Review of Biomass Feedstocks and Guidelines of Best Practice

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1 Executive Summary

This document is the result of the evaluation of biomass feedstocks, from Europe and Latin America, that took place as part of the DIBANET project. That project is co-financed from the 7th Framework Programme for Research and Technological Demonstration of the European Union. (Title: Enhancing international cooperation between the EU and Latin America in the field of biofuels; Grant Agreement No: 227248-2).

The work in Task 2.1 of Work Package 2 (WP2) at DIBANET partners UL, CTC, and UNICAMP involved evaluating, on a number of levels, potential feedstocks for utilisation in the DIBANET acid-hydrolysis process (WP3). In the early stage of the project a wide number of feedstocks were examined and relevant secondary compositional data were sought from the literature. Selected feedstocks were analysed at the laboratories of UL, CTC, and UNICAMP and, from these, a limited number of feedstocks were subjected to more in-depth analysis/evaluation.

Work at UL focused on Miscanthus, cereal straws, and waste papers. The wet-chemical and spectroscopic analysis that was carried out on a wide number of Miscanthus samples have allowed for in-depth understandings to be reached regarding the changes in lignocellulosic composition, and potential biomass/biofuel yields that could be realised over the harvest window. Straws present much less chemical variation but have enough structural carbohydrates to warrant their processing in the DIBANET technology. Waste papers can have amongst the highest total carbohydrate contents of any of the feedstocks studied.

Work at CTC focused on the residues of the sugarcane industry – sugarcane bagasse and sugarcane trash (field residues from harvesting). A large number of samples were collected from a variety of sugar mills and plantations. It has been seen that there can be a significant variation in the composition of different bagasse samples, particularly with regards to the ash content. Sugarcane trash has lower total carbohydrates contents than bagasse but is still a suitable feedstock for DIBANET.

Work at UNICAMP focused on the evaluation of residues from the banana, coffee, and coconut industries. It was found that these also have potential for utilisation in the DIBANET process, however the value of the residues for this end-use is dependent on which part of the plant is utilised. For instance, coffee husks have sufficient structural carbohydrates to allow for decent yields of levulinic acid, formic acid, and furfural in DIBANET, however the leaves of the coffee plant do not. Leaves from the banana plant are also of less value for DIBANET than the other parts of the plant (e.g. stem).

A major output of this Deliverable is the downloadable electronic database that contains all of the WP2 analytical data obtained during the course of the project. It contains analytical data and predicted biorefining yields for a total of 1,281 samples. It can be obtained, free of charge, from the DIBANET website and will be a valuable tool for stakeholders in biorefining projects.

This document presents summaries of the observations/conclusions made as part of Task 2.1. It also presents “guidelines of best practice” in terms of making the best use of the selected biomass resources. A longer and much more in-depth version of this document can also be downloaded from the DIBANET website.

2 Need for Analytical Data

- The yields that may be obtained from processing feedstocks in the DIBANET process will be highly dependent on the relative amounts of the different lignocellulosic sugars in the structural polysaccharides.

- The amount of solid residues produced from the DIBANET process, i.e. the feedstock for subsequent thermochemical processing (gasification), will be dependent on the polysaccharide, lignin, and ash contents.

- Much of the compositional data in the literature is not specific enough to accurately inform estimates of the potential yields that might result from processing feedstocks in the DIBANET process.

3 Biomass Analysis in DIBANET

- Hence, primary analysis of a number of feedstocks by DIBANET partners was necessary.

- DIBANET partner UL undertook an investigation of a range of Irish lignocellulosic feedstocks. These included energy crops, agricultural residues, and wastes.

- DIBANET partner CTC investigated residues from the sugarcane industry – sugarcane bagasse and sugarcane trash (harvesting residues).

- DIBANET partner UNICAMP investigated other Latin American feedstocks.

- The methodology involved in preparing and characterising biomass samples in the project was standardised and used by all three DIBANET partners. These methods can downloaded from the DIBANET website.

- A database containing compositional data of samples analysed by DIBANET partners can be downloaded from the DIABNET website at http://www.dibanet.org/chemicaldatabase.php.

- It contains the results from the wet-chemical and/or spectroscopic analysis of 1281 samples from Europe and Latin America.

