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Fractionation of Distillers Dried Grains with Solubles (DDGS) Through A Gravity Separator: Life Cycle Assessment and Techno-Economic Analysis

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Abstract

DDGS could have higher market price and wider use if it could be separated into higher protein and higher fiber fractions. In our work, DDGS was firstly sieved into three size categories, and one category was further separated into light, midlight, midheavy and heavy fractions using a gravity separator. This process was effective in getting enhanced DDGS with increased protein and oil. In this study, both Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA) of our approach to DDGS fractionation were conducted. Three scales, including lab scale, pilot scale, and commercial scale of DDGS fractionation were considered and analyzed. All equipment parameters were obtained from industrial manufacturers. Both the environmental impact and the cost per unit of DDGS fractionation decreased as the fractionation scale expanded.

Keywords

Ethanol, Corn, DDGS, Fractionation, Gravity Separator, Life Cycle Assessment, Techno-Economic Analysis

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Abstract. *DDGS could have higher market price and wider use if it could be separated into higher protein and higher fiber fractions. In our work, DDGS was firstly sieved into three size categories, and one category was further separated into light, midlight, midheavy and heavy fractions using a gravity separator. This process was effective in getting enhanced DDGS with increased protein and oil. In this study, both Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA) of our approach to DDGS fractionation were conducted. Three scales, including lab scale, pilot scale, and commercial scale of DDGS fractionation were considered and analyzed. All equipment parameters were obtained from industrial manufacturers. Both the environmental impact and the cost per unit of DDGS fractionation decreased as the fractionation scale expanded.*

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Introduction

In 2012, biofuels contributed to 7.1% of total transport fuel consumption in the U.S, which was about 13.8 billion gallons (USDA, 2013). Ethanol was the most important biofuel in the U.S. and made up to 94% of all biofuel production in 2012 (USDA, 2013). In the U.S., ethanol is mostly made from corn. Corn kernels are fermented and then separated, and will produce the main product—ethanol, as well as different wet and dried distillers grains co-products, including DDGS (USGC, 2012).

Distillers Dried Grains with Solubles (DDGS) are co-products of ethanol fermentation. DDGS includes protein, oil, fiber, and ash (Rosentrater and Muthukumarappan, 2006). DDGS can be widely used as feed ingredients for animals, such as fish, cattle, swine and poultry. However, use can be limited due to high fiber contents and not all animals have the ability to digest fiber.

Typically DDGS contains around 29% protein, 10% fat, 9% crude fiber and 5% ash (Lim et al, 2008). In the marketing year 2012-2013, DDGS was sold between average prices of $229.00-285.50 (USDA, 2014). According to Belyea et al, (2004), the price of DDGS with high oil (13%) and high protein (33%) contents costs about $5–20 more per ton than regular DDGS. It was estimated that about 38.95 million tonnes of DDGS were produced during the crop year 2013-2014 (AGMRC, 2014). The marketing potential is promising if we can produce DDGS with high protein content.

In our study, DDGS fractionation was conducted with a sifter and a gravity separator. DDGS was firstly sieved into three size categories, then one category was further separated into light, midlight, midheavy, and heavy fractions using a gravity separator. In this paper, we conducted both Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA) for this approach to fractionation.

Life Cycle Assessment (LCA) is an approach of assessing environmental impacts of a product or service during its cradle to grave lifetime. The environmental impact of each functional unit is the variable we concern. LCA provides environmental performance information that can be used in the comparison of products with equivalent functions, or in the determination of life cycle impacts that are important to the overall environmental impact (Robert et al., 2002). LCA is a decision-supporting tool when considering environmental management or making policies (Kodera, 2007).

Similarly, Techno-Economic Analysis (TEA) is an approach to assess technology and economic effects of a product or service during its cradle to grave lifetime. The overall cost and cost per functional unit are the variables of concern. TEA, to some extent, plays an even more critical role during manufacturing decisions than LCA due to its direct relationship to cost and profit.

In our study we evaluated both the environmental impacts, as well as economics of DDGS fractionation. Three scales of DDGS fractionation, including lab scale, pilot scale, and commercial scale, were considered and analyzed.

Methodology

The analysis was based on the assumption that an ethanol plant conducted the fractionation so the cost of raw DDGS was negligible.

System Boundary and Fractionation Flow Chart

Since the study was based on the assumption that an existing ethanol plant would fractionate DDGS and sell it as a co-product, the system boundaries had to adapt to this purpose. In this study we only considered LCA and TEA within the two processes of DDGS sieving and gravity separation. The system boundary and flowchart are shown in figure 1 and figure 2.

