Impact of distillers' grains moisture and inclusion level on greenhouse gas emissions in the corn-ethanol-livestock life cycle

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ABSTRACT

A model was previously developed (Biofuel Energy Systems Simulator; BESS; www.bess.unl.edu) to predict greenhouse gas (GHG) emissions and net energy yield when ethanol is produced from corn. The model predicts animal performance and subsequently the feed replacement value of the ethanol co-products. The BESS model was used to develop several scenarios over a range of livestock classes and amount of drying of co-products. New meta analysis equations for performance of feedlot cattle fed 0 to 500 g/kg of dietary dry matter (DM) as corn wet (WDGS, 320 g/kg DM), modified (MDGS, partially dried WDGS, 460 g/kg DM), or dry (DDGS, 900 g/kg DM) distillers' grains plus solubles (DGS) replacing dry rolled (DRC) and high moisture corn (HMC) were incorporated into the model. Equations were derived from pen-level performance for 20 trials evaluating WDGS, 4 trials evaluating MDGS, and 4 trials evaluating DDGS conducted at University of Nebraska research feedlots. Feeding value of WDGS was 145 to 131% of the corn replaced in diets at levels from 200 to 400 g/kg of diet DM. Using the same approach, feeding value of MDGS was 124 to 117% and 110 to 112% for DDGS. Midwest corn-ethanol-livestock life cycle GHG reduction relative to gasoline (97.7 g CO_2e/MJ ethanol) was greatest when WDGS was fed to feedlot cattle and decreased from 61 to 57% for 200 to 400 g/kg of diet DM as WDGS. Feeding MDGS and DDGS to feedlot cattle resulted in a reduction of GHG emissions by 53 to 50% and 46 to 41%, respectively. Life cycle GHG reduction for WDGS, MDGS, or DDGS for dairy cows was 53, 48, and 43%, respectively, and DDGS for swine was 42%. Reduction in GHG emissions are less when DDGS are fed compared to WDGS and MDGS for beef or dairy. Reduction in GHG emissions was comparable for all three livestock classes when DDGS was fed. Partial drying (MDGS) or complete drying (DDGS) of WDGS reduced both feeding value and GHG reductions for corn-ethanol relative to gasoline. Feeding WDGS to feedlot cattle was the optimum feed use of DGS based on feeding performance and GHG reduction. Accurate data for ethanol and gasoline GHG emissions are essential for providing a meaningful comparison of these fuels.

Keywords: Distillers' Grains, cattle performance, greenhouse gases, life cycle assessment

*Abbreviations:*ADG, average daily gain; BESS, Biofuel Energy Systems Simulator; DGS, distillers' grains plus solubles; DDGS, dried distillers' grains plus solubles; DM, dry matter; DMI, dry matter intake; gCO_2e, grams of carbon dioxide equivalents; G:F, feed efficiency; GHG, greenhouse gas; MDGS, modified distillers' grains plus solubles; WDGS, wet distillers' grains plus soluble.

1. Introduction

Corn (*Zea mays*) distillers' grains plus solubles (DGS) are an important part of the corn-ethanol-livestock life cycle when comparing greenhouse gas (GHG) emissions of ethanol to gasoline. Distillers' grains contain a significant quantity of energy and offsets corn, urea and soybean meal in livestock diets. The energy and protein replacement value of DGS is dependent on dietary inclusion level and livestock class fed. Ethanol plant energy use and associated GHG emissions are affected by moisture content of DGS produced. All ethanol plants produce wet DGS (WDGS; 650-690 g/kg moisture). Some plants choose to remove moisture from WDGS to form modified DGS (MDGS; 520-580 g/kg moisture) or dried DGS (DDGS; 80-120 g/kg moisture). Ethanol plant energy use (*e.g.*, natural gas) to remove moisture has been identified as a parameter of importance in comparing GHG emissions from ethanol relative to gasoline (Liska et al., 2009; Bremer et al., 2010b).

