422,000 $/y	713,000 $/y	1,323,000 $/y
Gross Margin	1.85%	0.88%	1.33%
Return On Investment	11.08%	7.32%	9.03%
Payback Time	9.03 years	13.67 years	11.08 years

(a) The model can treat 118,880 ton DDGS per year, which is from a 40 million gallon corn based ethanol plant.
(b) The model can treat 297,000 ton DDGS per year, which is from a 100 million gallon corn based ethanol plant.
(c) The model can treat 445,500 ton DDGS per year, which is from a 150 million gallon corn based ethanol plant.

Table 5. Executive summary of using a destoner to fractionate DDGS (2013 prices)

	Small scale [a]	Medium Scale [b]	Large Scale [c]
Total Capital Investment	3,810,000 $	9,751,000 $	14,656,000 $
Capital Investment Charged to Project	3,810,000 $	9,751,000 $	14,656,000 $
Operating Cost	24,161,000 $/y	60,999,000 $/y	91,088,000 $/y
Total Revenues	24,618,000 $/y	61,544,000 $/y	92,316,000 $/y
Cost Basis Annual Rate	9,711,456 kg /y	24,278,641 kg /y	36,417,962 kg /y
Gross Profit (J-K)	456,000 $/y	545,000 $/y	1,228,000 $/y
Unit Production Cost	2.49 $/kg	2.51 $/kg	2.50 $/kg
Unit Production Revenue	2.53 $/kg	2.53 $/kg	2.53 $/kg
Gross Margin	1.85%	0.88%	1.33%
Return On Investment	11.08%	7.32%	9.03%
Payback Time	9.03 years	13.67 years	11.08 years
IRR (After Taxes)	8.36%	3.52%	5.55%
NPV (at 7.0% Interest)	Interest 317,000 $	Interest -2,158,000 $	Interest - 1,452,000 $

(a) The model can treat 118,880 ton DDGS per year, which is from a 40 million gallon corn based ethanol plant.
(b) The model can treat 297,000 ton DDGS per year, which is from a 100 million gallon corn based ethanol plant.
(c) The model can treat 445,500 ton DDGS per year, which is from a 150 million gallon corn based ethanol plant.



Value-Added Bioprocessing Laboratory	
Iowa State Univeristy, Ames, 50010	
118,800 Ton / Year DDGS to Destoner Model	
PROCESS ANALYSIS	Weitao Zhang, Kurt Rosentrater
ECONOMIC ANALYSIS	Weitao Zhang, Kurt Rosentrater
LATEST REVISION	12/13/2013

Figure 1: SuperPro Model for 118,880 ton / year DDGS (Small Scale)