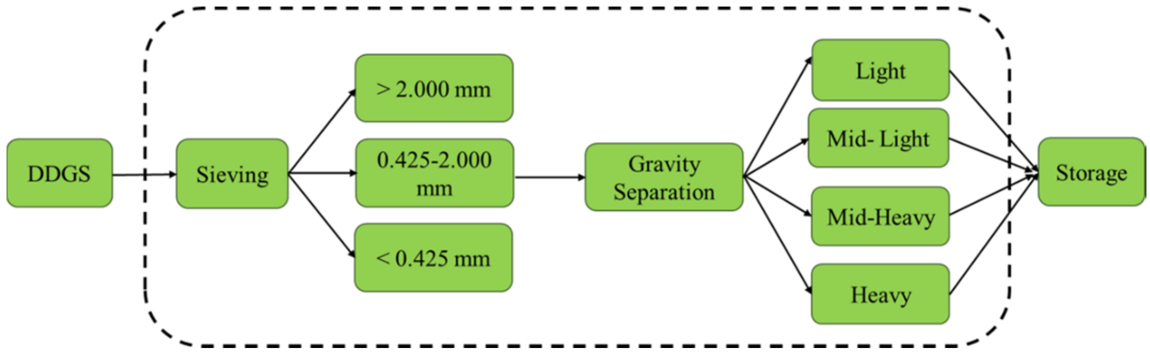

Figure 1. DDGS fractionation system boundary.

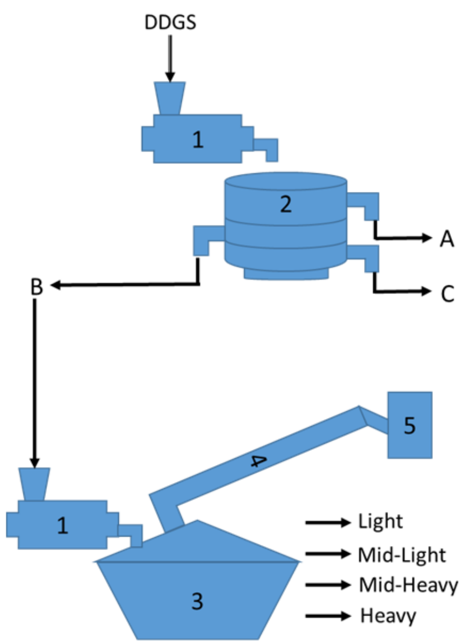

Figure 2. DDGS fractionation flowchart.

During the fractionation, DDGS was first sized using 10-mesh and 40-mesh screens to produce categories of Over 10 mesh (>2.000 mm), 10-40 mesh (0.425-2.000 mm) and Through 40 mesh (< 0.425 mm). The 0.425-2.000 mm DDGS fraction was further separated on the gravity separator. With the side slope 5^{o}, eccentric shaft vibration of 420 rpm of the gravity separator deck, and airflow rate of 0.8890 m/s, four fractions which were named Light, Midlight, Midheavy and Heavy were acquired. Table 1 shows the protein percentage and mass percentage for each fraction after gravity separation.

Functional Unit

We conducted both TEA and LCA based on a functional unit of 1 tonne DDGS. We analyzed total annual impact and impact per tonne of DDGS.

Lab scale

In the lab scale, 1 sifter (Sweco LS18_333) was used to sieve the DDGS and 1 gravity separator (Forsberg TKV 25) was used for gravity separation. 2 feeders (Vibra Screw Feeder 2" AccuFeed) were required, one for the sifter and one for the gravity separator.

Pilot scale

In the pilot scale, 1 sifter (Sweco MX40S666) was used to sieve the DDGS and 1 gravity separator (Forsberg TKV 2000) was used for gravity separation. 2 feeders (Vibra Screw Feeder 4" AccuFeed) were required, one for the sifter and one for the gravity separator.

Commercial scale

In the commercial scale, 5 sifters (Sweco MX60S888) were used to sieve DDGS and 34 gravity separators (Forsberg TKV 2000) were used for gravity separation. Two models of feeders (Vibra Screw Feeder 4" AccuFeed and Vibra Screw Feeder 8" HD Feeder) were required, 5 of 8" HD Feeder for each sifter and 34 of 4" AccuFeed for each gravity separator.

Assumptions for LCA

(1) The environmental impacts we considered contain energy use and air emissions. The electricity loss during transportation is negligible. Based on our experiments, electricity is the only energy consumed, and no water or fuel needs to be considered. The three air emission categories we considered were carbon dioxide, methane and NOx.

(2) The electricity comes from a coal-fired plant. The air emissions of producing electricity from coal are shown in table 2 (Spath et al., 1999).

Assumptions for TEA

(1) Based on our experiments, after sieving using the sifter, the weight of Over 10 mesh (>2.000 mm) DDGS accounts for 4.54%, 10-40 mesh (0.425-2.00 mm) DDGS accounts for 86.98%, and Through 40 mesh (<0.425 mm) accounts for 8.48%. After gravity separation, the protein percentage and mass percentage for each fraction are shown in table 1.

(2) The capacity of the sifter Model Sweco LS18_333 is 30 kg/h, the capacity of the sifter Model Sweco MX40S666 is 300 kg/h, and the capacity of the sifter Model Sweco MX60S888 is 3,000 kg/h.

(3) The capacity of the gravity separator Model TKV25 is 40 kg/h, while the capacity of the larger gravity separator Model TKV2000 is 400 kg/h.