4 European Feedstocks

4.1 Initial Evaluation

4.1.1 Energy Crops

- Miscanthus is a highly productive crop that has a significant amount of structural carbohydrates, it is most suitable for the DIBANET process.

- Reed canary grass and willow coppices also have attractive lignocellulosic compositions.

- Switchgrass also has a good lignocellulosic composition, providing it is productive. However, experimental plots of switchgrass in Ireland have experienced poor yields.

- If the land is productive and available for a significant period of time (10+ years), the production of Miscanthus, rather than coppices or reed canary grass, should be favoured.

- If the land is only to be used for energy crop production in the short term then reed canary grass is preferable to Miscanthus due to its significantly lower establishment costs.

- The longer cutting cycle of coppices, and the potential for year-round harvesting, are attractive properties and may help to minimise supply cycle constraints associated with the provision of energy crops to biorefineries.

- However, the biomass/yield losses associated with pathogenic attack on coppices in parts of Europe can be significant and need to be seriously addressed/considered by farmers.

4.1.2 Agricultural Residues

- Straw is a significant resource that has a lignocellulosic composition suitable for the DIBANET process.

- In order to preserve soil fertility, not all of the straw can be removed from the land. How much straw needs to be left will be dependent on local factors including climate, soil characteristics, tillage type, and crop rotations.

- Pig and cattle excrete have insufficient levels of structural carbohydrates to warrant their processing in the DIBANET process. Alternative end-uses for these resources need to be sought.

- Furthermore, their high moisture contents will make transportation difficult/expensive and will prohibit their utilisation in thermochemical biorefineries.

- Poultry litter, however, does appear to be a suitable feedstock for the DIBANET process given that it has greater structural carbohydrate contents.

- This feedstock also has a significantly higher dry matter content than the other animal wastes and so logistical problems regarding transportation are likely to be less.

- The secondary data for spent mushroom compost suggested that it had a structural carbohydrate content that was sufficient to warrant the utilisation of the feedstock in the DIBANET process.

- However, the primary data obtained at UL show much lower carbohydrate contents.

- Spent mushroom compost is not suitable for the production of biofuels via thermochemical or hydrolysis technologies. Alternative end-uses for this resource need to be sought.

- Forestry residues (wood and leaves) are suitable for utilisation in the DIBANET process but this will require a significant investment in the infrastructure required for their collection and transport.

- Sawmill residues are also of value for biorefining but there are other current end-uses for these resources.

4.1.3 Non-Agricultural Wastes

- Municipal wastes are predominately composed of waste papers, food waste, garden waste, and waste woods
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- Waste food does not contain sufficient lignocellulosic sugars to warrant its utilisation in the DIBANET process.

- Garden/green waste contains various types of materials such as grasses, leaves, twigs, and branches.

- Only the more woody materials have lignocellulosic compositions suitable for the DIBANET process.

- Garden/green waste taken as a composite (i.e. a sample from a compost pile) does not have a favourable proportion of wood to foliage. Hence, the sourcing of green waste for biorefineries needs to be specifically tailored to high-carbohydrate materials. This may necessitate for separate collection schemes or for processes to sorting the woody material from the total green-waste resource.

- Waste paper and cardboard materials can have total carbohydrate contents in excess of any other feedstock discussed in this report. They are extremely attractive feedstocks for the DIBANET process providing they can be sourced at reasonable prices.

4.1.4 Initial Conclusions

- At an early DIBANET meeting it was decided that only a limited number of feedstocks would be selected for processing in the DIBANET conversion technologies (principally the acid hydrolysis process developed in Work Package 3).

- The early evaluations that took place in Work Package 2 helped to inform the choice as to which feedstocks would be selected.

- It was decided that Miscanthus would be the main feedstock from Europe.

- As part of DIBANET Work Package 2 near infrared spectroscopy (NIRS) quantitative calibration models for the important mass constituents were also developed for Miscanthus.

- It was also decided that NIRS models would be developed for straws and paper wastes since these were found to have attractive total sugars contents and represented a significant waste resource that could sustain a number of commercial-scale biorefineries.

4.2 Miscanthus

4.2.1 Miscanthus as an Energy Crop for Biorefining

- Miscanthus is a productive energy crop that does not require significant time or expense for maintenance after plantation. It can be productive for up to 20 years without the need for replantation.

