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Biofuel policies for dynamic markets

AGRICULTURAL BY-PRODUCTS ASSOCIATED WITH BIOFUEL PRODUCTION CHAINS

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1. Introduction

The biofuel production process produces, simultaneously and inevitably, the fuel and other products (“by-products”). The type and quantity of by-products strongly depends on the biofuel production chain. By-products include biomass fuels (straw, husks), valuable animal feed (e.g. rape or soymeal), and diverse other materials used in industrial processes (e.g. glycerin).

The economic viability of the biofuel industry depends to a large extent on the ability of the industry to derive value from the biofuel it produces as well as the by-products that are generated during the process. Facilities integrating biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass are key characteristic of biorefineries, which have been identified as the most promising route to the creation of a new biobased industry. By producing multiple products, a biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value, energy content, and environmental benefit derived from the biomass feedstock.

By-products generate credits to the biofuel production chain and thereby greatly improve the energy and environmental performance. When by-products are used for heat and process energy the energy balance improves. Credits for by-products are an important element in the calculation of greenhouse gas (GHG) reductions of the different biofuel production chains compared to fossil fuel use (Edwards et.al 2006). Recently several studies have attempted to include attribution of those by-products, which can be used as animal feed in an analysis of land use requirements of biofuels (Özdemir et.al, 2009; Gallagher Review, 2008).

Especially ‘first generation’ biofuels production chains relying on conventional food and feed crops can produce significant quantities of by-products with a strong impact on the agricultural sector, especially the food and feed industry. First generation biofuels utilize food crops, which compete directly with food and feed production for resources such as land, labour and fertilizer. On the other hand these biofuel production chains generate significant quantities of by-products that can be used as valuable animal feed. Depending on quantities they can for example substitute for imported animal feed and potentially reduce input costs for the farmer and increase European self-sufficiency in agricultural commodities. They may as well exceed the absorption capacity of markets and affect other industries. The role of by-products is a crucial element in the debate on pros and cons of increased first generation biofuel deployment.

The ELOBIO modelling framework (Fischer, 2009) assumes use of all animal feed by-products (protein meals and cakes from crushing of oilseeds and starch-based ethanol) represented as additional input into feed markets. As a result in the biofuels scenarios the amount of required feed crops for the livestock production is lower compared to a ‘no biofuel’ scenario.

2. Bioethanol

The production of ethanol or ethyl alcohol from starch or sugar-based feedstocks is among man's earliest processing of value-added agricultural products. Sugar can be obtained either directly from sugar cane, sugar beet, or sweet sorghum, or derived from the conversion of starch contained in starchy plants, such as cereal grains (e.g. wheat, maize, and barley), millets, and roots and tuber crops (e.g. potato, cassava). While the basic processes for production of ethanol from sugar crops and starchy plants are similar, there are clear advantages in producing ethanol directly from sugar crops because of the additional process required to convert starches into sugar prior to fermentation. The conversion of complex polysaccharides (starch) in the biomass feedstock to simple sugars is a high-temperature process using acids and enzymes as catalyst. Because of this additional step, energy and greenhouse gas balances are mostly more favourable for producing ethanol directly from sugar crops as compared to starchy plants. The energy requirement for converting sugar directly from sugar cane into ethanol is about half that of using maize.

2.1 Ethanol from starchy crops

Starch crops used for biofuel production include cereal grains, millets, roots and tuber crops (potato), and cassava. Worldwide about 72.5 million tons of grains, mainly maize and wheat[1], were used to produce fuel ethanol in 2007. The vast majority of this was maize converted to ethanol in the USA (63 mio. tons). The remainder comprised mainly wheat used in the EU27 and China for ethanol production. In terms of gross grain consumption fuel ethanol represents 4.5% of the total worldwide grain production (compared with roughly 3.3% in 2006).

Starch based ethanol production produces several different by-products depending on the feedstocks used, the production process and where in the production process they are derived. Figure 1 presents an overview of grain based ethanol production including by-products generated during the different processing steps.

When crops are harvested agricultural residues (straw, husks, etc.) are generated as first by-products. Depending on specific local conditions up to half of the residues could potentially be used for heating, biogas production or second generation biofuel technologies without negative affecting soil fertility.