(4) In lab scale and pilot scale, 1 sifter and 1 gravity separator are required; while in commercial scale, 5 sifters and 34 gravity separators are required. The equipment model and number for three scales are shown in table 4.

(5) The screens have to be replaced every 2 months, so the required number of screens for one sifter is 12 per year.

(6) The filter has to be replaced every 2 months, so the required number of filter for one gravity separator is 6 per year.

(7) The feeding rate for sieving is fundamental for operating hours. In the lab and pilot scales, sifters are run 8 hours per day, and 360 days per year. In the commercial scale, 5 sifters are supposed to work 24 hours per day and 365 days per year.

(8) The price of electricity is $0.09/kWh, the yearly interest rate is 5.5%, the insurance rate is 0.462%, the hourly salary is $12/h, and equipment maintenance is $1/tonne.

(9) The life span of the equipment is 10 years, except filters and screens. All equipment price comes from manufacturers except filters. Due to the large scale of separation in the commercial scale, the equipment can be bought at 85% of the original price.

(10) The fractionated DDGS can be sold at a price of $8/ percent of protein. Based on the information in table 1, the average price is $270.31/tonne. The loss of DDGS during fractionation is negligible.

Results

All of the total environmental impact categories increase as the scale expands, while all of the unit environmental impact categories decrease as the scale expands. The details are shown in table 3 and figure 3-10. For the lab scale, the total cost was $ 74,432.67 /year and the unit cost was $861.49/ tonne. The cost detail is shown in tables 5 and 6. The total profit is $ -51,077.65/year and the unit profit is $ -591.18/tonne. For the pilot scale, the total cost was $ 96,001.15/year and the unit cost was $111.11/ tonne. The cost detail is shown in tables 7 and 8. The total profit was $ 137,549.04/year and the unit profit was $ 159.20/tonne.

For the commercial scale, the total cost was $ 1,674,075.34 /year and the unit cost was $12.74 / tonne. The cost detail is shown in tables 9 and 10. The total profit was $ 33,845,017.12 /year and the unit profit was $

257.57/tonne. As shown in table 11 and figures 11-14, the total cost of DDGS fractionation increases as the scale expands, and unit cost decreases as the scale expands. In the lab scale, the profit is negative while in the pilot and commercial scale, the profit is positive.

Conclusions

Based on our LCA and TEA analyses, both the environmental impact and the cost per unit of DDGS fractionation decrease as the fractionation scale expands. This study provides useful information for DDGS fractionation at different scales. The results indicate that when the scale is large enough, such as with a processing rate of 864 tonne/year and above, DDGS fractionation is profitable.

Acknowledgements

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Table 1. Protein percentage and mass percentage for each fraction after gravity separation.

Size Category(mm)	Fraction	Protein (%db)	Mass Percentage (%)
0.425-2.000	Light	28.27	23.45
	Midlight	31.54	26.71
	Midheavy	35.52	19.14
	Heavy	39.27	17.68
>2.000	NA	37.05	4.54
<0.425	NA	34.42	8.48
Raw	NA	32.13	100.00

Table 2. Air emission of producing electricity from coal

Emission Category	g/kWh
CO_2	1,022[a]
CH_4	4.4[a]
NO_x	16.1[a]

a: Spath, P. L., & Mann, M. K. (2002). Environmental Aspects of Producing Electricity from a Coal-Fired Power Generation System-A Life Cycle Assessment. National Renewable Energy Laboratory, USA.

Table 3. Life cycle assessment for DDGS fractionation.

Processing Rate(tonne/year)	86.4		864		131,400	
Environmental Impact	Total Annual Impact (per year)	Unit Impact (per tonne per year)	Total Annual Impact (per year)	Unit Impact (per tonne per year)	Total Annual Impact (per year)	Unit Impact (per tonne per year)
Electricity Use (kWh)	16,107.12	186.43	45,811.33	53.02	6,540,497.42	49.78
CO2 Emission (kg CO2 eq.)	16,461.48	190.53	46,819.18	54.19	6,684,388.36	50.87
CH4 Emission (g CH4 eq.)	14,657.48	169.65	41,688.31	48.25	5,951,825.65	45.30
NOx Emission (g NOx eq.)	53,958.85	624.52	153,467.97	177.62	21,910,666.34	166.75

Table 4. Equipment information for DDGS fractionation.

Scale		Lab	Pilot	Commercial
Capacity	tonne/year	86.4	864	131,400
	kg/h	30	300	15,000
Sifter	Model	Sweco LS18_333	Sweco MX40S666	Sweco MX60S888
	No.	1	1	5
Gravity Separator	Model	Forsberg TKV 25	Forsberg TKV 2000	Forsberg TKV 2000
	No.	1	1	34

Table 5. Lab scale capital costs (30 kg/h).

