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Availability of lignocellulosic feedstocks for lactic acid production

Feedstock availability, lactic acid production potential and selection criteria

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Colophon

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Content

Glossary

Crop = main agricultural commodity produced for various purposes, e.g. wheat, sugar cane, maize

Feedstock = any agricultural biomass (crop or residue) used as main raw material for production of biofuels or chemicals

Agricultural Residue = by-product of agricultural crop production. Residues could be produced either at the field (primary residue) or at a crop processing facility (secondary residue)

Agricultural Residue Production = total production of agricultural residues that is produced in the field (for primary residues) or at the processing site (for secondary residues).

Agricultural Residue Availability = fraction of total agricultural residue production that is available for use in non-agriculture related processes, such as production of lactic acid

Primary Residue = agricultural residue that is generated at the field level, generally during or after crop harvest

Secondary Residue = agricultural residue that is generated at the processing site (e.g. rice mill, sugar mill)

Crop residue = synonym for agricultural residue

Dry weight = total weight of crop or residue after removing moisture contained in the material. Synonym for dry matter.

Fresh weight = total weight of crop or residue as it is generated, without removing moisture

Area harvested = total area planted to a certain crop

Residue to Crop ratio (RCR): weight of agricultural residue (dry weight) as a function of the weight of harvested crop (dry weight) to which the residue is associated

Rate of Current utilisation (ROC): percentage of total crop or residue that is used for other applications, or is otherwise unavailable for collection.

1 Introduction

The overall objective of this study is to assess the worldwide availability and suitability of agricultural residues for lactic acid production, based on fermentation of carbohydrates. The study focuses on lignocellulosic biomass that is produced as a by-product of agricultural production. The results of the study can be used to rank different biomass types on their lactic acid or fermentable sugar production potential. For each residue, both total production (ton of fermentable sugars per year) and productivity (fermentable sugars produced per ha of agricultural land) are considered. Furthermore, the production of non-fermentable residues (e.g. lignin) is included as well in the study. The study is concluded by series of recommendations on what factors to consider when choosing a suitable lignocellulosic feedstock for production of lactic acid, or for other fermentation processes. The results of this study can be used to further evaluate suitability, cost and sustainability of using agricultural residues as feedstock for fermentative production of lactic acid production, or other biochemical conversion processes.

2 Methodology

2.1 General comment on methodology

The methodology used for assessment of agricultural residue availability is based on methods used in a recent study by the International Energy Agency (IEA), which analyses the (lignocellulosic) biomass production potential of a number of developing countries for biofuel and bioenergy production purposes. In the current study, the number of countries is expanded to include the major agricultural regions of the world, including Northern America, Europe, and Australia. Furthermore, information is added concerning the carbohydrate and lignin composition of the different biomass types in order to estimate fermentable sugar yield and lignin yield. For comparison purposes, data on main sugar or starch-producing crops (e.g. sugar cane, beet, wheat etc.) are also included in the model.

2.2 Methods

2.2.1 Region and Country selection

To estimate the world-wide availability of agricultural residues, a region-specific analysis was made. The following regions were selected, based on agricultural statistics data by the Food and Agricultural Organization (FAO) of the United Nations: Northern America, Central America, Southern America, Europe, Africa, Eastern Asia, Southern Asia, South-Eastern Asia. For Europe, the aggregate "Europe +" as it appears in the agricultural production database of FAO was taken as one region. The Europe + includes the following 37 countries: Albania, Andorra, Austria, Belarus, Belgium-Luxembourg, Bosnia, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Moldova, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Macedonia, Ukrain, and the United Kingdom. For the three Asian regions, the following countries belong the respective regions:

- Eastern Asia: China, Democratic People's Republic of Korea, Japan, Republic of Korea;
- Southern Asia: Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, and Sri Lanka;
- South-Eastern Asia: Brunei,. Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Viet Nam

To estimate the feedstock availability and lactic acid potential per type of agricultural residue, a country-by-country assessment was made. For this country-by-country assessment, a total of 22 countries and one region (Europe) was selected for the study. The countries/regions were selected on the basis of two criteria: they should have a significant agricultural production in both agricultural land area as well as production volume of crops, and the economic situation in the country is reasonably stable which would make contracting biomass in the future a possibility. Cost for collection and logistics of biomass are dealt with in a separate part of the study.

The following countries and region were selected for the country-by-country study:
- Americas: Canada, United States, Mexico, Colombia, Brazil, Argentina, Peru
- Africa: Nigeria, Sudan, Mozambique, South Africa
- Asia: India, China, Thailand, Malaysia, Indonesia, Australia, Pakistan, Viet Nam
- Continental Europe: Europe (aggregate), Russian Federation

For Europe, the same aggregate "Europe +" as used in the world-wide assessment (see aboven) was taken. The countries that are listed above encompass approximately 85% of all agricultural production in the world.

2.2.2 Crop production data

Based on the FAO's countries profile website (www.fao.org), for each country the top 20 agricultural commodities were studied. Based on this list, the primary agricultural crops that would lead to agricultural residue production were taken into account in the model. Since at the start of the study, not all statistical data for 2009-2010 were available, the agricultural production data from 2008 were taken as basis. For the main agricultural crops, the current production was recorded based on two primary statistical data contained in the FAOstat: Area harvested in hectare (ha), and crop production in ton harvested material. It should be noted that the crop production in the FAO data are not recorded on dry matter basis, but in the form as it is harvested (fresh weight, or wet weight). Therefore, for crop production, total dry matter of crop production was then estimated, based on date from literature on common moisture content of the crops.

For a number of crops (e.g. maize, sugar cane, palm oil) both primary residues (residues that are generated at the field) and secondary residues (residues generated later in the production chain, such as at the processing or mill site) are included. A description of the different residues follows in the paragraph below.

A number of residues were not considered in the assessment, for reason that they are not likely to be considered as feedstock for fermentative production of lactic acid. These include:
- Protein rich residues (e.g. rapeseed cake) that are commonly used as animal feed
- Very wet residues (> 80% moisture content) such as potato cutting residues and vegetable residues that are more likely to be used for anaerobic digestion
- Animal manure and other residues related to animal or dairy production.

Furthermore, woody residues (oil palm trunks, wood from rubber plantation, coconut lumber) are not included in the current assessment, as they are more likely to be used as feedstock for combustion rather than fermentation.

Table 1 presents the main agricultural crops for which data were collected in each country, the number of countries for which data were collected, along with the main residues that are associated with these crops. The following paragraph contains a short description of the various crops and their associated residues. In this description, the amount of residue produced per amount of main crop is described as well. This is known as the residue-to-crop ratio (see also par. 2.2.4)

2.2.3 Short description of main crops, associated residues, and current practices

Wheat and Barley

Wheat and barley are grown to produce wheat and barley grain. Most wheat (approx. 71% of global production) is used for human food, generally in the form of flour to produce bread. About 17% of global production is used for animal feed. The fraction of wheat used for animal feed in Europe and North America, is higher, however. Furthermore, in recent years, more wheat and barley grain have been used for the production of bioethanol. Barley grain (about two thirds of global production) is used for animal feed. Barley use for food manufacture is the second largest application, this includes the use of barley for beer production.

The primary agricultural residues associated to wheat and barley are wheat straw and barley straw. Straw is a term used for all harvestable residues after wheat and barley grain have been collected by combine harvesting, and includes major parts of the stem, leaves, and spikelets. For off-field utilisation, straw is collected in packs or bales, which are produced by self-propelled baling machines. If straw is not collected but left in the field, it can be ploughed into the field or left as mulch layer. In some regions, straw is burned in the field for fast disposal purposes, in this case there is no time to incorporate the straw as a second crop needs to be planted.

Unlike for rice straw, there are many current uses of wheat straw. Current uses of straw include soil improver, animal fodder supplement, frost prevention in horticulture (e.g. straw bedding in flower bulb production in open fields), ingredient for mushroom production substrate, traditional building materials, and energy. In Denmark, Spain and the United Kingdom as well as other countries around the world, dedicated power plants have been in use that use wheat straw as primary fuel. In addition, wheat straw is co-fired in coal-fired power plants. In most of these cases, a subsidy scheme has led to the commercial utilisation of wheat straw in energy market. Even with the many existing uses for wheat straw, in many regions and countries around the world there is a surplus of wheat straw. Field burning of wheat straw to dispose of this surplus exists as well, although it is practiced less frequently compared to rice straw.

Although there are quite some region-specific estimates for residue-to-crop ratios for wheat and barley, 1 kg of harvested wheat or barley grain is estimated to generate 1.0 kg of wheat straw or barley straw, respectively.

Maize

Maize ("corn" in the USA and other English-speaking countries) is a major source of starch. Cornstarch (maize flour) is a major ingredient in both home cooking and in many industrialized food products. Maize is also a major source of cooking oil (corn oil) and of maize gluten. Maize starch can be hydrolyzed and enzymatically treated to produce syrups, particularly high-fructose corn syrup, a sweetener; and also fermented and distilled to produce grain alcohol. In Africa and Central America, maize is a major staple crop and used for human consumption. In western countries, including the USA, most of the maize produced is used for animal feed. Currently, about 35% of maize produced in the USA is used for the production of bioethanol, as replacement for gasoline

Maize stems and stalks ("corn stover" in the USA) are the primary agricultural residue from maize production. It consists of the leaves and stalks of the maize plant left in the field after maize kernels have been collected by mechanical harvesting. Maize cobs are the central core of the plant part on which the starchy kernels grow. In some harvesting systems, maize cobs are separately collected and generated as residue, after separating the kernels from the cobs. In other systems, maize kernels are left as residue in the field, and may be collected together with stems and stalks. In the present study, 1 kg of harvested maize is estimated to generate 0.7 kg of maize stems/stalks, and 0.5 kg of maize cobs, all on dry matter mass basis.

Rice

The main product of rice production is rice grain, often referred to as paddy rice or rough rice. Most rice grain (about 90% of global production) is used for human food, with the remainder used for animal feed and other uses. There are two main lignocellulosic agricultural residues associated to rice production: rice straw and rice husk (also named rice hulls in the USA). As with wheat straw or barley straw, rice straw is the residue left in the field after rice grains are harvested. Rice husk is the inedible husk covering the rice kernel , which is removed from the starchy kernel during rice grain processing (rice milling).

Since rice is largely produced in developing countries, a lot of current uses of rice straw are traditional, such as fuel for cooking (either directly or by producing briquettes which are produced by compressing the material), animal feed, anaerobic digestion to biogas and building materials such a roof thatching. In many cases, straw is left in piles for composting and returned to the field. In most of these cases, straw is used together with other agricultural residues generated at village level. There are few official statistics on actual rice straw utilisation, and therefore quantitative estimates of current uses are difficult to make.

Modernization in rural areas leads to growing access to modern cooking and heating fuels, which means that in most regions, rice straw is no longer used as source of energy for cooking and heating. More modern uses of rice straw include using straw for fibers production, combustion

for electricity generation, production of bio-fertilizer, and materials such as erosion-control mats. Still, in many cases rice straw is not used, and disposed of by open field burning.
In many countries, rice husk is used for generation of electricity and heat, especially in countries where modern rice processing facilities are present (e.g. USA, Brazil, Thailand).
In the present study, 1 kg of harvested rice grain is estimated to generate 1.25 kg of rice straw, and 0.2 kg of rice husk, all on dry matter mass basis. The low residue-to-crop ratio of rice husk represents the fact that rice husk only constitutes a small fraction of the harvested rice grain.

Soybean
Soybeans provide both oil and protein for various applications and uses. Approximately 85% of the world's soybean crop is processed into soybean meal and vegetable oil. A very small proportion of the crop is consumed directly by humans. Soybean products do, however, appear in a large variety of processed foods.
As with wheat straw or barley straw, soybean stalks/stems is the residue left in the field soybeans are harvested. In the present study, 1 kg of harvested soybeans are estimated to generate 2.5 kg of soybean stalks/stems. The high residue-to-crop ratio are associated the relatively small fraction of the bean in relation to the rest of the plant.

Sorghum
The sorghum plant produces a small starchy grain that is small, ranging from 3 to 4 mm in diameter. The plant itself however can grow very tall, to approx. 4 m in height or higher. In Africa and Asia, two thirds of produced sorghum grain is used for human food, such as for the production of flat breads. In other regions, most sorghum is used for animal feed. Sorghum stalks/stems are the residue left when sorghum grains are collected. Due to its tall nature, the plant has one of the highers residue-to-crop ratios: 1 kg of harvested sorghum grain is estimated to yield 2.6 kg of stalks and stems, on dry weight basis.

Cotton
Cotton is the most widely used natural fiber cloth in clothing today. Cotton grows in a protective capsule, or boll, around the seeds of cotton plants. The fiber is most often spun into yarn or thread and used to make a soft fabric. Most cotton in the industrialised countries is harvested mechanically by a cotton picker, a machine that removes the cotton from the boll without damaging the cotton plant, or by a cotton stripper, which strips the entire boll off the plant. Cotton continues to be picked by hand in developing countries. Cotton stalks are left remaining standing in the field after cotton harvest. The stalks can be collected mechanically by a silage harvester. Burning of cotton stalk is done is some areas where a second crop has to be grown after the cotton harvest and there is no alternate use for the stalks. Given than only a small portion of the plant (the boll) is harvested as main product, cotton stalk has the highest residue to crop ratio of all agricultural residues. Per kg of harvested cotton, 3.5 kg of cotton stalks are produced.

Sugar cane

The majority of sugar cane is used for manufacturing of sugar for human consumption. The sugar is produced through production of sucrose from cane juice that is extracted from the cane stalk. Besides sugar for human consumption, cane juice can be fermented and distilled to produce ethanol. Other products produced from cane sugar are butanol, lactic acid, and citric acid. The fibrous residue of cane after juice extraction is called <u>bagasse</u>. In many refineries it is used as a fuel for the generation of energy needed for sugar manufacture, and in some cases selling electricity to the (external) grid. Bagasse may also serves as a fibre for paper, or production of furfural through chemical hydrolysis.

Sugarcane harvesting can be done manually or mechanically, and cane can be harvested green or burned prior to harvesting. When mechanically harvesting unburned cane, the <u>tops and leaves</u> (collectively known as straw, or trash) can be collected and brought to the mill, to either be burned for cogeneration, or for use as feedstock for other processes.

On a dry matter basis, one kg of harvested sugar cane produces 0.6 kg of bagasse, and 0.9 kg of sugar cane tops and leaves.

Sunflower

Sunflower is an oilseed crop that is primarily grown in Europe and Northern America. Sunflower seeds can be processed in a number of foods. Sunflower oil, extracted from the seeds, is used for cooking, or in the production of margarine and biodiesel. Sunflower stalks/stems are the main residue left in the field after harvest of sunflower seed, and are often left in the field as mulch, or incorporated in the top soil. 1 kg of harvested sunflower seeds is estimated to generate 1.0 kg of sunflower stalks/stems.

Oil palm

Crude palm oil is an edible plant oil and is derived from the mesocarp (pulp) of the fruit of the oil palms. Besides crude palm oil, palm kernel oil is also derived from the oil palm fruit, but from its kernel. Palm oil is a common cooking ingredient in the tropical belt of Africa, Southeast Asia and parts of Brazil. Its primary use today however is in the commercial food industry. Palm oil, like other vegetable oils, is also used to create biodiesel, processed through transesterification.

Oil palm fronds (leaves) are generally removed at harvest and left in the field, serving as compost. There is no current industrial use of oil palm fronds.

Empty fruit bunches (EFB) are the fibrous residue after the oil palm fruits are removed from fresh oil palm fruit. The EFB used to be combusted in incinerators and the ash was returned to the field to support the new plantations. At present, this practice has been discontinued in some countries due to the air pollution caused by incineration. Alternatively EFBs are returned directly as mulch to the plantation, yielding nutrients. This can reduce the fertilizer requirement because of reduced N fertilizer need. However, it is estimated that EFB mulch can only provide 1/5 of the nutrient requirement of the plantation. Currently, while some EFB is dried and shredded and used in products like matrasses, a large proportion of EFBs are unused therefore the disposal of

EFBs remains a real (waste) problem. In some regions (e.g. Thailand), stand-alone EFB boiler systems are now in operation that produce electricity for the public electricity grid.
Two other oil palm residues from palm oil produciton are shells and fibres. Both are generated during extraction of crude palm oil from the fruit. Currently, fibre and shells are mainly used a fuel to produce steam and electricity for the milling process. According to Bronzeoak (1999) in the traditional palm oil mill all of the fibre and 50% of the shell are burnt for energy in the boilers to support the mill operation. Currently, most palm oil mills still use the low_pressure boilers with quite low cycle efficiency for the production of electricity efficiency (about 3.5%).

Groundnuts

Groundnuts are commonly known as peanuts or by many other local names such as earthnuts or monkey nuts. Groundnuts have many uses: they can be eaten raw, used in recipes, made into solvents and oils, medicines, textile materials, and peanut butter, as well as many other uses. During the shelling of groundnuts (removing the outer shell that covers the main kernel), groundnut shells are left as residue.
Per 1 kg of groundnuts processed, 2.5 kg of groundnut shells (dry weight basis) is produced.

Cassava

Cassava is a rootcrop that is a major staple food in the developing world, in particular Africa and Southern America, providing food carbohydrates. Cassava roots can also provide starch for industrial processes, such as production of bioethanol or other fermentation processes, as is the case in Thailand and China, where human consumption of cassava is very small. Cassava (tapioca) chips have therefore gradually become a major source for ethanol production in certain regions. Cassava has been used worldwide for animal feed, as well.
There are two residues associated to production of cassava roots. At the field level, cassava stems are generated during the harvest of the roots. They are generally left in the field as mulch, used for local energy production, or disposed of by burning. Secondly, during starch processing a fibrous residue is generated, which is used as raw material for livestock feed. In this study, only the cassava stems are considered as agricultural residue. Based on data generated in South-East Asia, it is estimated that per 1 kg of cassave roots harvested, 0.2 kg of cassava stems (dry weight basis) is produced.

Coffee

After harvesting, coffee beans undergo either the wet or the dry method to produce green coffee for human consumption. After drying, the wet-processed coffee is stored and remains in this form until shortly before hulling. During hulling, the remaining outside layers of the coffee bean are removed, to generate coffeehusks. In certain regions, coffee husks are used to generate electricity and heat. Per 1 kg of coffee processed, 2.1 kg of coffee husk (dry weight basis) is produced.

Coconut

The coconut provides a large resource for food, feed, fuel, timber, fibre and other products. Coconuts are harvested year round. Besides coconut lumber, the main residue associated to coconut production are coconut husks. In recent years, technologies for the production of higher value added products for local and export markets have developed. Up to date, a lot of coconut residues are not utilised and they often create a disposal problems. Per 1 kg of coconuts harvested, 0.6 kg of coconut husk (dry weight basis) is produced.