- The lignocellulosic composition of the crop once at full production is highly attractive for use in biorefining technologies.

- The stem fractions of the plant, when processed in biorefining technologies, will provide higher chemical/biofuel yields than the leaf fractions. This is due to their higher total sugars contents and increased heating values. The lower acid soluble lignin, protein, and extractives contents in the stem sections are also likely to present fewer complications in many conversion processes (e.g. acid and enzymatic hydrolysis).

- The total sugars content of the crop in its first year of production is significantly less than in subsequent years. The total biomass yield of the crop is also less in this first year.

- Given this situation, **the commercial harvest of the first year growth of Miscanthus** and the subsequent transport of this crop to the biorefinery is not economical and **is not advised**.

- Instead, the crop should be cropped after the first year of growth with the biomass either left on the land for soil conditioning or used for other local uses.

4.2.2 Miscanthus Varieties

- Miscanthus x giganteus is the only Miscanthus variety in commercial production in Ireland. Other crops, e.g. sinensis, are grown experimentally but their yields in experimental plots have tended to be significantly lower than that of Miscanthus x giganteus.

- Hence, if climatic conditions are suitable for the growth of Miscanthus x giganteus (i.e. the winters are relatively mild) then this variety should be favoured in order to attain maximal yields.

- The non-giganteus varieties that have been analysed in this projected tended to have higher hemicellulose contents than giganteus but lower cellulose contents. Hence, more sugars may be liberated in pretreatment processes (e.g. dilute acid hydrolysis) with these varieties.

- The development of Miscanthus varieties has traditionally been focused on improving the resistance of the crop to cold winters or on maximising biomass yields.

- More recently research/breeding activities have considered improving the biorefining characteristics of the crop (e.g. polysaccharide contents, recalcitrance of the lignocellulosic matrix). Hence, future varieties may offer significant advantages over Miscanthus x giganteus for biorefining.

4.2.3 Harvest Window for Miscanthus x giganteus

- The harvest window for Miscanthus is between October and April.

- Between October and early December a relatively small amount of standing biomass is lost as leaf fall. This period is termed the “Early Harvest” in this report.

- Between mid-December and the end of February there is a rapid loss of leaves from the plant.

- By March the only remaining leaf material tend to be the sheaths. These are lost from the plant at a much slower rate than the leaf blades. Hence, the loss of standing biomass is much less after March. This period is termed the “Late Harvest” in this report.

- The best time for harvesting Miscanthus will be dependent on how the crop will be processed.

- The dry biomass yield associated with an Early Harvest can be approximately 30% more than that associated with a Late Harvest.

- If the maximal biomass yield is the primary desire the crop should be harvested in the Early period. The crop will have a significant amount of moisture (approximately 50% on a wet basis) at this time.

- An Early harvest will not provide a feedstock suitable for most thermochemical biorefining technologies (e.g. pyrolysis, gasification) since these will require lower moisture contents.

- An Early harvest is feasible for most hydrolysis biorefining technologies providing they do not use pretreatment method that require dry feedstock (e.g. ionic liquids).

- An early harvest will remove leaves that would, in a Late harvest, fall to the field. The amount of carbon and nitrogen provided to the soil would therefore be reduced.

- The removal of leaf material from the land can be addressed with increased fertiliser input.

- The amount of extra fertilisation required could be minimised by harvesting the crop towards the later period of the Early Harvest Window. This delay will allow for more of the nutrients present in the plant to translocate from the leaves to the rhizomes where they will be stored for utilisation in the subsequent year of plant growth. From the start to the end of this Early window the plant will change colour (leaves will be classified as “dead” rather than “live”) but relatively little leaf material will be lost from the plant.

- There are significant changes in lignocellulosic composition of the standing plant over the harvest window. The most important of these are an increase in the glucan and Klason lignin content.

- On a dry mass per-tonne basis the biomass collected during the Late harvest period is of more value for biorefining processes (hydrolysis and thermochemical) than the biomass collected in the Early harvested period.

- If a feedstock payment scheme at a biorefinery, using the hydrolysis platform, is based on total sugars content then the Late harvest crop would be worth approximately 10% more per tonne than the Early harvest crop.