Component	Type	Price ($/each)	Quantity	Total Cost ($)
Feeder	Vibra Screw Feeder 2" AccuFeed	4,000.00	2	8,000.00
Sifter	Sweco LS18_333	6,696.00	1	6,696.00
Gravity Separator	Forsberg TKV25	14,454.00	1	14,454.00
Fan	Forsberg Model 12-HA	3,379.00	1	3,379.00
Cyclone	Forsberg 33” HE	7,467.00	1	7,467.00
Equipment Initial Costs ($)				**39,996.00**
Electrical Wiring & Controls				1,599.84
Equipment Installation				15,998.40
Equipment Freight				399.96
Total Equipment Initial Costs ($)				**57,994.20**
Engineering & Design				2,911.71
Total Capital Costs ($)				**60,905.91**
Capital Costs per Year ($)				**8,080.25**

Table 6. Lab scale operating costs (30 kg/h).

Component	Total Cost ($/year)
Fixed Costs	
Interest	3,349.82
Insurance	281.39
Tax	213.17
Subtotal ($/year)	**3,844.38**
Variable Costs	
Screen	1,884.00
Filter	1,200.00
Electricity	1,449.64
Labor	57,888.00
Maintenance & Repair	86.40
Subtotal ($/year)	**62,508.04**
Total Costs ($/year)	**66,352.42**

Table 7. Pilot scale capital costs (300 kg/h).

Component	Type	Price ($/each)	Quantity	Total Cost ($)
Feeder	Vibra Screw Feeder 4" AccuFeed	4,100.00	2	8,200.00
Sifter	Sweco MX40S666	11,346.00	1	11,346.00
Gravity Separator	Forsberg TKV2000	51,249.00	1	51,249.00
Fan	Forsberg Model 21-HA	7,882.00	1	7,882.00
Cyclone	Forsberg 74” HE	15,083.00	1	15,083.00
Equipment Initial Costs ($)				**93,760.00**
Electrical Wiring & Controls				3,750.40
Equipment Installation				37,504.00
Equipment Freight				937.60
Total Equipment Initial Costs ($)				**135,952.00**
Engineering & Design				6,825.73
Total Capital Costs ($)				**142,777.73**
Capital Costs per Year ($)				**18,942.00**

Table 8. Lab scale operating costs (300 kg/h).

Component	Total Cost ($/year)
Fixed Costs	
Interest	7,852.78
Insurance	659.63
Tax	499.72
Subtotal ($/year)	**9,012.13**
Variable Costs	
Screen	3,072.00
Filter	2,100.00
Electricity	4,123.02
Labor	57,888.00
Maintenance & Repair	864.00
Subtotal ($/year)	**68,047.02**
Total Costs ($/year)	**77,059.15**

Table 9. Commercial scale capital cost (15,000 kg/h).

Component	Type	Price ($/each)	Quantity	Total Cost ($)
Feeder	Vibra Screw Feeder 4" AccuFeed	3485	34	118490
	Vibra Screw Feeder 8" HD	7,709.50	5	38,547.50
Sifter	Sweco MX40S666	18,045.75	5	90,228.75
Gravity Separator	Forsberg TKV2000	38,436.75	34	1,306,849.50
Fan	Forsberg Model 21-HA	5,911.50	34	200,991.00
Cyclone	Forsberg 74” HE	11,312.25	34	384,616.50
Equipment Initial Costs ($)				**2,139,723.25**
Electrical Wiring & Controls				85,588.93
Equipment Installation				855,889.30
Equipment Freight				21,397.23
Total Equipment Initial Costs ($)				**3,102,598.71**
Engineering & Design				155,771.85
Total Capital Costs ($)				**3,258,370.57**
Capital Costs per Year ($)				**432,280.75**

Table 10.Commercial scale operating costs (15,000 kg/h).

Component	Total Cost ($/year)
Fixed Cost	
Interest	179,210.38
Insurance	15,053.67
Tax	11,404.30
Subtotal ($/year)	**205,668.35**
Variable Cost	
Screen	19,560.00
Filter	71,400.00
Electricity	603,526.24
Labor	210,240.00
Maintenance & Repair	131,400.00
Subtotal ($/year)	**1,036,126.24**
Total Cost ($/year)	**1,241,794.59**

Table 11. Comprehensive cost and profit as determined by TEA.

Scale	Capacity (kg/h)	Total Separation Weight (tonne/year)	Total Costs ($/year)	Unit Costs ($/tonne)	Total Benefits ($/year)	Total Profits ($/year)	Unit Profits ($/tonne)
Lab	30	86.4	72,844..00	861.49	23,355.02	--51,077.65	--591.18
Pilot	300	864	94,915.90	111.11	233,550.20	137,549.04	159.20
Commercial	15,000	131,400	1,654,839.24	12.74	35,519,092.46	33,845,017.12	257.57