2.2.4 *Agricultural Residue assessment*

In a two-step procedure, the agricultural residue availability was estimated, based on agricultural production data by FAO. In the first step, the total residue production is estimated, regardless of current utilisation. Therefore, for each biomass type, the Residue-to-Crop ratio (RCR) was used to determine total biomass residue produced at the field or mill site. The RCR indicates how much residue is generated as a function of the main agricultural crop produced, on a total dry matter basis. RCR is defined as the ratio of crop residue (dry matter mass of residue) per crop (dry matter mass of crop) as follows:

$$RCR_{cropresidu} = \frac{Cropresidu(kg;drymatter)}{Cropproduction(kg;drymatter)}$$

wherein RCR is residue-to-crop ratio of a certain crop residue, MC is the moisture content of the crop, and Cropproduction is the reported annual production of the crop. The reason for applying the RCR is that in most cases, data on the production of agricultural residues are not included in agricultural databases. RCR differs from crop to crop, and can range from 0.2 (kg residue/kg crop for rice husk) to 2.6 (for sorghum stalks). There is quite some variation in RCR values: this depends largely on which part of the plant is harvested (e.g. grain, kernel, fruit, flower, bean, etc.), and plant characteristics-in particular the relative amount of the harvested crop in relation to the total amount of plant matter produced. The RCR values were both taken from the existing IEA study, other studies (e.g. McKinsey, 2011; Reith et al, 2007; Kim and Dale, 2004) as well as expert judgment. RCR values can also differ from region to region, however regional differences are not taken into account in the assessment at this time. The assumed RCR values as well as MC for crops used in the assessment are presented in Appendix A.

Applying the RCR to the annual agricultural crop production data results in a value for agricultural residue production or "Residue Production" in ton per year, which represents the total amount of biomass residue produced in a certain country. The agricultural residue production (in tonnes dry matter per year) or "residue production" for a certain crop residue is calculated as a function of the reported crop production (in fresh weight per year) to which this crop residue is associated to:

$$Agriculturalresiduproduction_{cropresidu} = RCR_{cropresidu} * (100 - MC_{crop}) * Cropproduction_{crop}$$

wherein *RCR* = residue-to-crop ratio of a certain crop residue, *MC* is the moisture content of the crop, and *Cropproduction* is the reported annual production of the crop. Moisture contents of the crops vary widely (15% for wheat and barley to 75% for sugar cane), and assumed values are presented in Appendix A. The agricultural residue production represents the total production for a certain residue that is produced in the field (for primary residues) or at the processing site (for secondary residues). However, it does not take into account what the current use is, or how much of the residue can be removed from the field. This is calculated by the availability of the agricultural residue.

The Agricultural residue Availability of a certain crop residue is calculated as a function of the agricultural residue production:

$$Agriculturalresiduavailability_{cropresidu} = (1 - 0.01 * ROC_{cropresidu}) * Agriculturalresiduproduction_{cropresidu}$$

where *ROC* is the rate of current utilisation in percentage of total produced residue utilised, and agricultural residue production is calculated from the agricultural production data (see previous paragraph).

The use of the ROC to determine available resembles the "availability factor" used in other studies, however ROC does not take economic factors into account for competing uses. In this study, the ROC for primary agricultural residues (those that are generated in the field, after crop harvest) indicates to what extent the residues cannot be collected as they need to be left on the field for nutrient and carbon recycling purposes, or for ground cover/erosion control. Often, "sustainable harvest" practices of primary residues are described in literature, which includes leaving a fraction of biomass on the field for ground cover and soil organic carbon retaining purposes. It should be noted however that there are quite different values in literature as to how large the fraction of residues to be left in the field is, as this also depends heavily on the location, crop type, soil type, climate, as well as agricultural practices. For example, DOE (2005) conducted a quite extensive study on the sustainable harvest of agricultural residues in the USA, and concluded that 100% of residues can be sustainably removed for rice, 87% for maize, 36% for winter wheat, and that no residues should be removed for sorghum and soybean. Following is a summary of ROC's used for primary agricultural residues that were used in this study:

- Conservative values for ROC (75% current utilisation; i.e. 25% is available for use) were used for crop residues where it is generally understood that a large fraction of residues needs to be left in the field for ground cover and retaining soil organic carbon (e.g. soybean, sorghum, etc.)

- Medium values for ROC (50% current utilisation) were used for most cereal crops where a smaller part of the primary residues is or needs to be left in field (e.g. wheat, maize)
- Progressive values for ROC (25% current utilisation; i.e. 75% is available for use) were used for crop residues that are generally in surplus and do not play a large role in retaining ground cover (e.g. sugar cane tops/leaves, empty fruit bunch) or nutrient recycling. In many case, these residues are burnt in the field as growers have no other disposal methods available.

Table 1. Agricultural Crops and associated residues, ranked by total area harvested (2008).

Crop	Area harvested (1000 Ha)	Crop Production (1000 t/yr)	Number of countries/regions	Agricultural Residue
Wheat	175,745	589,312	17	wheat straw
Maize	129,987	723,202	22	maize stalks, stems maize cobs
Rice	117,420	455,221	19	rice straw rice husk
Soybean	90,287	212,465	13	soybean stalks, leaves
Sorghum	38,175	57,134	15	sorghum leaves, stems
Barley	30,476	108,597	9	barley straw
Cotton	17,053	40,362	9	cotton stalks
Sugar cane	17,038	1,200,372	18	sugar cane bagasse sugar cane tops/leaves
Sunflower	16,187	25,167	6	sunflower stalks, stems
Oil palm fruit	15,971	196,697	8	empty fruit bunch oil palm fibres oil palm shells oil palm fronds
Groundnuts	15,258	28,588	9	groundnut shells
Rapeseed	13,840	17,813	2	rapeseed straw
Cassava	13,206	180,838	11	cassave residue
Millets	10,800	12,670	1	millet stalks, stems
Beans	10,730	4,390	2	bean stalks, stems
Coffee	4,910	3,979	7	coffee husk
Coconut	3,962	26,576	9	coconut husk
Banana	228	4,200	2	banana leaves
Total	721,272	3,887,583		

For secondary biomass residues (those that are generated at the processing site, such as a sugar refinery or grain mill), the ROC value represents an estimate the amount of biomass that is currently used for other applications. As with the determination of ROC values for primary residues, it is difficult to estimate the current utilisation of secondary residues, in particular in developing countries. In many cases, a significant fraction of primary and secondary residues are used for animal feed or energy needs. A the same time, when economies emerge, access to more modern forms of energy is increased and use of agricultural residues for energy declines. In its study of 9 developing countries, IEA (2010) estimated the rates of utilisation in a number of countries. For example, in Brazil, 50% of primary and 75% of secondary agricultural residues are used, however for a number of residues such as sugar cane tops/leaves, there is no current utilisation. In China, 60% of primary agricultural residues and 50% of secondary residues are currently used, and certain residues such as rice straw and maize stalks/stems are in general in surplus. In Mexico, the current utilisation can vary from 30 – 70% for primary residues (0 – 85% for secondary residues), and for Thailand the utilisation varies from 0 – 100%. As this study represents a global availability assessment, regional differences in ROC were not taken into account. However, in future study, when more region- or country-focused studies are undertaken, ROC values could be adapted to represent the actual utilisation in a certain region more closely. Furthermore, ROC could be adapted to indicate biomass availability based on different scenarios for competing uses, such as the use of lignocellulosic biomass for energy and heat. This is done for instance by a study commissioned by AgentschapNL (AgentschapNL, 2012) on the availability of sugar cane bagasse and tops/leaves in Brazil, which is briefly summarised in later paragraphs in this report. Excerpts of this study are included in Appendix D.

2.2.5 Fermentable sugar production potential, and lactic acid production potential

In order to estimate the fermentable sugar production potential of different agricultural residues, the fermentable sugar production potential (in tonnes of sugar per year) was calculated. Fermentable sugar production potential or "fermentable sugar potential" (in tonnes of sugar per year) for a specific agricultural residue is a function of the availability of that agricultural residue, and its carbohydrate content:

$$Fermentablesugarpotential_{cropresidu} = CH_{cropresidu} * Agriculturalresiduavailability_{cropresidu}$$

where CH is the carbohydrate content of the crop residue, based on its biochemical composition, and measured as kg fermentable sugar per kg crop residue on dry matter basis (for *Agriculturalresiduavailability*, refer to previous paragraph). For each crop and agricultural residue, carbohydrate compositions were established based on based on literature (e.g. Harmsen et al, 2011; Kim & Dale, 2004; website NREL) and biomass compositional data generated at WUR-FBR. For agricultural residues for which no reliable compositional data were found, the carbohydrate composition of wheat straw was assumed (53% carbohydrates on dry weight basis). The model was set up is such a way that once new compositional data become available, they can be easily introduced in the model. Assumed values for the carbohydrate compositions for the various agricultural residues are included in Appendix B.

The Lactic acid production potential or "lactate potential" (in tonnes of lactic acid per year) of a certain crop residue is a function of the fermentable sugar potential, as follows:

$$Lactateproductionpotential_{cropresidu} = Conversionfactor * Fermentablesugarpotential_{cropresidu}$$

where *Conversionfactor* is the amount of lactic acid that can be produced per amount of fermentable sugars (kg fermentable sugar per kg of carbohydrate), depending on the type of carbohydrates contained in the feedstock (e.g. starch, sugars, cellulose, hemicellulose), and the conversion of fermentable sugars into lactic acid. In order to estimate conversion factors, the following conversion factors were taken into account (estimated by WUR):
- 0.80 for hemicellulose and cellulose (kg fermentable sugar per kg of hemicellulose or cellulose)
- 0.95 for starch crops (wheat, barley, etc.)
- 0.95 for sugar cane-derived sugar, and
- 0.99 for sugar beet-derived sugar

The lactic acid production potential was then determined, by applying a general conversion factor of 0.9 kg lactic acid per kg of fermentable sugar (based on experimental data from WUR). In addition, for all lignocellulosic agricultural residues, it was assumed that both C5 and C6 sugars are both converted into lactic acid.

Finally, the fermentable sugar productivity or "Fermentable sugar yield (in tonnes sugar per ha per y)" is measured by dividing the Fermentable sugar production potential (in tonnes sugar per year) by the area harvested to the crop to which the crop or crop residue is associated to:

$$Fermentablesugaryield_{crop/cropresidu} = \frac{Fermentablesugarpotential_{crop/cropresidu}}{Areaharvested_{crop}}$$

where *Area harvested* is the total area harvested of a crop in the reported year in a specific country or region.

2.2.6 Non-fermentable byproduct production (lignin)

To estimate the non-fermentable production from each agricultural residue, lignin concentrations were estimated for each agricultural residue, based on literature and other sources. As noted above, the lignin concentration of wheat straw was assumed for those residues for which no reliable lignin data are available.

As the most likely application for lignin is energy for the process or export to the electricity grid, total lignin yield was determined in energy terms, based on a lower heating value of lignin of 15 GJ/ton (dry matter basis). For each agricultural residue, both total lignin production potential (GJ/y) was determined, as well as the lignin production per ha of agricultural land (GJ/ha).

Calculated values for the lignin yields for the various agricultural residues are included in Appendix B.

3 Results and discussion

3.1 Distribution of crops and agricultural residues in the world

Table 2 presents the aggregated data for crop production, total area harvested, and agricultural residue production for the world, along with distribution of the crops in different continents. Data show that the primary crop in terms of harvested area is wheat (more than 200 million ha), with maize and rice as second and third crop. The other crops are generally much lower in planted area (less than 50 million ha), with the exception of barley. In terms of crop production, sugar cane is by far the highest producer, however it should be noted that harvested cane is reported to contain 75% of water, and all crop production data are presented on fresh weight basis. Following sugar cane, maize is the main crop in terms of crop production (more than 800 million tons annually), followed by rice and wheat (both approx. 680 million tons). Furthermore, noteworthy is the production of palm oil fruit (214 million tons) that are produced on only 15 million ha. When both primary and secondary agricultural residues that are associated to a crop are summed up, rice and maize are shown to be the highest "producers" of agricultural residues (more than 840 million tons of residues produced, on dry matter basis), followed by sugar cane, and wheat. The distribution of the harvested area over the five continents (Table 2) shows that sorghum and cassava are primary crops in Africa, maize, sugar cane and coffee are primary crops in the Americas, and that rice, oil palm and coconut are primary crops in Asia. Finally, barley, sunflower and sugar beet are crops that are primarily grown in Europe.

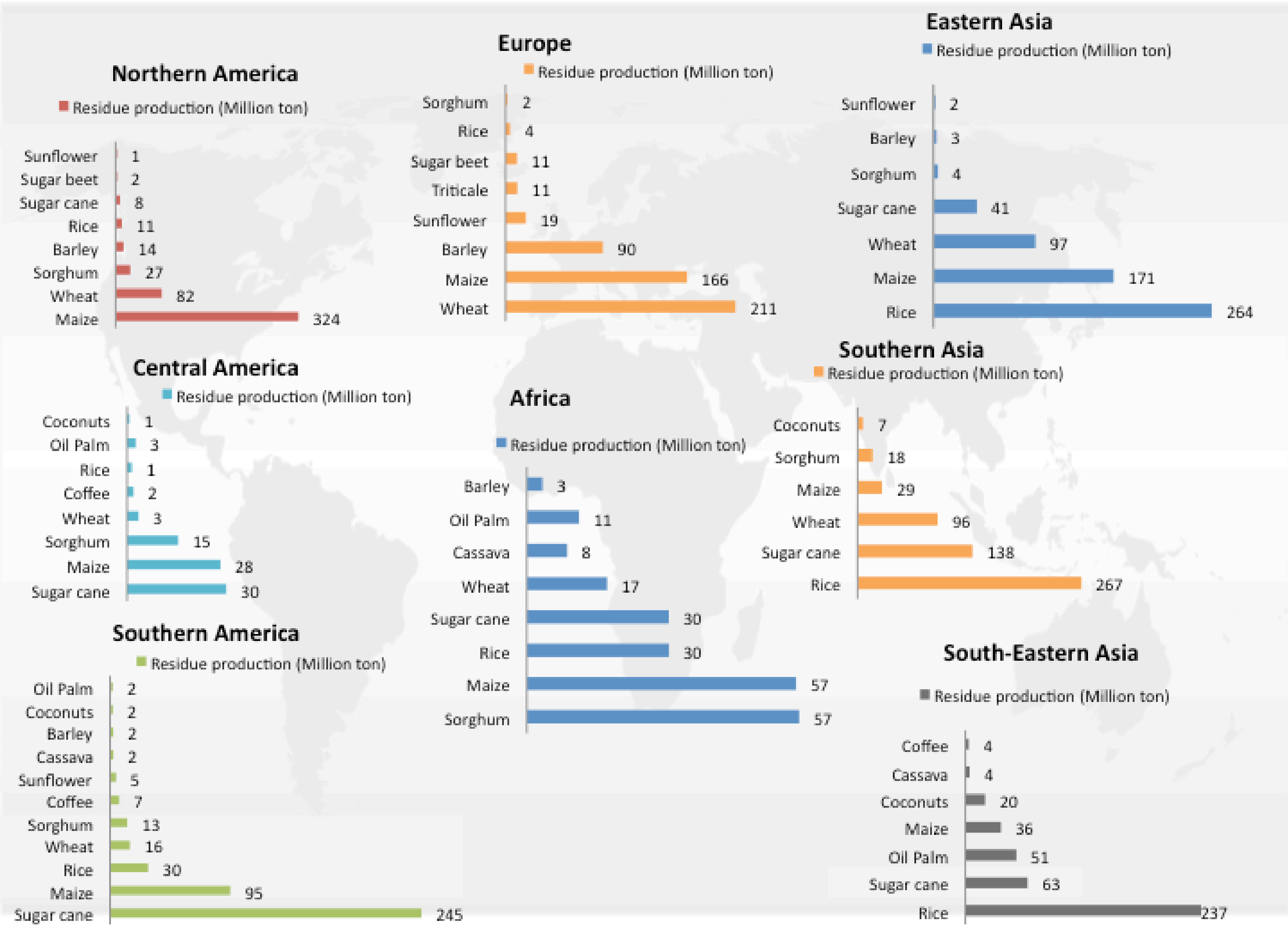
The agricultural residue production data are also graphically shown on the world map depicted in Figure 1, with data for Americas and for Asia displayed for each of their three main sub-regions (Northern-, Central-, and Southern America for the Americas, and Eastern-, Southern- , and South-Eastern Asia for Asia, respectively). For the Americas, the figure shows that maize residues are primarily produced in Northern America, that sugar cane residues are mainly produced in South America, and that Central America is producer of both maize and sugar cane residues, although at lower level compared to the other sub-regions. The primary agricultural residue in Europe is provided by wheat production (i.e. wheat straw), followed by residues from maize (maize stalks, cobs) and barley (barley straw). In all three sub-regions of Asia, residues from rice production (rice straw, rice husk) are the primary residues produced, however residues from other crops differ per Asia sub-region. Maize residues are primarily produced in Eastern Asia (which includes China), sugar cane residues are largely produced in South Asia (which includes India), and oil palm residues are mostly produced in South-Eastern (which includes, among others, Indonesia and Malaysia). In comparison with other continents, Africa is shown to produce agricultural residues at a much lower level compared to the other regions, which is primarily related to the lower output of agricultural crops in this continent. Overall, the distribution of crops and agricultural residues in the world provides a good first basis for the selection of lignocellulosic feedstock, based on their production in different regions of the world.