- This dynamic means that the advantage of an Early harvest (as opposed to a Late harvest) is less in biofuel terms (approximately 20%) than in biomass terms (approximately 30%).

- Farmers should consider their own local practices to determine whether the potential extra 20% in revenue per hectare associated with an Early harvest is sufficient to cover the extra costs associated with the harvest and transport of a wet crop and with the need to increase fertilisation levels.

- Considering the needs of the biorefinery, it is not practical or economical to receive all of the feedstock in a relatively short window since this will necessitate for larger storage facilities or for a need to utilise multiple biomass feedstocks over the course of a year.

- Hydrolysis biorefineries could receive Miscanthus for seven months of the year (from the start of the Early window to the end of the Late window).

- If Miscanthus is to be received at biorefineries over the whole course of the harvest window it may be necessary for the facility to pay variable prices for the crop over this period. For example, such a scheme could compensate farmers that harvest late in the window since they would otherwise receive less revenue per hectare under a flat-rate payment scheme.

- Alternatively the biorefinery could enter onto contracts with each feedstock supplier so that Miscanthus is supplied in a staggered manner using different months for harvest in different years. In this way, the total revenue over the lifespan of a plantation would be consistent between suppliers.

- Due to their requirements for low moisture-content feedstocks, the effective harvest window for Miscanthus is much lower for many thermochemical biorefineries. It is unlikely/unpractical for a thermochemical facility to operate throughout the year using Miscanthus as a sole feedstock. Hence, thermochemical biorefineries processing Miscanthus will also require the supply of other feedstocks in periods outside of the reduced harvest window.

4.3 Straws

- Straws have suitable carbohydrate contents for utilisation in the DIBANET process.

- The variation in composition between different varieties within a species is relatively low.

- The range in composition is greater between species but still less than seen in other feedstocks, e.g. Miscanthus.

- This lower range will allow for increased confidence in the values for the expected yields from biorefining, since these will be based on the expected composition.

4.4 Waste Papers/Cardboards

- There is a large range in the total sugars contents of the paper and cardboard samples analysed in the UL laboratories, however event the sample that has the lowest total carbohydrate content had a sufficient sugar content to warrant its processing in DIBANET.

- The lignocellulosic composition of these wastes is significantly different from that of herbaceous feedstocks (e.g. Miscanthus, straws, sugarcane residues). For example, the mannose content is higher and the xylose content lower.

- Klason lignin also varies substantially between samples (1-26%), this will greatly influence the amount of solid residues that may be expected after the DIBANET hydrolysis process.

4.5 Projected Biorefining Yields from Waste Feedstocks in Ireland

- It was concluded that the main waste feedstocks in Ireland that were suitable for utilisation in the DIBANET process (and other biorefining technologies) were straws and waste papers.

- Based on the composition data obtained in DIBANET and the estimates that were made for the quantities of these wastes that could practically be used, it was possible to estimate the biofuel/chemical yields that may be possible from processing these resources.

- A scenario was considered whereby all of the paper that is currently exported from Ireland is instead biorefined. In addition, the upper estimates for the practical and sustainable quantities of barley, wheat, and oat straws that can be used were also biorefined

- The calculated total biofuel yields that could be obtained from processing these feedstocks in a range of representative biorefining technologies (with technology F being the DIBANET process; see the main document for descriptions of each technology) are presented in Table 1. For each process the yields are summed across all feedstocks to provide a total biofuel energy yield which is then expressed as a percentage of the total energy demand, estimated for the year 2010 for petrol and diesel transport fuels in the Irish Republic.

- Table 1 shows that exported paper/cardboard contributes the greatest quantity of biomass (54.9% of the total), followed by spring barley straw (22.9%), whilst the other feedstocks contribute much less to the total biomass resource. These total quantities of biomass allow for between 1.76% and 3.34% of the estimated current demand for petrol and diesel transport fuels in Ireland to be met. This is a significant amount and is possible from using sustainable quantities of residues and wastes.

- The removal of straws from the field, rather than letting them contribute to the soil organic matter, can be a contentious issue, however the scenario put forward still allows for the retention of a portion of these straws on the land.