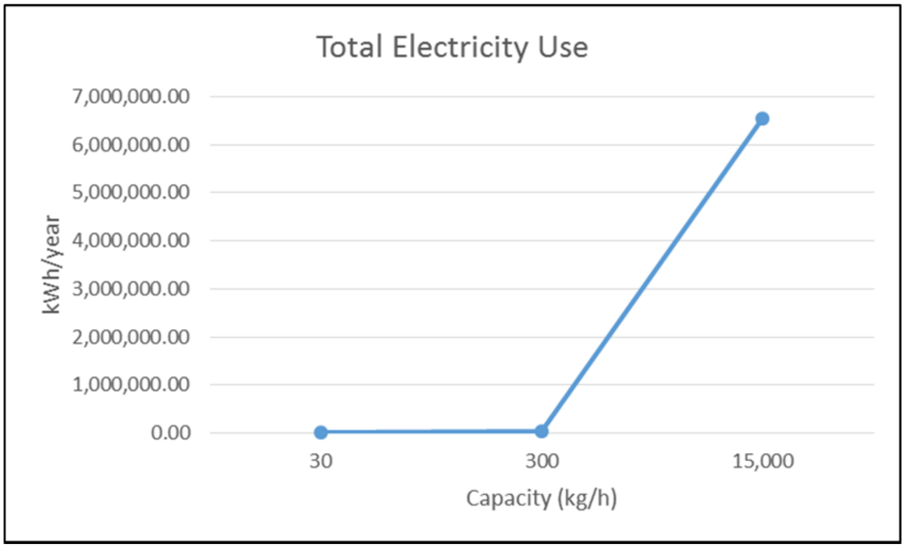

Figure 3. Total Electricity use as determined by LCA.

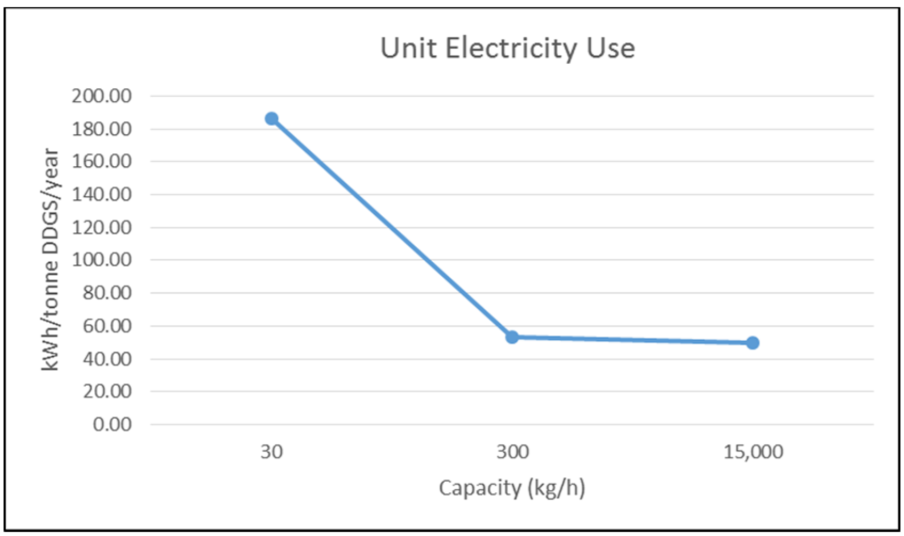

Figure 4. Unit Electricity use as determined by LCA.

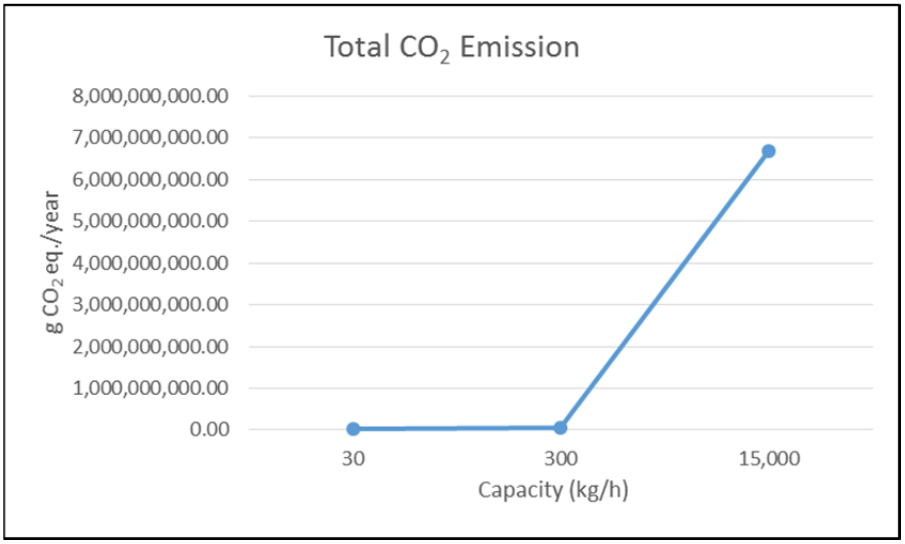

Figure 5. Total CO2 emission as determined by LCA.

