# SUBSTITUTION OF TRADITIONAL ANIMAL FEED WITH CO-PRODUCTS OF BIOFUEL PRODUCTION: ECONOMIC, LAND-USE AND GHG EMISSIONS IMPLICATIONS

# A hagyományos takarmány helyettesítése a bioüzemanyagipar melléktermékeivel: gazdasági, földhasználati és környezeti hatások

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## Abstract

Growth in biofuel production has been accompanied by increased output of animal feed co-products from common biofuel processes. Co-product generation in early biofuel impact assessments was ignored leading to an overestimation of land requirements and GHG emissions. The output of feed co-products is relatively high in the USA and the EU due to the large share of grains used in ethanol production with high feed yields. Co-product yields are low for rapeseed and soybean used in the biodiesel industry. The ethanol industry in the U.S. and EU produces about 43 million metric tonnes of high-quality feed, however, the co-products of biodiesel production have a moderate impact on the feed market contributing to just 41 million tonnes of protein meal output a year. By economically displacing traditional feed ingredients co-products from biofuel production are an important and valuable component of the biofuels sector and the global feed market. Moreover, the return of co-products to the feed market has economic, land use and GHG emissions implications as well. The prospect of advanced biofuels is also analysed in this chapter. Giant reed is considered as a potential feedstock for advanced biofuels, however the advanced biofuels industry faces several challenges today including regulatory uncertainty.

**Keywords:** bioenergy, biofuels, co-products, feed potential, land use
**JEL codes:** Q41, Q42, Q43

## Összefoglalás

A globális bioüzemanyag-előállítás exponenciálisan emelkedett az elmúlt évtizedben, mert egyrészt számos országban bevezették a bioüzemanyag kötelező felhasználásának szabályozását, másrészt folyamatosan nőtt a kereslet az alternatív üzemanyagok iránt. Ehhez hozzájárult még az enegiárak drasztikus fluktuációja, ráadásul a növekvő olajáraknál előtérbe került az energiabiztonság kérdése. A bioüzemanyagok még hosszú ideig a hagyományos folyékony motorhajtóanyagokba bekeverve azok kiegészítői, nem pedig versenytársai lesznek. Az élelmiszer-növényekre alapozott bioüzemanyag-előáállítás csupán átmenet a nem élelmezési célú biomassza alapú bioüzemanyag termeléshez. A jövőben nyersanyagként elsősorban a cellulóztartalmú mezőgazdasági melléktermékek – szalma, kukoricaszár, erdészeti, faipari hulladék – felhasználása jöhet szóba a lágy- és fásszárú növények mellett, habár az új technológia piaci bevezetése még várat magára. A növekvő bioüzemanyag-előállítással párhuzamosan a melléktermékek (ikertermékek) egyre inkább hozzájárulnak a gazdasági és környezeti fenntarthatósághoz. Ma a számítások még alábecsülik a melléktermékek szerepét a nettó földhasználat és ÜHG-kibocsátás alakulásában. Mivel a felhasznált nyersanyag egy része takarmányként visszakerül az állattenyésztéshez, az energianövények nettó földhasználata és nettó ÜHG-kibocsátása csökken.

**Kulcszsavak:** bioenergia, bioüzemanyagok, melléktermék, takarmány, földhasználat

## Introduction

Energy consumption is still increasing rapidly, with an approximate 540 EJ consumed at the primary energy level in 2011. Of this total 78.3% was provided by fossil fuels, 2.5% from nuclear and about 19.2% from renewables (Figure 1). Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources. The bioenergy sector is relatively complex because there are many forms of biomass resources; various solid, liquid, and gaseous bioenergy carriers; and numerous routes available for their conversion to useful energy services. Biomass is the source of bioenergy and can be used to produce renewable electricity, thermal energy, or transportation biofuels. In the last 35 years global energy supplies have nearly doubled but the relative contribution from renewables has increased from 13% to 19.2%, including about 8.9% from traditional biomass and about 10.2% from modern renewables (Figure 1). The contribution of "modern" renewables (e.g., solar, wind, biofuel) is still a marginal component of total global renewable energy supply, however, they are continuously growing. Traditional biomass is already a major source of energy in developing countries, primarily for heating and cooking in rural areas. The future trends in developing countries continue with a shift away from traditional biomass cookstoves to more modern forms of stoves and fuels, including efficient biomass cookstoves and stoves that burn biogas or biofuels. The "traditional" share of biomass has been relatively stable for many years, while the "modern" share has grown since the late 1990s.

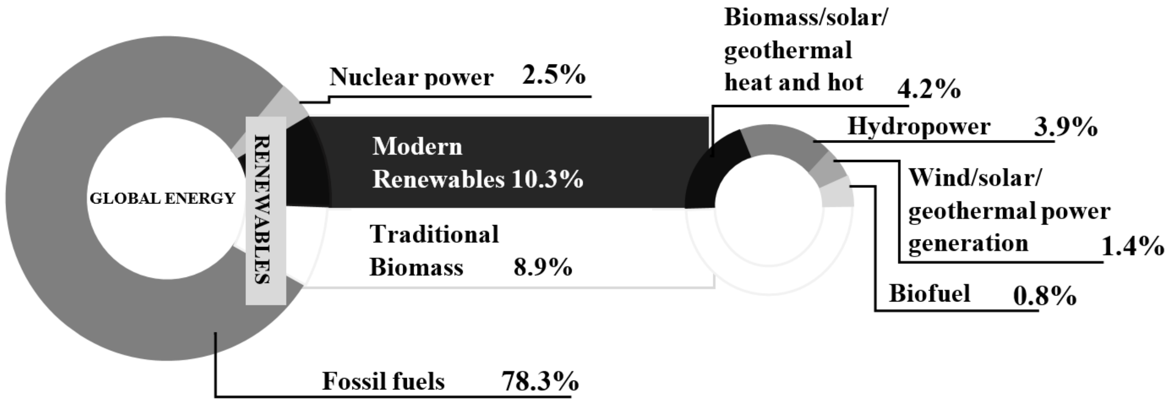

Figure 1. **Estimated renewable energy share of global final energy consumption in 2014.** Source: REN21, 2016