- The alternative is that only the waste paper/cardboard resource is biorefined. This scenario results in between 1.03% and 1.97% of the estimated 2010 demand for petrol and diesel transport fuels in Ireland to be met. Taking the yield from technology E as an example, this level of biofuel supply is 58.5% of the level of biofuel supply in the straw and paper scenario. Therefore, the drop in output is less than the loss in total biomass. This is a result of the exported paper resource offering superior yields per tonne to the straws in the hydrolysis biorefining technologies.

- However, if instead technology G was used to process these national resources of biomass then the biofuel yield in an exported-paper only scenario would be 51.4% of the biofuel yield in a straw and exported paper scenario. This is because paper provides lower yields per tonne, compared with straws, in this process.

Table 1: Expected total biofuel yields from processing the estimated national resources of straws and paper considered available for biorefining technologies. The yields are in million litres of ethanol for proceses A, B, C, D, E, G, million kg of levulinic acid for process F, million litres of diesel from H (D, million litres of naptha from H (N) and million litres of diesel and naptha for process H. The yields are also expressed in energy terms (TJ). These total energy outputs from each technology are expressed as a percentage of total estimated petrol and diesel demand in Ireland in 2010. H (D) = FT-diesel; H (N) = FT-naptha.

Feedstock	**Dry Tonnes per Year**	**Million Litres of Product (million kg for Process F)**										**TJ**									
		A	**B**	**C**	**D**	**E**	**F (kg)**	**G**	**H**	**H (D)**	**H (N)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**H (D)**	**H (N)**
Spring Barley	161,863	37.59	54.02	58.04	45.44	70.11	53.71	68.42	27.17	21.15	6.02	792	1,138	1,223	957	1,477	1,105	1,441	916	729	187
Winter Barley	19,317	4.35	6.32	6.78	5.29	8.14	6.24	8.03	3.19	2.48	0.71	92	133	143	112	171	128	169	108	86	22
Spring Oats	17,667	4.09	5.96	6.38	4.98	7.65	5.87	7.45	2.96	2.30	0.65	86	126	134	105	161	121	157	100	79	20
Winter Oats	18,502	4.21	6.10	6.54	5.11	7.86	6.03	7.51	2.98	2.32	0.66	89	128	138	108	166	124	158	101	80	21
Spring Wheat	30,318	6.55	9.38	10.09	7.91	12.22	9.35	12.36	4.91	3.82	1.09	138	198	213	167	257	192	260	165	132	34
Winter Wheat	70,830	16.06	22.86	24.60	19.31	29.90	22.87	29.74	11.81	9.19	2.62	338	482	518	407	630	471	627	398	317	81
Exported Paper	387,000	102.20	167.85	175.94	133.67	196.17	153.20	142.54	56.59	44.06	12.54	2,153	3,536	3,706	2,816	4,133	3,153	3,003	1,908	1,519	390
TOTAL	705,496	175	272	288	222	332	257	276	110	85	24	3,688	5,740	6,075	4,671	6,995	5,295	5,815	3,696	2,941	755
% of 2010 Demand												1.76%	2.74%	2.90%	2.23%	3.34%	2.53%	2.78%	1.76%		
% of 2010 Demand (Only Exported Paper is Biorefined)												1.03%	1.69%	1.77%	1.34%	1.97%	1.51%	1.43%	0.91%		

Processes: A = Dilute acid hydrolysis of biomass in two plug-flow reactors; B = Dilute acid hydrolysis of cellulose in a counter-current reactor with an uncatalysed steam hydrolysis pre-treatment; C = Concentrated acid hydrolysis of biomass; D = Enzymatic hydrolysis of biomas - sequential hydrolysis and fermentation; E = Enzymatic hydrolysis and fermentation of biomass via consolidated bioprocessing; F = Dilute acid processing of biomass for the production of levulinic acid and furfural – the DIBANET process; G = Gasification of biomass followed by mixed alcohol synthesis; H = Gasification of biomass followed by Fischer-Tropsch (FT) synthesis

5 Latin American Feedstocks

5.1 Initial Evaluation

- CTC undertook the responsibility of analysing and evaluating residues from the sugarcane industry (sugarcane bagasse and sugarcane trash).

- UNICAMP was responsible for the analysis and evaluation of other Latin American feedstocks.