After the complex polysaccharides (starch) in the raw biomass feedstock have been converted to simple sugars (glucose)[2], yeasts or bacteria, which feed on sugar, carry out ethanol fermentation in the absence of oxygen. As yeast ferment the sugar, they release large amounts of carbon dioxide gas. The CO_2 by-product is commonly captured and purified with a scrubber so it can be marketed to the food processing industry for use in carbonated beverages or the production of dry ice.

Today two ethanol production processes are widely employed, wet milling and dry milling. The main difference is the treatment of the grain before fermentation and differences in resulting by-products.

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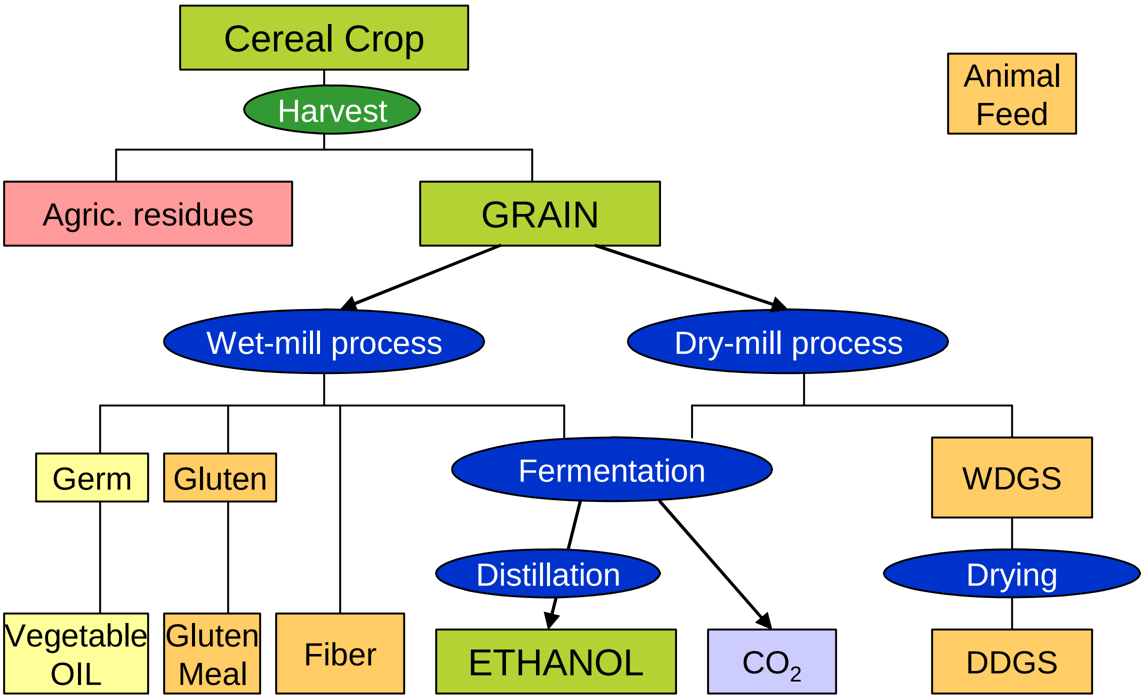
[1] Rye, triticale and pearl millet are currently much less grown cereals but have similar potential for starch to energy conversion as wheat. Cassava (*Manihot esculenta*) is a woody shrub of the Euphorbiaceae native to South America that is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates.

[2] This process is referred to as hydrolysis. It uses acids and enzymes to catalyze this reaction.

Figure 1. Process flow and by-products of ethanol production from starchy crops



2.1.1 Wet-mill ethanol production

The wet mill process soaks the grain kernels in water usually together with sulphurous acid until the components are able to be separated mechanically into its component parts: (i) the starch-rich endosperm; (ii) the high-protein germ and (iii) the high-fiber husks. The starch is extracted for food or industrial uses such as ethanol production. Today the majority of feedstock for wet-mill ethanol production is corn. The corn oil from the germ is either extracted on-site or sold to crushers who extract the corn oil. The gluten component (protein) is filtered and dried to produce the corn gluten meal by-product, which is highly valuable as a feed ingredient in poultry broiler operations. The fiber derived from the husks or corn oil processing is another valuable feed product.

Although wet-mill facilities were common in the industry's early days, dry-mill facilities now account for the majority of industry capacity. Wet milling facility is considered more versatile compared to a dry mill ethanol plant because it yields more by-products. The economies of scale are also lower for dry-mill facilities, which make it easier for farmers to raise the capital and resources to build an ethanol plant. If the objective of building a cereal processing plant is to produce ethanol, it can be done at a lower cost with a dry mill plant.