Table 2 Distribution of main crops produced in the world by region, and associated agricultural residue production (2008 data)

Crop	World Production Crop*	Total area harvested	Agric. Residue production**	Africa	Americas	Asia	Europe	Oceania
	Million ton	Million ha	Million ton					
Rice	689	156	849	4%	5%	91%	1%	0%
Maize	827	161	843	7%	53%	29%	11%	0%
Wheat	683	223	581	3%	17%	40%	36%	3%
Sugar cane	1734	24	677	5%	52%	41%	0%	2%
Soybeans	96	231	491	1%	86%	12%	1%	0%
Seed cotton	31	66	197	6%	18%	74%	1%	0%
Sorghum	66	45	148	39%	38%	25%	1%	6%
Barley	155	56	132	3%	13%	11%	68%	0%
Oil Palm Fruit	214	15	70	8%	5%	86%	0%	0%
Coconuts	60	12	33	3%	9%	83%	0%	4%
Sunflower seed	36	25	31	4%	19%	16%	61%	0%
Cassava	232	19	16	52%	15%	33%	0%	0%
Sugar beet	221	4	16	4%	12%	15%	69%	0%
Coffee beans	8	11	15	11%	61%	28%	0%	7%
Total Agricultural area (Million ha)		1052		101.7	151.5	355.6	127.7	21.3

*crop production in million ton fresh weight (total weight of crop including moisture) harvest, as reported by FAO
**residue production in million ton dry weight basis, based on residue-to-crop ratio

Figure 1. Mapping of agricultural residue production by continent and sub-region (based on 2008 data; FAO)



3.2 Aggregated results per agricultural residue

Table 3 presents the results of agricultural residue production as well as agricultural residue availability for each agricultural residue considered in the study. In this table, the country-by-country data are summed up to yield one value per residue type. Results show that, based on the assumed residue-to-crop ratio (RCR) and rate of current utilisation (ROC), rice straw is the primary available residue (more than 300 million ton dry matter per year), followed by wheat straw (234 million ton). Maize stalks/stems (215 million ton) and sugar cane tops/leaves (214 million ton) are also very prominent in terms of agricultural residue availability. The higher value for rice straw compared to wheat straw and maize stalks represents the larger surplus of straw from rice production in comparison to wheat and maize, as rice straw does not play a large role in retaining ground cover and in many cases is disposed of by open field burning. Beside the straw from cereal and maize production, agricultural residues that are widely available include soybean stalks/leaves (113 million ton), maize cobs (76 million ton), oil palm fronds (50 million ton), barley straw (46 million tons) and sugar cane bagasse (44 million ton). Bagasse and maize cobs are of particular interest as they are secondary biomass residues, with associated lower logistics costs (refer to Chapter 4).

In general, the availability data in Table 3 are correlated with the surface area planted to different crops in the world: there is much more surface area planted to wheat, maize and rice compared to the other crops (e.g. barley, sugar cane, oil palm, etc.), and as a result the residues from the crops show a large available volume.

Table 4 presents the aggregated data for fermentable sugar potential, lactic acid potential, and the lignin availability, based on the assumed carbohydrate and lignin concentrations, as well as assumed conversion efficiencies for carbohydrate conversion to fermentable sugars (refer to Appendix B for assumed values). The production potential for fermentable sugars, lactic acid, and lignin availability follow quite closely the residue availability data from Table 3 with primary potential represented by rice straw (140 million tons of fermentable sugars per year), maize stalks and stems, and wheat straw (100 million tons fermentable sugars for both residues), and sugar cane tops/leaves (91 million tons fermentable sugars). Table 4 also shows that the main secondary agricultural residues for production of fermentable sugars includes sugar cane bagasse (20 million ton sugar/y) and rice husk (18 million tons sugars/y) . Other secondary residues, such as empty fruit bunch, coffee husk, and coconut husk show generally a lower fermentable sugar potential compared to bagasse and maize cobs, however their availability is often concentrated in a smaller geographic area, and therefore still represent an important potential source of fermentable sugars in particular countries. It should be further noted that, depending on harvesting regime and method, maize cobs can be generated at the field rather than at a central site, and therefore should be considered in part as a primary biomass residue.

Finally, agricultural residues availability and lactic acid potential from beans and banana are relatively insignificant, and are not considered in the further sections of this study.

Table 3 Total Agricultural Residue production per crop, and Agricultural Residue availability

Crop	Agricultural Residue	Total Residue Production	rank production	Agr. Residue availability	rank availability
		(1000 ton/y; dry weight)		(1000 ton/y; dry weight)	
Rice	rice straw	540,545	1	328,314	1
Wheat	wheat straw	500,915	2	233,713	2
Soybean	soybean stalks, leaves	451,488	3	112,872	5
Maize	maize stalks, stems	430,305	4	215,153	3
Maize	maize cobs	307,335	5	76,834	6
Sugar cane	sugar cane tops/leaves	285,394	6	214,045	4
Sugar cane	sugar cane bagasse	175,228	7	43,807	9
Sorghum	sorghum leaves, stems	124,908	8	31,227	11
Cotton	cotton stalks	120,077	9	30,019	12
Oil palm fruit	oil palm fronds	100,510	10	50,255	7
Barley	barley straw	92,308	11	46,154	8
Rice	rice husk	86,927	12	43,495	10
Groundnuts	groundnut shells	60,750	13	15,187	13
Cassava	cassave residue	20,054	14	7,324	16
Oil palm fruit	oil palm fibres	17,473	15	4,368	19
Oil palm fruit	empty fruit bunch	17,339	16	13,004	14
Rapeseed	rapeseed straw	15,141	17	7,571	15
Sunflower	sunflower stalks, stems	14,615	18	7,307	17
Coconut	coconut husk	13,279	19	6,640	18
Millets	millet stalks, stems	10,770	20	2,692	20
Coffee	coffee husk	9,476	21	2,369	21
Oil palm fruit	oil palm shells	6,573	22	1,643	22
Beans	bean stalks, stems	878	23	439	23
Banana	banana leaves	840	24	420	24
Total		3,403,127		1,494,853	

Table 4 Potential Fermentable sugar production, lactic acid potential and lignin availability. Data ranked by fermentable sugar production potential

Crop	Residue	Fermentable sugar potential from residue	Lactic acid potential	Lignin availability
		(1000 ton/y; dry weight)	(1000 ton/y; dry weight)	(GJ/y)
Rice	rice straw	139,993	125,994	942,997
Maize	maize stalks, stems	100,003	90,003	487,321
Wheat	wheat straw	99,094	89,185	823,837
Sugar cane	sugar cane tops/leaves	90,755	81,680	754,510
Soybean	soybean stalks, leaves	47,858	43,072	397,874
Maize	maize cobs	42,451	38,206	138,301
Oil palm fruit	oil palm fronds	24,122	21,710	164,469
Barley	barley straw	22,147	19,933	124,021
Sugar cane	sugar cane bagasse	20,642	18,578	124,850
Rice	rice husk	18,442	16,598	149,016
Sorghum	sorghum leaves, stems	13,240	11,916	110,075
Cotton	cotton stalks	12,728	11,455	105,818
Groundnuts	groundnut shells	6,439	5,796	53,212
Oil palm fruit	empty fruit bunch	6,003	5,402	33,161
Rapeseed	rapeseed straw	3,210	2,889	26,686
Cassava	cassave residue	3,113	2,802	5,493
Sunflower	sunflower stalks, stems	3,098	2,789	25,759
Coconut	coconut husk	2,390	2,151	32,666
Oil palm fruit	oil palm fibres	1,852	1,667	15,398
Millets	millet stalks, stems	1,251	1,126	9,491
Coffee	coffee husk	1,004	904	7,818
Oil palm fruit	oil palm shells	697	627	5,793
Banana	banana leaves	252	101	605
Beans	bean stalks, stems	211	190	1,179

3.3 Availability of Agricultural Residues; Top 50

Table 5 shows the country-by-country agricultural residue availability ranked by total availability per agricultural residue (50 are shown out of a total of 224 data points). As shown in the table, there are 20 cases where at least 20 million tons of a particular agricultural residue could be produced in a certain country or region, per year. As noted earlier, the major available biomass type are primary residues: rice straw, maize stalks/stems, and wheat straw, sugar cane residues, with sugar cane tops/leaves in Brazil on a prominent third place. However, the geographic distribution of the residues differs. While China and India are major "suppliers" of rice straw, the United States and China are suppliers of maize stalks/stems, and Europe and China are suppliers of wheat straw and barley straw. Interestingly, primary residues of soybean appear within the top 10 (9th rank, United States, 43 million ton/y), although the extent to which soybean residues can be removed from the field is under discussion, and soybean residues exhibit a conservative value for Rate of Current utilisation. As mentioned, the top secondary biomass residue is sugar cane bagasse produced in Brazil (22nd ranking; 17 million ton/y availability), even though it is assumed that 75% of produced bagasse is used for other purposes. Other interesting sources of biomass in terms of volume are sugar can tops/leaves (commonly known as trash) in Brazil and India, rice straw in Viet Nam, cotton stalks and rice husk in China, and Oil Palm Fronds in Indonesia and Malaysia.

Table 5 Availability of agricultural residues per country, Top 50 out of 224
(note: Table 5 continues on next page)

Rank	Country	Agricultural Residue *	Agricultural Residue availability
			(1000 ton/y; dry weight basis)
1	China	rice straw (P)	129,421
2	United States	maize stalks, stems (P)	91,375
3	Brazil	sugar cane tops/leaves (P)	82,304
4	Europe +	wheat straw (P)	78,362
5	India	rice straw (P)	76,803
6	India	sugar cane tops/leaves (P)	63,958
7	China	wheat straw (P)	46,452
8	China	maize stalks, stems (P)	45,205
9	United States	soybean stalks, leaves (P)	42,898
10	Indonesia	rice straw (P)	41,611
11	United States	maize cobs (S)	32,634
12	United States	wheat straw (P)	28,907

Rank	Country	Agricultural Residue *	Agric. Residue availability
13	Brazil	soybean stalks, leaves (P)	27,872
14	Russian Federation	wheat straw (P)	27,100
15	Viet Nam	rice straw (P)	25,678
16	Europe +	barley straw (P)	25,109
17	Argentina	soybean stalks, leaves (P)	24,564
18	Europe +	maize stalks, stems (P)	23,760
19	Indonesia	oil palm fronds (P)	22,076
20	Malaysia	oil palm fronds (P)	21,557
21	Thailand	rice straw (P)	19,192
22	Brazil	sugar cane bagasse (S)	17,147
23	China	cotton stalks (P)	17,011
24	China	maize cobs (S)	16,145
25	India	wheat straw (P)	16,108
26	China	rice husk (S)	15,929
27	India	sugar cane bagasse (S)	13,325
28	Brazil	maize stalks, stems (P)	12,692
29	India	rice husk (S)	12,288
30	Canada	wheat straw (P)	12,160
31	Thailand	sugar cane tops/leaves (P)	11,586
32	Pakistan	sugar cane tops/leaves (P)	11,506
33	Russian Federation	barley straw (P)	9,838
34	India	cotton stalks (P)	9,818
35	Mexico	sugar cane tops/leaves (P)	9,122
36	Australia	wheat straw (P)	9,104
37	China	soybean stalks, leaves (P)	8,925
38	Pakistan	wheat straw (P)	8,907
39	Europe +	maize cobs (S)	8,486
40	Brazil	rice straw (P)	7,961
41	China	groundnut shells (S)	6,942
42	Colombia	sugar cane tops/leaves (P)	6,930
43	Pakistan	rice straw (P)	6,914
44	Mexico	maize stalks, stems (P)	6,694
45	Argentina	maize stalks, stems (P)	6,550
46	United States	sorghum leaves, stems (P)	6,374
47	Australia	sugar cane tops/leaves (P)	5,872
48	India	soybean stalks, leaves (P)	5,827
49	India	maize stalks, stems (P)	5,641
50	United States	rice straw (P)	5,637

* P = primary agricultural residue; S = secondary agricultural residue

3.4 Agricultural Residue Production; Top 30

Table 6 shows the total agricultural residue production, which are based on residue-to-crop ratios but not considering current rate of utilisation, or sustainable harvest practices. The data follow the general trend of the previous table (Table 5; biomass availability) and indicate that if harvesting and collection regimes were further improved and current uses are made more efficient, the total biomass available could further increase. An example can be found in the study on sugar cane residues in Brazil presented by AgentschapNL (AgentschapNL, 2012), which showed that if cane harvesting methods would be further optimised, more tops and leaves would become available for off-field uses. In addition, the same study estimates that if bagasse boiler systems would be made more efficient, more sugar cane bagasse could be made available for other purposes, and an excess of 30 million tons of sugar cane bagasse (dry weight basis) would be available above what is currently used to supply the sugar refineries with electricity and heat. This is more than double the estimated bagasse availability presented in Table 5.

Table 6. Agricultural Residue Production per country; Top 30 (out of 224)

Rank	Country	Agricultural Residue*	Residue production
			(1000 t/y ; dry weight)
1	China	rice straw (P)	199,109
2	United States	maize stalks, stems (P)	182,749
3	United States	soybean stalks, leaves (P)	171,591
4	Europe +	wheat straw (P)	156,724
5	India	rice straw (P)	153,606
6	United States	maize cobs (S)	130,535
7	Brazil	soybean stalks, leaves (P)	111,488
8	Brazil	sugar cane tops/leaves (P)	109,739
9	Argentina	soybean stalks, leaves (P)	98,256
10	China	wheat straw (P)	92,903
11	China	maize stalks, stems (P)	90,410
12	India	sugar cane tops/leaves (P)	85,277
13	Brazil	sugar cane bagasse (S)	68,587
14	China	cotton stalks (P)	68,044
15	China	maize cobs (S)	64,578
16	India	wheat straw (P)	64,430
17	Indonesia	rice straw (P)	64,017
18	United States	wheat straw (P)	57,814
19	Russian Federation	wheat straw (P)	54,200
20	India	sugar cane bagasse (S)	53,298
21	Europe +	barley straw (P)	50,219
22	Europe +	maize stalks, stems (P)	47,519
23	Indonesia	oil palm fronds (P)	44,152
24	Malaysia	oil palm fronds (P)	43,114
25	Viet Nam	rice straw (P)	39,504
26	India	cotton stalks (P)	39,270
27	China	soybean stalks, leaves (P)	35,700
28	Europe +	maize cobs (S)	33,942
29	China	rice husk (S)	31,857
30	Thailand	rice straw (P)	29,526

* P = primary agricultural residue; S = secondary agricultural residue

3.5 Lactic Acid Production Potential from agricultural residues and comparison with primary crops

Table 7 shows the top 25 of agricultural residues based on the potential lactic acid production from fermentable sugars contained in agricultural residues (as calculated in this report). As noted earlier, the main agricultural residues in terms of lactic acid volume include rice straw (China, India, Indonesia), maize stalks/stems (United States, China), wheat straw (Europe, China) and sugar cane tops/leaves (Brazil, India). For secondary residues, sugar cane bagasse is shown to hold a potential of more than 7 million ton of lactic acid, if all available bagasse would be used for lactic acid production. Interestingly, oil palm fronds (Indonesia, Malaysia) show a tremendous potential as well, with 19 million ton of lactic acid combined in the two countries.

In order to compare the lactic acid production potential with primary agricultural crops, Table 8 shows the same ranking of Table 7, however, included are similar data of main sugar and starch containing crops. As is the case with the agricultural residues, the assumption is made that all starch or sugar in these crops is converted into lactic acid. The results show that within the Top 30 ranking, there are 11 agricultural residues that could provide lactic acid at a comparable volume as the primary agricultural crops. If it is assumed that only 25% of the starch or sugar in primary agricultural crops is used for non-food purposes (as is currently the case with utilising maize in the United States for bioethanol production), the potential lactic acid production of most of the listed agricultural residues is higher than that of the primary crops including maize, wheat and barley.

Table 7 Lactic acid production potential per country; top 25 (out of 224)

Rank	Country	Feedstock*	Lactic acid potential
			(1000 ton/y; dry weight)
1	China	rice straw (P)	49,667
2	United States	maize stalks, stems (P)	38,224
3	Brazil	sugar cane tops/leaves (P)	31,407
4	Europe +	wheat straw (P)	29,903
5	India	rice straw (P)	29,474
6	India	sugar cane tops/leaves (P)	24,406
7	China	maize stalks, stems (P)	18,910
8	China	wheat straw (P)	17,726
9	United States	soybean stalks, leaves (P)	16,370
10	United States	maize cobs (S)	16,227
11	Indonesia	rice straw (P)	15,969
12	United States	wheat straw (P)	11,031
13	Europe +	barley straw (P)	10,847
14	Brazil	soybean stalks, leaves (P)	10,636
15	Russian Federation	wheat straw (P)	10,341
16	Europe +	maize stalks, stems (P)	9,939
17	Viet Nam	rice straw (P)	9,854
18	Indonesia	oil palm fronds (P)	9,537
19	Argentina	soybean stalks, leaves (P)	9,374
20	Malaysia	oil palm fronds (P)	9,313
21	China	maize cobs (S)	8,028
22	Thailand	rice straw (P)	7,365
23	Brazil	sugar cane bagasse (S)	7,272
24	China	cotton stalks (P)	6,491
25	India	wheat straw (P)	6,147

* P = primary agricultural residue; S = secondary agricultural residue

Table 8 Lactic acid production potential from crops and agricultural residues; top 30 (out of 447)

Rank	Country	Feedstock*	Lactic acid potential
			(1000 ton/y; dry weight)
1	United States	maize	160,715
2	Europe +	wheat	87,099
3	China	rice	81,714
4	China	maize	79,509
5	India	rice	63,040
6	China	wheat	51,631
7	China	rice straw (P)	49,667
8	Europe +	maize	41,790
9	Brazil	sugar cane	39,095
10	United States	maize stalks, stems (P)	38,224
11	India	wheat	35,807
12	United States	wheat	32,130
13	Brazil	sugar cane tops/leaves (P)	31,407
14	India	sugar cane	30,380
15	Russian Federation	wheat	30,122
16	Europe +	wheat straw (P)	29,903
17	India	rice straw (P)	29,474
18	Indonesia	rice	26,272
19	Europe +	barley	25,333
20	India	sugar cane tops/leaves (P)	24,406
21	Brazil	maize	22,323
22	China	maize stalks, stems (P)	18,910
23	Europe +	sugar beet	17,762
24	China	wheat straw (P)	17,726
25	United States	soybean stalks, leaves (P)	16,370
26	United States	maize cobs (S)	16,227
27	Indonesia	rice straw (P)	15,969
28	Canada	wheat	13,516
29	Thailand	rice	12,117
30	Mexico	maize	11,773

* P = primary agricultural residue; S = secondary agricultural residue

3.6 Fermentable sugar yield (ton/ha) based on agricultural residues and comparison with primary crops

From both a logistical as well as sustainability point of view, it is interesting to study the productivity of fermentable sugars from agricultural residues, based on total sugars produced per ha of agricultural land. The higher the productivity, the lower the collection costs and costs for replacing inputs.

Table 9 shows the country-by-country data of fermentable sugar yield (ton/ha) for all residues that exceed 6 ton of fermentable sugars/ha in productivity. Results show that on the whole, sugar cane residues (both tops/leaves and bagasse) are by far the most productive agricultural residue with productivities ranging from 4.2 to 8.7 ton/ha. In addition, the productivity of oil palm fronds (4.6 – 5.3/ha) and cotton stalks show a high productivity (4.1 – 5.3 ton/ha), although data for these two residues should be viewed with some caution as reliable data for carbohydrate composition are still lacking. The productivity of the other primary agricultural residues, wheat straw and maize stems/stalks (not shown) is generally lower, in the range of 0.7 to 2.0 ton/ha, depending on crop productivity and location.

