October, 2009

Costs of Pelleting to Enhance the Logistics of Distillers Grains Shipping

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An ASABE Conference Presentation

Paper Number: BIO-097992

Costs of Pelleting to Enhance the Logistics of Distillers Grains Shipping

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Written for presentation at the
2009 Bioenergy Engineering Conference
Sponsored by ASABE
Hyatt Regency
Seattle, Washington
October 11-14, 2009

Abstract. *Biofuels, especially corn-based ethanol, can help meet some of the increasing demand for transportation fuels. Currently, the most heavily utilized substrate is corn grain, which is readily converted into ethanol at a relatively low cost compared to other biomass sources. The production of ethanol in the U.S. has been dramatically increasing during the last several years; so too has the quantity of manufacturing coproducts. These nonfermentable residues are most often dried and sold as distillers dried grains with solubles – DDGS. Even though these materials are used to feed livestock in local markets, as the size of the industry continues to grow, the need to ship large quantities of coproducts nationally and internationally will also increase. Various processing options offer the potential to increase the sustainability and improve the economics of each ethanol plant, and thus the industry overall. However, implementation will be dependent upon how new costs interact with current processing costs. This paper focuses specifically on determining the costs to add a pelleting operation at an existing fuel ethanol manufacturing plant. We have examined all captial and operational costs, as well as benefits for pelleting DDGS at varying production rates (100 to 1000 tons/d). We have determined that as the DDGS generation rate increases, the cost of pelleting drastically declines, due to the development of economies of scale. For example, at a DDGS generation of 100 ton/d, the cost to pellet was $14.07/ton/y; whereas at a scale of 1000 ton/d, the cost to pellet was only $3.95/ton/y. Thus at large production scales, the cost of adding and operating a pelleting line is minimized compared to the lower production rates. The sustainability of the ethanol industry can be improved by implementing pelleting technology, especially at those plants that ship their DDGS via rail.*

Keywords. Biofuels, DDGS, distillers grains, coproducts, logistics.

Introduction

In recent years the increasing cost of nonrenewable fossil fuels has become a focal point for many energy-dependent nations, including the U.S. There are two primary ways to approach these challenges: 1) reducing energy dependency, and/or 2) developing alternative methods of energy production (RFA, 2008). Biofuels are renewable sources of energy, and are a promising alternative. There are many biomass materials that may be used to produce biofuels (i.e., crop residues, corn stover, grasses, legumes, MSW, biological wastes, etc.). Currently, the material which is most used, at least in the U.S., is corn starch, since fuel ethanol production from corn can be accomplished very efficiently and at a relatively low cost compared to other biomass sources. In fact, corn starch is currently the only biological material that can be economically converted into ethanol on an industrial scale in the U.S.

The number of corn ethanol plants has been dramatically increasing in recent years – due in part to the U.S. Renewable Fuel Standard. In 2005, for example, 87 manufacturing plants in the U.S. had an aggregate production capacity of 13.46 billion L/y (3.56 billion gal/y). At the beginning of 2009, however, that number had risen to over 193 plants with a production capacity of nearly 46.86 billion L/y (12.38 billion gal/y) (RFA, 2009), which represents an increase of nearly 350% in just four years. As the ethanol industry continues to grow, so too have the quantities of processing residues, or coproducts, which are generated by this industry. In 2008, approximately 23 million metric tons of coproducts were produced.

Most ethanol production plants employ several key operations, including grinding, cooking, liquefying, saccharifying, fermenting, and distilling. In-depth details on ethanol manufacturing practices, which are beyond the scope of this paper, can be found in Bothast et al. (2005), Dien et al. (2003), Jaques et al. (2003), Maisch (2003), Tibelius (1996), and Weigel et al. (2005), among others. Fuel ethanol is the primary end product of this process along with two byproducts: residual nonfermentable corn kernel components, and carbon dioxide. The nonfermentable materials (i.e., corn protein, fiber, and oil) are usually dewatered, combined, dried, and then sold as 'distillers dried grains with solubles', or DDGS. Currently, DDGS is the coproduct which is of most utility to ethanol plants.