2.1.2 Dry-mill ethanol production

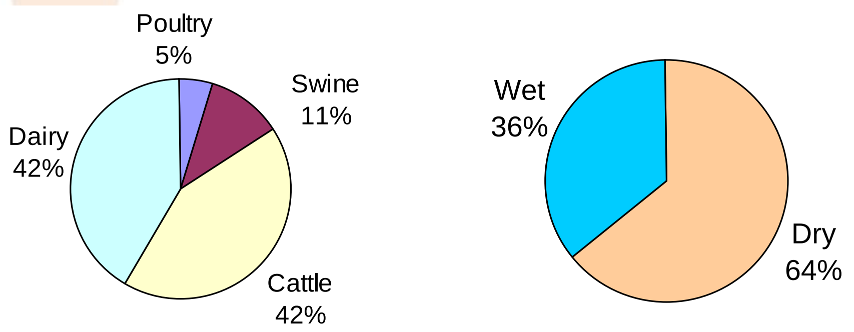
Dry-mill ethanol plants are optimized to produce ethanol with carbon dioxide and animal feed as by-products. While ethanol fermentation consumes the grain's starch, the protein, minerals, vitamins, fat and fiber can be concentrated during the production process to produce highly valued and nutritious livestock feed. After fermentation is completed the alcohol content of the mash (beer) is sent to a distillation unit where the alcohol is separated from the solids and water. The alcohol-free solids and liquids remaining after distillation are generally recombined for sale as high-protein animal feed. In its wet form they are known as wet distillers grains with solubles (WDGS) and can be sold to nearby markets. The dried form, dried distillers grains with solubles (DDGS), can be transported over long distances and is available for domestic markets and for exports.

DDGS is a high quality feedstuff ration for dairy cattle, beef cattle, swine, poultry, and aquaculture. The feed is an economical partial replacement for corn, soybean meal, and dicalcium phosphate in livestock and poultry feeds. However, nutrient composition and quality of DDGS can vary depending on the ethanol plants feedstock use, geographical location and time of the year.

2.1.3 DDGS use in the United States

In the U.S., by far the largest producer of grain ethanol, ethanol biorefeneries produced in 2007 approximately 14.6 million metric tons of distillers grains up from 2.7 million tons in 2000. Approximately 40% of distillers grains with solubles are marketed as a wet by-products for use in dairy operation and beef cattle feedlots. The remaining 60% of distillers grains with solubles is dried (DDGS) and marketed domestically and internationally for use in dairy, beef, swine and poultry feeds (Figure 2).

Figure 2. North American distillers grains consumption in 2007



Source: http://www.ethanolrfa.org/industry/resources/coproducts/

In 2006, the US biofuel industry produced around 7 million tons of DDGS, of which more than 800000 were exported to the European Union[3].

One ton of raw grain (corn or wheat) produces approximately the same amount of ethanol and DDGS in terms of mass both amounting to some 300 to 330 kg (Merkl, 2008; Ziggers, 2007; RFA, 2009).

[3] See “By-products for livestock feeding” http://www.allaboutfeed.net/raw_materials/id795/by-products.html

2.2 Sugar cane ethanol

A relatively long historical evolution of cane-based sugar and ethanol industry facilitated the evolvement of a modern cane based sugar industry into a complex agro-industrial activity. The majority of mills are designed to produce sugar and ethanol simultaneously[4]. There are three types of product streams: sugar/solids, molasses/juice, and crop residues.

The key crop residue is bagasse, fiber left over after the sugar-rich juice has been squeezed out of the stalks. It is used as a primary fuel source for sugar mills enabling them to be more than self-sufficient in energy and allows sugar cane-based ethanol to achieve energy balances that are from two to eight times more efficient than those of fossil fuels. Often co-generation of heat and electricity is possible and surplus electricity can be sold on to the consumer electricity grid thus offering an additional source of income. Surplus bagasse can be used for livestock feed, as well as for the paper industry, or for making insulated disposable food containers.

Due to co-generation of heat and electricity, Brazilian sugar cane ethanol industry operates today without significant fossil fuel inputs; achieving a high overall greenhouse gas saving of 80–90 percent in comparison to fossil fuel.

Surplus bagasse can also be used for animal feed, in paper manufacture, or is used to make insulated disposable food containers, replacing materials such as styrofoam, which are increasingly regarded as environmentally unacceptable.