Figures 2a and 2b show a similar ranking by fermentable sugar yield, but in this case the primary agricultural crops are shown (Figure 2a) as well as the agricultural residues (Figure 2b). Results of the model show that oil palm fronds, sugar cane tops/leaves, and sugar cane bagasse show a similar productivity in comparison with the highest crops in terms of fermentable sugar yield: sugar beet, sugar cane, and cassava, crops with highest sugar production. Therefore, data in Table 8 further show that sugar cane bagasse, oil palm fronds, sugar cane tops/leaves and cotton stalks could compete with the main sugar and starch crops in terms of fermentable sugar yield (ton/ha). The data also indicate the need to further improve the pretreatment efficiency for lignocellulosic biomass conversion to fermentable sugars, which would improve the fermentable sugar yield of most agricultural residues include maize and wheat residues.

Table 9. Fermentable sugar yield (ton/ha) from agricultural residues; Top 35 (out of 228)

Rank	Country	Feedstock*	Fermentable sugar yield (ton/ha)
1	Australia	sugar cane tops/leaves (P)	8.7
2	Colombia	sugar cane tops/leaves (P)	8.1
3	Mexico	sugar cane tops/leaves (P)	7.6
4	Brazil	sugar cane tops/leaves (P)	7.6
5	India	sugar cane tops/leaves (P)	7.4
6	United States	sugar cane tops/leaves (P)	7.3
7	Sudan	sugar cane tops/leaves (P)	6.8
8	Thailand	sugar cane tops/leaves (P)	6.5
9	Indonesia	sugar cane tops/leaves (P)	6.4
10	South Africa	sugar cane tops/leaves (P)	6.1
11	Viet Nam	sugar cane tops/leaves (P)	6.1
12	Australia	sugar cane bagasse (S)	6.1
13	Argentina	sugar cane bagasse (S)	6.0
14	Colombia	sugar cane bagasse (S)	5.6
15	Argentina	sugar cane tops/leaves (P)	5.4
16	China	cotton stalks (P)	5.3
17	Malaysia	oil palm fronds (P)	5.3
18	Mexico	sugar cane bagasse (S)	5.3
19	Brazil	sugar cane bagasse (S)	5.3
20	Pakistan	sugar cane tops/leaves (P)	5.2
21	India	sugar cane bagasse (S)	5.1
22	Malaysia	sugar cane tops/leaves (P)	5.0
23	United States	sugar cane bagasse (S)	5.0
24	Sudan	sugar cane bagasse (S)	4.7
25	Peru	oil palm fronds (P)	4.7
26	Australia	sugar cane tops/leaves (P)	8.7
27	Colombia	sugar cane tops/leaves (P)	8.1
28	Mexico	sugar cane tops/leaves (P)	7.6
29	Brazil	sugar cane tops/leaves (P)	7.6
30	India	sugar cane tops/leaves (P)	7.4
31	United States	sugar cane tops/leaves (P)	7.3
32	Sudan	sugar cane tops/leaves (P)	6.8
33	Thailand	sugar cane tops/leaves (P)	6.5
34	Indonesia	sugar cane tops/leaves (P)	6.4
35	South Africa	sugar cane tops/leaves (P)	6.1

* P = primary agricultural residue; S = secondary agricultural residue

Figure 2a. Fermentable sugar yield (ton/ha) of main crops; Top 40

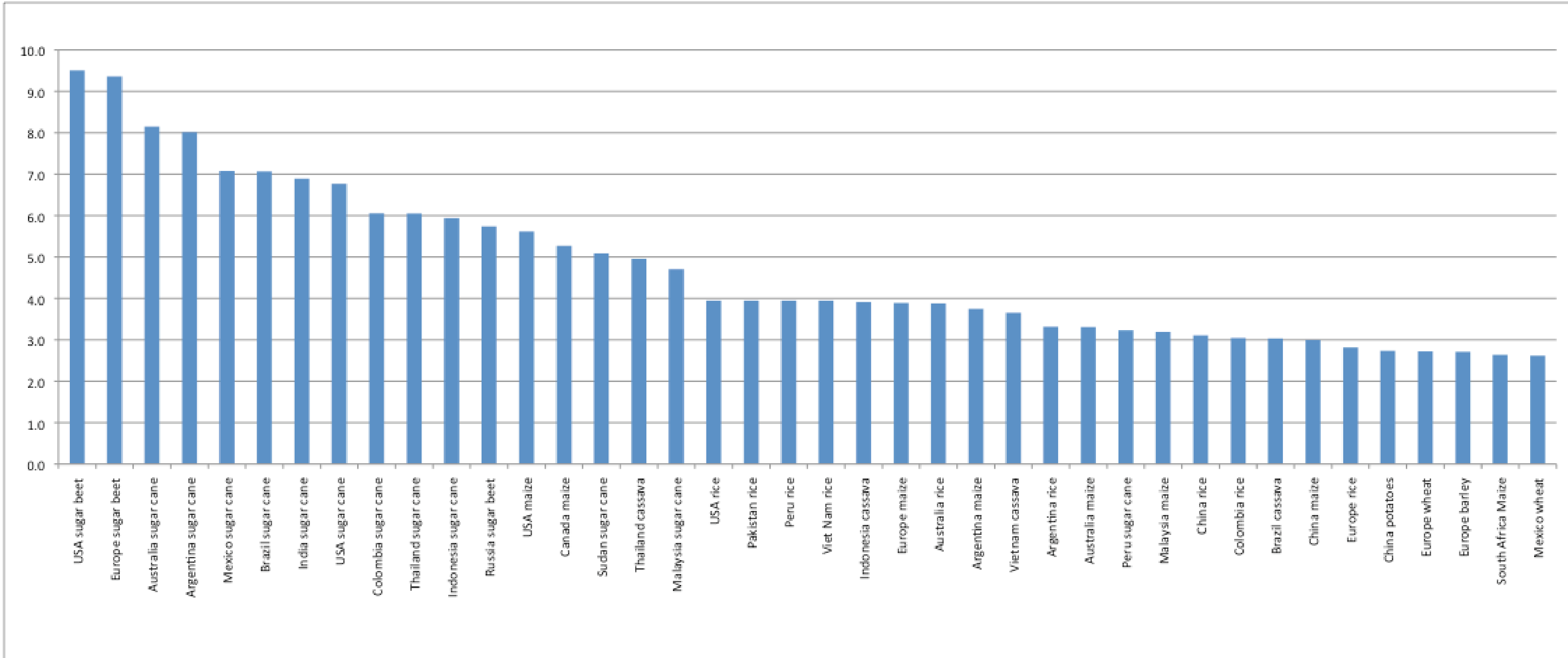
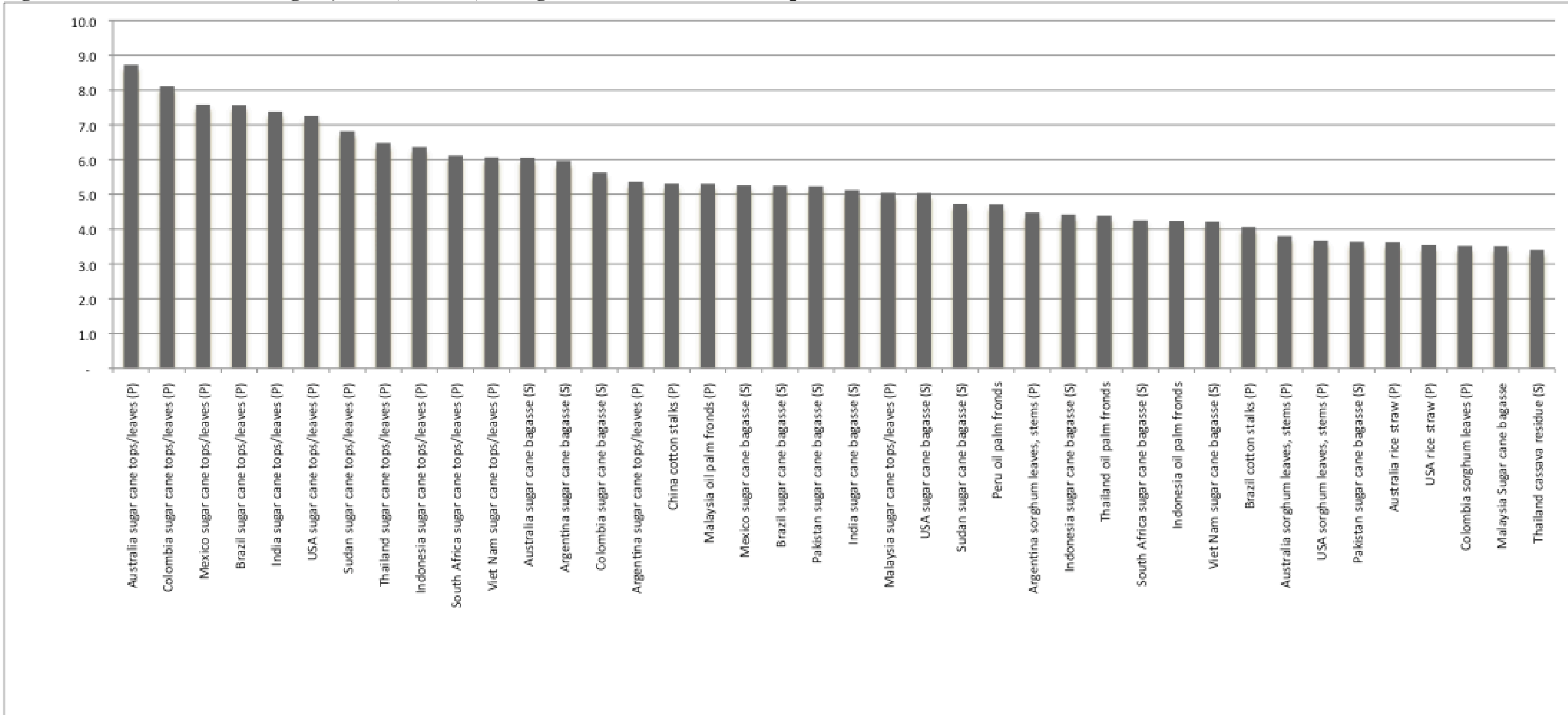


Figure 2b. Fermentable sugar yield (ton/ha) of agricultural residues; Top 40



3.7 Potential lignin production potential from available agricultural residues

As noted earlier, from a sustainability point of view it is important to consider the production potential of non-fermentable lignin from the available agricultural residues. Table 10 presents the Top 25 of agricultural residues in terms of total lignin production in GJ/y (Note: for comparison purposes, the amount of GJ can be divided by 41.868 to yield the energy production in ton of oil equivalent). The data show that the main lignin production potential is provided by those crop residues that also exhibit a large fermentable sugar production potential: rice and wheat straw, maize stalks/stems, sugar cane tops/leaves, bagasse and oil palm fronds. Further data analysis (not shown) indicates that there is a good correlation between fermentable sugar yield, and lignin production. In contrast with the data shown on biomass availability and fermentable sugar production potential, the lignin production potential of rice and wheat straw exceeds that of maize stalks/stems, due to a slightly higher lignin concentration in straw.

Table 10. Potential lignin production potential from available agricultural residues; Top 25

Rank	Country	Feedstock	Lignin production potential (GJ/y)
1	China	rice straw (P)	376,615
2	Brazil	sugar cane tops/leaves (P)	290,123
3	Europe +	wheat straw (P)	276,226
4	India	sugar cane tops/leaves (P)	225,451
5	India	rice straw (P)	223,496
6	United States	maize stalks, stems (P)	206,964
7	China	wheat straw (P)	163,742
8	United States	soybean stalks, leaves (P)	151,215
9	Indonesia	rice straw (P)	121,088
10	China	maize stalks, stems (P)	102,389
11	United States	wheat straw (P)	101,897
12	Brazil	soybean stalks, leaves (P)	98,249
13	Russian Federation	wheat straw (P)	95,528
14	Argentina	soybean stalks, leaves (P)	86,588
15	Indonesia	oil palm fronds (P)	77,819
16	Europe +	barley straw (P)	67,419
17	Malaysia	oil palm fronds (P)	66,287
18	Viet Nam	rice straw (P)	65,479
19	China	cotton stalks (P)	59,964
20	United States	maize cobs (S)	58,741
21	India	wheat straw (P)	56,779
22	China	rice husk (S)	56,149
23	Thailand	rice straw (P)	55,848
24	Europe +	maize stalks, stems (P)	53,815
25	Brazil	sugar cane bagasse (S)	48,868

4 Selection criteria for economical and sustainable use of agricultural feedstocks

4.1 Logistic requirements of utilising agricultural residues

As presented in the earlier chapters of this report, a number of important characteristics of agricultural residues can be distinguished that determine their suitability as feedstock for the production of lactic acid. Examples of these characteristics are the total availability of agricultural residues in a certain region, the lactic acid production potential (kg lactic acid per kg of feedstock) of certain residue, and the fermentable sugar yield (ton sugar per ha of agricultural land). These characteristics could therefore be used as criteria to rank lignocellulosic feedstocks, based on their technical suitability for lactic acid production. However, they do not include characteristics that determine the economic feasibility of collecting the feedstock, and transporting it to the lactic acid production facility. As one of the main economic criteria that affect the cost of the feedstock at the factory gate are cost associated to collection, storage, transport and pre-processing of the feedstock, it is worthwhile to distinguish how the origin of the feedstock affects logistical costs, and hence feedstock purchase cost.

Based on the origin of the agricultural residues, four groups of agricultural residues could be distinguished that determine logistical requirements (and hence cost) for agricultural residues. The main distinction of the groups is based on whether the agricultural residue is a primary residue (residue is generated at the field at harvest), or a secondary residue (residue is generated at a crop processing facility, such as a rice mill). A short description of these groups follows below.

To the first group (Group 1) belong secondary agricultural residues that are produced in significant quantities for direct use in a 2nd generation fermentation facility. This means that a lactic acid fermentation facility could be sited near an existing crop processing facility. Agricultural residues that belong to this group are sugar cane bagasse, maize cobs, and, depending on location, rice husk (in particular in countries where large, centralised rice mills are located). Logistical costs for the feedstocks in this group are minimal, as in most cases no feedstock transport is required. This however does not mean that the feedstock is "free of charge" , as in general these secondary residues are already used in some way: without this build-up of residues would occur at the site which would lead to disposal problems. For example, rice husk and sugar cane bagasse are widely used for generation of energy at rice mills or sugar mills. Therefore, the purchase price paid for the residues would, at a minimum, be comparable to the energy value contained in the feedstock.

To the second group (Group 2) belong secondary residues that are produced at (much) smaller processing facilities compared to Group 1. Although significant quantities of residues are generated at these smaller facilities, they are not generated in sufficient volume to supply one fermentation plant for lactic acid production (e.g. residues are produced at a annual rate of 5,000 to 25,000 tonnes of lignocellulosic residue-depending on the size of the processing plant). Examples of agricultural residues that belong to this group are empty fruit bunches, oil palm fibres and shells, coffee husks, coconut shells, and groundnut shells. In countries where rice and maize processing industries are quite fragmented, rice husk and maize residue are also included in this group. Although the agricultural residues in this group are secondary residues, they still need to be transported to a central site for use in a fermentation plant, and therefore transport costs will be added to the purchase cost of the feedstock. In some case, the residues will also need pre-processing prior to transport, such as densification to reduce transport volume, or drying to improve storage stability. The advantage over feedstocks from the first group however is that often the residues in this group are under-utilised and they do lead to disposal problems in particular in developing countries (e.g. dumping in waterways, or pile burning). Therefore, cost of acquiring these residues may be comparable, or even lower as agricultural residues from Group 1. Furthermore, using these residues to avoid disposal may generate additional environmental benefits.

Most of the primary agricultural residues are located in the third, Group 3. The main characteristic of this group of primary residues is that logistics for collecting the residues at the field level and transporting them to a central site, are already in place. For these agricultural residues already a certain market exist, although in general not all of the residues are already collected and used. Examples of agricultural residues belonging to Group 3 are wheat straw, maize Stalks/stems, barley straw, and, depending on location: rice straw, soybean stalks, cotton stalks. Although the residues in itself do not represent a high cost of acquisition, the main cost associated to the feedstock is collection in the field, from the field to the road-side, and road transportation to the conversion facility. The costs for collection and transport of primary agricultural residues are site- and region-specific, and depend, among others, on the productivity of the agricultural residue (ton of residue per ha of land) and how much of the residue is removed from any particular field or location. For example, costs for acquiring wheat straw in Southern Europe from a 90 km collection radius (for collection of 300,000 tons of straw/year) were estimated at 40 €/ton straw, which includes 6 €/ton as payment to the farmer, 18 €/ton for baling, and 12 €/ton for transport to the conversion facility (JRC, 2007). For collection of a 160,000 tons of straw, the collection radius would be 33 km if 100% of straw is collected, 39 km if 70% is collected, and 46 km if 50% is collected. For a discussion on how much residues can be sustainably removed, please refer to the following paragraph.

The final group, Group 4, is characterised by primary agricultural residue for which in general, logistics are not in place and thus need to be developed. The primary residues in this group are not collected in any organised manner, are left in the field, disposed of, or used locally. This means that significant investments will need to be made in to build up logistics of feedstock supply in order to mobilise these agricultural residues i.e. collect them and transport them to a central facility. In addition, there is considerable uncertainty regarding the year-to-year availability of residues, as no previous experience with residue collection has been built up. Residues that belong to this group are rice straw (in particular in regions with many smallholder farms), sorghum stalks, cotton stalks, cassava residues, and oil palm fronds. The advantage of this group over Group 3 is that, since these residues are under-utilised to a much greater extent, costs for acquiring the feedstock may be lower. In addition, residues of Group 4 are often disposed of by open field burning, and therefore utilising them may generate additional environmental benefits.

In conclusion, an initial indication of feedstock cost for different agricultural residues can be made by distinguishing in which of the groups the agricultural residue belongs.

4.2 Sustainable use of agricultural residues

Besides meeting certain technical suitability and economic criteria, the use of agricultural residues for lactic acid production will have to meet sustainability criteria. Sustainability criteria are met to make sure that the production of chemicals or fuels from agricultural biomass leads to more sustainable production compared to alternate production routes, including fossil-fuel based routes. So far, sustainability criteria for processes that rely on using renewable biomass as raw material have been in development, and some are implemented for the production of liquid biofuels and renewable electricity. While it is beyond the scope of this study to complete a full analysis of these sustainability criteria for using agricultural residues, some general remarks regarding sustainability are summarised in this paragraph.

The main sustainability factors related to using agricultural residues as feedstock for 2nd generation fermentation processes include: greenhouse gas balance, biodiversity maintenance, soil fertility maintenance, waste management, and competition with food (often referred to as iLUC: indirect land use changes).