The Biofuel Energy Systems Simulator (BESS; www.bess.unl.edu) was developed to compare life cycle GHG emissions from ethanol production relative to gasoline as a motor fuel, while accounting for the dynamic interactions of corn production, ethanol plant operation, and co-product feeding to livestock. The co-products fed to livestock replace other feedstuffs that supply protein, energy and minerals. The replacement values vary with livestock class and nutrient, such as protein, that is replaced. Modeling GHG emissions requires accurate biological equations derived from animal performance over a broad range of DGS feeding conditions. Good summaries of DGS feeding to swine and dairy cattle were available, but limited data on feeding DGS to feedlot cattle were available. The BESS model was developed with feedlot cattle performance equations available at the time. A meta-analysis using a limited number of experiments was used to develop equations for feeding of WDGS while individual feeding trials of MDGS and DDGS were used (Liska et al., 2009; Bremer et al., 2010b). Multiple trials for all three DGS moistures have been completed more recently to augment the initial datasets. Revised meta-analyses of cattle performance equations developed from these more complete databases should improve the accuracy of modeling GHG emissions from ethanol production.

Therefore, the objectives of the current study were to update equations predicting cattle performance when fed WDGS, MDGS, and DDGS in BESS with the most complete data available and to evaluate the impact of DGS moisture and inclusion level in livestock diets on ethanol GHG emissions from the corn-ethanol-livestock life cycle relative to gasoline.

2. Materials and methods

2.1 Cattle performance data

Several scenarios were developed using the BESS model in order to compare GHG reduction when ethanol is produced compared to gasoline. The scenarios were developed over a range of livestock classes and amount of drying of co-products. Feedlot cattle were evaluated when fed levels (100-400 g/kg) of WDGS, MDGS, or DDGS. Lactating dairy cows were evaluated when fed WDGS, MDGS, and DDGS. Swine were evaluated only when fed DDGS.

*2.2 Dataset*Prior to conducting the analysis using the BESS model to estimate GHG emissions in the various scenarios, a new dataset was developed to update the equations in the BESS model. Prediction equations of performance of cattle fed wet DGS were developed from 20 feedlot cattle finishing trials with 350 pen means, representing 3,365 steers fed (Larson et al., 1993; Ham et al., 1994; Al-Suwaiegh et al., 2002; Vander Pol et al., 2005; Godsey et al., 2008a, 2008b; Meyer et al., 2008; Wilken et al., 2008; Corrigan et al., 2009; Rich et al., 2009; Vander Pol et al., 2009; Loza et al., 2010; Luebbe et al., 2010; Moore et al., 2010; Nuttelman et al., 2010; Rich et al., 2010; Sarturi et al., 2010). Equations for modified DGS were also developed from four University of Nebraska-Lincoln (UNL) feedlot trials with 85 pens, representing 680 steers (Adams et al., 2007; Huls et al., 2008; Luebbe et al., 2010; Nuttelman et al., 2010). Equations to predict performance of cattle fed wet DGSwere developed from four UNL feedlot trials with 66 pens, representing 581 steers (Ham et al., 1994; Buckner et al., 2010; Nuttelman et al., 2010; Sarturi et al., 2010). In all trials cattle performance traits measured included average daily gain (ADG), dry matter intake (DMI), feed efficiency (G:F), hot carcass weight (HCW), ribeye area (REA), and 12th rib fat thickness.

All trials included in the analyses evaluated feeding corn DGS replacing dry-rolled corn, high-moisture corn, or a blend of the two corn types. Individual animal carcass data were collected on all steers and feeding performance was calculated from carcass adjusted final weight. In each trial a single DGS moisture type co-product was fed as 0 to 500 g/kg DM in the diet. All trials were conducted under similarly managed feedlot research settings at University of Nebraska Beef Research Feedlots. Animal use procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee.

2.3 Data analysis

In order to develop equations to update the BESS model, it was necessary to combine data from the various experiments. Meta-analysis methodology for integrating quantitative findings from multiple studies was utilized for data analysis of the three DGS products (St-Pierre, 2001). This method accounts for the random effect of individual trials with a structured iterative analytical process using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC, USA). Pen mean was the experimental unit of analysis. Trials were weighted by number of WDGS levels to prevent artificial linear responses from trials with 0 and one other level of DGS evaluated. Each DGS moisture type was analyzed with a separate dataset. Biological performance equations were developed based on significant model variables. Variables tested included ADG, DMI, and G:F. The intercepts (no DGS diet) of the MDGS and DDGS predicted performance equations were scaled to the intercept of the WDGS dataset to compare differences in cattle performance relative to a common no DGS diet. A common no DGS diet in the Midwestern United States would include a combination of DRC and HMC at 800-900 g/kg of the diet DM, DGS is added to the diet to replace corn. The equation adjustment allowed the evaluation of how an individual steer would perform if given one of the three products relative to a common base point.

