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"Production of Biofuel (Ethanol) from Corn and co product evolution": A Review

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Abstract : *This paper present a general review of production of biofuel (bio ethanol) and co product evolution. As the sources of fuels such as diesel and petroleum are said to be in shortage in a couple of years and due to increase in population there is increase in demand of fuel hence we require the need of other sources of fuel which can be generated by natural resources.. One of many of the sources being biomass which is generated using wastes such as food waste, animal waste, toilets waste. Bio fuels are the fuels which are generated from living things or from the waste that ling things produce. It is also believed that these bio fuels reduce the green house effect and reduces carbon dioxide produced due to burning which helps in the nourishment and growth of plants.*

Keywords: Bio Ethanol, Dry Milling, Wet Milling Fermentation.

1. INTRODUCTION

Modern societies face many challenges, including growing populations, increased demands for food, clothing, housing, consumer goods, and the raw materials required to produce all of these. Additionally, there is a growing need for energy, which is most easily met by use of fossil fuels (e.g., coal, natural gas, petroleum). For example, in 2008, the overall U.S. demand for energy was 99.3 x 10^{15} Btu (1.05 x 10^{14} MJ); 84% of this was supplied by fossil sources. Transportation fuels accounted for 28% of all energy consumed during this time, and nearly 97% of this came from fossil sources. Domestic production of crude oil was 4.96 million barrels per day, whereas imports were 9.76 million barrels per day (nearly 2/3 of the total U.S. demand) (U.S. EIA, 2011). Many argue that this scenario is not sustainable in the long term, and other alternatives are needed.[1]

Biofuels, which are renewable sources of energy, can help meet some of these increasing needs. They can technically be produced from a variety of materials which contain either carbohydrates or lipids, including cereal grains (such as corn, barley, and wheat), oilseeds (such as soybean, canola, and flax), legumes (such as alfalfa), perennial grasses (such as switchgrass, miscanthus, prairie cord grass, and others), agricultural residues (such as corn stover and wheat stems), algae, food processing wastes, and other biological materials. Indeed, the lignocellulosic ethanol industry is poised to consume large quantities of biomass in the future. At this point in time, however, the most heavily used feedstock for biofuel production in the U.S. is corn grain. Industrial-scale alcohol production from corn starch is readily accomplished, and at a lower cost (generally between $1/gallon and $1.4/gallon), compared to other available biomass substrates in the U.S. The most commonly used process for the production of fuel ethanol from corn is the dry grind process, the primary coproduct of which is distillers dried grains with solubles (DDGS) (Figure1), which will be discussed subsequently.

Corn-based ethanol has been used as a liquid transportation fuel for more than 150 years, although up until recent times the industry has been quite small. The modern corn-based fuel ethanol industry, however, has reached a scale which can augment the nation's supply of transportation fuels.[2]

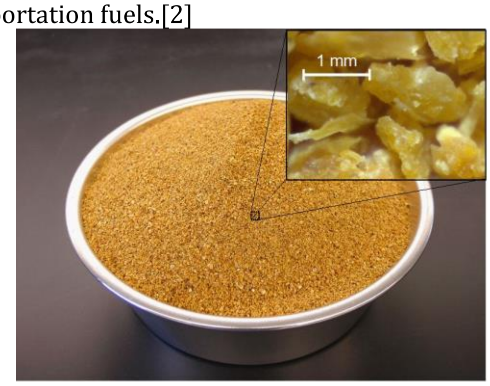

FIGURE 1.
Corn-based distillers dried grains with solubles (DDGS), which is currently available from most U.S. fuel ethanol plants.

In 2005, 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 2011, however, that number had risen to 204 plants with a production capacity of nearly 51.1 billion L/y (13.5 billion gal/y), which is an increase of nearly 380% in six years (RFA, 2011). Most new ethanol plants have been dry-grind facilities (Figure 2), which will be discussed subsequently. [3]

FIGURE 2.
U.S. dry grind corn-to-ethanol manufacturing plants. A. 450 x 10^6 L/y plant. B. 80 x 10^6 L/y plant.