Most capacity expansion and financing need is expected for next generation biofuels in the longer term and strong competition from other renewable energy projects with lower risks (wind and solar) can be experienced. Liquid biofuels for transport are generating the most attention, although only a small fraction of biomass is used globally for biofuels production at present (POPP et al. 2016). The transport sector is responsible for about 20% of world primary energy demand. Transport biofuels are currently the fastest growing bioenergy sectors even they represent around 3-4% of total road transport fuel and only 7% of total bioenergy consumption today. Favourable market conditions and renewable energy policies have led to large increases in biofuel use globally. Demand for biofuels in the transportation sector was mostly driven by blending mandates in the main biofuels producing countries. Since 2006 prices of traditional transportation fuels have moderated to a point where policies mandating biofuel production and consumption have become critical to the market for renewable fuels (BECKMAN, 2015). In 2040 the share of biofuels in road transport fuels would range – depending on policies – from 5% to 18% globally, from 11% to 31% in the European Union and from 11% to 29% in the United States (IEA, 2015).

Liquid biofuels continue to make a small but growing contribution to transport fuel demand worldwide, currently providing about 3-4% of global road transport fuels and around 7% (3.5 EJ/year) of bioenergy. Still small but increasing use in the aviation and marine sectors can be experienced. At present around 80% of the global production of liquid biofuels is in the form of ethanol. In 2015 on average global fuel ethanol production reached 116 billion litres and global biodiesel production amounted to 31 billion litres (Figures 2 and 3). The two world's top ethanol producers, the United States and Brazil, accounted for around 75% of total production. Global expansion of biofuel production is projected to continue during the next decade, although at a slower pace than over the last half decade. Global ethanol production is expected to expand modestly from 116 billion litres in 2015 to 128 billion litres by 2025. Most of the additional ethanol production is expected to take place in Brazil and Thailand. The U.S. is projected to remain the major ethanol producer and exporter, followed by Brazil and the EU.

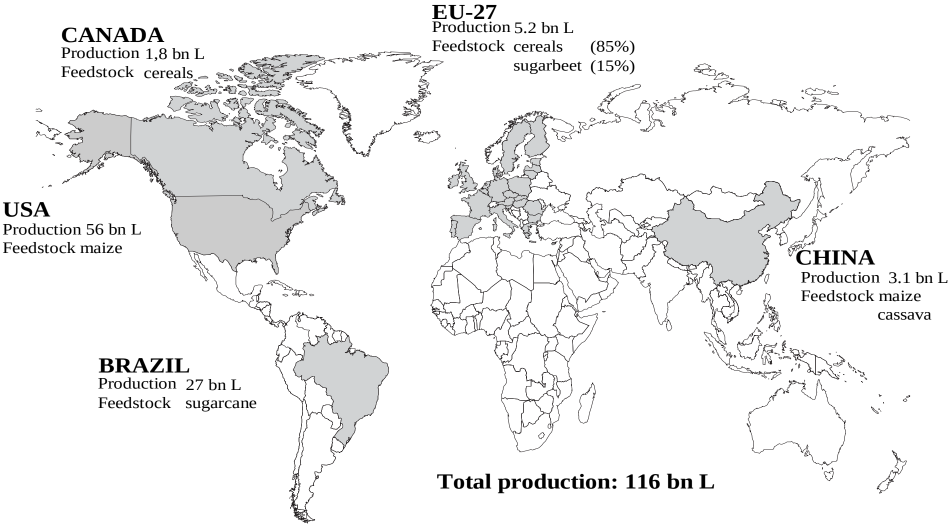

Figure 2: **Word fuel ethanol production, 2015**
Source: OECD/FAO, 2016; RFA, 2016

Global biodiesel production is expected to increase from 31 billion litres in 2015 to 41 billion litres by 2025. The expansion of global biodiesel production will be driven by biofuels policies in place in the USA, EU, Argentina, Brazil and Indonesia. Biodiesel production is far less concentrated than ethanol. The European Union remained the centre of global biodiesel production, with 12.5 billion litres in 2015 representing roughly 40% of total output, followed by the U.S. and Brazil with 5.3 and 4.1 billion litres biodiesel output, respectively (Figure 3). The EU will remain to be the major producer of biodiesel and other significant players are the U.S., Brazil, Argentina and Indonesia.