2.4 Model parameters

The assumptions and calculations of BESS have been discussed extensively (Liska et al., 2009, Bremer et al., 2010b). The BESS model estimates the net energy yield from producing ethanol (ethanol plus co-product credits minus energy inputs). The model also estimates GHG emissions (CO_2 equivalents) from non-renewable energy sources needed to produce the corn, produce the ethanol, dry co-products (if needed) and transport co-products to feedlots. The GHG emissions are then compared to that from gasoline used as liquid fuel and reported as percentage reduction. Energy costs and GHG emissions with production of fossil fuels, fertilizer inputs and electricity are included. Non fossil fuel GHG emissions include N_2O from fertilizer and manure. Bremer et al. (2010b) further discussed the dynamic livestock and DGS components of the BESS model. Midwestern United States corn production efficiency of 362 g CO_2eq/kg of corn DM was used for all scenarios (Bremer et al., 2010b). Ethanol plant GHG emissions from ethanol production and dryer operation were developed from a survey of 9 ethanol plants (Bremer et al., 2010b). Average ethanol plant GHG emissions from natural gas and electricity use for plant operation and DGS drying were 21.0, 25.6, and 30.5 g CO_2e/MJ ethanol for WDGS, MDGS, and DDGS, respectively.

We have assumed that livestock production would be similar in quantity whether DGS is fed or if not. Therefore, a partial budget approach was used assuming GHG emissions would be the same except for any direct effects the use of DGS would have on GHG emissions, such as transportation. It was further assumed that CO_2 originating from corn and converted to CO_2, either in the biorefinery or by the livestock, is resynthesized into organic, energy containing nutrients the subsequent growing season (renewable energy). McGinn et al. (2009) reported that feeding DDGS in forage based growing diets reduced methane emissions. This was also shown by Behlke et al. (2007) in lambs. However, Behlke et al. (2007) showed greater methane emissions in lambs fed high grain diets when DGS was included, even though the unsaturated lipid in the DGS would be expected to reduce methane emissions. Alternatively, the digestion of the fiber in DGS compared to starch in the corn replaced would be expected to increase methane production. Because of these conflicting reports and mechanisms, we chose to assume similar methane production by cattle fed diets containing DGS and those containing primarily corn.

The BESS model contains equations that predict animal DMI and G:F. These equations are used to predict cattle growth to a common weight (Bremer et al., 2010b). The equations for WDGS, MDGS, and DDGS were updated based on the meta-analyses previously described. Distillers' grains replaced corn and urea nitrogen in beef finishing diets (Klopfenstein et al., 2008a),but replaced corn and soybean meal in swine finishing and dairy lactating diets (Bremer et al., 2010b). Summaries of dairy and swine DGS feeding data (Schingoethe, 2008; Stein, 2008) do not indicate a feeding value of DGS greater than a combination of soybean meal and corn. Therefore, a direct replacement of corn and soybean meal (kg for kg of DM) was utilized when DGS is fed to these animal classes.

An average emissions intensity for gasoline considering a tar sands fraction (7/100 barrels of petroleum) and California reformulated gasoline blendstock is estimated at 97.7 gCO_2e/MJ. This value was used as the gasoline reference point for all scenarios (Liska and Perrin, 2009).

2.5 Scenarios evaluated

Corn production efficiency and ethanol plant operation except for drying of DGS was held constant for all scenarios. Greenhouse gas emissions of ethanol produced from the corn-ethanol-livestock life cycle relative to gasoline were calculated for the following scenarios. The ethanol plant produces WDGS fed at 100, 200, 300, or 400 g/kg of diet DM to feedlot cattle or fed at 100, 200, or 300 g/kg of diet DM to lactating dairy cows. Similar scenarios for both feedlot and dairy were evaluated for MDGS and DDGS. Swine use of DGS is limited to DDGS and scenarios of 90,180, or 270 g/kg of finishing diet DM were evaluated.