Renewable Fuel Standard (RFS) mandates the use of 15 billion gal/y (56.8 billion L/y) of renewable biofuels (i.e., which will primarily be corn-based ethanol) (RFA, 2009a), although the RFS does mandate the growing use of advanced and cellulosic biofuels as well. Because the industry is dynamic and still evolving, these current production numbers will surely be outdated by the time this book is published. As production volume increases, the processing residues. It is anticipated that over 40 million metric tons (t) of distiller's grains (both wet and dry) will eventually be produced by the U.S. fuel ethanol industry as production reaches equilibrium due to the RFS.

Since 2008, for example, over 30% of the U.S. corn crop has been used to produce ethanol. When examining these numbers, however, it is important to be aware of several key points: exports have been relatively constant over time, there has been a slight decline in the corn used for animal feed, and the overall quantity of corn which is produced by U.S. farmers has been substantially increasing over time. Thus, it appears that the corn which is used to produce ethanol is actually arising mostly from the growing corn supply. It is also important to note that the corn which is redirected away from animal feed is actually being replaced by DDGS and other ethanol co-products in these animal feeds. Thus co-products (especially DDGDS) are key to the sustainability of both the ethanol and livestock industries. In other words, fuel, feed, and food needs can be simultaneously met.[4]

2. MANUFACTURING PROCESSES

Corn can be converted into fuel ethanol by three commercial processes: wet milling, dry milling, and dry grind processing. Over the last decade, many new fuel ethanol plants have been built, and considerable innovations have occurred throughout the industry vis-à-vis production processes used and final products produced, as well as raw materials, water, and energy consumption. Many of these innovations have arisen with the advent of dry grind processing. Due to many advantages, including lower capital and operating costs (including energy inputs), most new ethanol plants are dry grind facilities as opposed to the older style mills. For example, in 2002, 50% of U.S. ethanol plants were dry grind; in 2004 that number had risen to 67%; in 2006 dry grind plants constituted 79% of all facilities; and in 2009 the fraction had grown to over 80% (RFA, 2009a).[5]

The dry grind process (Figure 3) entails several key steps, including grain receiving, distribution, storage, cleaning, grinding, cooking, liquefaction, saccharification, fermentation, distillation, ethanol storage and loadout, centrifugation, coproduct drying, coproduct storage and loadout. Additional systems that play key roles include energy / heat recovery, waste management, grain aeration, CO_2scrubbing and extraction, dust control, facility sanitation, instrumentation and controls, and sampling and inspection. Figure 3 depicts how all of these pieces fit together in a commercial plant.

Grinding, cooking, and liquefying release and convert the corn starch into glucose, which is consumed during the fermentation process by yeast (Sacchharomyces cerevisiae). After fermentation, the ethanol is separated from the water and non-fermentable residues (which consist of corn kernel proteins, fibers, oils, and minerals) by distillation. Downstream dewatering, separation, evaporation, mixing, and drying are then used to remove water from the solid residues and to produce a variety of co product streams (known collectively as distiller's grains): wet or dry, with or without the addition of condensed soluble (CDS). Distillers dried grains with soluble (known as DDGS), is the most popular, and is often dried to approximately 10% moisture content (or even less at some plants), to ensure an extended shelf life and good flow ability, and then sold to local livestock producers or shipped by truck or rail to various destinations throughout the nation. DDGS is increasingly being exported to overseas markets as well. Distiller's wet grains (or DWG) have been gaining popularity with livestock producers near ethanol plants in recent years; in fact, it has been estimated that, nationwide, more than 25% of distiller's grains sales are now DWG.[6]

Dry grind ethanol manufacturing results in three main products: ethanol, the primary end product; residual non fermentable corn kernel components, which are sold as distillers grains; and carbon dioxide. A common rule of thumb is that for each 1 kg of corn processed, approximately 1/3 kg of each of the constituent streams will be produced. Another rule of thumb states that each bushel of corn (~ 56 lb; 25.4 kg) will yield up to 2.9 gal (11.0 L) of ethanol, approximately 18 lb (8.2 kg) of distillers grains, and nearly 18 lb (8.2 kg) of carbon dioxide. Of course, these will vary to some degree over time due to production practices, equipment settings, residence times, concentrations, maintenance schedules, equipment conditions, environmental conditions, the composition and quality of the raw corn itself, the location where the corn was grown, as well as the growing season that produced the corn.[2]

During fermentation, carbon dioxide arises from the metabolic conversion of sugars into ethanol by the yeast. This byproduct stream can be captured and sold to compressed gas markets, such as beverage or dry ice manufacturers. Often, however, it is released to the atmosphere because location and/or logistics make the sales and marketing of this gas economically unfeasible. In the future, however, the release of carbon dioxide may eventually be impacted by greenhouse gas emission constraints and regulations.