- The <u>greenhouse gas balance</u> of using agricultural residues is primarily affected by direct emissions associated to the feedstock supply chain, which includes collection, transport, and pre-processing operations. In these operations, energy is consumed, which in turn leads to emission of additional greenhouse gases that are related to fossil energy use. Besides the direct emissions from supply chain operations, indirect greenhouse gas emissions may occur, in particular when removal of agricultural residues leads to an increase in use of fertilizers to maintain the agricultural productivity of the land from which the agricultural residue was removed. The greenhouse gas balance of agricultural residue utilization can be calculated with available methodology, and input data are generally very specific for a situation. Generally speaking, the lower the primary energy demand of the agricultural residue supply chain, the better.

- To what extent use of agricultural residues leads to decline in Biodiversity is very difficult to assess. In general, sustainability criteria for Biodiversity dictate that the biomass cannot be derived from nature-sensitive areas or from marginal lands, where removal of ground cover leads to undesirable changes in biodiversity. In general, the agricultural residues from the main agricultural crops described in this study, are not derived from nature-sensitive areas, and changes in biodiversity due to removal and use of agricultural residues are not anticipated. Site-specific studies however should be undertaken to assess whether removal of agricultural residues from a specific region will lead to changes in biodiversity.
- Maintaining soil fertility is a primary factor in assessing sustainability of agricultural residue utilization. Maintenance of soil fertility generally deals with the question how much agricultural residue can be sustainably removed from year to year, without long-term negative effects on agricultural productivity of the land. As stipulated by Kim and Dale (2004), the fraction of agricultural residues collectable for biofuel, or other purposes, is not easily quantified because it depends on the weather, crop rotation, existing soil fertility, slope of the land, and farming practices which are all very location specific. For maize stalks (corn stover) in the United States, there are very site-specific guidelines as to how much residue should remain in the field, in order to prevent soil erosion. This is especially true in cases where the agricultural land is sloping, and there is no (other) ground cover during winter time, except for maize residues. The impact of the removal rate of other agricultural residue on long-term soil fertility is a topic of many research projects, and general recommendations are difficult to find. It is known however that removal of wheat straw or rice straw can lead to higher fertilization rates in subsequent years (in general 20% higher fertilizer use), however if properly managed, soil fertility can be maintained even when agricultural residues are removed on a season-to-season basis. It is further known that alternatives to straw removal, such as incorporation of straw in the soil, may lead to nitrogen immobilization in the soil, which again leads to higher fertilization requirements. Incorporation of residues may also lead to increased N_2O emissions from soils, which will have a large effect on the greenhouse gas balance.
- How waste management is organised is very important in any sustainability assessment, however, waste management is more an issue related to the conversion process itself where the agricultural residue is converted into a product, rather than the choice of agricultural feedstock alone, or its supply chain. Utilising certain agricultural residues, in particular those that otherwise are disposed of by field burning or dumping in the environment, may actually generate benefits in terms of waste management, as noted earlier in this report.
- The use of agricultural residues for producing biofuels or chemicals is generally not associated to lead to an increase in competition for available agricultural land (iLUC principle). Often, agricultural residues are considered to be "iLUC-free" biomass feedstocks: the use of these feedstocks does not lead to changes in land use on a large scale. However, the use of certain agricultural residues, in particular those with higher

protein content and high digestibility that are used as animal feeds, could lead to increased use of other animal fodders, and hence lead to displacement of agricultural land. The international debate on iLUC is very much on-going and researchers around the world are seeking ways to quantify these effects. ILUC can potentially undermine sustainability of biomass chains, even if the direct effects result overall positive. As long as there is no agreed upon iLUC factor, no biomass chain sustainability study should claim to have the final answer. In the vast majority of cases, the agricultural residues described in this report are underutilised, and hence utilising them is not likely to lead to displacement of agricultural crop production in other areas of the world.

In summary, several factors can be distinguished that affect the sustainability of using agricultural residues as feedstock for fermentation processes. The most important factors are the greenhouse gas balance of the supply chain, the extent to which soil fertility can be maintained while removing agricultural residues, and waste management. In cases where current disposal methods of agricultural residues lead to environmental pollution (e.g. open field burning of straw), residue utilization may lead to a positive effect on sustainability. Most factors that affect sustainability are very location- and residue specific, and therefore they need to be assessed on a case-to-case basis.

4.3 Ranking of criteria for selecting agricultural residues as feedstocks

By taking the results of the recently finalised EU project HYVOLUTION as example (refer to www.biohydrogen.nl/hyvolution/26240/7/0/20), a suitability map was drafted that assesses the suitability of using different agricultural residues for lactic acid production. The suitability map is presented by a spider diagram that incorporates the various characteristics from a technical, economic, and sustainability viewpoint. The suitability map serves to make initial comparisons between agricultural feedstocks of a different nature or origin, and encompasses the following:

- agricultural residue availability (ton/y)
- fermentable sugar yield (t/ha)
- lactic acid production potential (t/y)
- logistical requirements of the feedstock (based on 4 groups of feedstocks according to their logistics requirement, see paragraph 4.1), and
- sustainability of the feedstock supply chain

For each of these five characteristics, a certain agricultural residue receives a score of one to four, with one being the least favourable condition, and four being the most favourable conditions. The following guidelines for ranking were used:

- Residue availability:
    - score 1 : lowest availability to

- score 4 : highest availability, depending on range of data of selected group of feedstocks,

- Fermentable Sugar yield:
  - score 1 : less than 1.0 t/ha,
  - score 2 : 1 to 2 t/ha;
  - score 3 : 2 to 3 t/ha; and
  - score 4 : 3 t/ha or higher,
- Lactic acid production potential:
  - score 1 = lowest potential to score 4 = highest potential, depending on range of data of selected group of feedstocks,
- Logistical requirement:
  - score 1 = residue belongs to group 4 (primary residue with no existing infrastructure for collection),
  - score 2 = residue belonging to group 3 (primary residue with existing infrastructure),
  - score 3 = residue belonging to group 2 (secondary residue produced at small facilities), and
  - score 4 = residue belonging to group 1 (secondary residue produced at larger processing facilities)
- Sustainability: it is assumed that all agricultural residues can be sustainably removed, the greenhouse gas balance of their supply chain is acceptable, residue use does not interfere with biodiversity decline or competition for agricultural land, score = 4 (most favorable sustainability)

Figure 3 shows an example of the suitability map for four residues, based on the data from the availability model: shown are sugar cane bagasse in Brazil, wheat straw in Canada, empty fruit bunch in Malaysia, and rice straw in Vietnam. The results that sugar cane bagasse and rice straw show better characteristics compared to wheat straw and empty fruit bunch, with bagasse scoring better on fermentable sugar yield and logistics requirements, and rice straw scoring better on availability and lactic acid potential.

Figure 3. Suitability map of four agricultural residues from different countries

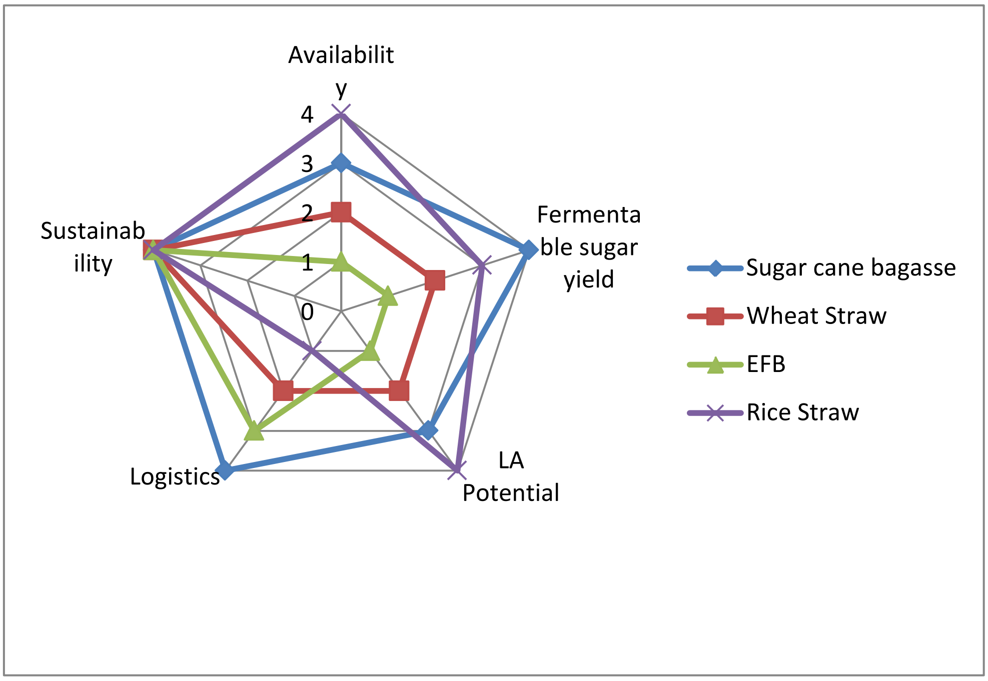


Figure 4. Suitability map of maize stalks from four different countries

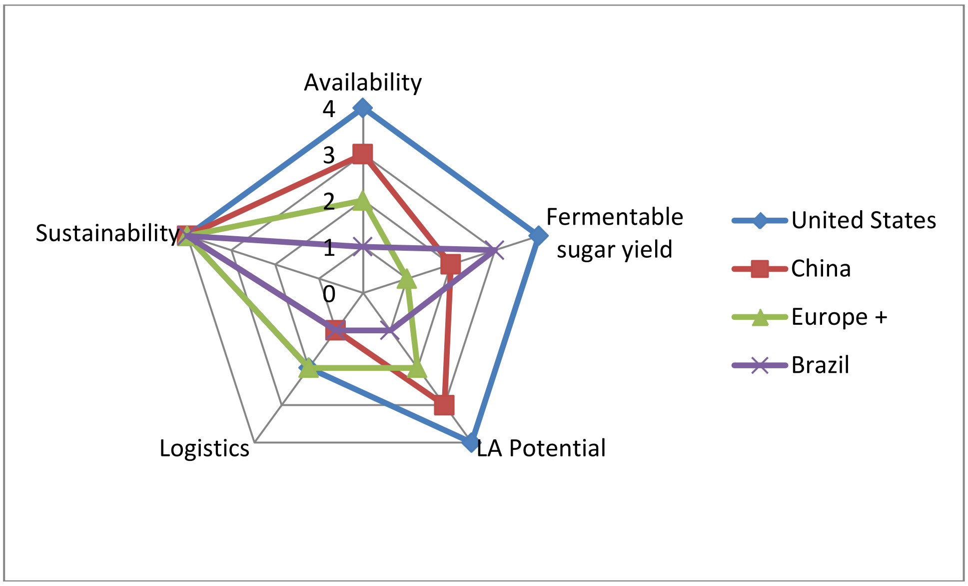


Figure 4 shows a suitability map for the same agricultural residue, maize stalks/stems, produced in four countries, United States, China, Europe, and Brazil. In the scoring for logistics requirement, it is assumed that in United States and Europe logistical infrastructure to collect maize residues on a large, commercial scale are already in place, whereas in China and Brazil, the infrastructure still needs to be developed. The results in Figure 4 show that the United States would be the preferable location to implement utilisation of maize stalks as feedstock for fermentation purposes, followed by China and Europe.

In summary, the suitability map provides a tool to do an initial screening and selection of agricultural residues as feedstocks for lactic acid fermentation, based on characteristics such as residue availability and fermentable sugars. It could be easily adapted to include other characteristics, and more region-specific data.

5 Conclusions and Recommendations

This study presented an overview of both world-wide and country-by-country availability of (lignocellulose) agricultural residues from the major agricultural crops in the world. Results show that in terms of agricultural residue availability and associated fermentable sugar production, agricultural residues can provide vast amount of fermentable sugars, even if current rate of utilisation is considered. For the 22 countries and one region (Europe; 37 countries aggregated) combined, the total availability of agricultural residues combined based on agricultural production in 2008 amounts to 1496 million tons of lignocellulose feedstock (dry weight basis). The main agricultural residues in terms of volume include the primary and secondary residues of maize, rice, wheat, and sugar cane. In addition, in certain regions the available biomass includes oil palm residues, cotton stalks, residues from root crops (cassava) as well as other agricultural crops. In terms of productivity per ha, sugar cane residues (both bagasse as well as sugar cane tops/leaves), oil palm fronds and rice straw show highest productivity. Finally, the conversion of agricultural residues into fermentable sugars would also result in considerable production of non-fermentable lignin, that can be used to generate energy. This is often overlooked when fermentable sugar production potential of agricultural residues is compared with sugar production from starch or sugar crops. The country-by-country data for 447 crops and agricultural residues are comprised in a spreadsheet model that can be adapted when newer data become available, or used for scenario-based studies. A copy of the current spreadsheet model is provided in Appendix C.

Based on the origin of the agricultural residues, four groups of agricultural residues were distinguished that determine logistical requirements (and hence cost) for agricultural residues. The main distinction of the groups is based on whether the agricultural residue is a primary residue (residue is generated at the field at harvest), or a secondary residue (residue is generated at a crop processing facility, such as a rice mill).

Besides availability, lactic acid production potential, and logistic requirements several factors can be distinguished that affect the sustainability of using agricultural residues as feedstock for fermentation processes. The most important factors are the greenhouse gas balance of the supply chain, the extent to which soil fertility can be maintained while removing agricultural residues, and waste management. In cases where current disposal methods of agricultural residues lead to environmental pollution (e.g. open field burning or dumping of agricultural residues), residue utilization may lead to a positive effect on sustainability. Most factors that affect sustainability are very location- and residue specific however, and therefore they need to be assessed on a location-specific basis.

A simple suitability map was presented as a tool to do initial comparison and selection of agricultural residues as feedstocks for lactic acid fermentation, based on characteristics such as agricultural residue availability, fermentable sugar yield, logistics and sustainability.

The following recommendations should be taken into account for further study of biomass availability:

- In the current study, the Residue to Crop ratio (kg residue per kg crop produced) for each crop was standardised and no regional differences were included in the spreadsheet model so far. In further studies, region-to-region differences in the assessment of biomass availability should be incorporated to improve the reliability of country-by-country data.

- While in most cases conservative or medium values were taken for "Rate of Current utilisation" (ROC) of agricultural residues, the current rate of utilisation should be adapted to more closely represent regional differences. It is likely that residues for which a 75% ROC is taken, current utilisation can be optimised, which would increase biomass availability for lactic acid production or other non-food purposes. At the same time, for residues for which a medium or low (25%) ROC was assumed, it is possible that actual demand for these residues is higher (e.g. by increasing use as animal feed, or combustion for energy), which would lower the biomass availability for these residues.

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Appendices

Appendix A. Assumed values for calculational model: moisture content crops, residue-to-crop ratio (RCR), and current utilisation rate (ROC)

Appendix B. Assumed values for carbohydrate content of crops and agricultural residues, pretreatment/hydrolysis efficiency, and lignin content (All concentrations on % dry matter basis; NA = data not applicable)

Appendix C. Screenshot of Agricultural residue assessment spreadsheet model

Appendix D: Excerpts from AgentschapNL commissioned study on sugar cane bagasse and trash availability (AgentschapNL, 2012)

Appendix A. Assumed values for calculational model: moisture content crops, residu-to-crop ratio (RCR), and current utilisation rate (ROC)

Crop Residu	Moisture content crop (%)	RCR (residu to crop ratio, g/g)	ROC (rate of current utilisation, %)
Soybeans stalks, stems	15	2.5	75
Wheat straw	15	1.0	50
Maize stalks, leaves	15	0.7	50
Sorghum stalks, stems	15	2.62	75
Sugar cane tops/leaves	75	0.96	25
Seed cotton stalks	15	3.5	75
Rice straw	15	1.25	35
Groundnuts residues	15	2.5	75
Cassava residues	65	0.2	75
Coconut husk	10	0.6	50
Coffee husk	15	2.1	75
Oil Palm fronds	60	1.50	50
Oil palm EFB	60	0.16	25
Oil palm Shells	40	0.07	75
Oil palm Fibre	40	0.17	75
Rice husk	15	0.2	50
Maize cobs	15	0.5	75
Sugar cane bagasse	75	0.6	75
Barley straw	15	1.0	50

Appendix B. Assumed values for carbohydrate content of crops and agricultural residues, pretreatment/hydrolysis efficiency, and lignin content (All concentrations on % dry matter basis; NA = data not applicable)

Product	Carbohydrate content	Pretreatment/hydrolysis Efficiency	Fermentable sugar/feedstock	lignin content	lignin energy/feedstock
	(wt-%)	(%)	(kg sugar/kg feedstock)	(%)	(GJ/ton feedstock)
Soybeans	NA			NA	
soybean stalks, leaves (P)	53	80	0.424	23.5	3.5
Wheat	65	95	0.618	NA	
wheat straw (P)	53	80	0.424	23.5	3.5
sunflower seed	NA			NA	
sunflower stalks, stems (P)	53	80	0.424	23.5	3.5
Sorghum	50	95	0.475	NA	
sorghum leaves, stems (P)	53	80	0.424	23.5	3.5
Sugar cane	10	95	0.095	NA	
sugar cane bagasse (S)	58.9	80	0.471	19	2.9
sugar cane tops/leaves (P)	53	80	0.424	23.5	3.5
Seed cotton	NA			NA	
cotton stalks (P)	53	80	0.424	23.5	3.5
Rice, paddy	60	95	0.570	NA	
rice straw (P)	53.3	80	0.426	19.4	2.9
rice husk (S)	53	80	0.424	23.5	3.5
Groundnuts, with shell	NA			NA	
groundnut shells (S)	53	80	0.424	23.5	3.5
Cassava	65	95	0.618	5	0.8
cassave residu (S)	50	85	0.425	NA	
Coconuts	NA			NA	
coconut husk (S)	45	80	0.360	32.8	4.9
Coffee, green	NA			NA	
coffee husk (S)	53	80	0.424	22	3.3
Oil palm fruit	NA			NA	
oil palm fronds (P)	60	80	0.480	20.5	3.1
empty fruit bunch (S)	57.7	80	0.462	17	2.6
oil palm fibres (S)	53	80	0.424	23.5	3.5
oil palm shells (S)	53	80	0.424	23.5	3.5
Maize	72	95	0.684	NA	
maize stalks, stems	58.1	80	0.465	15.1	2.3
maize cobs (S)	65	85	0.553	12	1.8
sugar beet	16	99	0.158	NA	
Barley	59	95	0.561	NA	
Barley straw (P)	60	80	0.480	17.9	2.7