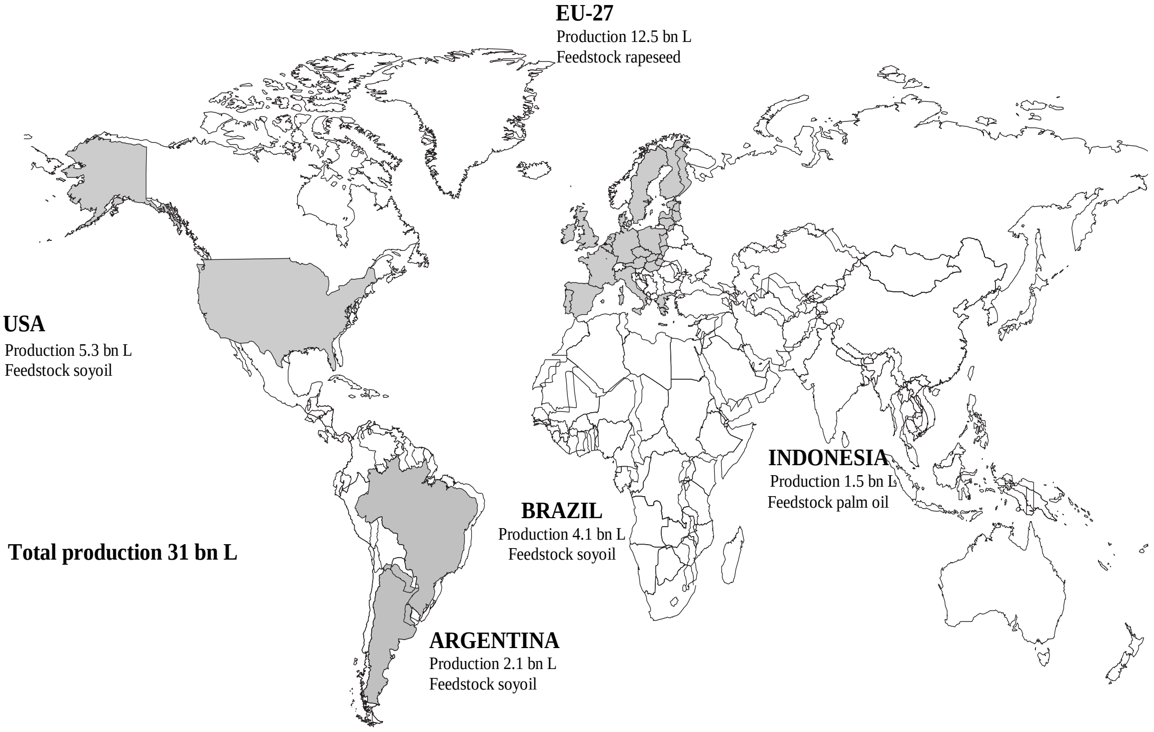

Figure 3: **Word biodiesel production, 2015**
Source: OECD/FAO, 2016; STATISTA, 2016

World ethanol and biodiesel prices continued to decrease in nominal terms in 2015 due to weak crude oil and biofuel feedstock prices. However, in conjunction with the evolution of crude oil prices, the world ethanol price is projected to increase by 33% and biodiesel prices by 22% in nominal terms by 2025. Biofuel trade will remain limited around 5-6% of global production. Mandated biofuel consumption and market conditions in the United States and Brazil spurred trade in biofuels between these two countries. In the face of higher sugar prices, Brazil substantially increased its (maize) ethanol imports from the United States. The EU, China, Japan and Canada are the major ethanol importers. Biodiesel trade will be mostly directed from Argentina to the U.S. in order to meet the biodiesel mandates and remain limited in the rest of the world because of high duties in place. The current weak energy prices prevent investment in research and development for advanced biofuels produced from lignocellulosic biomass, waste or non-food feedstock. Most of the biofuels to be produced in the next decade will be produced out of agricultural feedstock. Biofuel production will have direct or indirect effects on the environment, on land use and to a certain extent on agricultural markets in the medium term. Revisions to biofuel policies are likely to take this into account and may contain more stringent sustainability criteria (OECD/FAO, 2016; USDA 2016). Global production of biofuel is projected to continue to increase during the next decade, although at a slower pace than over the last half decade. This slowdown in part reflects lower crude oil prices. As a result, demand for biofuel feedstocks will grow more slowly.

Coarse grains, sugarcane and molasses (in India) will remain the dominant ethanol feedstock and vegetable oil the feedstock in biodiesel production. Almost all U.S. production of ethanol uses corn as a feedstock. Even with the U.S. ethanol production decline, demand for maize to produce ethanol continues to have a strong presence in the sector, it accounts for over a third of total U.S. maize use throughout the period of 2015-2025. By 2025, 22% of global sugarcane and 10-11% of global coarse grains production is expected to be used to produce ethanol. Lignocellulosic biomass based ethanol is projected to account for less than 1% of world ethanol production. Biodiesel production is projected to consume 12% of global vegetable oil production and the use of non-agricultural feedstock and in particular waste oil and tallow will develop in the EU and the United States (OECD/FAO 2016; USDA 2016).

## Animal feed produced from the ethanol and biodiesel industry

Growth in biofuel production has been accompanied by increased output of animal feed co-products from common biofuel processes. Globally, these feed co-products are growing in volume and importance. The output of feed co-products is relatively high in the USA and the EU due to the large share of grains used in ethanol production with high feed yields. It is low in Brazil where ethanol production is dominated by sugarcane which generates no feed co-products.

Both the wet and dry mill processes in ethanol production utilize only the starch portion of the corn kernel for ethanol production. The remaining protein, fat, fiber and other nutritional components remain available for use as animal feed. In distillers dried grains with solubles (DDGS) or distillers dried grains (DDG), these remaining nutritional components from the corn kernel are essentially concentrated by a factor of three, meaning typical distillers grains have at least three times as much protein and fat as an equivalent amount of corn. If the distillers grains are being fed to livestock in close proximity to the ethanol plant, the drying step can be avoided and the product is called wet distillers grains (WDG). Dry mills have the capability to extract corn oil, which is then sold as an individual feed ingredient or as a feedstock for biodiesel production. Another co-product from the ethanol production process is CO2, which is used to carbonate beverages and make dry ice. In the wet milling process corn oil from the germ is either extracted on-site or sold to crushers who extract the corn oil. The remaining fiber, gluten and starch components are further segregated and sold as corn gluten feed (CGF) or corn gluten meal (CGM). The remaining starch can then be processed in one of three ways: fermented into ethanol, dried or modified corn starch, or processed into corn syrup.

The U.S. ethanol industry’s primary market for distillers grains has historically been as a commodity livestock feed ingredient. Most often this has been in the form of DDGS, and in recent years in the form of DWG. Using ethanol co-products for livestock feed or feed supplements have become effective methods for using these materials. Co-products contain appropriate nutrients and they are highly digestible (depending on the species). Since these co-products are primarily used as animal feed ingredients, monitoring and maintaining the consistency of co-product compositions is critical to sales and utilization. DDGS from U.S. fuel ethanol plants typically contains about 30% protein, 10% fat, at least 40% neutral detergent fibre, and up to 12% starch. DDGS composition can vary somewhat between plants. Within a single plant over time, however, DDGS is much less variable than amongst plants. Furthermore, use of co-products in animal feeds (in place of corn grain) will actually help offset corn which has been used for ethanol production (the so-called food vs. fuel debate). In fact, it has been shown that DDGS can replace corn in livestock diets on a 1:1 up to a 1:1.2 level, depending on the species. The majority (over 80%) of U.S. distillers coproducts are used in beef and dairy feeds, because ruminants can use high levels of fibre. As feed ingredient prices have increased in recent years, coupled with increasing knowledge about how to effectively use these feed ingredients, ethanol co-product use in swine and poultry diets have increased in recent years. Depending on the diet composition used, all livestock