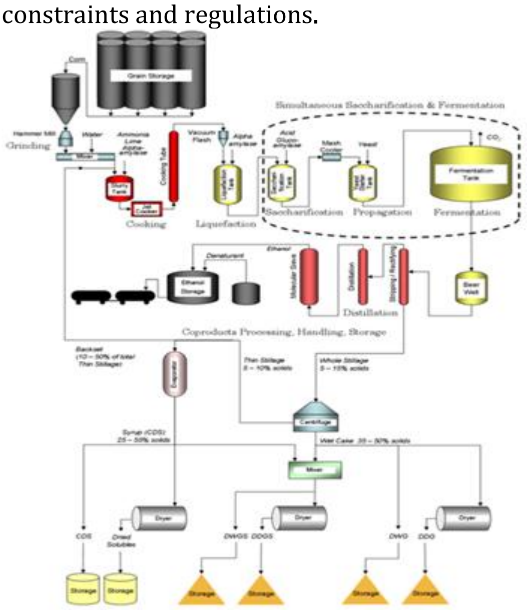

FIGURE 3.
Flow chart of typical corn dry grind fuel ethanol and co-products processing.

3. CO-PRODUCT EVOLUTION

The ethanol industry is dynamic and has been evolving over the years in order to overcome various challenges associated with both fuel and co-product processing and use (Rosentrater, 2007). A modern dry grind ethanol plant is considerably different from the inefficient, input-intensive Gasohol plants of the 1970s. New developments and technological innovations, to name but a few, include more effective enzymes, higher starch conversions, better fermentations, cold cook technologies, improved drying systems, decreased energy consumption throughout the plant, increased water efficiency and recycling, and decreased emissions. Energy and mass balances are becoming more efficient over time. Many of these improvements can be attributed to the design and operation of the equipment used in modern ethanol plants. A large part is also due to computer-based instrumentation and control systems. [7]

Many formal and informal studies have been devoted to adjusting existing processes in order to improve and optimize the quality of the co-products which are produced. Ethanol companies have recognized the need to produce more consistent, higher quality DDGS which will better serve the needs of livestock producers. The sale of DDGS and the other co-products has been one key to the industry's success so far, and will continue to be important to the long-term sustainability of the industry. Although the majority of DDGS is currently consumed by beef and dairy cattle, use in monogastric diets, especially swine and poultry, continues to increase. And use in non-traditional species, such as fish, horses, and pets have been increasing as well. [8]

Additionally, there has been considerable interest in developing improved mechanisms for delivering and feeding DDGS to livestock vis-à-vis pelleting/densification (Figure 4). This is a processing operation that could result in significantly better storage and handling characteristics of the DDGS, and it would drastically lower the cost of rail transportation and logistics. Pelleting could also broaden the use of DDGS domestically (e.g., improved ability to use DDGS for rangeland beef cattle feeding and dairy cattle feeding) as well as globally (e.g., increased bulk density would result in considerable freight savings in bulk vessels and containers).[8]There are also many new developments underway in terms of evolving co-products. These will ultimately result in more value streams from the corn kernel (i.e., upstream fractionation) as well as the resulting distillers grains (i.e., downstream fractionation). Effective fractionation can result in the separation of high-, mid-, and low-value components. Many plants have begun adding capabilities to concentrate nutrient streams such as oil, protein, and fiber into specific fractions, which can then be used for targeted markets and specific uses. These new processes are resulting in new types of distiller's grains.[9]

FIGURE 4.
Pelleting is a unit operation that can improve the utility of DDGS, because it improves storage and handling characteristics, and allows more effective use in dairy cattle feeding and range land settings for beef cattle.