DDGS is a dry, granular bulk material, often with particle sizes less than 1.0 mm in diameter. Water activity values are often below 0.5, thermal conductivity is typically near 0.7 W/m^{o}C, and angle of repose can range from nearly 25° to 35° (Rosentrater, 2006). Protein content of DDGS often varies between 26 and 34% (db), fat can range from 3 to 13% (db), neutral detergent fiber (NDF) is often between 25 and 50% (db), and ash can range from 2 to 10% (db) (Rosentrater and Muthukumarappan, 2006).

DDGS coproduct streams are typically dried to approximately 10% moisture content, to ensure a long shelf life and facilitate transportation, and then are either sold to local livestock producers or shipped via rail to livestock feed markets throughout North America. And they are increasingly being exported to overseas destinations as well. Feeding distillers grains to animals is a viable method for utilizing these coproducts because they contain high nutrient levels. Aines et al. (1986) and UMN (2009) provide comprehensive reviews of much of this research. The sale of distillers grains contributes substantially to the economic viability of ethanol manufacturing. In fact, between 10 and 40% of an ethanol plant's entire revenue stream results from the sale of DDGS, depending upon DDGS sales price (which historically has ranged between $50/ton and $200/ton) (USDA ERS, 2008), corn feedstock price, natural gas price, and other market conditions. Because of the dynamics of the free market economy, the quantity of processing residues that will be produced as this industry continues to grow (and the ability to sell and utilize them) will significantly impact the future of the fuel ethanol industry.

There are several issues that influence the value and utilization of distillers grains (Rosentrater, 2007a; Saunders and Rosentrater, 2009). Over the years, one of the most persistent barriers to effective utilization of distillers grains has been product storability and flowability, because it directly impacts the ability to ship DDGS (Rosentrater, 2007a; Ganesan et al., 2008a). DDGS is typically shipped in trains and trucks throughout the U.S. and internationally. However, DDGS is often difficult to unload once the vessel reaches destination, because the particles lock together. This necessitates manual unloading, which can create substantial financial burdens for the ethanol manufacturer (e.g., sledgehammers, shovels, and pick axes must be used to get the DDGS to discharge). These economic losses include rail car repairs (due to damage), and labor expenses. Remediating flowability problems has been the subject of considerable research in recent years (see, for example, Ganesan et al., 2007; Ganesan et al., 2008a,b,c,d; Ganesan et al., 2009). Another issue with the transportation of DDGS entails vessel capacity (i.e., weight vs. volume). Railcars or trucks containing DDGS are filled to volumetric capacity for shipping, but are often not at maximum allowable weight, due to the low bulk density of the granular material itself (approximately 30 lb/ft^3 [480 kg/m^3]) – this wasted capacity thus causes additional economic loss to the ethanol manufacturer.

In order to alleviate DDGS flowability problems, it is essential to modify the DDGS that is currently produced in the industry, or to alter the storage and transportation systems for these coproducts. One way to do this is by altering the physical form of the DDGS itself. Pelleting is a manufacturing process that is commonly used to densify granular materials, alter particle size and shape, and ultimately product flowability and storage characteristics (Rosentrater, 2005). Rosentrater (2007b) has shown that this process is feasible for DDGS, and can be accomplished using conventional feed milling equipment. In fact, pelleting of DDGS (Figure 1) can readily be added to existing ethanol plants, and would simultaneously overcome the flowability problem, as well as allow shipping vessels to be filled to both weight and volumetric capacity simultaneously. Ultimately, however, the adoption of this technology will be contingent upon price ramifications to the ethanol plant. Costs associated with pelleting of DDGS have not yet been thoroughly explored.

To investigate the cost-effectiveness of pelleting DDGS versus shipping DDGS as-is (i.e., in granular bulk form), we have developed a computer model to assess these cost ramifications (Rosentrater and Kongar, 2007, 2009). We have subsequently expanded the model's capabilities by adding stochastic market prices for the DDGS and adding dynamic response using Arena software (Rosentrater and Kongar, 2008). The functionality of this model depends upon the accuracy of the data used as model inputs. Therefore, the objective of the current study was to quantify actual capital and operational cost data for installing pelleting equipment, for a range of DDGS production rates, at actual ethanol manufacturing plants. The results from this study will subsequently be incorporated into the computer model and used to refine the predicted results.

Materials and Methods

Typically, ethanol production facilities store DDGS in piles after it has been discharged from the dryer. After it has cooled to ambient temperatures, it is then loaded onto train cars for shipping. Pelleting could be added as an additional step prior to loading the DDGS (Figure 1; Table 1) by installing supplementary equipment. The best location for this would probably be either immediately after exiting the dryers, or after storage, which would give the DDGS time to cool (i.e., cure).