3. Results

3.1 Dataset

Steer DMI increased quadratically as DGS inclusion level increased (Table 1). The greatest improvement in DMI occurred when DDGS replaced corn (DRC and HMC). The DMI response to MDGS inclusion was intermediate to DDGS and WDGS. Maximum DMI of steers fed DDGS occurred at a greater level of DGS inclusion than MDGS, and the maximum DMI of steers fed WDGS occurred at the lowest level of DGS inclusion of the three DGS moisture products. Quadratic increases in ADG and G:F were observed when steers were fed WDGS or MDGS. Steer ADG and G:F improved linearly as DDGS replaced corn in the diet. Steer ADG was similar for the three DGS moisture products. All DGS products contained greater feeding value than corn, measured by the increase in feed efficiency of DGS diets compared to corn based diets. The feeding values of WDGS, MDGS, and DDGS, when fed at 200 to 400 g/kg of diet DM, were 143 to 130, 124 to 117, and a constant 112% of corn (DM basis), respectively. The feeding value of DGS decreased as moisture level decreases. The feeding value of WDGS and MDGS decreased as inclusion level increases. The feeding value of DDGS was a constant 112% of corn DM.

3.2 GHG emissions of ethanol

All scenarios evaluated had ethanol life cycle emissions less than gasoline (Table 2). The life cycle that included feeding WDGS to feedlot cattle had the least ethanol GHG emissions of the scenarios evaluated. The next best option was feeding WDGS to dairy cows. Feeding MDGS to feedlot cattle created fewer GHG emissions than feeding MDGS or DDGS to dairy cattle. Feeding DDGS to feedlot cattle had slightly fewer GHG emissions than feeding DDGS to swine and dairy cows.

4. Discussion

4.1 DGS moisture

A decrease in steer performance as moisture is removed from WDGS, as indicated by the results of the meta-analyses, is in agreement with individual studies that evaluated both WDGS and DDGS (Ham et al., 1994; Sarturi et al., 2010; Nuttelman et al., 2010). Those three studies evaluated feeding DGS in the WDGS or DDGS forms and found the feeding value of WDGS to be greater than that of DDGS. Nuttelman et al. (2010) conducted the first study to evaluate feeding multiple dietary inclusion levels of WDGS, MDGS, and DDGS in the same trial. In addition, the MDGS and DDGS were sourced from the same ethanol plant and all 3 types of DGS were identical in nutrient composition. The researchers observed the feeding value of WDGS to be greater than MDGS, which were both greater than DDGS. Their results indicate cattle fed drier DGS products eat to a constant energy intake, which are supported by the findings from our study that DMI of steers increased as DGS moisture decreased, when compared at the same ADG.

The feeding value of DGS is set at the ethanol plant with management decisions on how to market WDGS. Target market livestock populations and DGS transportation costs are drivers of how WDGS is processed at the ethanol plant (Buckner et al., 2008; Bremer et al., 2010b). Drying WDGS improves shelf life and decreases shipping costs due to less moisture being hauled. Drying DGS allows access to markets unattainable with WDGS by moving DDGS into export markets, the swine industry, and livestock industries in other regions within North America. This flexibility comes at a cost. In addition to the decrease in feeding value of DDGS relative to WDGS, the fixed and variable cost of owning and operating a dryer in an ethanol plant are significant (Baumel, 2008). Ethanol plant decisions on DGS moisture management also impact the GHG balance of ethanol produced. Ethanol plants producing DDGS require 167% of the energy and produce 145% of the GHG emissions of ethanol plants producing WDGS (Liska et al., 2009). This emphasizes making ethanol production decisions that are economically and environmentally sound.

Cleary, the greatest reduction of GHG emissions occurred when WDGS were fed to feedlot cattle (beef). This is because of the greater replacement value of the co-product for beef compared to other livestock types and because drying is not required. Dairy cattle have slightly lower GHG reductions than feedlot cattle because there is less replacement value of the co-products. All livestock types had lower reduction in GHG emissions when DDGS was fed, obviously because of the use of fossil fuel to dry the co-product.

4.2 Gasoline reference point

The evaluation of ethanol relative to gasoline not only requires accurate evaluation of the ethanol production cycle, but also an accurate reference point for the GHG-intensity of gasoline.

Gasoline emissions not only include combustion emissions, but also upstream emissions from crude oil recovery, refinery emission, and flaring losses (Brandt and Farrell, 2007). Emissions due to military security associated with acquisition of Middle Eastern petroleum, changes in the composition of petroleum supplies toward more GHG-intensive fuels, and other additional emissions from petroleum processing must also be considered (Liska and Perrin, 2009). Indirect GHG emissions from military security for maritime oil transit are estimated to raise the GHG intensity of gasoline from the Middle East by roughly 20% over the conventional baseline (Liska and Perrin 2010).