For example, if the lipids are removed from the DDGS (Figure 5), they can readily be converted into biodiesel, although they cannot be used for food grade corn oil, because they are too degraded structurally. Another example is concentrated proteins, which can be used for high-value animal feeds (such as aquaculture or pet foods), or other feed applications which require high protein levels. Additionally, DDGS proteins can be used in human foods (Figure 6). Furthermore, other components, such as amino acids, organic acids, or even nutraceutical compounds (such as phytosterols and tycopherols) can be harvested and used in high-value applications.[10]
Mid-value components, such as fiber, can be used as biofillers for plastic composites (Figure 7), as feed stocks for the production of bioenergy (e.g., heat and electricity at the ethanol plant via thermochemical conversion) or, after pretreatment to break down the lignocellulosic structures, as substrates for the further production of ethanol or other biofuels.[11]
In terms of potential uses for the low-value components, hopefully mechanisms will be developed to alter their structures and render them useful, so that they will not have to be landfilled. Fertilizers are necessary in order to sustainably maintain the flow of corn grain into the ethanol plant, so land application may be an appropriate venue for the low value components.As these process modifications are developed, validated, and commercially implemented, improvements in the generated co-products will be realized and unique materials will be produced. Of course, these new products will require extensive investigation in order to determine how to optimally use them and to quantify their value propositions in the marketplace.[12]

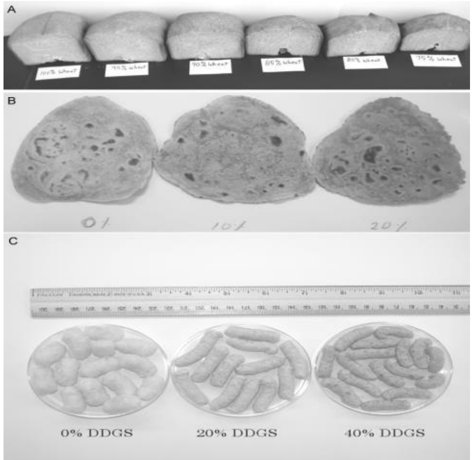

FIGURE 5.
Corn oil which has been extracted from DDGS can be used to manufacture biodiesel

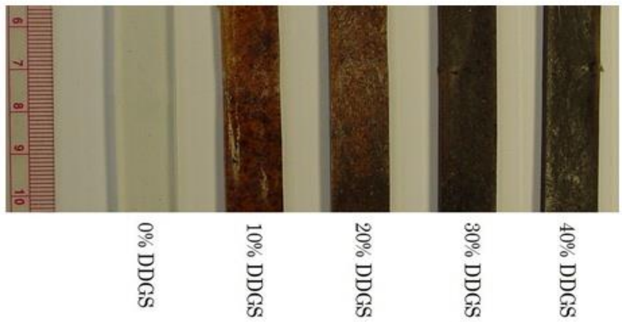

FIGURE 6.

Mid-value or low-value fractions from DDGS (such as fiber) have been shown to be an effective filler in plastics, replacing petroleum additives and increasing biodegradability. Scale bar indicates mm.

FIGURE 7.

Mid-value or low-value fractions from DDGS (such as fiber) can be thermochemically converted into biochar, which can subsequently be used to produce energy, fertilizer, or as a precursor to other bio-based materials.

4. CONCLUSION

The fuel ethanol industry has been rapidly expanding in recent years in response to government mandates, but also due to increased demand for alternative fuels. This has become especially true as the price of gasoline has escalated and fluctuated so drastically, and the consumer has begun to perceive fuel prices as problematic. Corn-based ethanol is not the entire solution to our transportation fuel needs. But it is clearly a key component to the overall goal of energy independence. Corn ethanol will continue to play a leading role in the emerging bioeconomy, as it has proven the effectiveness of industrial-scale biotechnology and bioprocessing for the production of fuel. And it has set the stage for advanced bio-refineries and manufacturing techniques that will produce the next several generations of advanced biofuels. As the biofuel industry continues to evolve, co-product materials (which ultimately may take a variety of forms, from a variety of biomass substrates) will remain a cornerstone to resource and economic sustainability. A promising mechanism to achieve sustainability will entail integrated systems, where material and energy streams cycle and recycle (i.e., upstream outputs become downstream inputs) between various components of a bio-refinery, animal feeding operation, energy (i.e., heat, electricity, steam, etc.) production system, feedstock production system, and other systems. By integrating these various components, a diversified portfolio will not only produce fuel, but also fertilizer, feed, food, industrial products, energy, and most importantly, will be self-sustaining. [2]

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