species have been shown to thrive at 10% DDGS inclusion, and most can tolerate levels up to and even greater than 20%. Many feeding trials have been conducted on co-products in livestock diets over the years, for both monogastric and ruminant feeds (LIU et al. 2016).
DDGS use in livestock diets has continued to increase over the years. Various predictions of peak potential DDGS use in domestic U.S. beef, dairy, swine, and poultry markets have estimated that 60 million tonnes could be used in the U.S. each year, depending upon inclusion rates, age, etc., for each species. Around the world, the need for protein-based animal feeds continues to grow, and DDGS has become a global commodity. The potential for global exports is projected to increase for the future. In recent years, China has become the dominant global importer of DDGS. The U.S. ethanol industry makes an enormous contribution to the global animal feed supply. One-third of every bushel of grain that enters the ethanol process is enhanced and returned to the feed market, most often in the form of distillers grains (DDGS), corn gluten feed and corn gluten meal. Only the starch portion of the grain is made into ethanol, the remaining protein, fat and fiber pass through the process. In 2015, ethanol biorefineries produced approximately 40 million metric tonnes of high-quality feed, namely distillers grains (90%), gluten feed and gluten meal. Ethanol co-products are fed to beef cattle, dairy cows, swine, poultry, and fish around the world. Feed co-products represent an increasingly important share of profit opportunities for ethanol producers as well (RFA, 2016).

Over the past decade, the ethanol industry has also emerged as a major producer of corn distillers oil (CDO), which is used as an animal feed ingredient or feedstock for biodiesel production. In 2015, approximately 85% of dry mills were extracting oil, and it is estimated that more than 1.2 million tonnes of CDO were produced. Exports of distillers grains surged to record levels in 2015, at approximately 12.6 million metric tonnes, 11% higher than in 2014. Nearly one-third of total distillers grains production in 2015 was exported. Increases in ethanol co-product exports are supplementing corn export levels, meaning total exports of corn and corn products continue to trend upward. Internationally distillers grains are gaining widespread acceptance as a high quality livestock feed component. These markets are particularly important to the U.S. as domestic co-products markets near saturation. China – the largest customer – was the cornerstone of international market expansion in 2015, receiving over half of all U.S. shipments. Mexico was the second-leading market for exports, followed by Vietnam, South Korea, Canada and Thailand (RFA, 2016).

The ethanol industry continues to develop new, valued-added materials from the corn kernels as well as from the co-product materials resulting in more products from the corn kernel itself (an approach known as upstream fractionation) and the distillers grains (known as downstream fractionation). These types of fractionation approaches can result in the separation of components of high, medium, and low value. For example, several mechanical and chemical approaches have been developed to remove protein, fibre, or oil components from the endosperm (which contains the starch). This type of separation will allow a highly-concentrated starch substrate to be introduced to the fermentation process, and will allow the other corn kernel components to be used for human food or other high-value applications.
Many plants have recently begun adding capabilities to concentrate nutrient streams such as oil, protein, and fibre into specific fractions, which can then be used for targeted markets and specific uses. For example, fibre is separated from the DDGS and used as a feedstock for cellulosic ethanol production. Additionally, many companies have begun removing oil from the whole stillage and/or CDS streams. This oil, which is officially known as Distillers Oil, Feed Grade can readily be converted into biodiesel or animal feed ingredients, but they cannot be used for food grade corn oil, because they are too degraded. In fact, more than 85% of U.S.

ethanol plants are now removing oil, because the economics are so favourable. In 2010 almost no ethanol plants were extracting oil and the rapid increase has solely been due to added value streams for the ethanol plants. On the horizon is concentrated corn 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 (such as monogastrics or younger animals). As these process modifications are developed, tested, and implemented at commercial facilities, improvements in co-products will be realized and increasingly used in the marketplace. These new products will require extensive investigation in order to determine how to optimally use them and to quantify their values in the marketplace.

In the EU, the required feedstock for bioethanol production is estimated at 10 million metric tonnes of cereals and 11 million metric tonnes of sugar beets accounting for about 3% of total EU cereal production and about 9% of total sugar beet production. In 2014 around 3.3 million tonnes of highly valuable animal feed (DDG, wheat gluten and yeast concentrates) was produced in the EU, which displaced nearly 10% of soybean and soybean meal imports by volume. However, by generating high-protein animal feed as a co-product of ethanol reduces the need for farmers to use imported animal feed, such as soya. For every tonne of cereals used by the ethanol industry as much animal feed is produced as ethanol. Reducing imports of animal feed improves environmental footprint in the EU and helps reduce land conversion and GHG emissions resulting from agricultural land use outside of Europe (ePURE, 2015).

Ethanol producers make both fuel and feed. Only the starch in the grain feedstock is converted to ethanol, while 100% of protein, fat, and fiber remain available to the feed market in the form of distillers grains or other co-products. Co-products from grain ethanol production are an increasingly important and valuable component of the biofuels sector and the global feed market. The ethanol industry in the U.S and the EU produces an estimated 43 million metric tonnes of feed, including distillers grains (90%) and gluten feed and gluten meal. The demand for protein is increasing and not for carbohydrates. Furthermore, using grain for ethanol has absolutely no impact on global protein supplies.