Ethanol production does not displace average gasoline, but displaces a marginal unit of gasoline that may have a much greater environmental cost than average gasoline (US EPA, 2010). As the proportion of gasoline derived from more energy intense processes increases, the GHG life cycle reference point of gasoline should be updated to compare a marginal liter of gasoline to an equal energy quantity from ethanol. The GHG-intensity of gasoline is increasing due to depletion of efficiently accessible deposits (Brandt and Farrell, 2007). Unconventional and less efficiently processed sources of petroleum such as tar sands, coal-to-liquids, and oil shale will likely be used to fill the difference between current petroleum supply and energy demand. In fact, Canadian tar sands could supply 20 out of every 100 barrels of US gasoline by 2020 (Liska and Perrin, 2009).

4.3 Indirect GHG impacts of ethanol and gasoline

Indirect GHG emissions from ethanol and gasoline, such as land use change, were not evaluated in this study due to the immense complexity in calculating the totality of significant indirect GHG emissions (Liska and Perrin, 2009; US EPA, 2010). A methodology to incorporate both reasonably accurate scientific knowledge about direct life cycle emissions and relatively diffuse and uncertain scientific knowledge concerning potentially significant indirect emissions must be developed to fully evaluate the GHG mitigation potential of ethanol (Liska and Perrin, 2009; US EPA, 2010). This is especially true when the indirect effects may provide a large impact on the life cycle being analyzed.

One may be tempted to add the single indirect emission from land use change due to increased ethanol production (Searchinger et al., 2008), yet land use change is only one significant indirect GHG emission among many. Other significant indirect emissions include military security emissions, changes in rice cultivation, and changes in livestock globally (Liska and Perrin, 2009; Liska and Perrin 2010; US EPA, 2010). Further research is needed before we can have reasonable confidence in the net effects of indirect GHG emissions of both biofuels and petroleum fuels (Liska and Perrin, 2009). A comprehensive assessment of the total GHG emissions implications of substituting ethanol for petroleum needs to be completed before the impact of indirect GHG emissions from land use change alone can be accurately determined.

4.4 Current ethanol production vs. future expansion GHG emissions

Indirect land use change is associated primarily with future expansion of the ethanol industry. Emissions from existing ethanol production facilities are limited to direct emissions, given whatever indirect emissions were associated with initiating ethanol production at these facilities has already occurred. Because of this, biofuels use now from existing facilities not only reduces GHG emissions from transportation fuel use compared to petroleum, but also supports national security goals and rural development objectives. Evaluation of these additional policy objectives are not considered in GHG emissions modeling frameworks, but are important considerations when comparing fuels.

4.5 Future co-products

Distillers' grains are used not only as a protein source but also as an energy source by feedlot cattle (Klopfenstein et al., 2008a; NRC, 1996). Ruminants are able to utilize the fat, fiber, and protein components of DGS. Utilization of protein as a source of energy increases N excretion and NH_3 emissions, however. Fractionation of DGS products for biodiesel production from the fat component and cellulosic ethanol production of the fiber fraction will result in a concentrated protein source. The GHG balance of ethanol and other co-products produced from fractionated corn processes may be significantly different from the current systems analyzed due to uses of co-products produced, change in corn processing, and environmental costs of implementing the technology. The feeding value of these products may also be reduced (Buckner et al., 2010). Furthermore, exploitation of fibrous biomass fermentation for ethanol production would directly compete for the resource niche that cattle currently utilize.

Although ethanol production has altered the availability of corn for livestock production, the use of DGS as livestock feed has helped to maintain the synergistic relationship between the livestock and corn production industries. Feeding DGS results in up to 0.43 kg of corn DM offset as DGS for each kg of corn DM fermented at the ethanol plant. The US livestock industry is of sufficient scope to fully utilize DGS production from a 69 billion liters per year corn ethanol industry (Bremer et al., 2010b). That is a corn ethanol industry 1.7 times larger than the current 40 billion liters per year ethanol production capacity (RFA, 2009). These DGS use calculations are conservative since they do not account for exporting DGS and feeding DGS to non-lactating dairy cows, beef cattle on grass, feedlot cattle finished in yards less than 1,000 cattle capacity, and poultry (Klopfenstein et al., 2008b). Increasing the scope of corn ethanol production would not significantly alter ethanol GHG emissions of individual plants (Bremer et al., 2010b).