Appendix C. Screenshot of Agricultural residue assessment spreadsheet model

C	49	Indonesia	rice	12309	60251	4.9	15	51213						0.570	29192	2.4	29192	26272		
P	50	Indonesia	rice straw (P)	12309					1.25	64017	5.2	35	41611	0.426	27297	2.2	17743	15969	2.9	121088
S	51	Indonesia	rice husk (S)	12309					0.2	10243	0.8	50	5121	0.424	4343	0.4	2171	1954	3.5	18053
C	52	Indonesia	oil palm fruit	5000	85000	17.0	50	42500						0.000	0	0.0	0	0		
P	53	Indonesia	oil palm fronds (P)	5000					1.5	63750	12.8	50	31875	0.595	37931	7.6	18966	17069	3.5	112359
S	54	Indonesia	empty fruit bunch (S)	5000					0.161	6843	1.4	25	5132	0.462	3158	0.6	2369	2132	2.6	13086
S	55	Indonesia	oil palm fibres (S)	5000					0.168	7140	1.4	75	1785	0.424	3027	0.6	757	681	3.5	6292
S	56	Indonesia	oil palm shells (S)	5000					0.072	3060	0.6	75	765	0.424	1297	0.3	324	292	3.5	2697
C	57	Indonesia	maize	4003	16324	4.1	15	13875						0.684	9491	2.4	9491	8542		
P	58	Indonesia	maize stalks, stems (P)	4003					0.7	9713	2.4	50	4856	0.465	4515	1.1	2257	2032	2.3	11000
S	59	Indonesia	maize cobs (S)	4003					0.5	6938	1.7	75	1734	0.553	3833	1.0	958	862	1.8	3122
C	60	Indonesia	coconuts	2950	19500	6.6	10	17550						0.000	0	0.0	0	0		
S	61	Indonesia	coconut husk (S)	2950					0.6	10530	3.6	50	5265	0.360	3791	1.3	1895	1706	4.9	25904
C	62	Indonesia	cassava	1193	21593	18.1	65	7558						0.618	4667	3.9	4667	4200		
S	63	Indonesia	cassave residu (S)	1193					0.2	1512	1.3	75	378	0.425	642	0.5	161	145	0.8	283
C	64	Indonesia	coffee	977	683	0.7	15	581						0.000	0	0.0	0	0		
S	65	Indonesia	coffee husk (S)	977					2.1	1219	1.2	75	305	0.424	517	0.5	129	116	3.3	1006
C	66	Indonesia	groundnuts	636	774	1.2	15	657.9						0.000	0	0.0	0	0		
S	67	Indonesia	groundnut shells (S)	636					2.5	1645	2.6	75	411	0.424	697	1.1	174	157	3.5	1449
C	68	Indonesia	soybeans	592	776	1.3	15	660						0.000	0	0.0	0	0		
P	69	Indonesia	soybean stalks, leaves (P)	592					2.5	1649	2.8	75	412	0.424	699	1.2	175	157	3.5	1453
C	70	Indonesia	sugar cane	416	26000	62.5	75	6500						0.095	2470	5.9	2470	2223		
S	71	Indonesia	sugar cane bagasse (S)	416					0.6	3900	9.4	75	975	0.471	1838	4.4	459	413	2.9	2779
P	72	Indonesia	sugar cane tops/leaves (P)	416					0.96	6240	15.0	25	4680	0.424	2646	6.4	1984	1786	3.5	16497
C	73	Indonesia	seed cotton	22	32	1.5	15	27						0.000	0	0.0	0	0		
P	74	Indonesia	cotton stalks (P)	22					3.5	95	4.3	75	24	0.424	40	1.8	10	9	3.5	84
C	75	Malaysia	oil palm fruit	3900	83000	21.3	50	41500						0.000	0	0.0	0	0		
P	76	Malaysia	oil palm fronds (P)	3900					1.5	62250	16.0	50	31125	0.595	37039	9.5	18519	16667	3.1	95709
S	77	Malaysia	empty fruit bunch (S)	3900					0.161	6682	1.7	25	5011	0.462	3084	0.8	2313	2082	2.6	12778
S	78	Malaysia	oil palm fibres (S)	3900					0.168	6972	1.8	75	1743	0.424	2956	0.8	739	665	3.5	6144
S	79	Malaysia	oil palm shells (S)	3900					0.072	2988	0.8	75	747	0.424	1267	0.3	317	285	3.5	2633
C	80	Malaysia	rice	656	2353	3.6	15	2000						0.570	1140	1.7	1140	1026		
P	81	Malaysia	rice straw (P)	656					1.25	2500	3.8	35	1625	0.426	1066	1.6	693	624	2.9	4729
S	82	Malaysia	rice husk (S)	656					0.2	400	0.6	50	200	0.424	170	0.3	85	76	3.5	705
C	83	Malaysia	coconuts	174	455	2.6	10	410						0.000	0	0.0	0	0		
S	84	Malaysia	coconut husk (S)	174					0.6	246	1.4	50	123	0.360	88	0.5	44	40	4.9	604
C	85	Malaysia	coffee	50	29	0.6	15	25						0.000	0	0.0	0	0		
S	86	Malaysia	coffee husk (S)	50					2.1	52	1.0	75	13	0.424	22	0.4	5	5	3.3	43
C	87	Malaysia	cassava	41	430	10.5	65	151						0.618	93	2.3	93	84		
S	88	Malaysia	cassave residu (S)	41					0.2	30	0.7	75	8	0.425	13	0.3	3	3	0.8	6
C	89	Malaysia	sugar cane	14	694	49.6	75	173.5						0.095	66	4.7	66	59		
S	90	Malaysia	sugar cane bagasse (S)	14					0.6	104	7.4	75	26	0.471	49	3.5	12	11	2.9	74
P	91	Malaysia	sugar cane tops/leaves (P)	14					0.96	167	11.9	25	125	0.424	71	5.0	53	48	3.5	440
C	92	Malaysia	maize	6	33	5.5	15	28						0.684	19	3.2	19	17		
P	93	Malaysia	maize stalks, stems (P)	6					0.7	20	3.3	50	10	0.465	9	1.5	5	4	2.3	22
S	94	Malaysia	maize cobs (S)	6					0.5	14	2.3	75	4	0.553	8	1.3	2	2	1.8	6
C	95	Nigeria	sorghum	7617	9318	1.2	15	7920						0.475	3762	0.5	3762	3386		
P	96	Nigeria	sorghum leaves, stems (P)	7617					2.62	20751	2.7	75	5188	0.424	8799	1.2	2200	1980	3.5	18287
C	97	Nigeria	maize	3845	7525	2.0	15	6396						0.684	4375	1.1	4375	3938		
P	98	Nigeria	maize stalks, stems (P)	3845					0.7	4477	1.2	50	2239	0.465	2081	0.5	1041	936	2.3	5071
S	99	Nigeria	maize cobs (S)	3845					0.5	3198	0.8	75	800	0.553	1767	0.5	442	398	1.8	1439
C	100	Nigeria	cassava	3778	44582	11.8	65	15604						0.618	9635	2.6	9635	8672		
S	101	Nigeria	cassave residu (S)	3778					0.2	3121	0.8	75	780	0.425	1326	0.4	332	298	0.8	585
C	102	Nigeria	oil palm fruit	3200	8500	2.7	50	4250						0.000	0	0.0	0	0		
P	103	Nigeria	oil palm fronds (P)	3200					1.5	6375	2.0	50	3188	0.595	3793	1.2	1897	1707	3.1	9802
S	104	Nigeria	empty fruit bunch (S)	3200					0.161	684	0.2	25	513	0.462	316	0.1	237	213	2.6	1309
S	105	Nigeria	oil palm fibres (S)	3200					0.168	714	0.2	75	179	0.424	303	0.1	76	68	3.5	629
S	106	Nigeria	oil palm shells (S)	3200					0.072	306	0.1	75	77	0.424	130	0.0	32	29	3.5	270
C	107	Nigeria	rice	2382	4179	1.8	15	3552						0.570	2025	0.9	2025	1822		
P	108	Nigeria	rice straw (P)	2382					1.25	4440	1.9	35	2886	0.426	1893	0.8	1231	1108	2.9	8399
S	109	Nigeria	rice husk (S)	2382					0.2	710	0.3	50	355	0.424	301	0.1	151	136	3.5	1252
C	110	Nigeria	groundnuts	2300	3900	1.7	15	3315						0.000	0	0.0	0	0		
S	111	Nigeria	groundnut shells (S)	2300					2.5	8288	3.6	75	2072	0.424	3514	1.5	878	791	3.5	7303
C	112	Nigeria	soybeans	609	591	1.0	15	502						0.000	0	0.0	0	0		
P	113	Nigeria	soybean stalks, leaves (P)	609					2.5	1256	2.1	75	314	0.424	532	0.9	133	120	3.5	1107
C	114	Nigeria	seed cotton	427	492	1.2	15	418						0.000	0	0.0	0	0		
P	115	Nigeria	cotton stalks (P)	427					3.5	1464	3.4	75	366	0.424	621	1.5	155	140	3.5	1290
C	116	Nigeria	sugar cane	62	1412	22.8	75	353						0.095	134	2.2	134	121		
S	117	Nigeria	sugar cane bagasse (S)	62					0.6	212	3.4	75	53	0.471	100	1.6	25	22	2.9	151
P	118	Nigeria	sugar cane tops/leaves (P)	62					0.96	339	5.5	25	254	0.424	144	2.3	108	97	3.5	896
C	119	Nigeria	coconuts	41	234	5.7	10	211						0.000	0	0.0	0	0		
S	120	Nigeria	coconut husk (S)	41					0.6	126	3.1	50	63	0.360	45	1.1	23	20	4.9	311
C	121	Nigeria	wheat	32	53	1.7	15	45						0.618	28	0.9	28	25		
P	122	Nigeria	wheat straw (P)	32					1	45	1.4	50	23	0.424	19	0.6	10	9	3.5	79
C	123	Nigeria	coffee	4	5	1.3	15	4						0.000	0	0.0	0	0		
S	124	Nigeria	coffee husk (S)	4					2.1	9	2.2	75	2	0.424	4	0.9	1	1	3.3	7

C	125	Sudan	sorghum	6619	3869	0.6	15	3289						0.475	1562	0.2	1562	1406		
P	126	Sudan	sorghum leaves, stems (P)	6619					2.62	8616	1.3	75	2154	0.424	3653	0.6	913	822	3.5	7593
C	127	Sudan	groundnuts	954	716	0.8	15	608.6						0.000	0	0.0	0	0		
S	128	Sudan	groundnut shells (S)	954					2.5	1522	1.6	75	380	0.424	645	0.7	161	145	3.5	1341
C	129	Sudan	wheat	302	587	1.9	15	499						0.618	308	1.0	308	277		
P	130	Sudan	wheat straw (P)	302					1	499	1.7	50	249	0.424	212	0.7	106	95	3.5	879
C	131	Sudan	seed cotton	97	107	1.1	15	91						0.000	0	0.0	0	0		
P	132	Sudan	cotton stalks (P)	97					3.5	318	3.3	75	80	0.424	135	1.4	34	30	3.5	281
C	133	Sudan	sugar cane	89	5962.4	67.0	75	1490.6						0.076	453	5.1	453	408		
S	134	Sudan	sugar cane bagasse (S)	89					0.6	894	10.0	75	224	0.471	421	4.7	105	95	2.9	637
P	135	Sudan	sugar cane tops/leaves (P)	89					0.96	1431	16.1	25	1073	0.424	607	6.8	455	410	3.5	3783
C	136	Sudan	maize	31	62	2.0	15	53						0.684	36	1.2	36	32		
P	137	Sudan	maize stalks, stems (P)	31					0.7	37	1.2	50	18	0.465	17	0.6	9	8	2.3	42
C	138	Sudan	rice	7	30	4.3	15	26						0.570	15	2.1	15	13		
P	139	Sudan	rice straw (P)	7					1.25	32	4.6	35	21	0.426	14	1.9	9	8	2.9	60
S	140	Sudan	rice husk (S)	7					0.2	5	0.7	50	3	0.424	2	0.3	1	1	3.5	9
C	141	Brazil	soybeans	22047	52465	2.4	15	44595						0.000	0	0.0	0	0		
P	142	Brazil	soybean stalks, leaves (P)	22047					2.5	111488	5.1	75	27872	0.424	47271	2.1	11818	10636	3.5	98249
C	143	Brazil	maize	12613	42662	3.4	15	36263						0.684	24804	2.0	24804	22323		
P	144	Brazil	maize stalks, stems (P)	12613					0.7	25384	2.0	50	12692	0.465	11798	0.9	5899	5309	2.3	28747
S	145	Brazil	maize cobs (S)	12613					0.5	18131	1.4	75	4533	0.553	10018	0.8	2504	2254	1.8	8159
C	146	Brazil	sugar cane	6144	457246	74.4	75	114312						0.095	43438	7.1	43438	39095		
S	147	Brazil	sugar cane bagasse (S)	6144					0.6	68587	11.2	75	17147	0.471	32318	5.3	8080	7272	2.9	48868
P	148	Brazil	sugar cane tops/leaves (P)	6144					0.96	109739	17.9	25	82304	0.424	46529	7.6	34897	31407	3.5	290123
C	149	Brazil	rice	2971	11527	3.9	15	9798						0.570	5585	1.9	5585	5026		
P	150	Brazil	rice straw (P)	2971					1.25	12247	4.1	35	7961	0.426	5222	1.8	3394	3055	2.9	23166
S	151	Brazil	rice husk (S)	2971					0.2	1960	0.7	50	980	0.424	831	0.3	415	374	3.5	3454
C	152	Brazil	coffee	2312	2573	1.1	15	2187						0.000	0	0.0	0	0		
S	153	Brazil	coffee husk (S)	2312					2.1	4593	2.0	75	1148	0.424	1947	0.8	487	438	3.3	3789
C	154	Brazil	cassava	1897	26639	14.0	65	9324						0.618	5757	3.0	5757	5182		
S	155	Brazil	cassave residu (S)	1897					0.2	1865	1.0	75	466	0.425	793	0.4	198	178	0.8	350
C	156	Brazil	wheat	1560	2485	1.6	15	2112						0.618	1304	0.8	1304	1174		
P	157	Brazil	wheat straw (P)	1560					1	2112	1.4	50	1056	0.424	896	0.6	448	403	3.5	3723
C	158	Brazil	seed cotton	899	2899	3.2	15	2464						0.000	0	0.0	0	0		
P	159	Brazil	cotton stalks (P)	899					3.5	8625	9.6	75	2156	0.424	3657	4.1	914	823	3.5	7600
C	160	Brazil	sorghum	722	1605	2.2	15	1364						0.475	648	0.9	648	583		
P	161	Brazil	sorghum leaves, stems (P)	722					2.62	3574	5.0	75	894	0.424	1516	2.1	379	341	3.5	3150
C	162	Brazil	coconuts	290	2978	10.3	10	2680						0.000	0	0.0	0	0		
S	163	Brazil	coconut husk (S)	290					0.2	536	1.8	50	268	0.360	193	0.7	96	87	4.9	1319
C	164	Brazil	groundnuts	111	250	2.3	15	213						0.000	0	0.0	0	0		
S	165	Brazil	groundnut shells (S)	111					2.5	531	4.8	75	133	0.424	225	2.0	56	51	3.5	468
C	166	Brazil	oil palm fruit	57	590	10.4	50	295						0.000	0	0.0	0	0		
P	167	Brazil	oil palm fronds (P)	57					1.5	443	7.8	50	221	0.595	263	4.6	132	118	3.1	680
S	168	Brazil	empty fruit bunch (S)	57					0.161	47	0.8	25	36	0.462	22	0.4	16	15	2.6	91
S	169	Brazil	oil palm fibres (S)	57					0.168	50	0.9	75	12	0.424	21	0.4	5	5	3.5	44
S	170	Brazil	oil palm shells (S)	57					0.072	21	0.4	75	5	0.424	9	0.2	2	2	3.5	19
C	171	Thailand	rice	10360	27789	2.7	15	23621						0.570	13464	1.3	13464	12117		
P	172	Thailand	rice straw (P)	10360					1.25	29526	2.8	35	19192	0.426	12590	1.2	8183	7365	2.9	55848
S	173	Thailand	rice husk (S)	10360					0.2	4724	0.5	50	2362	0.424	2003	0.2	1002	901	3.5	8326
C	174	Thailand	natural rubber	1762	3121	1.8	50	1561						0.000	0	0.0	0	0		
C	175	Thailand	cassava	1152	26411	22.9	65	9244						0.618	5708	5.0	5708	5137		
S	176	Thailand	cassave residu (S)	1152					1	9244	8.0	50	4622	0.425	3929	3.4	1964	1768	0.8	3466
C	177	Thailand	sugar cane	1010	64365	63.7	75	16091						0.095	6115	6.1	6115	5503		
S	178	Thailand	sugar cane bagasse (S)	1010					0.6	4827	4.8	75	1207	0.471	2275	2.3	569	512	2.9	3440
P	179	Thailand	sugar cane tops/leaves (P)	1010					0.96	15448	15.3	25	11586	0.424	6550	6.5	4912	4421	3.5	40840
C	180	Thailand	maize	942	3619	3.8	15	3076						0.684	2104	2.2	2104	1894		
P	181	Thailand	maize stalks, stems (P)	942					0.7	2153	2.3	50	1077	0.465	1001	1.1	500	450	2.3	2439
S	182	Thailand	maize cobs (S)	942					0.5	1538	1.6	75	385	0.553	850	0.9	212	191	1.8	692
C	183	Thailand	oil palm fruit	435	7642	17.6	50	3821						0.000	0	0.0	0	0		
P	184	Thailand	oil palm fronds (P)	435					1.5	5732	13.2	50	2866	0.595	3410	7.8	1705	1535	3.1	8812
S	185	Thailand	empty fruit bunch (S)	435					0.161	615	1.4	25	461	0.462	284	0.7	213	192	2.6	1177
S	186	Thailand	oil palm fibres (S)	435					0.168	642	1.5	75	160	0.424	272	0.6	68	61	3.5	566
S	187	Thailand	oil palm shells (S)	435					0.072	275	0.6	75	69	0.424	117	0.3	29	26	3.5	242
C	188	Thailand	coconuts	255	1705	6.7	10	1535						0.000	0	0.0	0	0		
S	189	Thailand	coconut husk (S)	255					0.6	921	3.6	50	460	0.360	331	1.3	166	149	4.9	2265
C	190	Thailand	bananas	153	2000	13.1	50	1000						0.000	0	0.0	0	0		
C	191	Thailand	beans	144	113	0.8	50	57						0.000	0	0.0	0	0		
C	192	Thailand	soybeans	139	217	1.6	15	184						0.000	0	0.0	0	0		
P	193	Thailand	soybean stalks, leaves (P)	139					2.5	461	3.3	75	115	0.424	196	1.4	49	44	3.5	406
C	194	China	maize	29497	151949	5.2	15	129157						0.684	88343	3.0	88343	79509		
P	195	China	maize stalks, stems (P)	29497					0.7	90410	3.1	50	45205	0.465	42022	1.4	21011	18910	2.3	102389
S	196	China	maize cobs (S)	29497					0.5	64578	2.2	75	16145	0.553	35680	1.2	8920	8028	1.8	29060
C	197	China	rice	29179	187397	6.4	15	159287						0.570	90794	3.1	90794	81714		
P	198	China	rice straw (P)	29179					1.25	199109	6.8	35	129421	0.426	84900	2.9	55185	49667	2.9	376615
S	199	China	rice husk (S)	29179					0.2	31857	1.1	50	15929	0.424	13508	0.5	6754	6078	3.5	56149
C	200	China	wheat	23721	109298	4.6	15	92903						0.618	57368	2.4	57368	51631		
P	201	China	wheat straw (P)	23721					1	92903	3.9	50	46452	0.424	39391	1.7	19695	17726	3.5	163742
C	202	China	soybeans	8900	16800	1.9	15	14280						0.000	0	0.0	0	0		
P	203	China	soybean stalks, leaves (P)	8900					2.5	35700	4.0	75	8925	0.424	15137	1.7	3784	3406	3.5	31461
C	204	China	vegetables	8573	147212	17.2	80	29442						0.000	0	0.0	0	0		
C	205	China	rapeseed	7050	10375	1.5	15	8819						0.000	0	0.0	0	0		
C	206	China	rapeseed straw	7050					1	8819	1.3	50	4409	0.424	3739	0.5	1870	1683	3.5	15543
C	207	China	seed cotton	5433	22872	4.2	15	19441						0.000	0	0.0	0	0		
P	208	China	cotton stalks (P)	5433					3.5	68044	12.5	75	17011	0.424	28851	5.3	7213	6491	3.5	59964
C	209	China	groundnuts	4573	13068	2.9	15	11108						0.000	0	0.0	0	0		
S	210	China	groundnut shells (S)	4573					2.5	27770	6.1	75	6942	0.424	11774	2.6	2944	2649	3.5	24472
C	211	China	potatoes	4437	56196	12.7	65	19669						0.618	12145	2.7	12145	10931		
C	212	China	sweet potatoes	3657	84431	23.1	65	29551						0.000	0	0.0	0	0		
C	213	China	watermelons	2113	66455	31.5	80	13291						0.000	0	0.0	0	0		