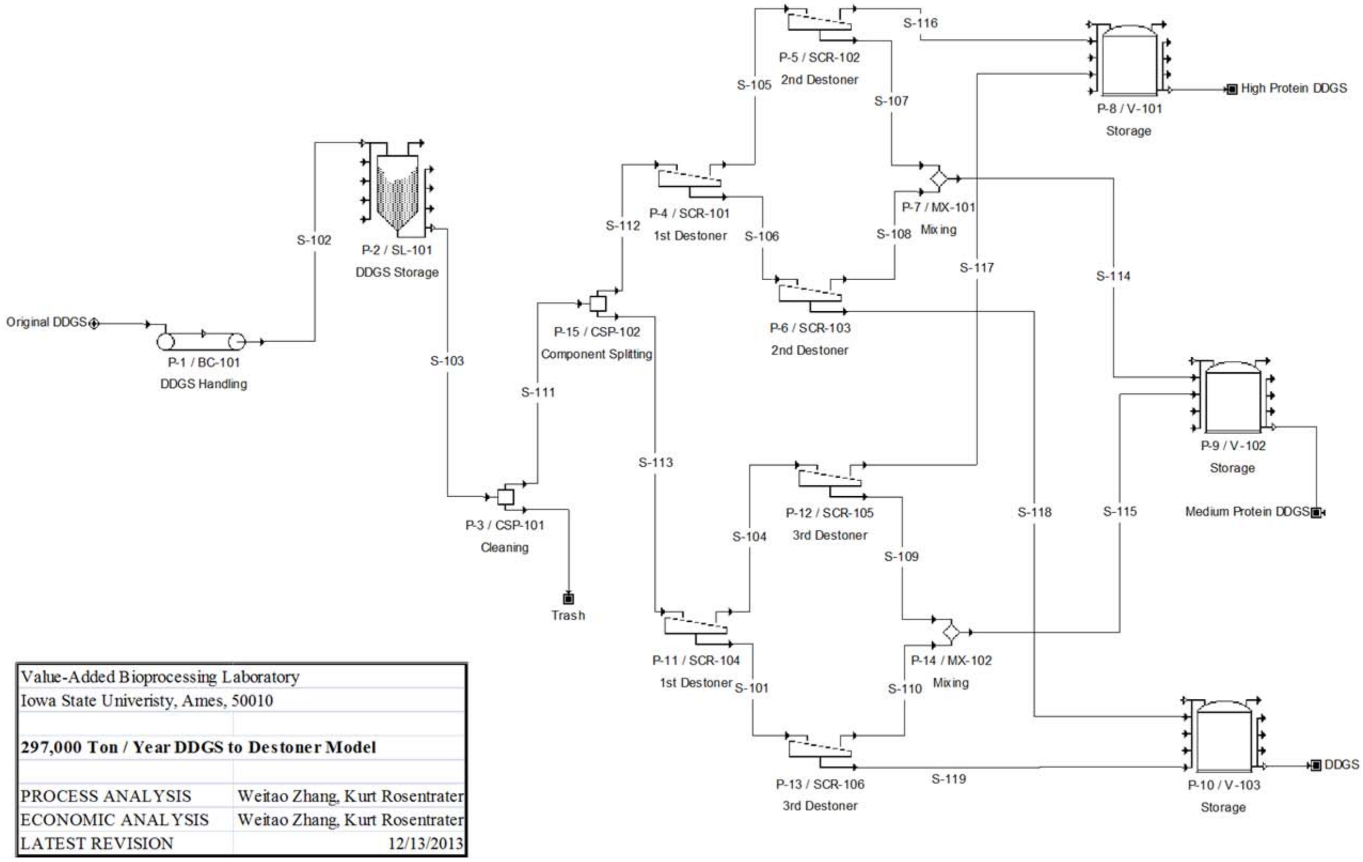


Figure 2: SuperPro Model for 297,000 ton / year DDGS (Medium Scale)