5. Conclusion

Feeding DGS to livestock is a significant contribution to the environmental benefit of fuel ethanol relative to gasoline. The GHG emissions benefits of ethanol are determined by how DGS moisture is managed at the ethanol plant and what animal classes are fed DGS. Feeding WDGS to feedlot cattle provided the optimum feed use of DGS for livestock. Partial drying (MDGS) or complete drying (DDGS) of WDGS reduced the feeding value and increased ethanol GHG emissions relative to WDGS. In state and federal GHG regulations for fuels, regulators must continually update and use the most representative and accurate data for assessing ethanol and gasoline GHG emissions. Yet, achieving this accuracy requires much more complete research on the underlying systems involved, such as the research results presented here.

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Table 1.

Finishing steer performance when fed different dietary inclusions of corn wet distillers' grains plus solubles (WDGS[a]), modified distillers' grains plus solubles (MDGS) or dried distillers' grains plus solubles (DDGS) replacing dry rolled and high moisture corn.

DGS Inclusion [b]:	0DGS	10DGS	20DGS	30DGS	40DGS	Lin [c]	Quad [c]
WDGS [d]							
DMI[a], kg/d	10.4	10.6	10.6	10.4	10.2	0.01	< 0.01
ADG[a], kg	1.60	1.71	1.77	1.78	1.75	< 0.01	< 0.01
G:F[a]	0.155	0.162	0.168	0.171	0.173	< 0.01	< 0.01
Feeding value, %[e]		150	143	136	130		
MDGS[f]							
DMI, kg/d	10.4	10.8	10.9	10.9	10.6	0.95	< 0.01
ADG, kg	1.60	1.71	1.77	1.78	1.74	< 0.01	< 0.01

G:F	0.155	0.159	0.162	0.164	0.165	< 0.01	0.05
Feeding value, %[e]		128	124	120	117		
DDGS[f]							
DMI, kg/d	10.4	10.9	11.2	11.3	11.3	< 0.01	0.03
ADG, kg	1.60	1.66	1.72	1.77	1.83	< 0.01	0.50
G:F	0.155	0.156	0.158	0.160	0.162	< 0.01	0.45
Feeding value, %[e]		112	112	112	112		

[a] WDGS = wet distillers' grains with solubles, MDGS = modified wet distillers' grains with solubles, DDGS = dried distillers' grains with solubles, DMI = dry matter intake, ADG = average daily gain, and G:F = feed efficiency.

[b] Dietary treatment levels (DM basis) of distillers' grains plus solubles (DGS), 0DGS = 0 g/kg DGS, 10DGS = 100 g/kg DGS, 20DGS = 200 g/kg DGS, 30DGS = 300 g/kg DGS, 40DGS = 400 g/kg DGS.

[c] Estimation equation linear and quadratic term t-statistic for variable of interest response to DGS level.

[d]WDGS data presented are summarized from Bremer et al., 2010.

[e] Percent of corn feeding value, calculated from DGS inclusion level feed efficiency relative to 0WDGS feed efficiency, divided by DGS inclusion.

[f] MDGS and DDGS steer performance was scaled to the WDGS intercept for equal comparison across byproduct types. This process was validated by Nuttelman et al. (2010).

Table 2.

Percent reduction in greenhouse gas (GHG) emissions for an equivalent quantity of energy from ethanol relative to gasoline when accounting for distillers' grains (DGS) moisture content, dietary inclusion level, and livestock type fed.

Livestock Type	Beef				Dairy	Swine
DGS, g/kg of diet DM[a]	100	200	300	400	100-300	90-270
WDGS, GHG % reduction to gasoline[b]	62.4	60.6	58.4	56.7	52.6	---
MDGS, GHG % reduction to gasoline[b]	53.9	52.6	50.9	49.7	47.9	---
DDGS, GHG % reduction to gasoline[b]	46.1	45.4	44.4	43.9	42.8	42.3

[a] DM = dry matter, WDGS = wet distillers' grains with solubles, MDGS = modified wet distillers' grains with solubles, and DDGS = dried distillers' grains with solubles.

[b] Gasoline reference point is 97.7 g CO2e/MJ (Liska and Perrin, 2009).