The main components used to make biodiesel are rapeseed and soybean oil. An estimated 80% of soybean seed 60% of rapeseed is left from the extraction process as seed meal. About 7 million tonnes of soybean oil and 9 million tonnes of rapeseed oil is used in biodiesel production contributing to almost 28 million tonnes of soybean meal 13 million tonnes of rapeseed meal output (IEA, 2015). Out of this 9 million tonnes or 70% was produced in the EU. Taking into consideration that 210 million tonnes of soymeal and 40 million tonnes of rapeseed meal is produced a year globally, the co-products of biodiesel production have a moderate impact on the feed market (POPP et al. 2016). The EU is the most important global biodiesel and seed meal producer. A significant share of domestically produced biodiesel feedstock is crushed from imported oilseeds (soybeans and rapeseed). The 6 million tonnes of rapeseed oil feedstock used for biodiesel production is equivalent to about 15 million tonnes of rapeseed. This also generates about 9 million tonnes of rapeseed meal as co-product, most of which is used for animal feed. Similarly, the 0.9 million tonnes of soybean oil has to be crushed from 4.3 million tonnes of soybeans generating about 3.4 million tonnes of soybean meal as co-product. In addition, about 0.8 million tonnes of sunflower is also used for biodiesel production with a co-production of 0.5 million tonnes of sunflower meal (USDA, 2015). The share of oilseed meals as feed material in the compound feed industry reached 42 million tonnes in 2014 and the contribution of the biodiesel industry accounted for over 30% (FEFAC, 2015).

### *Economic and environmental implications*

Growth in biofuel production has been accompanied by increased output of animal feed co-products from common biofuel processes. Globally, these feed co-products are growing in volume and importance. Estimates on impacts of biofuel production often use models with limited ability to incorporate economic and environmental implications by ignoring generation of co-products from biofuel production. Co-product generation in early biofuel impact assessments was ignored leading to an overestimation of land requirements and GHG emissions. The output of feed co-products is relatively high in the USA and the EU due to the large share of grains used in ethanol production with high feed yields. It is low in Brazil where ethanol production is dominated by sugarcane which generates no feed co-products. Co-product yields are low for rapeseed and soybean used in the biodiesel industry. By economically displacing traditional feed ingredients co-products from biofuel production are an important and valuable component of the biofuels sector and the global feed market. Moreover, the return of co-products to the feed market has economic, land use and GHG emissions implications as well. Models used to evaluate biofuel policies should be enriched by incorporating more and better information on changes in land use, and economic and environmental implications of co-products.

Though some experts associated the unprecedented price spikes in food grain and oilseed in 2007/2008 with these countries' biofuels policies (DE GORTER – DRABIK 2012a; DE GORTER – DRABIK 2012b, DE GORTER et al. 2013), most of them now agree that these policies are unlikely to have been the main culprit, although they may have been a factor emphasizing that biofuel policy is only responsible for part of that fraction of price increases in food grain commodities that is due to biofuels (DURHAM et al. 2012) . Another study estimates that the impact of EU biofuels demand from 2000 until 2010 has increased world grain prices by about 1%-2% and oilseed prices by around 4%. It also estimates that without any cap on crop-based biofuels, EU policy could raise grain prices by 1%, and oilseed prices by 10% by 2020 (HAMELINCK, 2013). Increasing the productivity of current and emerging bioenergy crops per unit land area is not only critical to economic viability, but also to biodiversity by minimizing the total land area needed. Land sparing is found far more effective than land sharing in strategies to realize bioenergy. Maize ethanol, often portrayed as the villain of the piece in the food *versus* fuel debate, may in fact have been key in stimulating yield improvement, including through genetically modified (GM) traits, that has resulted in increased exports of grain from the USA while providing a buffer in drought years

Co-products are important to the ethanol industry for a number of reasons. First and foremost, co-products are additional sources of revenue to ethanol plants. The sale of nonfermentable co-products is critical to the fuel ethanol industry as a source of revenue; and these materials have also become important feed ingredients to the livestock industry over the last decade. Sales of dry and wet distillers co-products generally translates into 10 to 20% of an ethanol plant's total revenues, and can even be as high as 40% (depending on the economics). These materials really are "co-products", not "by-products" or "waste materials". The prices of corn and DDGS have generally paralleled each other fairly well over the years. This trend occurs due, in large part, to the fact that DDGS is often used to replace corn in livestock diets. In the last decade, DDGS has increasingly been used as a soybean meal replacement also. Because soybean meal has a higher protein content, DDGS is often sold at a lower price compared to either corn or soybean meal. This has been true volumetrically as well as per unit protein. For some years in the early 2010s DDGS has actually been sold at more than 100% the value of corn. This is frequently due to external impacts on the marketplace, including international exports (USDA, 2016).

DDGS and corn prices are highly correlated, and their correlation has strengthened in recent years. Soy and rapeseed meals have always been a major component of animal feeds, because they are excellent sources of protein. Prices of co-products are highly correlated with prices of feedstocks, such as grains and oilseeds and they represent an important component of total industry revenues. As a result, co-products prices fall relative to other feed ingredients. This encourages livestock producers to use more biofuel co-products in their production processes. On the other hand, any reduction in the prices of co-products diminishes total revenue and acts as a brake on growth of the biofuel industry. Biofuel co-products function as both a shock absorber and a price adjuster (TAHERIPOUR et al. 2010). Between 1983 and 2006 the price of DDGS relative to maize has fallen by nearly 50%. This has provided a strong incentive for livestock producers to use more DDGS in their production process and has also enhanced US exports of DDGS (TAHERIPOUR et al. 2010). The ratio of the average price of DDGS to the average price of maize reported for Iowa plants from 2007 through March 2015 ranged from 0.67 to 1.48 and averaged 0.91 for the entire period (IRWIN – GOOD, 2015). Further, the relative contribution of distillers' grains to gross returns has varied over time as the price of DDGS has varied.

Changes in land use, principally those associated with deforestation and expansion of agricultural production for food, contribute about 15% of global emissions of GHG. Currently, less than 3% of global agricultural land is used for cultivating biofuel crops and land use change associated with bioenergy represents only around 1% of the total emissions caused by land-use change globally most of which are produced by changes in land use for food and fodder production, or other reasons (EU, 2009). Indirect land-use changes, however, are more difficult to identify and model explicitly in GHG balances. Most current biofuel production systems have significant reductions in GHG emissions relative to the fossil fuels displaced, if no indirect land use change (ILUC) effects are considered.