C	214	India	rice	43770	144570	3.3	15	122885						0.570	70044	1.6	70044	63040		
P	215	India	rice straw (P)	43770					1.25	153606	3.5	50	76803	0.426	65497	1.5	32749	29474	2.9	223496
S	216	India	rice husk (S)	43770					0.2	24577	0.6	50	12288	0.424	10421	0.2	5210	4689	3.5	43317
C	217	India	wheat	28035	75800	2.7	15	64430						0.618	39786	1.4	39786	35807		
P	218	India	wheat straw (P)	28035					1	64430	2.3	75	16108	0.424	27318	1.0	6830	6147	3.5	56779
C	219	India	millet	10800	12670	1.2	15	10770						0.000	0	0.0	0	0		
P	220	India	millet stalks, stems (P)	10800					1	10770	1.0	75	2692	0.465	5006	0.5	1251	1126	3.5	9491
C	221	India	seed cotton	9430	13200	1.4	15	11220						0.000	0	0.0	0	0		
P	222	India	cotton stalks (P)	9430					3.5	39270	4.2	75	9818	0.424	16650	1.8	4163	3746	3.5	34607
C	223	India	beans	9000	3000	0.3	80	600						0.000	0	0.0	0	0		
P	224	India	bean stalks, stems (P)	9000					1	600	0.1	50	300	0.480	288	0.0	144	130	2.7	806
C	225	India	soybeans	8880	10968	1.2	15	9323						0.000	0	0.0	0	0		
P	226	India	soybean stalks, leaves (P)	8880					2.5	23307	2.6	75	5827	0.424	9882	1.1	2471	2223	3.5	20539
C	227	India	sorghum	8451	7150	0.8	15	6078						0.475	2887	0.3	2887	2598		
P	228	India	sorghum leaves, stems (P)	8451					2.62	15923	1.9	75	3981	0.424	6751	0.8	1688	1519	3.5	14032
C	229	India	maize	7770	18960	2.4	15	16116						0.684	11023	1.4	11023	9921		
P	230	India	maize stalks, stems (P)	7770					0.7	11281	1.5	50	5641	0.465	5244	0.7	2622	2360	2.3	12776
S	231	India	maize cobs (S)	7770					0.5	8058	1.0	75	2015	0.553	4452	0.6	1113	1002	1.8	3626
C	232	India	chick peas	7490	6330	0.8	50	3165						0.000	0	0.0	0	0		
C	233	India	rapeseed	6790	7438	1.1	15	6322						0.000	0	0.0	0	0		
C	234	India	rapeseed straw	6790					1	6322	0.9	50	3161	0.424	2681	0.4	1340	1206	3.5	11143
C	235	India	groundnuts	6410	9183	1.4	15	7806						0.000	0	0.0	0	0		
S	236	India	groundnut shells (S)	6410					2.5	19514	3.0	75	4878	0.424	8274	1.3	2068	1862	3.5	17197
C	237	India	sugar cane	4900	355320	72.5	75	88830						0.095	33755	6.9	33755	30380		
S	238	India	sugar cane bagasse (S)	4900					0.6	53298	10.9	75	13325	0.471	25114	5.1	6279	5651	2.9	37975
P	239	India	sugar cane tops/leaves (P)	4900					0.96	85277	17.4	25	63958	0.424	36157	7.4	27118	24406	3.5	225451
C	240	Mexico	maize	7800	22500	2.9	15	19125						0.684	13082	1.7	13082	11773		
P	241	Mexico	maize stalks, stems (P)	7800					0.7	13388	1.7	50	6694	0.465	6223	0.8	3111	2800	2.3	15161
S	242	Mexico	maize cobs (S)	7800					0.5	9563	1.2	75	2391	0.553	5283	0.7	1321	1189	1.8	4303
C	243	Mexico	beans	1730	1390	0.8	80	278						0.000	0	0.0	0	0		
P	244	Mexico	bean stalks, stems (P)	1730					1	278	0.2	50	139	0.480	133	0.1	67	60	2.7	373
C	245	Mexico	sorghum	1600	5500	3.4	15	4675						0.475	2221	1.4	2221	1999		
P	246	Mexico	sorghum leaves, stems (P)	1600					2.62	12249	7.7	75	3062	0.424	5193	3.2	1298	1169	3.5	10794
C	247	Mexico	sugar cane	680	50680	74.5	75	12670						0.095	4815	7.1	4815	4333		
S	248	Mexico	sugar cane bagasse (S)	680					0.6	7602	11.2	75	1901	0.471	3582	5.3	896	806	2.9	5416
P	249	Mexico	sugar cane tops/leaves (P)	680					0.96	12163	17.9	25	9122	0.424	5157	7.6	3868	3481	3.5	32156
C	250	Mexico	wheat	602	3000	5.0	15	2550						0.618	1575	2.6	1575	1417		
P	251	Mexico	wheat straw (P)	602					1	2550	4.2	75	638	0.424	1081	1.8	270	243	3.5	2247
C	252	Mexico	barley	329	895	2.7	15	761						0.561	426	1.3	426	384		
P	253	Mexico	barley straw (P)	329					1	761	2.3	50	380	0.480	365	1.1	183	164	2.7	1021
C	254	Mexico	bananas	75	2200	29.3	90	220						0.000	0	0.0	0	0		
C	255	Mexico	rice	71	350	4.9	15	298						0.570	170	2.4	170	153		
P	256	Mexico	rice straw (P)	71					1.25	372	5.2	35	242	0.426	159	2.2	103	93	2.9	703
S	257	Mexico	rice husk (S)	71					0.2	60	0.8	50	30	0.424	25	0.4	13	11	3.5	105
C	258	Mexico	soybeans	55	82	1.5	15	70						0.000	0	0.0	0	0		
P	259	Mexico	soybean stalks, leaves (P)	55					2.5	174	3.2	75	44	0.424	74	1.3	18	17	3.5	154
C	260	Mexico	groundnuts	45	69	1.5	15	59						0.000	0	0.0	0	0		
S	261	Mexico	groundnut shells (S)	45					2.5	147	3.3	75	37	0.424	62	1.4	16	14	3.5	129
C	262	Australia	barley	5015	7997	1.6	15	6797						0.561	3810	0.8	3810	3429		
P	263	Australia	barley straw (P)	5015					1	6797	1.4	50	3399	0.480	3263	0.7	1631	1468	2.7	9125
C	264	Australia	maize	68	387	5.7	15	329						0.684	225	3.3	225	203		
P	265	Australia	maize stalks, stems (P)	68					0.7	230	3.4	50	115	0.465	107	1.6	54	48	2.3	261
S	266	Australia	maize cobs (S)	68					0.5	164	2.4	75	41	0.553	91	1.3	23	20	1.8	74
C	267	Australia	rice	2	18	8.0	15	15						0.570	9	3.9	9	8		
P	268	Australia	rice straw (P)	2					1.25	19	8.5	35	12	0.426	8	3.6	5	5	2.9	35
S	269	Australia	rice husk (S)	2					0.2	3	1.4	50	1	0.424	1	0.6	1	1	3.5	5
C	270	Australia	sorghum	942	3790	4.0	15	3221						0.475	1530	1.6	1530	1377		
P	271	Australia	sorghum leaves, stems (P)	942					2.62	8440	9.0	75	2110	0.424	3579	3.8	895	805	3.5	7438
C	272	Australia	soybeans	15	35	2.3	15	29						0.000	0	0.0	0	0		
P	273	Australia	soybean stalks, leaves (P)	15					2.5	74	4.9	75	18	0.424	31	2.1	8	7	3.5	65
C	274	Australia	sugar cane	381	32621	85.7	75	8155						0.095	3099	8.1	3099	2789		
S	275	Australia	sugar cane bagasse (S)	381					0.6	4893	12.9	75	1223	0.471	2306	6.1	576	519	2.9	3486
P	276	Australia	sugar cane tops/leaves (P)	381					0.96	7829	20.6	25	5872	0.424	3320	8.7	2490	2241	3.5	20698
C	277	Australia	sunflower seed	48	73	1.5	15	62						0.000	0	0.0	0	0		
P	278	Australia	sunflower stalks, stems (P)	48					0.7	43	0.9	50	22	0.424	18	0.4	9	8	3.5	77
C	279	Australia	wheat	13530	21420	1.6	15	18207						0.618	11243	0.8	11243	10119		
P	280	Australia	wheat straw (P)	13530					1	18207	1.3	50	9104	0.424	7720	0.6	3860	3474	3.5	32090

C	281	Russian Federa	barley	9421	23149	2.5	15	19676						0.561	11029	1.2	11029	9926		
P	282	Russian Federa	barley straw (P)	9421					1	19676	2.1	50	9838	0.480	9445	1.0	4722	4250	2.7	26415
C	283	Russian Federa	maize	1732	6682	3.9	15	5680						0.684	3885	2.2	3885	3497		
P	284	Russian Federa	maize stalks, stems (P)	1732					0.7	3976	2.3	50	1988	0.465	1848	1.1	924	832	2.3	4503
S	285	Russian Federa	maize cobs (S)	1732					0.5	2840	1.6	75	710	0.553	1569	0.9	392	353	1.8	1278
C	286	Russian Federa	rice	160	738	4.6	15	628						0.570	358	2.2	358	322		
P	287	Russian Federa	rice straw (P)	160					1.25	784	4.9	35	510	0.426	334	2.1	217	196	2.9	1484
S	288	Russian Federa	rice husk (S)	160					0.2	126	0.8	50	63	0.424	53	0.3	27	24	3.5	221
C	289	Russian Federa	sorghum	65	76	1.2	15	64						0.475	31	0.5	31	27		
P	290	Russian Federa	sorghum leaves, stems (P)	65					2.5	161	2.5	75	40	0.424	68	1.1	17	15	3.5	142
C	291	Russian Federa	soybeans	712	746	1.0	15	634						0.000	0	0.0	0	0		
P	292	Russian Federa	soybean stalks, leaves (P)	712					2.5	1585	2.2	75	396	0.424	672	0.9	168	151	3.5	1397
C	293	Russian Federa	sugar beet	800	28995	36.2	70	8699						0.158	4593	5.7	4593	4134		
C	294	Russian Federa	sunflower seed	5980	7350	1.2	15	6248						0.000	0	0.0	0	0		
P	295	Russian Federa	sunflower stalks, stems (P)	5980					0.7	4373	0.7	50	2187	0.424	1854	0.3	927	834	3.5	7708
C	296	Russian Federa	wheat	26070	63765	2.4	15	54200						0.618	33469	1.3	33469	30122		
P	297	Russian Federa	wheat straw (P)	26070					1	54200	2.1	50	27100	0.424	22981	0.9	11490	10341	3.5	95528
C	298	United States	barley	1529	5230	3.4	15	4445						0.561	2492	1.6	2492	2242		
P	299	United States	barley straw (P)	1529					1	4445	2.9	50	2223	0.480	2134	1.4	1067	960	2.7	5968
C	300	United States	maize	31797	307142	9.7	15	261071						0.684	178572	5.6	178572	160715		
P	301	United States	maize stalks, stems (P)	31797					0.7	182749	5.7	50	91375	0.465	84942	2.7	42471	38224	2.3	206964
S	302	United States	maize cobs (S)	31797					0.5	130535	4.1	75	32634	0.553	72121	2.3	18030	16227	1.8	58741
C	303	United States	rice	1044	8503	8.1	15	7228						0.570	4120	3.9	4120	3708		
P	304	United States	rice straw (P)	1044					1.2	8673	8.3	35	5637	0.426	3698	3.5	2404	2163	2.9	16405
S	305	United States	rice husk (S)	1204					0.2	1446	1.4	50	723	0.424	613	0.5	306	276	3.5	2548
C	306	United States	sorghum	2943	11998	4.1	15	10198						0.475	4844	1.6	4844	4360		
P	307	United States	sorghum leaves, stems (P)	2943					2.5	25496	8.7	75	6374	0.424	10810	3.7	2703	2432	3.5	22468
C	308	United States	soybeans	30223	80749	2.7	15	68636						0.000	0	0.0	0	0		
P	309	United States	soybean stalks, leaves (P)	30223					2.5	171591	5.7	75	42898	0.424	72755	2.4	18189	16370	3.5	151215
C	310	United States	sugar beet	407	24386	60.0	70	7316						0.158	3863	9.5	3863	3476		
C	311	United States	sugar cane	351	25041	71.3	75	6260						0.095	2379	6.8	2379	2141		
S	312	United States	sugar cane bagasse (S)	351					0.6	3756	10.7	75	939	0.471	1770	5.0	442	398	2.9	2676
P	313	United States	sugar cane tops/leaves (P)	351					0.96	6010	17.1	25	4507	0.424	2548	7.3	1911	1720	3.5	15889
C	314	United States	sunflower seed	970	1553	1.6	15	1320						0.000	0	0.0	0	0		
P	315	United States	sunflower stalks, stems (P)	970					0.7	924	1.0	50	462	0.424	392	0.4	196	176	3.5	1628
C	316	United States	wheat	22541	68016	3.0	15	57814						0.618	35700	1.6	35700	32130		
P	317	United States	wheat straw (P)	22541					1	57814	2.6	50	28907	0.424	24513	1.1	12257	11031	3.5	101897
C	318	Europe +	barley	10374	59081	5.7	15	50219						0.561	28148	2.7	28148	25333		
P	319	Europe +	barley straw (P)	10374					1	50219	4.8	50	25109	0.480	24105	2.3	12053	10847	2.7	67419
C	320	Europe +	maize	11944	79864	6.7	15	67884						0.684	46433	3.9	46433	41790		
P	321	Europe +	maize stalks, stems (P)	11944					0.7	47519	4.0	50	23760	0.465	22087	1.8	11043	9939	2.3	53815
S	322	Europe +	maize cobs (S)	13676					0.5	33942	2.8	75	8486	0.553	18753	1.4	4688	4219	1.8	15274
C	323	Europe +	rice	597	3478	5.8	15	2956						0.570	1685	2.8	1685	1516		
P	324	Europe +	rice straw (P)	597					1.25	3695	6.2	35	2402	0.426	1576	2.6	1024	922	2.9	6989
P	325	Europe +	rice husk (S)	597					0.2	591	1.0	50	296	0.424	251	0.4	125	113	3.5	1042
C	326	Europe +	sorghum	276	833	3.0	15	708						0.475	336	1.2	336	303		
P	327	Europe +	sorghum leaves, stems (P)	276					2.5	1769	6.4	75	442	0.424	750	2.7	188	169	3.5	1559
C	328	Europe +	soybeans	1702	2743	1.6	15	2331						0.000	0	0.0	0	0		
P	329	Europe +	soybean stalks, leaves (P)	1702					2.5	5828	3.4	75	1457	0.424	2471	1.5	618	556	3.5	5136
C	330	Europe +	sugar beet	2108	124595	59.1	70	37379						0.158	19736	9.4	19736	17762		
C	331	Europe +	sunflower seed	8555	14603	1.7	15	12413						0.000	0	0.0	0	0		
P	332	Europe +	sunflower stalks, stems (P)	8555					0.7	8689	1.0	50	4344	0.424	3684	0.4	1842	1658	3.5	15314
C	333	Europe +	wheat	35535	184381	5.2	15	156724						0.618	96777	2.7	96777	87099		
P	334	Europe +	wheat straw (P)	35535					1	156724	4.4	50	78362	0.424	66451	1.9	33225	29903	3.5	276226
C	335	Canada	Barley	3502	11781	3.4	15	10014						0.561	5613	1.6	5613	5052		
P	336	Canada	barley straw (P)	3502					1	10014	2.9	50	5007	0.480	4807	1.4	2403	2163	2.7	13444
C	337	Canada	Maize	1169	10592	9.1	15	9003						0.684	6158	5.3	6158	5542		
P	338	Canada	maize stalks, stems (P)	1169					0.7	6302	5.4	50	3151	0.465	2929	2.5	1465	1318	2.3	7137
S	339	Canada	maize cobs (S)	1169					0.5	4502	3.9	75	1125	0.553	2487	2.1	622	560	1.8	2026
C	340	Canada	Sunflower seed	69	112	1.6	15	95						0.000	0	0.0	0	0		
P	341	Canada	sunflower stalks, stems (P)	69					0.7	67	1.0	50	33	0.424	28	0.4	14	13	3.5	118
C	342	Canada	Wheat	10032	28611	2.9	15	24319						0.618	15017	1.5	15017	13516		
P	343	Canada	wheat straw (P)	10032					1	24319	2.4	50	12160	0.424	10311	1.0	5156	4640	3.5	42863