When developing the algorithms for this model, relevant variables were selected, and values for each were based on data available for a range of current ethanol processing facilities. Daily DDGS generation rate, *g* (tons/d), was selected at various levels:

$$g = 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 \quad (1)$$

Roughly speaking, these rates are appropriate estimates for fuel ethanol plants of processing capacities up to 150 million gallon per year.

Based on Rosentrater et al. (2003), the total cost of pelleting was estimated by calculating all annualized fixed and variable costs, as well as annual benefits, associated with installing and operating a pelleting process for each DDGS generation rate (*g*). To begin this process, all capital costs and electricity costs were determined as follows:

I = Interest rate (%) = 5 (2)
L = Equipment life expectancy (y) = 15 (3)
OH = Yearly operational hours (h/y) = 2000 (4)
EP = Electricity price ($/kW-h) = 0.07 (5)

C1 = Equipment initial cost ($) = Σ (purchase price of each piece of equipment) (6)
C2 = Electrical wiring and controls ($) = 4% of C1 (7)
C3 = Equipment freight ($) = 1% of C1 (8)
C4 = Equipment installation ($) = 40% of C1 (9)
C5 = Spouting ($) = 816 (10)
C6 = Total equipment initial cost ($) = Σ (C1 + C2 + C3 + C4 + C5) (11)

B1 = Total building space required (ft^2) = 2000 (12)
B2 = Building construction cost ($/$ft^2$) = 12.5 (13)
C7 = Total building cost ($) = B1 * B2 (14)

C8 = Engineering and design cost ($) = 7% of Σ (C6 + C7) (15)

E1 = Electricity consumed for lighting (kW-h) = 1 * g (16)
E2 = Electricity consumed for connected motor load (kW-h) = connected load*OH/efficiency (17)
E3 = Total electricity consumed (kW-h) = Σ (E1 + E2) (18)
C9 = Total electricity cost ($) = E3 * EP (19)

After all capital investment costs and electricity costs were calculated, then all benefits and costs were determined on an annualized basis, in order to determine the net cost to produce pelleted DDGS, following Rosentrater et al. (2003):

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ESV = Equipment salvage value ($/y) = 15% of Σ (C6 + C7 + C8) (20)
TAB = Total Annual Benefits ($/y) = ESV (21)

AFC1 = Annualized capital costs ($/y) = Σ (C6 + C7 + C8) (22)

AFC2 = Depreciation ($/y) = straight line depreciation based on L of 15 y (23)

AFC3 = Insurance ($/y) = 0.00462 * (C6 + C7) (24)

AFC4 = Interest ($/y) = 0.055 * (C6 + C7) (25)

AFC5 = Overhead ($/y) = 0.16 * g (26)

AFC6 = Taxes ($/y) = 0.0035 * (C6 + C7) (27)

TAFC = Total annual fixed costs ($/y) = Σ (AFC1 + AFC2 + AFC3 + AFC4 + AFC5 + AFC6) (28)

AVC1 = Boiler fuel (steam) ($/y) = 1.05 * g (29)

AVC2 = Electricity ($/y) = C9 (30)

AVC3 = Labor ($/y) = wage rate ($/man-h) * 1.25 (salary + benefits) * 1.59 (man-h/ton) * g (ton/y) (31)

AVC4 = Maintenance & repairs ($/y) = 3 * g (32)

AVC5 = Misc. supplies ($/y) = 1 * g (33)

AVC6 = Other ($/y) = 0.25 * g (34)

AVC7 = Water ($/y) = 0.02 * g (35)

TAVC = Total annual variable costs ($/y) = Σ (AVC1 + AVC2 + AVC3 + AVC4 + AVC5 + AVC6 + AVC7) (36)

Cop = Yearly Cost to Pellet DDGS ($/y/Mg) = (TAFC + TAVC – TAB) / g (37)

For more information regarding this approach and the specific assumptions used in the development of this cost model, refer to Rosentrater et al. (2003). All calculations were performed via electronic spreadsheet (Excel v.2003, Microsoft Corp., Redmond, WA).