In the EU, the biofuels policy is determined by the 2009 Renewable Energy Directive (RED), which states that renewable fuels (including non-liquids) should increase to 10% of total transport fuel use by 2020 on an energy equivalent basis, and by the Fuel Quality Directive (FQD), which requires fuel producers to reduce the GHG intensity of transport fuels by 6 % by 2020 and also regulates the sustainability of biofuels. Both directives (RED, FQD) were amended in September 2015 by a new Directive referred as the "Indirect Land Use Changes" (ILUC) Directive that introduced a 7% cap on renewable energy in the transport sector coming from food and feed crops (EU, 2015). Member States were given an indicative target value of 0.5% for the share of advanced biofuels consumed in transport in 2020. The EU biofuels industry believes the emphasis on the production of advanced biofuels from waste feedstocks will increase uncertainties and further constrain biofuels production in Europe. According to the European Biofuels Technology Platform (EBTP), the ILUC debate has caused many uncertainties and blocked many investment decisions for the past three years. Furthermore, the non-binding and double counted advanced biofuels target of 0.5% is not ambitious enough to foster the deployment of advanced biofuels (EBTP, 2015).

The Energy Policy Act of 2005 originated the Renewable Fuel Standard (RFS) program, which initially mandated 4.0 billion gallons of renewable fuel to be blended into gasoline in 2006, growing to 7.5 billion gallons in 2012. The scope of the RFS was expanded and extended in the Energy Independence and Security Act (EISA) of 2007. The new mandates include 18.15 billion gallons of renewable fuel use in U.S. transportation fuel in 2014, growing to 36 billion gallons in 2022. The Environmental Protection Agency (EPA) provided on an annual basis the minimum quantities for each of the four classes of biofuels required. However, the mandates specified by the EPA in 2015 are considerably lower than the initial levels proposed in 2007. By 2022, due to several factors the total mandate should be 50% lower than what was initially specified in EISA of 2007. EISA established four quantitative annual mandates up to 2022: the total and advanced mandates that require fuels to achieve respectively at least a 20% and a 50% GHG reduction as well as the biodiesel and the cellulosic mandates that are nested within the advanced mandate. The advanced mandate is assumed to expand in the next decade, given lower gasoline use prospects and the restricted availability of blends going behind the 10% blend wall, the implied corn based ethanol mandate is projected to decline after 2018. Biodiesel mandate will rise because biodiesel like sugarcane based ethanol qualifies for the advanced mandate (USDA, 2016).

The advanced mandates are defined by eligible feedstock types and lifecycle GHG emission reductions. Biofuel that does not qualify for these specific mandates can still count toward the overall RFS. The potential annual amounts of biofuel in this last category are not specified explicitly in EISA, but are derived as the residual from the total RFS and the advanced biofuel mandates. This residual category is frequently referred to as the “non-advanced” mandate or the “conventional” mandate and has typically been met with corn-starch based ethanol. Argentinean soybean oil based biodiesel is certified to meet the biodiesel and advanced mandates. The need for sugarcane based ethanol imports to fill the advanced gap is expected to decrease in the next years. By 2025 only about 2% of the cellulosic mandate specified by EISA will be filled (USDA, 2016).

Biofuel co-products help mitigate the environmental consequences of expansion by the biofuel industry. Co-products are supposed to be credited with the area of cropland required to produce the amount of feed they substitute. If co-products are taken into account, the net use of feedstocks decline. By adding co-products substituted for grains and oilseeds the land required for cultivation of feedstocks declines from about 2% to 1.5% net land requirement of the global crop area. Moreover, it is important to include the co-products in GHG assessment, because of their potential impact on the overall emissions. Most existing biofuel regulations significantly undervalue the contribution of co-products when assessing the net land use and GHG impacts of biofuel production. In the future accurate co-products accounting is of increasing importance. The future use of agricultural crops for biofuel resulting in a small increase in livestock feed costs, which will be offset to some extent by the use of co-products as feed and by increases in crop yields over time. Feed co-product output is expected to grow more slowly in the coming years. However, a number of new and emerging technologies may change the composition and further improve the nutritional quality and utility of feed co-products. New technologies and practices promise to change the complexion of the ethanol co-products market in the years ahead (POPP et al. 2016).

## Advanced biofuels

Growth in the use of agricultural commodities for biofuels is expected to continue through to 2020, but growth rates will slow in key producing countries as government-imposed limits on grain use for biofuels are reached and advanced biofuels capacity is expected to expand only slowly. The second reason for moderation in the growth in the use of agricultural commodities for biofuels is the expectation that future growth in biofuels production will primarily come from new feedstocks that currently have no or limited application in the animal feed market, such as perennial grasses, agricultural residues, algae and other materials.

However, advanced biofuels capacity is expected to expand only slowly, though the first commercial-scale plants in the United States, Brazil and Europe were recently commissioned. There is no commonly agreed upon set of criteria used to define advanced biofuels. Advanced biofuels include cellulosic ethanol, butanol, methanol, and dimethyl ether (DME), Fischer-Tropsch diesel, drop-in fuels, and biofuels made from algae. Second generation biofuels are commonly agreed to be biofuels derived from non-food feedstocks. In the RED, second generation biofuels get a double credit. This means that biofuels made out of lignocellulosic, non-food cellulosic, waste and residue materials will count double towards the 10% target for renewable energy in transport in 2020. Furthermore, a 0.5% non-binding Member State target was set for advanced biofuels in 2020. Through Ministerial Decree of October 10, 2014, Italy was the first EU Member State to mandate the use of advanced biofuel. The Italian Decree requires gasoline and diesel to contain at least 1.2% of advanced biofuel as of January 2018, rising to 2% by 2022. With the goal to support the commercialization of advanced biofuels and the bio-based economy in general the EC developed several programs since 2012, namely the „Innovating for Sustainable Growth: a Bioeconomy for Europe", the Bio-based Industries Consortium (BIC) and the European Bioeconomy Alliance (EBA). Since the past several years, the production of hydrotreated vegetable oils (HVO) has taken off in the EU, however the commercialization of cellulosic ethanol is lagging behind compared to the development of HVO. Currently there are less a dozen advanced biofuel plants operational at commercial scale in the EU (EC, 2009).