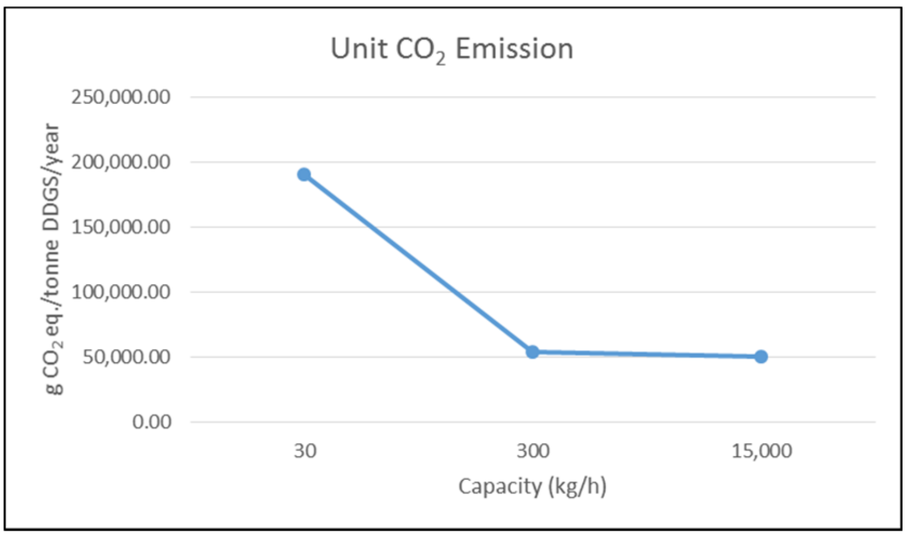

Figure 6. Unit CO_2 emission as determined by LCA.

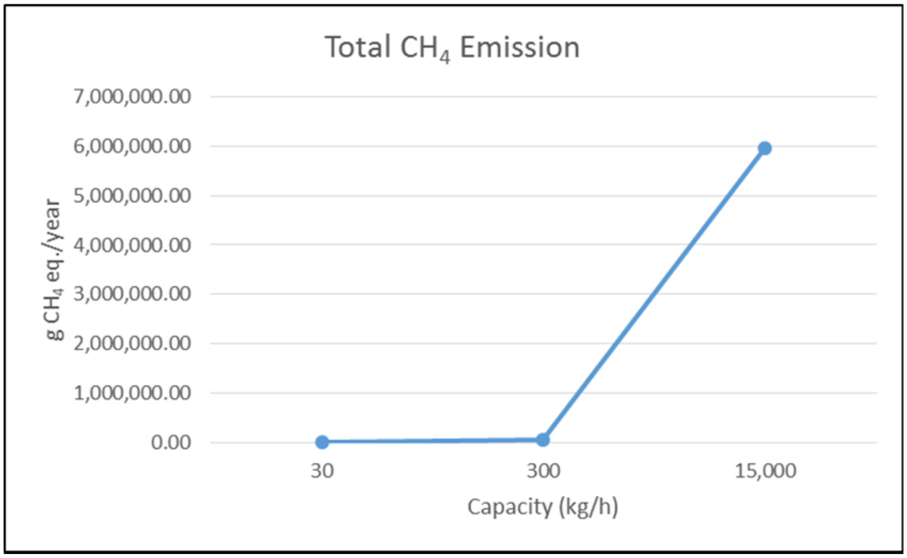

Figure 7. Total CH_4 emission as determined by LCA.

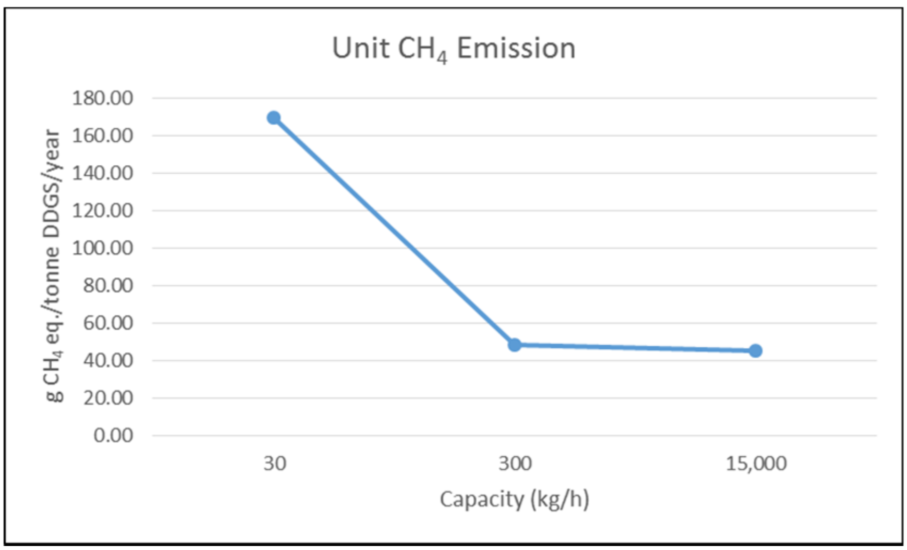

Figure 8. Unit CH_4 emission as determined by LCA.