Results and Discussion

Table 2 is the primary output from the model. It shows all estimates for the aforementioned cost categories, including total annualized benefits (TAB), total annualized fixed costs (TAFC), and total annualized variable costs (TAVC), as well as the major cost categories associated with each of them. It also provides the total cost to produce DDGS pellets on a yearly-mass basis (Cop). Figure 2 graphically depicts the increase in both fixed and variable costs as the DDGS generation rate, and thus required pelleting capacity, increases. This is due to the need for larger equipment as well as increased consumption of electricity, steam, water, etc. As shown, the annual benefits also increase (because the annualized salvage value increases with a greater capital outlay), but at a much lower rate than the fixed and variable costs. At a DDGS generation rate of 1000 tons/d, all cost categories (fixed, variable, and benefits) were approximately 412% greater compared to those at a DDGS generation rate of 100 tons/d.

As with most industrial systems, even though the costs (i.e., fixed, variable, and benefit cash flows) were greater as DDGS production rate increased, economies of scale (on a yearly per ton basis) were achieved as the generation rate increased. Figure 3 shows this decreasing behavior as the DDGS generation rate increased. At a generation rate of 1000 tons/d, the overall cost to product DDGS pellets (Cop) was reduced by 72% compared to the costs associated with pelleting at a scale of 100 tons/d. This decrease in overall pelleting cost followed an exponential curve, as described by the resulting regression equations in Figure 3. Thus at the largest production scales, the overall cost of adding and operating a pelleting line (Cop) is minimized compared to the lower production rates. This suggests that, the larger the ethanol company, the more attractive pelleting becomes.

Conclusions

DDGS is the main coproduct from fuel ethanol manufacturing. Transportation of DDGS is becoming a pressing issue as the ethanol industry grows, however. Pelleting of DDGS may help alleviate some of the logistical challenges associated with DDGS, such as poor flowability and incomplete car fill. Because the costs associated with pelleting of DDGS have not yet been fully explored, a DDGS transportation-logistics simulation model is being developed. This study was conducted in order to provide accurate input data for that model. Specifically, this study quantified actual capital and operational cost data for installing pelleting equipment at an ethanol plant, for a range of DDGS production rates. By examining all annualized fixed, variable, and benefit costs, economies of scale clearly prevailed as DDGS generation rate increased. In fact, on a yearly basis, the overall cost to pelletize DDGS was reduced by 72% at a scale of 1000 tons/d compared to 100 tons/d. By determining the actual cost to produce pellets, for a variety of DDGS production rates, accurate cost data can be used as inputs to the logistics model. Ultimately, cost will impact whether a technology is adopted in industry or not. Hopefully the logistics model which is being developed will help provide insight into the potential benefits of pelleting.

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Table 1. Equipment necessary to install a pelleting operation at a fuel ethanol plant.

Item	Description	Item	Description
001	Conveyor	008	Pellet mill
002	Bucket elevator	009	Cooler
003	Scale / surge bin	010	Conveyor
004	Vibrator	011	Bucket elevator
005	Gate	012	Scale / surge bin
006	Conveyor	013	Gate
007	Conditioner		

Table 2. Cost estimates for installing and operating a pelleting operation, according to DDGS generation rate.

Pelleting Capacity (Mg/y)	**3333.33**	**8333.33**	**16666.67**	**33333.33**	**66666.67**
Equipment initial cost ($)	334549	334588.1	347808.1	422966.5	705764.5
Total capital investment ($)	546675.8935	546736.5572	567247.3872	683855.6448	1122616.742
ANNUAL BENEFITS ($/y)					
Annualized equipment salvage value	3800.13	3800.55	3943.13	4753.72	7803.69
Total Annual Benefits ($/y)	**3800.13**	**3800.55**	**3943.13**	**4753.72**	**7803.69**
ANNUAL FIXED COSTS ($/y)					
Annualized Capital Costs	52668.01	52673.85	54649.91	65884.22	108155.47
Depreciation	30978.30	30981.74	32144.02	38751.82	63614.95
Insurance	2360.41	2360.68	2449.24	2952.72	4847.19
Interest	28100.16	28103.28	29157.58	35151.46	57704.60
Overhead	533.33	1333.33	2666.67	5333.33	10666.67
Taxes	1788.19	1788.39	1855.48	2236.91	3672.11
Total Annual Fixed Costs ($/y)	**116428.41**	**117241.27**	**122922.89**	**150310.46**	**248660.98**
ANNUAL VARIABLE COSTS ($/y)					
Boiler fuel (steam)	3500.00	8750.00	17500.00	35000.00	70000.00
Electricity	41409.80	41819.60	57835.27	74494.07	115058.73
Labor	34118.72	85296.84	170593.78	341187.47	682375.03
Maintenance & repairs	9999.99	24999.99	50000.01	99999.99	200000.01
Misc. supplies	3333.33	8333.33	16666.67	33333.33	66666.67
Other	833.33	2083.33	4166.67	8333.33	16666.67
Water	66.67	166.67	333.33	666.67	1333.33
Total Annual Variable Costs ($/y)	**112628.28**	**113440.72**	**118979.76**	**145556.75**	**240857.28**
Yearly Cost to Pellet ($/y)	225256.55	226881.43	237959.52	291113.49	481714.57
Cop = Yearly Cost to Pellet ($/y/Mg)	**67.58**	**27.23**	**14.28**	**8.73**	**7.23**