According to OECD projection the blending of first generation biofuels in total gasoline and diesel use expressed in energy terms will remain below the 7% cap at 6,3% by 2020 including advanced biofuel produced from used cooking oil and tallow, which counts double for the purpose of the Directive. Additional progress towards the RED target should be related to the development of other energy sources for transportation including electric cars (OECD/FAO, 2016). Low oil prices and poor margins continue to challenge biofuel producers in Europe. Under current market conditions it is unlikely that the 7% cap will be reached in the EU by 2020. Further market expansion is hampered by the lower fossil fuel use, adjustment of national mandates, and the double counting of biofuels made from non-food inputs. While consumption fell, production took advantage of the low feedstock prices and protective trade measures by the European Commission. Since the past five years, production of biodiesel from waste and animal fats has taken off, while the commercialization of cellulosic ethanol is lagging behind compared to this development. Currently the policy and financial structure is insufficient to support the switch from food based to the production of cellulosic bioethanol. The blending of non-food based ethanol and biodiesel is estimated at respectively 0.2 and 0.7%, combined about 0.6%, and thus already surpassing the non-binding target of 0.5% for second generation biofuels by 2020 (USDA, 2016).

North American advanced biofuel capacity topped 800 million gallons in 2014, almost double the capacity in 2011. By 2017, as many as 180 companies are expected to produce 1.7 billion gallons of advanced biofuel. In 2014 a total of 181 companies were actively working on advanced biofuels in North America, with 167 commercial facilities and nine demonstration facilities either operating, under construction or in advanced planning stages. The majority were multifeedstock biodiesel facilities. Just five of the other, nonbiodiesel, facilities operated at commercial scale. Advanced biofuel is a nonpetroleum liquid fuel that achieves a 50% reduction in carbon intensity compared to a petroleum-fuel baseline, as determined by the EPA and the California Air Resources Board. Nationwide, the private sector has invested $4 billion between 2007 and 2014, and an additional $848 million in grants have been distributed since 2007 (E2, 2015).

For biodiesel, the volume coming from nonvirgin feedstocks was estimated between 512 and 619 million gallons in 2014. The second largest volume of advanced biofuel capacity in 2014 was categorized as drop-in fuel (between 214 million and 216 million gallons), renewable hydrocarbons that can be refined into gasoline, diesel or jet fuel. Cellulosic ethanol capacity reached just 58 million gallons in 2014. The advanced biofuels industry faces several challenges including regulatory instability, feedstock availability, operating and capital costs. Regulatory uncertainty remains a continued challenge, and is likely the cause of the decline in investments since 2012. Companies are working carefully and deliberately to overcome industry challenges. While many companies continue to commercialize with a large biorefinery, other companies are looking at more distributed generation models, which are less capital and feedstock intensive. Algae is well represented among the many technologies being pursued by the advanced biofuels community. A number of companies in the U.S. that are looking to algae for advanced biofuels, including Algae Systems, producing biocrude, Algenol, producing ethanol, Altranex, producing renewable diesel, Aquatech Bioenergy, producing ethanol (E2, 2015).

## ***Giant reed as potential feedstock***

Biofuels from dedicated lignocelluloses energy crops on marginal land is likely to be a cost-efficient contribution. However, extreme territorial and climatic conditions resistant species and varieties are required. Perennial crops may be sustainable because the annual soil cultivation increases the air’s carbon-dioxide level and these plants can mobilize mineral nutrients from the stems and leaves to rhizomes at the end of growing season, reducing the fertilizer needs. These species can rehabilitate the quality of marginal land (ANTAL et al. 2015).

*Arundo donax* L. (common name “giant cane” or “giant reed”) is a perennial, rhizomatous species which has been introduced around the world by humans as an ornamental/crop plant. Giant reed is a sterile plant (not produced any viable seeds), but it can be propagated vegetatively from the rhizome or stems (PILU et al. 2013; BELL 1997). Propagules can be produced also by hydroponic or *in vitro* micropropagation methods (ANTAL et al. 2014). From the second half of the 1990s, giant reed is regarded as one of the most promising plants of the biomass industry due to high biomass production per hectare (PILU et al. 2013). For example in Central Italy, a 12-year field trial without irrigation could produce 38 tonnes dry matter per hectare per average year (ANGELINI et al. 2009) 20 and 20 tonnes dry matter with no fertilization on sandy soil (DI NASSO et al. 2013). For its cultivation low agronomic and energetic input is required (PILU et al. 2013). Giant reed can be cultivated almost in all climatic zones, the cold seems to be limitation factor. Therefore researchers have started to develop cold resistant giant reed varieties (ANTAL et al. 2014; POMPEIANO et al. 2015).

There is increasing commercial demand for giant reed production (PILU et al. 2013; MARIANI et al. 2010). Particularly, it is produced for bioenergy, biogas, biofuels purposes, but also for direct biomass combustion. However, there are limited available data about production of biogas or bio-ethanol from giant reed. According to (SCHIEVANO et al. 2012) giant reed has lower potential production of biogas per dry matter unit, than other traditional energy crops, such as maize, sorghum or triticale. The high biomass productivity of *A. donax* has resulted in higher bio-methane production in comparison in terms of surface area unit per year. SCHIEVANO et al. (2012) reported average 9200 $Nm^3$ $CH_4$ $ha^{-1}$ depending on biomass yield (7170-11280 $Nm^3$ $CH_4$ $ha^{-1}$ under single harvest management). Results of RAGAGLINI et al. (2014) showed that double harvest can increase the methane yield per hectare by 20-35% (in case of one mowing 9580 $Nm^3$ $CH_4$ $ha^{-1}$, two mowing 11585 - 12981 $Nm^3$ $CH_4$ $ha^{-1}$

could be reached). However, CORNO et al. (2014) reported 19440 $Nm^3$ $CH_4$ $ha^{-1}$, from 3 years old giant reed plantation by harvested one time in early October. In case of two mowing during the same year, the total methane production was 9930 $Nm^3$ $CH_4$ $ha^{-1}$, so one harvesting time per year results much higher methane production per hectare. Therefore, bio-methane production from giant reed is depending on environment and agronomics factors and it is also influenced by biomass yield and dry matter content (Table 1).