2.3 Sugar beet ethanol

Beet processing facilities convert raw sugar beets directly into refined sugar in a one step process. Sugar beets are very bulky and relatively expensive to transport and must be processed fairly quickly before the sucrose deteriorates. Therefore, all sugar beet processing plants are located in the production areas. This limited storage ability is a major drawback of sugar beet use for ethanol production.

Despite the simple processing technique, the cost of ethanol production from sugar beet is approximately twice that of sugar cane-based ethanol in Brazil, or maize-based ethanol in the USA (USDA 2006). This is primarily due to differences in feedstock costs.

Sugar beet by-products include the beet top, which can be used as green fodder, while beet pulp and filter cake from industry can be used as cattle feed.

When 7.9 kg of sugar beet is used to produce 1 litre of ethanol, 600 grams of a by-product called vinasse is produced at the same time. Vinasse can be used as rich fertiliser, animal feed or source of biogas production. Additionally, the process produces 600 kg of carbohydrate rich dried beet pulp used as animal feed concentrate[5].

[4] In Brazil there are currently 378 ethanol plants operating, 126 dedicated to ethanol production and 252 producing both sugar and ethanol. An additional 15 plants are dedicated exclusively to sugar production.
[5] Data based on German production. Source: European Bioethanol Fuel Association (www.ebio.org)

3. Biodiesel from vegetable oils and fats

Biodiesel is currently manufactured from vegetable oils (such as rapeseed, sunflower seed, soybean, palm oil), and other waste oils and fats using the process of transesterification catalyzed with alkali, acid or enzyme. Processing of vegetable oils provides meals and cakes as a by-product, which is a high-protein livestock feed. The principal by-product of the transesterification process for biodiesel production is glycerin.

3.1 Animal feed by-products

Vegetable oils are produced by pressing the oil from the seeds and refining it to remove free fatty acids and other impurities. Processing of the seeds for oil production provides protein meal and cake as by-products. In the case of soybean the feed demand for soymeal drives has driven soybean production growth. Growth of soymeal feed production took off in the mid-1970s and accelerated in the early 1990s, propelled by rapidly growing demand for animal feed in developing countries (FAO, 2006).

In oil extraction, soybeans yield 18 to 19 percent oil and 73 to 74 percent meal (Schnittker, 1997), the rest is waste. Soymeal is used primarily in the diet of monogastric species, particularly chickens and to a lesser extent pigs.

Per ton of rapeseed about 0.4 tons of vegetable oil and 0.6 tons of rapeseed cake is produced, which is excellent for livestock feed.

Worldwide, the feed demand for soymeal has skyrocketed over the past four decades, reaching 130 million tonnes in 2002. This far outstrips the second largest oilcake, made of rape and mustard seed, with 20.4 million tones of production in 2002.

Sources of protein for animal feed differ in their protein content. The highest protein content occurs in fish meal (60%), meat and bone meal (55%) and soy meal (48-50%). Medium protein content animal feed includes skim milk powder (35% protein), rapeseed meal (32%), sunflower seed meal (28%), peas and beans (23%) and corn gluten feed (22%). In the European Union the use of meat and bone meals in feed was prohibited in 2000 in a fight against BSE (mad cow disease). As a result more than 400,000 tonnes of high-quality protein feedstuffs from animal origin had to be replaced by protein from vegetable sources with subsequent rising imports of soy cake.

Oil palm vegetable oil production can provide diverse animal feed. By chopping, drying, cubing and pelletizing, oil palm fronds can be transformed into an attractive source of ruminant feed, while oil palm trunks are a readily available source of fiber in feed. Oil palm fronds, used either alone or combined with other ingredients such as palm kernel cake and palm oil mill effluent, have been successfully transformed into feed in pellet or cube form for ruminant animals.

3.2 Industrial by-products

The principal by-product of this biodiesel production is glycerol, also known as glycerin. Transesterification of vegetable oils yields 100kg of glycerol (also known as glycerin) for every tonne of biodiesel produced. The bio-glycerin can substitute conventional fossil glycerin, serving manifold uses in the food and beverages industry, in medical and pharmaceutical applications, plastic industries and is used to produce nitroglycerine (Meher et al., 2006b; Srivastava and Prasad, 2000).