C	344	Mozambique	Cassava	525	4055	7.7	65	1419						0.618	876	1.7	876	789		
S	345	Mozambique	cassave residu (S)	525					0.2	284	0.5	75	71	0.425	121	0.2	30	27	0.8	53
C	346	Mozambique	Coconuts	74	265	3.6	10	239						0.000	0	0.0	0	0		
S	347	Mozambique	coconut husk (S)	74					0.6	143	1.9	50	72	0.360	52	0.7	26	23	4.9	352
C	348	Mozambique	Maize	1400	1285	0.9	15	1092						0.684	747	0.5	747	672		
P	349	Mozambique	maize stalks, stems (P)	1400					0.7	765	0.5	50	382	0.465	355	0.3	178	160	2.3	866
S	350	Mozambique	maize cobs (S)	1400					0.5	546	0.4	75	137	0.553	302	0.2	75	68	1.8	246
C	351	Mozambique	Seed cotton	398	189	0.5	15	161						0.000	0	0.0	0	0		
P	352	Mozambique	cotton stalks (P)	398					3.5	562	1.4	75	141	0.424	238	0.6	60	54	3.5	496
C	353	Mozambique	Sorghum	320	187	0.6	15	159						0.475	76	0.2	76	68		
P	354	Mozambique	sorghum leaves, stems (P)	320					2.5	398	1.2	75	99	0.424	169	0.5	42	38	3.5	351
C	355	Mozambique	Sugar cane	180	2451	13.6	75	613						0.095	233	1.3	233	210		
S	356	Mozambique	sugar cane bagasse (S)	180					0.6	368	2.0	75	92	0.471	173	1.0	43	39	2.9	262
P	357	Mozambique	sugar cane tops/leaves (P)	180					0.96	588	3.3	25	441	0.424	249	1.4	187	168	3.5	1555
C	358	South Africa	Barley	68	192	2.8	15	163						0.561	91	1.3	91	82		
P	359	South Africa	barley straw (P)	68					1	163	2.4	50	82	0.480	78	1.1	39	35	2.7	219
C	360	South Africa	Maize	2799	12700	4.5	15	10795						0.684	7384	2.6	7384	6645		
P	361	South Africa	maize stalks, stems (P)	2799					0.7	7557	2.7	50	3778	0.465	3512	1.3	1756	1581	2.3	8558
S	362	South Africa	maize cobs (S)	2799					0.5	5398	1.9	75	1349	0.553	2982	1.1	746	671	1.8	2429
C	363	South Africa	Sorghum	87	255	2.9	15	217						0.475	103	1.2	103	93		
P	364	South Africa	sorghum leaves, stems (P)	87					2.5	542	6.2	75	135	0.424	230	2.6	57	52	3.5	478
C	365	South Africa	Sugar cane	320	19255	60.2	75	4814						0.095	457	1.4	457	412		
S	366	South Africa	sugar cane bagasse (S)	320					0.6	2888	9.0	75	722	0.471	1361	4.3	340	306	2.9	2058
P	367	South Africa	sugar cane tops/leaves (P)	320					0.96	4621	14.4	25	3466	0.424	1959	6.1	1470	1323	3.5	12218
C	368	South Africa	Sunflower seed	564	872	1.5	15	741						0.000	0	0.0	0	0		
P	369	South Africa	sunflower stalks, stems (P)	564					0.7	519	0.9	50	259	0.424	220	0.4	110	99	3.5	914
C	370	South Africa	Wheat	748	2130	2.8	15	1811						0.618	1118	1.5	1118	1006		
P	371	South Africa	wheat straw (P)	748					1	1811	2.4	50	905	0.424	768	1.0	384	345	3.5	3191
C	372	Nigeria	Cassava	3778	44582	11.8	65	15604						0.618	9635	2.6	9635	8672		
S	373	Nigeria	cassave residu (S)	3778					0.2	3121	0.8	75	780	0.425	1326	0.4	332	298	0.8	585
C	374	Nigeria	Coconuts	41	234	5.7	10	211						0.000	0	0.0	0	0		
S	375	Nigeria	coconut husk (S)	41					0.6	126	3.1	50	63	0.360	45	1.1	23	20	4.9	311
C	376	Nigeria	Maize	3845	7525	2.0	15	6396						0.684	4375	1.1	4375	3938		
P	377	Nigeria	maize stalks, stems (P)	3845					0.7	4477	1.2	50	2239	0.465	2081	0.5	1041	936	2.3	5071
S	378	Nigeria	maize cobs (S)	3845					0.5	3198	0.8	75	800	0.553	1767	0.5	442	398	1.8	1439
C	379	Nigeria	Oil palm fruit	3200	8500	2.7	50	4250						0.000	0	0.0	0	0		
P	380	Nigeria	oil palm fronds (P)	3200					1.5	6375	2.0	50	3188	0.595	3793	1.2	1897	1707	3.1	9802
S	381	Nigeria	empty fruit bunch (S)	3200					0.161	684	0.2	25	513	0.462	316	0.1	237	213	2.6	1309
S	382	Nigeria	oil palm fibres (S)	3200					0.168	714	0.2	75	179	0.424	303	0.1	76	68	3.5	629
S	383	Nigeria	oil palm shells (S)	3200					0.072	306	0.1	75	77	0.424	130	0.0	32	29	3.5	270
C	384	Nigeria	Rice, paddy	2382	4179	1.8	15	3552						0.570	2025	0.9	2025	1822		
P	385	Nigeria	rice straw (P)	2382					1.2	4263	1.8	35	2771	0.426	1818	0.8	1181	1063	2.9	8063
S	386	Nigeria	rice husk (S)	2382					0.2	710	0.3	50	355	0.424	301	0.1	151	136	3.5	1252
C	387	Nigeria	Sorghum	7617	9318	1.2	15	7920						0.475	3762	0.5	3762	3386		
P	388	Nigeria	sorghum leaves, stems (P)	7617					2.5	19801	2.6	75	4950	0.424	8396	1.1	2099	1889	3.5	17449
C	389	Nigeria	Sugar cane	72	1412	19.6	75	353						0.095	34	0.5	34	30		
S	390	Nigeria	sugar cane bagasse (S)	72					0.6	212	2.9	75	53	0.471	100	1.4	25	22	2.9	151
P	391	Nigeria	sugar cane tops/leaves (P)	72					0.96	339	4.7	25	254	0.424	144	2.0	108	97	3.5	896
C	392	Nigeria	Wheat	32	53	1.7	15	45						0.618	28	0.9	28	25		
P	393	Nigeria	wheat straw (P)	32					1	45	1.4	50	23	0.424	19	0.6	10	9	3.5	79
C	394	Pakistan	Barley	91	87	1.0	15	74						0.618	46	0.5	46	41		
P	395	Pakistan	barley straw (P)	91					1	74	0.8	50	37	0.424	31	0.3	16	14	3.5	131
C	396	Pakistan	Maize	1052	3593	3.4	15	3054						0.684	2089	2.0	2089	1880		
P	397	Pakistan	maize stalks, stems (P)	1052					0.7	2138	2.0	50	1069	0.465	994	0.9	497	447	2.3	2421
S	398	Pakistan	maize cobs (S)	1052					0.5	1527	1.5	75	382	0.553	844	0.8	211	190	1.8	687
C	399	Pakistan	Rice, paddy	2963	10428	8.1	15	8864						0.570	4120	3.9	4120	3708		
P	400	Pakistan	rice straw (P)	2963					1.2	10637	3.6	35	6914	0.426	4535	1.5	2948	2653	2.6	17630
S	401	Pakistan	rice husk (S)	2963					0.2	1773	0.6	50	886	0.424	752	0.3	376	338	2.6	2260
C	402	Pakistan	Sorghum	263	165	0.6	15	140						0.475	66	0.3	66	60		
P	403	Pakistan	sorghum leaves, stems (P)	263					2.5	350	1.3	75	87	0.424	148	0.6	37	33	3.5	308
C	404	Pakistan	Sugar cane	1241	63920	51.5	75	15980						0.095	1518	1.2	1518	1366		
S	405	Pakistan	sugar cane bagasse (S)	1241					0.6	9588	7.7	75	2397	0.471	4518	3.6	1129	1017	2.9	6831
S	406	Pakistan	sugar cane tops/leaves (P)	1241					0.96	15341	12.4	25	11506	0.424	6504	5.2	4878	4391	3.5	40557
C	407	Pakistan	Sunflower seed	397	604	1.5	15	513						0.618	317	0.8	317	285		
P	408	Pakistan	sunflower leaves, stems (P)	397					1	513	1.3	50	257	0.424	218	0.5	109	98	3.5	905
C	409	Pakistan	Wheat	8550	20959	2.5	15	17815						0.618	11001	1.3	11001	9901		
P	410	Pakistan	wheat straw (P)	8550					1	17815	2.1	50	8907	0.424	7554	0.9	3777	3399	3.5	31399

C	411	Peru	Barley	147	186	1.3	15	158						0.618	98	0.7	98	88		
P	412	Peru	barley straw (P)	147					1	158	1.1	50	79	0.424	67	0.5	34	30	3.5	279
C	413	Peru	Cassava	103	1172	11.3	65	410						0.618	253	2.5	253	228		
S	414	Peru	cassave residu (S)	103					0.2	82	0.8	75	21	0.425	35	0.3	9	8	0.8	15
C	415	Peru	Coffee, green	333	274	0.8	15	233						0.000	0	0.0	0	0		
S	416	Peru	coffee husk (S)	333					2.1	489	1.5	75	122	0.424	207	0.6	52	47	3.3	403
C	417	Peru	Maize	499	1481	3.0	15	1259						0.684	861	1.7	861	775		
P	418	Peru	maize stalks, stems (P)	499					0.7	881	1.8	50	441	0.465	410	0.8	205	184	2.3	998
S	419	Peru	maize cobs (S)	499					0.5	629	1.3	75	157	0.553	348	0.7	87	78	1.8	283
C	420	Peru	Oil palm fruit	14	265	18.9	50	132.625						0.000	0	0.0	0	0		
P	421	Peru	oil palm fronds (P)	14					1.5	199	14.2	50	99	0.595	118	8.5	59	53	3.1	306
S	422	Peru	empty fruit bunch (S)	14					0.161	21	1.5	25	16	0.462	10	0.7	7	7	2.6	41
S	423	Peru	oil palm fibres (S)	14					0.168	22	1.6	75	6	0.424	9	0.7	2	2	3.5	20
S	424	Peru	oil palm shells (S)	14					0.072	10	0.7	75	2	0.424	4	0.3	1	1	3.5	8
C	425	Peru	Rice, paddy	380	2776	8.1	15	2359						0.570	4120	3.9	4120	3708		
P	426	Peru	rice straw (P)	380					1.2	2831	7.5	35	1840	0.426	1207	3.2	785	706	2.6	4693
S	427	Peru	rice husk (S)	380					0.2	472	1.2	50	236	0.424	200	0.5	100	90	2.6	602
C	428	Peru	Sugar cane	69	9396	135.9	75	2349						0.095	223	3.2	223	201		
S	429	Peru	sugar cane bagasse (S)	69					0.6	1409	20.4	75	352	0.471	664	9.6	166	149	2.9	1004
P	430	Peru	sugar cane tops/leaves (P)	69					0.96	2255	32.6	25	1691	0.424	956	13.8	717	645	3.5	5962
C	431	Peru	Wheat	150	207	1.4	15	176						0.618	109	0.7	109	98		
P	432	Peru	wheat straw (P)	150					1	176	1.2	50	88	0.424	75	0.5	37	34	3.5	310
C	433	Viet Nam	Cassava	556	9396	16.9	65	3289						0.618	2031	3.7	2031	1828		
S	434	Viet Nam	cassave residu (S)	556					0.2	658	1.2	75	164	0.425	280	0.5	70	63	0.8	123
C	435	Viet Nam	Coconuts	121	1095	9.0	10	986						0.000	0	0.0	0	0		
S	436	Viet Nam	coconut husk (S)	121					0.6	591	4.9	50	296	0.360	213	1.8	106	96	4.9	1455
C	437	Viet Nam	Coffee, green	500	1056	2.1	15	897						0.000	0	0.0	0	0		
S	438	Viet Nam	coffee husk (S)	500					2.1	1885	3.8	75	471	0.424	799	1.6	200	180	3.3	1555
C	439	Viet Nam	Maize	1440	4573	3.2	15	3887						0.684	2659	1.8	2659	2393		
P	440	Viet Nam	maize stalks, stems (P)	1440					0.7	2721	1.9	50	1360	0.465	1265	0.9	632	569	2.3	3082
S	441	Viet Nam	maize cobs (S)	1440					0.5	1944	1.3	75	486	0.553	1074	0.7	268	242	1.8	875
C	442	Viet Nam	Rice, paddy	7400	38730	8.1	15	32920						0.570	4120	3.9	4120	3708		
P	443	Viet Nam	rice straw (P)	7400					1.2	39504	5.3	35	25678	0.426	16845	2.3	10949	9854	2.6	65479
S	444	Viet Nam	rice husk (S)	7400					0.2	6584	0.9	50	3292	0.424	2792	0.4	1396	1256	2.6	8395
C	445	Viet Nam	Sugar cane	271	16146	59.6	75	4036						0.095	383	1.4	383	345		
S	446	Viet Nam	sugar cane bagasse (S)	271					0.6	2422	8.9	75	605	0.471	1141	4.2	285	257	2.9	1726
P	447	Viet Nam	sugar cane tops/leaves (P)	271					0.96	3875	14.3	25	2906	0.424	1643	6.1	1232	1109	3.5	10244
Crop/Primary/S	Number	Country	Crop/Residue	Area harvested	Production	Crop Yield	Moisture conte	Crop Productio	RCR	Residue produ	Residue Yield	Rate of current	Agr.Residu Ava	Fermentable Su	Fermentable s	Fermentable s	Fermentable s	Lactate availab	Lignin yield	Lignin availabili
				(1000 Ha)	(1000 Ton)	(ton/ha)	(%)	(1000 tonne dr	(residu to crop	(1000 tonne dr	(ton/ha)	(%)	(1000t dm/yr)	(ton sugar/ton f	(1000t dm/yr)	(ton/ha)	(1000t dm/yr)	(1000t dm/yr)	(GJ/ton fdstk)	(GJ/yr)

Appendix D: Excerpts from AgentschapNL commissioned study on sugar cane bagasse and trash availability (AgentschapNL, 2012)

(note: in this study sugar cane tops/leaves or trash, is also referred to as "straw")

Bagasse

The most prominent residue from sugar cane processing is bagasse. Bagasse is readily available at the mill after crushing the cane, and used to produce the heat and power necessary by the mill for the sugar cane processing allowing the mill to be self sufficient in terms of energy use. However, since the amount of bagasse available is very large, thermal systems have been designed to be very inefficient, so as to reduce the leftover bagasse, which has otherwise to be burnt separately. While some mills optimize the use of bagasse for surplus electricity production, in most mills technical optimisation could generate a (larger) bagasse surplus that could be used for other applications like generating additional electricity, production of pellets, or additional ethanol production through second generation technologies

In 2010, Brazil had 430 ethanol-producing plants (distilleries and mixed sugarethanol processing mills) (UNICA, 2010a) officially registered at the Ministry of Agriculture. Of these mills, 18% are large plants processing each over 4 million tons annually (most are in the States of São Paulo, Goias, and Mato Grosso), 69% are medium-size plants processing less than 2 million tons per year, and 13% are smaller plants processing less than 1 million tons per year (USDA 2011).

About 87% of sugarcane production in Brazil takes place in the Center-South region (including states of São Paulo, Rio, Minas Gerais and Espirito Santo) and the remaining 13% is located in the Northeast, mostly close the coast where rainfall is abundant.

Brazilian plants can be classified in three categories: Sugar mills that only produce sugar; sugar mills with distilleries (producing both sugar and bioethanol) and independent distilleries that only produce bioethanol. The largest group is the one that combines sugar mills and distilleries (close to 60% of the plants), followed by a considerable quantity of independent distilleries (close to 35%) and then by units that only process sugar.

Over 98% of Brazilian sugar mills (with integrated distilleries) are electrically self sufficient . In order to provide just enough steam and electricity to meet onsite factory needs, they use small bagasse-fired steam turbine systems, supplied with steam at 21 bar, with most of these units dating from about 20 years ago. However, Brazilian mills are increasingly using excess bagasse to produce excess electricity, which can be sold to the national grid.

Historically, commercialisation of excess electricity from distilleries started in the second half of the 1980s, initially on a small scale in the Northeast, and later in the state of São Paulo. The growth in sales of excess electricity generated from bagasse was accentuated in the 2000s, due mainly to the electricity supply crises of 2001- 2002, but also to policies stimulating electricity

production from biomass, and a window of opportunity in replacing old power systems in use since the beginning of the Proálcool programme4 (Barbosa et al 2008).
Since 2005, electricity sold to the grid as a by-product from the sugar industry has benefitted from government feed-in tariffs through the PROINFA feed-in law. Under this law, the price paid for electricity supplied by bio was 93.00 BRL5 / MWhe. However, in practice nobody sells electricity at that price and this system has not been very effective in encouraging the production of bioelectricity so far (Teixeira and Conceição 2009).

Currently most bioelectricity is sold through the energy auctions, which means the value may be higher or lower than the feed-in price. The effective price depends on the demand and supply. Some studies count with an optimistic 150 BRL / MWhe for electricity sold to the grid (Sparovek et al 2011). Remaining challenges in practice include getting access to the grid, which can be problematic, especially in areas where land costs are low, where electrical infrastructure is likely to be missing.

State of the grid connection
From the 430 sugar mills operating in 2010, 23% were connected to the national public grid, with 16% of that capacity being exported (UNICA). The distribution of these refineries in regions is shown in Figure 5.

The potential availability of biomass for excess electricity, cellulosic ethanol and pellets, depends on the following factors:
• The availability of cane-based residues (bagasse and straw). When introducing mechanical harvesting, the tops and leaves of the sugarcane plant (called straw) can be collected;
• The efficiency of energy (co)-generation of energy at the plant. This includes efficiency of the cogeneration systems, including boilers and turbines, which typically depend on steam pressures, condensing technology etc;
• The efficiency of energy use by the milling and distillation processes. This includes demand for steam, mechanical power and electrical power. These can often be improved by thermal integration and use of newer technologies.