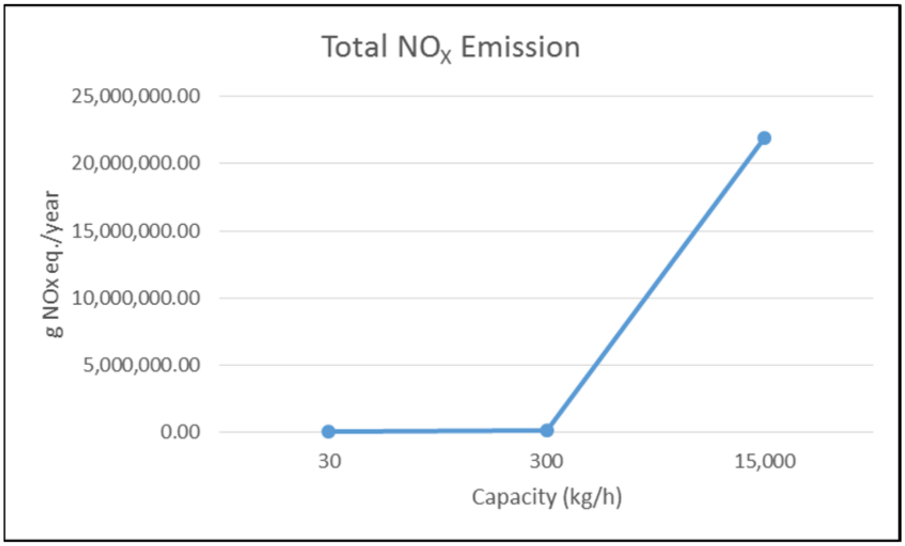

Figure 9. Total NOx emission as determined by LCA.

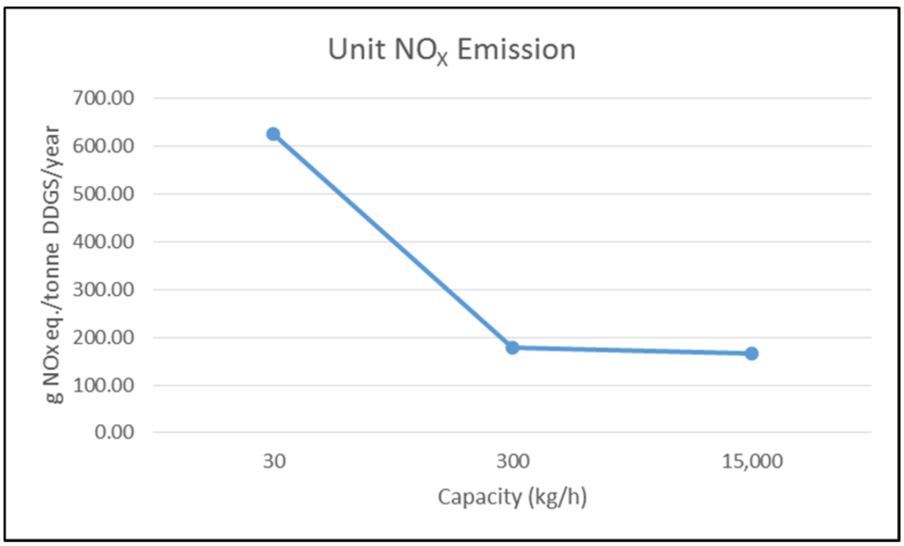

Figure 10. Unit NOx emission as determined by LCA.

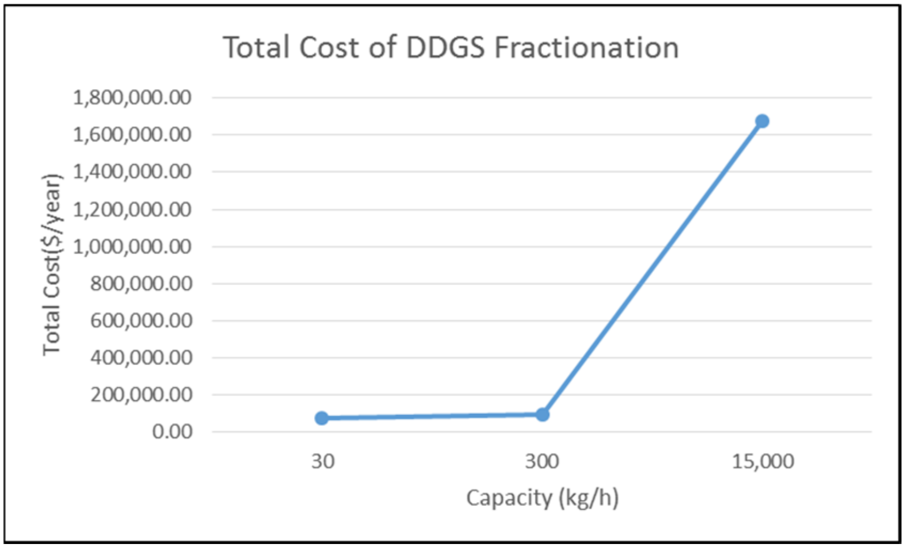

Figure 11. Total cost of DDGS fractionation as determined by TEA.