Pelleting Capacity (Mg/y)	**100000.00**	**133333.33**	**166666.67**	**200000.00**	**233333.33**
Equipment initial cost ($)	711677.5	1124207.8	1385047.1	1796511.1	2063099.1
Total capital investment ($)	1131790.761	1771831.522	2176523.696	2814910.092	3228521.374
ANNUAL BENEFITS ($/y)					
Annualized equipment salvage value	7867.47	12316.61	15129.76	19567.41	22442.56
Total Annual Benefits ($/y)	**7867.47**	**12316.61**	**15129.76**	**19567.41**	**22442.56**
ANNUAL FIXED COSTS ($/y)					
Annualized Capital Costs	109039.31	170702.30	209691.27	271194.88	311043.13
Depreciation	64134.81	100403.79	123336.34	159511.57	182949.54
Insurance	4886.80	7650.34	9397.70	12154.10	13939.97
Interest	58176.16	91075.45	111877.39	144691.64	165952.03
Overhead	16000.00	21333.33	26666.67	32000.00	37333.33
Taxes	3702.12	5795.71	7119.47	9207.65	10560.58
Total Annual Fixed Costs ($/y)	**255939.20**	**396960.92**	**488088.84**	**628759.84**	**721778.60**
ANNUAL VARIABLE COSTS ($/y)					
Boiler fuel (steam)	105000.00	140000.00	175000.00	210000.00	245000.00
Electricity	129270.44	224956.67	253882.11	349568.33	379042.79
Labor	1023562.50	1364749.97	1705937.53	2047125.00	2388312.47
Maintenance & repairs	300000.00	399999.99	500000.01	600000.00	699999.99
Misc. supplies	100000.00	133333.33	166666.67	200000.00	233333.33
Other	25000.00	33333.33	41666.67	50000.00	58333.33
Water	2000.00	2666.67	3333.33	4000.00	4666.67
Total Annual Variable Costs ($/y)	**248071.73**	**384644.31**	**472959.08**	**609192.43**	**699336.04**
Yearly Cost to Pellet ($/y)	496143.46	769288.63	945918.15	1218384.86	1398672.08
Cop = Yearly Cost to Pellet ($/y/Mg)	**4.96**	**5.77**	**5.68**	**6.09**	**5.99**