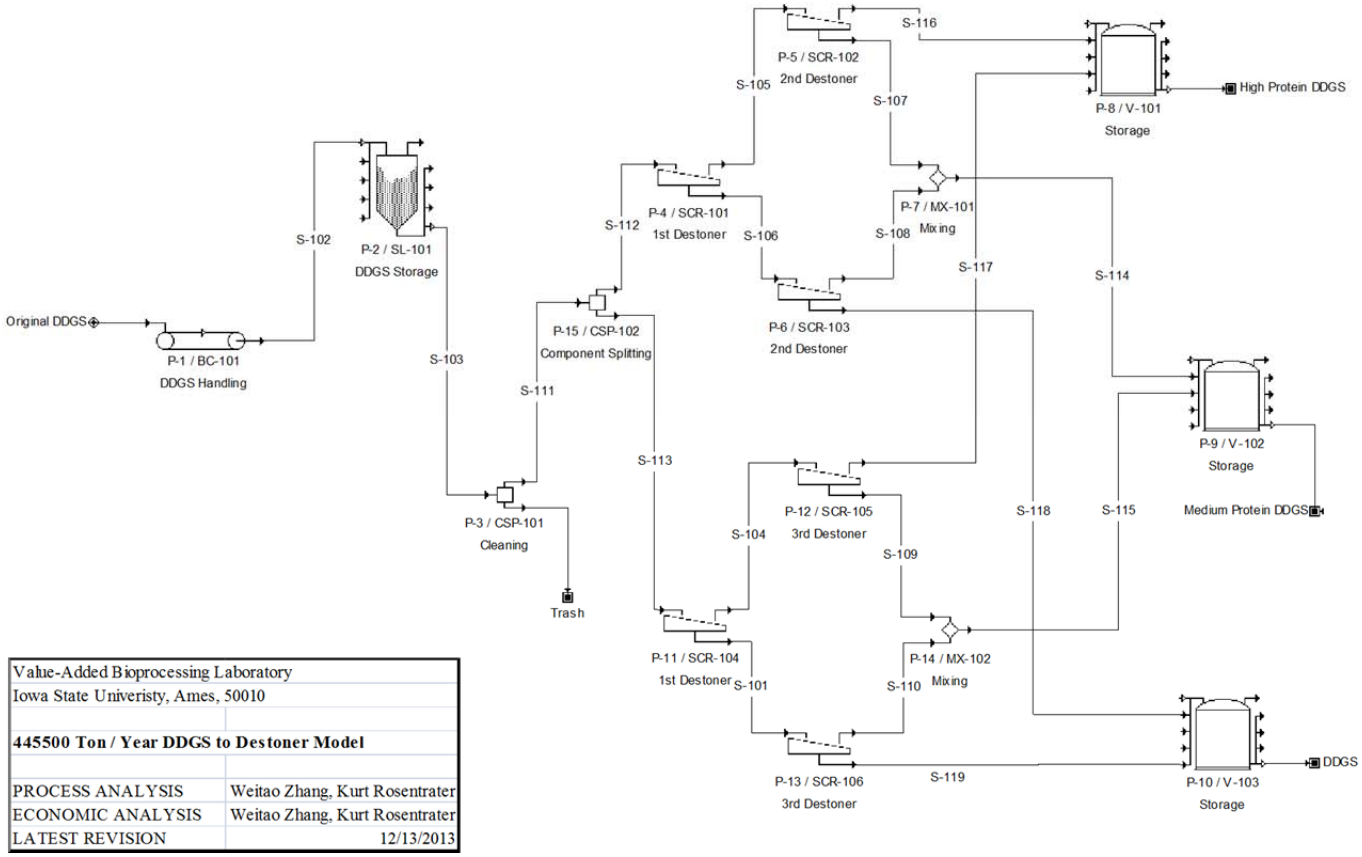


Figure 3: SuperPro Model for 445,500 ton / year DDGS (Large Scale)

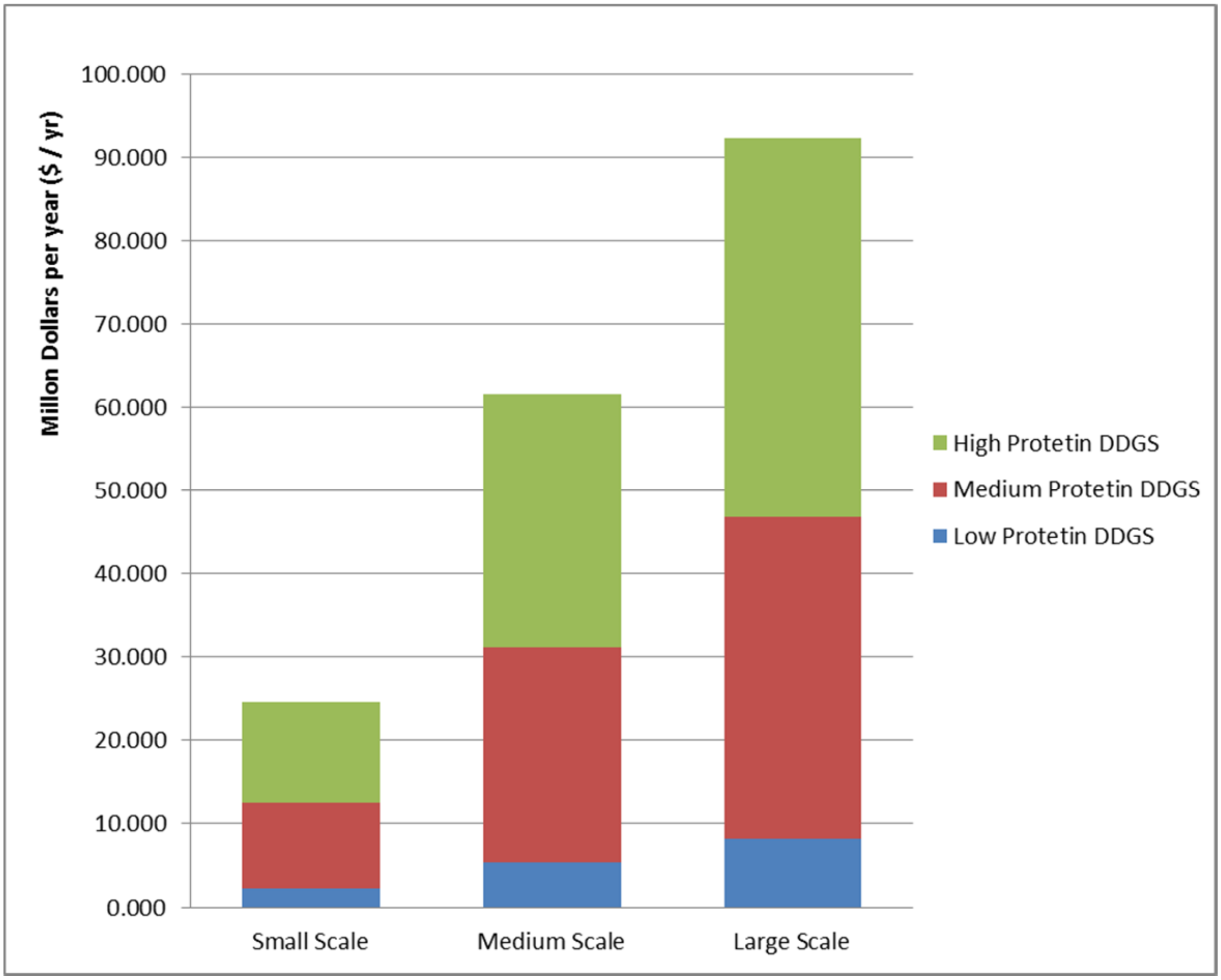


Figure 4: Annual revenues of various DDGS for various scales (Million $ / y); small scale can treat 118,880 ton DDGS per year; medium scale can treat 297,000 ton DDGS per year; large scale can treat 445,500 ton DDGS per year.