Table 1. **Potential bio-methane production of Arundo donax L.**

| **References** | **Fresh matter** | **Dry matter content** | **Dry matter (DM)** | **Bio–methane production** | |
|---|---|---|---|---|---|
| | **$Mg\ ha^{-1}$** | **%** | **$Mg\ ha^{-1}$** | **$Nm^3\ CH_4\ ha^{-1}$** | **$Nm^3\ Mg^{-1}\ DM^{-1}$** |
| SCHIEVANO et al. (2012) (one mowing, average minimum biomass yield) | 97 | 36 | 35 | 7 536 | approx. 450 |
| SCHIEVANO et al. (2012) (one mowing, average maximum biomass yield) | 131 | 42 | 55 | 11 843 | approx. 450 |
| CORNO et al. (2014) (one mowing, early October,3 years old plant) | n.d. | 34,5 | 71,8 ± 8,4 | 19 440 | 524 ± 2 |
| CORNO et al. (2014) (first mowing, early June, 3 years old plant) | n.d. | 19,7 | 25,7 ± 5,3 | 9 930 | 495 ± 7 |
| CORNO et al. (2014) (second mowing, early October,3 years old plant) | n.d. | 28,5 | 13,5 ± 1,8 | | 482 ± 7 |
| RAGAGLINI et al. (2014) (one mowing, average data, from 4 harvesting time between June and Sept) | n.d. | 51 | 23–38 | 9 580 | n.d. |
| RAGAGLINI et al. (2014) (two mowing, average data, first harvesting time June and July, second harvesting time October) | n.d. | 39,6 – 46,9 | 17–13 | 11 585 – 12 981 | n.d. |

Source: Authors’ composition based on literature review

The second generation bio-ethanol production is conducted also from lignocellulosic raw materials. Compared to sugar and starch based biomass, lignocellulosic biomass processing is more complex. Due to the resulting recalcitrant materials, pretreatment of raw material is essential to hydrolyze hemicelluloses, removing or arranging lignin structure and converting cellulose structures for following enzymatic hydrolysis. Biological (funghi or special bacteria), physical (grinding or milling), microwave or chemical (with acids or lyes) or physicochemical (steam explosion) pretreatment can be used as well (KOMOLWANICH et al.; 2014, DE BARI et al.; 2013, SCORDIA et al. 2011; SCORDIA et al. 2012). Due to the high biomass per hectare and chemical composition of giant reed large amounts bio-ethanol can be produced (Table 2.). WILLIAMS et al. (2008) and JARADAT (2010) reported same bio-ethanol production (11 000 L $ha^{-1}$) in case of 45 tones $ha^{-1}$ biomass yield. According to CORNO et al. 12 960-15 228 L $ha^{-1}$ bioethanol can be produced, which is higher than reported from other energy crops.

Table 2. **Chemical composition of A. donax**

| References | Hemi–cellulose % | Cellulose % | Lignin % | Ashes % |
|---|---|---|---|---|
| RABEMANOLONTSOA et al. (2013) | 24,2 | 41,6 | 24,9 | 3,2 |
| FRANSCISCO et al. (2010) | 34,8 | 20,9 | 23,0 | n.d. |
| SHATALOV – PEREIRA (2012) | 25,61 ± 0,07 | 33,85 ± 0,06 | 24,02 ± 0,04 | 5,04 ± 0,03 |
| KOMOLWANICH et al. (2014) | 24,4 ± 0,52 | 39,1 ± 0,25 | 19,2 ± 3,25 | 4,2 ± 0,67 |
| CORNO et al. (2014) | 14,5 | 39,6 | 24,3 | 5,3 |
| E SILVA et al. (2015) | 35,27 ± 2,80 | 31,10 ± 1,03 | 18,49 ± 0,10 | n.d. |

Source: Authors' composition based on literature review

## Conclusions

The global biofuel industry has grown exponentially during the last decade in response to government mandates and due to increased demand for alternative fuels. This has become especially pronounced as the prices of fossil fuels have drastically fluctuated. Additionally, energy has become an issue of national security. Biofuel is not the entire solution to transportation fuel needs but it is clearly a key component to addressing energy needs. Food based biofuel is seen by many as a transition to other bio-based fuels in the long run. However, this industrial sector will continue to play a key role in the bioeconomy, as it is a proven approach to large-scale industrial bioprocessing. And as the industry grows, co-products will become increasingly important for economic and environmental sustainability. One way to improve sustainability is to diversify co-products as well as integrate systems, where materials and energy cycle and recycle. For example, upstream outputs become downstream inputs for various components of a biorefinery factory, animal operation, energy production (i.e., heat, electricity, steam, etc.), feedstock operation, and other systems. By integrating these various components, and developing a diversified portfolio (beyond just ethanol, biodiesel and animal feed) the biorefinery will not only produce fuel, but also fertilizer, feed, food, industrial products and energy. Biofuels produced from non-food feedstocks, lignocellulosic feedstocks are developing slowly due to several challenges including regulatory instability, feedstock availability, operating and capital costs. However, giant reed seems to be a potential lignocellulosic feedstock.

Biofuel co-products help mitigate the environmental consequences of expansion by the biofuel industry. Most existing biofuel regulations significantly undervalue the contribution of co-products when assessing the net land use and GHG impacts of biofuel production. In the future accurate co-products accounting is of increasing importance. Co-products are supposed to be credited with the area of cropland required to produce the amount of feed they substitute. If co-products are taken into account, the net use of feedstocks decline. By adding co-products substituted for grains and oilseeds the land required for cultivation of feedstocks declines from about 2% to 1.5% net land requirement of the global crop area. Moreover, it is important to include the co-products in GHG assessment, because of their potential impact on the overall emissions. Feed co-product output is expected to grow more slowly in the coming years. However, a number of new and emerging technologies may change the composition and further improve the nutritional quality and utility of feed co-products.

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