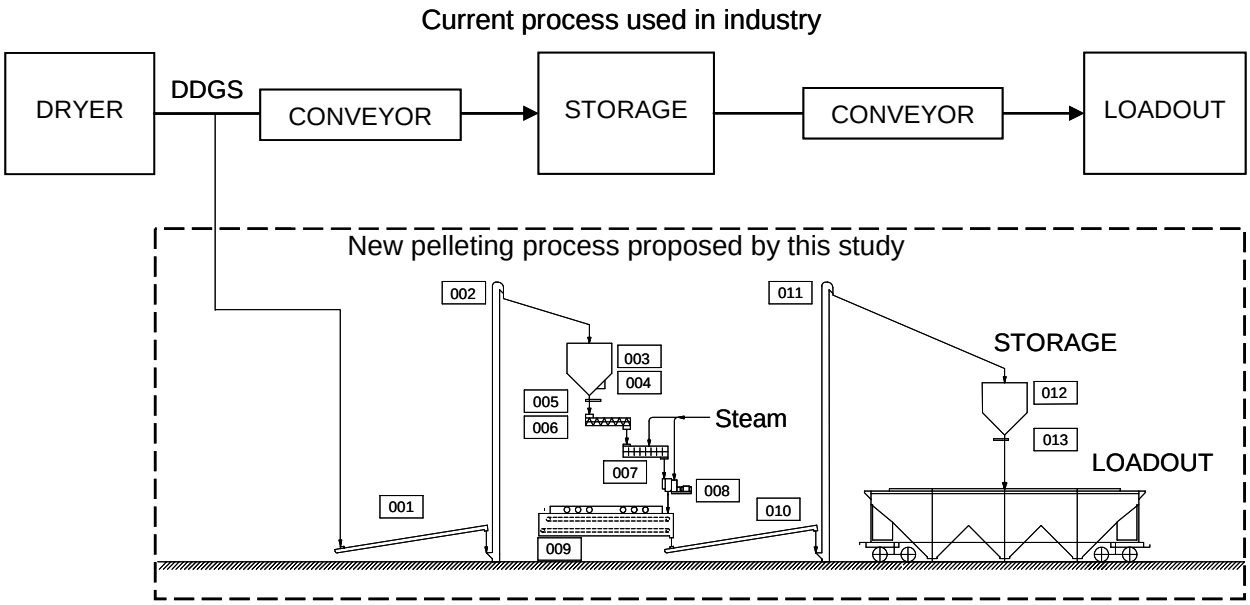

Figure 1. Flowchart for DDGS manufacturing augmented by a pelleting process.

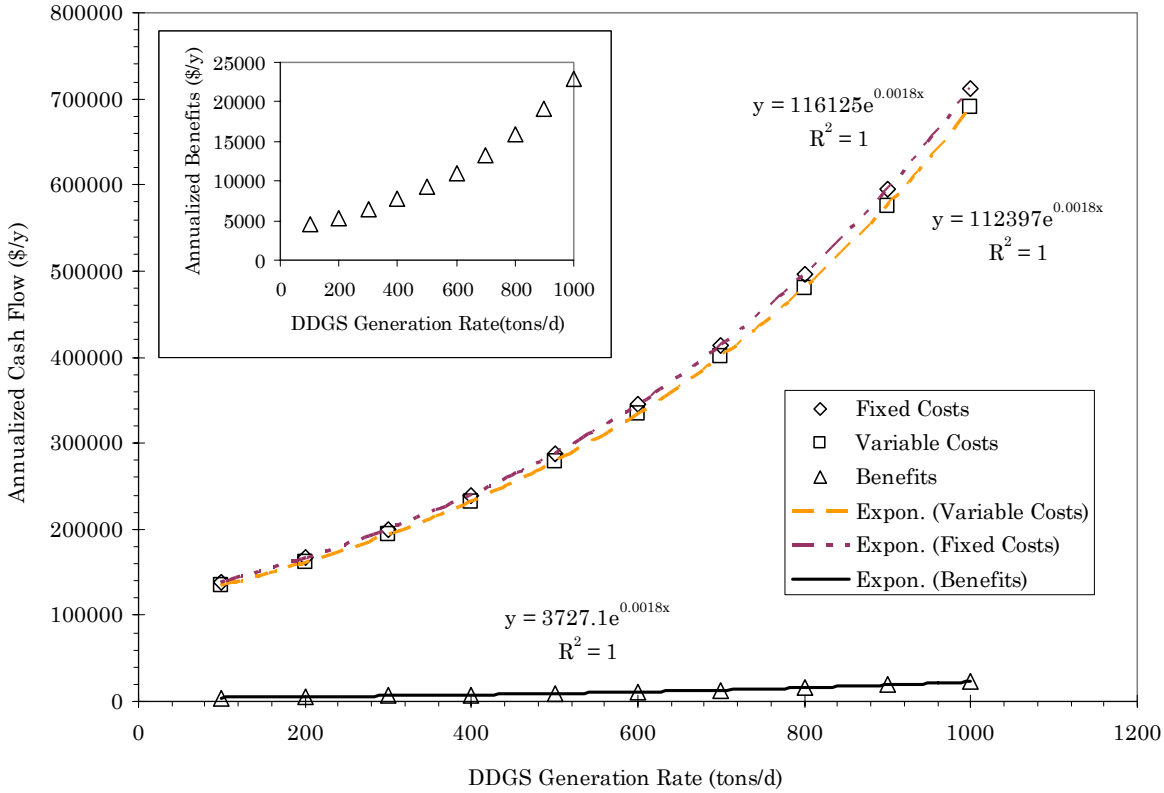

Figure 2. Annualized fixed and variable costs with annualized benefits as a function of DDGS generation rate (inset shows annual benefits at a greater scale).