As biodiesel production soars, so does crude natural glycerin. This has resulted in excess glycerin production making the conventional epichlorohydrin production process no longer economical. The overabundance of glycerin endangers the economic viability of an expanding biodiesel production because refiners operate on narrow profit margins and often sell glycerin to subsidize production.

Currently disposal of surplus glycerol is by incineration. The challenge is to find value-added alternatives to glycerol incineration and thereby improve environmental benefits and economic viability of the biodiesel supply chain[6].

Palm oil by-products include palm soapstock, palm acid oil and palm fatty acid distillates (PFAD). They have a wide range of quality and composition and also consist of many impurities and minor components. Oleochemicals from fatty acids have found applications in food, paper, plastics, rubber, lubricants, soap, cosmetics, toiletries, surfactants, pharmaceuticals, fertilizers, textiles, etc..

4. Agricultural residues

Agricultural residues such as straw and husks are readily available as by-products from biofuel feedstock production. When used for co-firing they greatly improve the energy and greenhouse gas balance of the biofuel production chain.

Brazilian sugar cane ethanol utilizes wastes and by-products from the milling process to generate heat and electricity. This permits the industry to operate without significant fossil fuel inputs; achieving a high overall greenhouse gas saving of 80–90 percent in comparison to fossil fuel.

However, at the same time crop residues especially straw have alternative uses such as animal feeding and bedding and when returned to the fields meet important ecosystem services essential to maintenance of soil fertility and erosion protection.

Factors that determine the amount of residues include crop type and yields, the biomass ratio of crop residues to crop main produce, and percentages of residues removed from the field for potential use[7].

The maximum amount of crop residues that can be removed from the field without significantly affecting soil fertility is debated. Some consider crop residues as currently unused waste material and make a strong case for its use for biofuel production (e.g. Sommerville, 2006). Others perceive crop residues as a valuable resource that provides irreplaceable environmental services (Smil, 1999) and argue removal of crop residues would exacerbate risks of soil erosion by water and wind, deplete soil organic matter, degrade soil quality, increase non-point source pollution, decrease agronomic productivity, and reduce

[6] The glycerin by-product is usually a disposal problem for small producers. It may contain up to 40% methanol so it is flammable, and releases methanol to the atmosphere. The methanol is an air pollutant and a potential ground water contaminant if the glycerin is spread on the ground. Methanol is also toxic to human beings and animals.

[7] Conversion factors for estimation of crop residues of different crops are summarized in Fischer et.al (2009).

crop yields per unit input of fertilizers and water (Lal, 2007). The importance of retaining residues on fields depends largely upon specific local conditions (USDA, 2006).

5. Attribution of by-products

When by-products are used credits can be attributed to the biofuel production chain. Credits include GHG emission savings, avoided land use or avoided energy use. The challenge is to decide how to distribute quantities of potential credits between the fuel and the by-products. For the evaluation of GHG emission savings the following two methods have been developed:

I. In the *substitution* approach it is first determined what the by-product is used for and what product would otherwise have been used to perform the function. Then GHG emissions that would arise if the substituted product were produced are calculated and subtracted from total GHG emissions caused by the bio-fuel production chain. Only the remaining GHG emissions are ascribed to the bio-fuel of interest.

II. In the *allocation* approach, total emissions are divided between the fuel of interest and the by-product in proportion to some attribute that they share. Common methods include (i) Mass based (allocation by mass); (ii) Market value-based (allocation by price); and (iii) Energy content-based (allocation by energy content).

For reasons of feasibility the EC recommends in its regulatory framework of the proposal for a directive on renewable energy targets to apply allocation by energy content to determine GHG savings compared to fossil fuels (EC, 2009).

> *"Co-products from the production and use of fuels should be taken into account in the calculation of greenhouse gas emissions. The substitution method is appropriate for the purposes of policy analysis, but not for the regulation of individual economic operators and individual consignments of transport fuels. In those cases the energy allocation method is the most appropriate method, as it is easy to apply, is predictable over time, minimises counter-productive incentives and produces results that are generally comparable with those produced by the substitution method. For the purposes of policy analysis the Commission should also, in its reporting, present results using the substitution method."*
> *Source: EC, 2009. page 25, paragraph 81*

For example for a fuel supplier (who has to report to the Commission) it is not possible to know for certain what the substituted product really is and thus GHG emissions of these substituted products are uncertain. Moreover by-products used as animal feed can replace many different animal feed products, which have differing GHG performances.

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