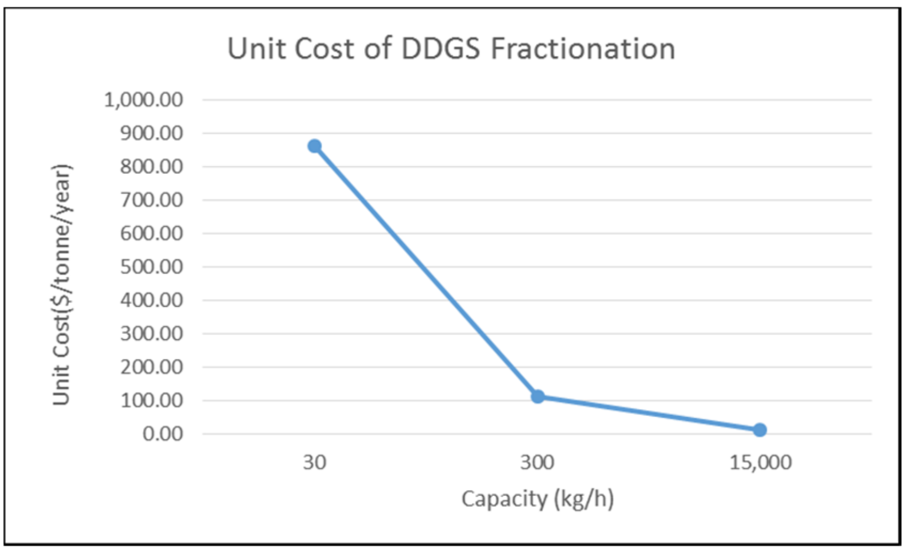

Figure 12. Unit cost of DDGS fractionation as determined by TEA.

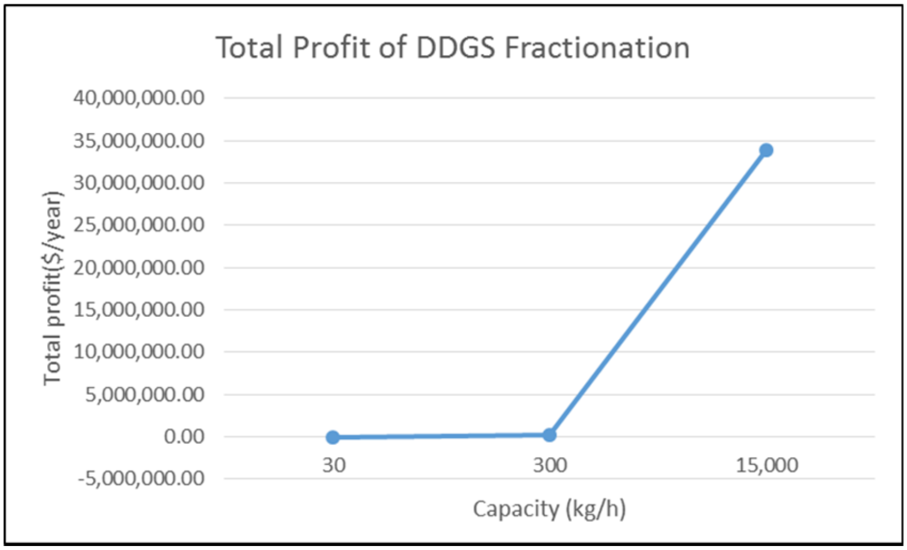

Figure 13. Total profit of DDGS fractionation as determined by TEA.

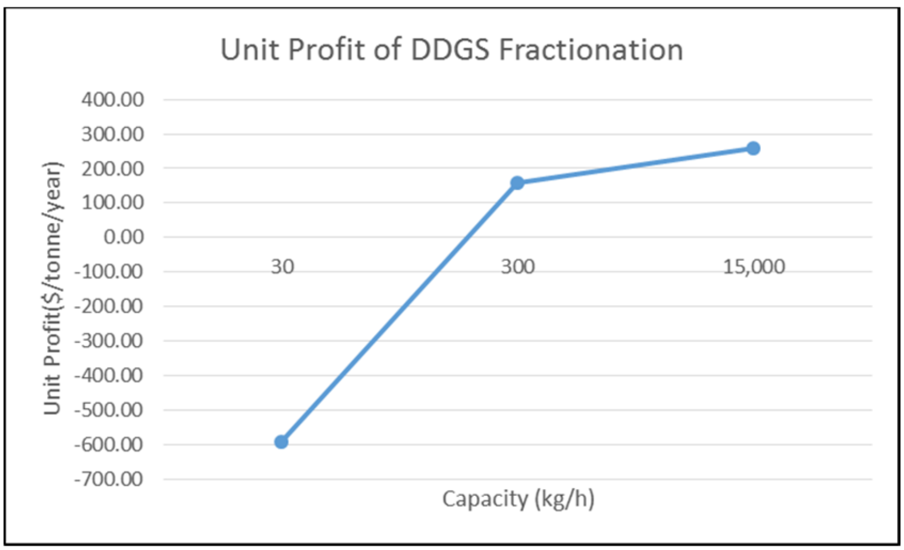

Figure 14. Unit profit of DDGS fractionation as determined by TEA.