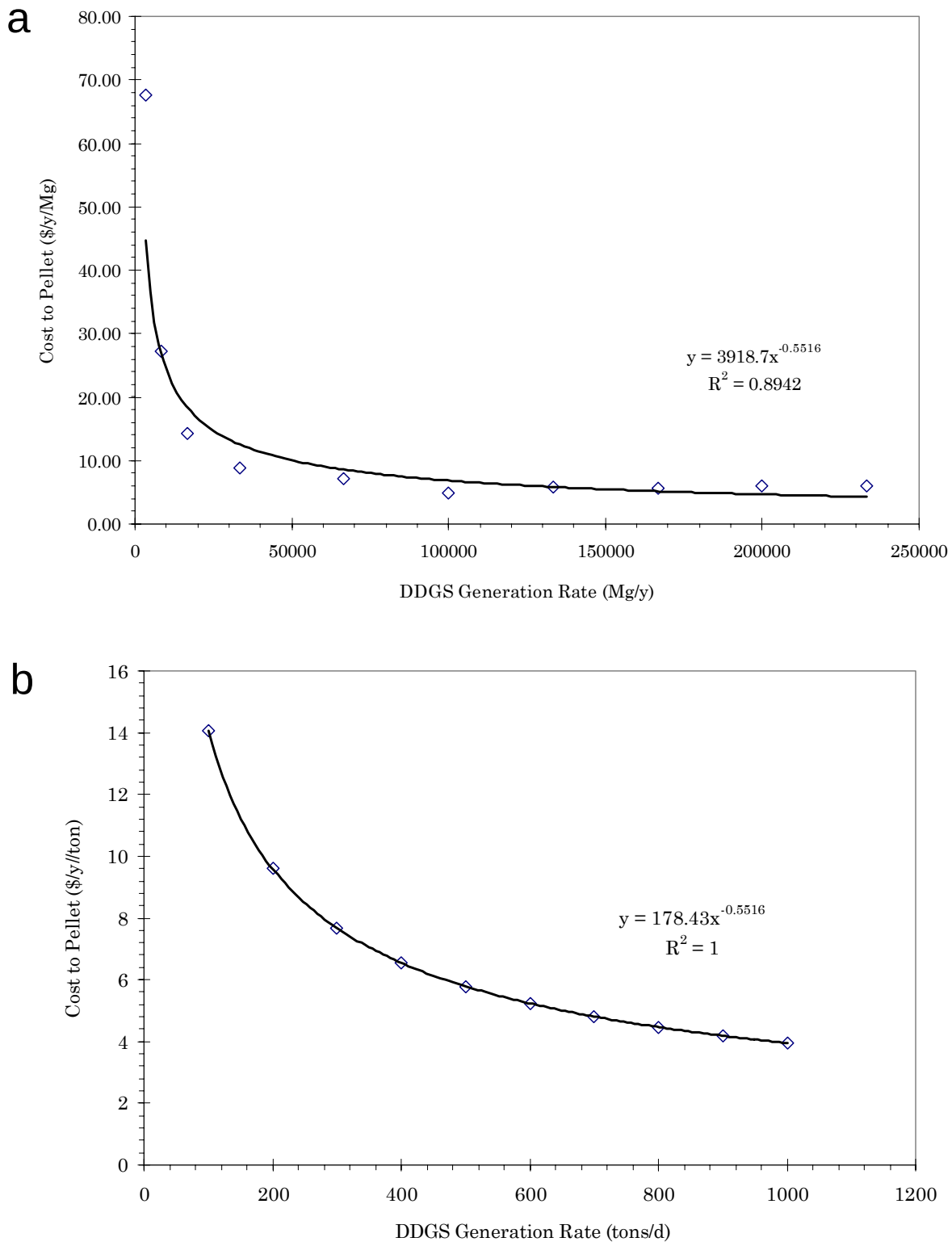

Figure 3. Total annual cost required to pellet DDGS according to scale of processing (Cop); a) DDGS generation rate quantified in Mg/y; b) quantified as tons/d.