- A total of 10 different feedstocks were studied and analysed and, from these, three types were selected for more in depth analysis and for the development of quantitative near infrared spectroscopy models. These three feedstocks were residues from the banana, coconut, and coffee industries.

5.2 Sugarcane Residues

- Both sugarcane bagasse and sugarcane trash have sufficient amounts of lignocellulosic sugars to justify their processing in hydrolysis biorefining technologies.

- The compositions of the bagasse samples that were analysed tended to be more varied than those of the trash samples analysed.

- Ash, in particular, can vary significantly in bagasse samples. There also seems to be a tendency for the ash contents of bagasse to be higher in some mills.

- The ash content can be particularly important for thermochemical biorefining technologies and also can affect the amount of acid required in acid-hydrolysis.

- Hence, it is recommended that careful determinations and observations, over a period of time, of the ash contents, associated with the harvesting/milling process of any mill that is being considered for a biorefining scheme, be carried out.

- Operational practices of sugar mills in Brazil do not allow the sampler to trace the bagasse sample being collected to a particular location, sugarcane variety, or harvesting practice. Hence, the effects of variations in these on lignocellulosic compositions, and the suitability of a sample for biorefining, cannot yet be ascertained.

- However, all commercial sugarcane variety development to date has focussed on traditional quality parameters related to sugar production (e.g. sucrose content). The increasing interest in the use of sugarcane residues for biorefining may allow for targeted improvements to be made in the relevant physicochemical characteristics in the future (e.g. increased cellulose content and reduced Klason lignin content for feedstocks intended for enzymatic hydrolysis).

- No significant relationship between harvest date and the lignocellulosic composition of the bagasse was found.

- All of the sugarcane trash should not be collected from the field since this well lead to deterioration in soil fertility. The amount of material that should be left in the field will depend on local characteristics and fertilisation practices (for example, if sugarcane vinasse is applied to the land then it may be acceptable to remove a larger amount of trash for biorefining).

- Using the average lignocellulosic compositions of sugarcane bagasse and sugarcane trash determined in DIBANET analyses along with the estimated arisings for the 2009/2010 season (165m dry tonnes of bagasse and 128m dry tonnes of straw), the total potential yields possible from processing these feedstocks in representative technologies A-F are presented in Table 2. These potential levels of ethanol production are far in excess of the current ethanol output from sugarcane sucrose in Brazil (29 billion litres).

- However, using all of the bagasse and trash resources is neither practical nor environmentally acceptable. Approximately half of the bagasse produced in a sugar mill will be required to supply process heat and steam for the production of sucrose and first-generation ethanol. Furthermore, all of the sugarcane trash should not be removed from the land or soil quality will deteriorate. However, even if the figures in Table 2 are halved, the potential production levels of ethanol/levulinic-acid from practicable resources of sugarcane residues are still large and will significantly increase (more than double) the ethanol output from sugarcane in Brazil.

- The manual harvesting of sugarcane is being phased out in Brazil and other counties in favour of mechanical harvesting. This will mean that the crop will no longer be burnt prior to harvest meaning that the total quantities of trash resources available nationally will increase over time.

Table 2: Potential ethanol and levulinic acid yields (in billion litres and petajoules (PJ)) from processing all of the estimated sugarcane bagasse and sugarcane trash arisings in biorefining technologies A-F.

	Billion Litres of Ethanol					**Billion Litres Levulinic Acid**
	Tech. A	**Tech. B**	**Tech. C**	**Tech. D**	**Tech. E**	**Tech. F (DIBANET)**
Bagasse	36.6	52.4	56.4	44.2	68.2	52.2
Trash	26.3	37.1	40.0	31.4	48.8	37.3
TOTAL	62.9	89.5	96.3	75.6	117.1	89.6
	Total Energy Yield (PJ)					
Bagasse	771	1104	1187	930	1437	1075
Trash	554	781	842	662	1029	768
TOTAL	1325	1886	2030	1593	2466	1843

5.3 Banana Residues

- The stem, rachis and stalk fractions of the plant, when processed in biorefinery technologies, will provide higher chemical/biofuel yields. This is due to their higher total sugars contents and increased heating values.

- However, the leaves are not such a good resource due to the lowest sugars content (only 37%). The rhizome also cannot be used for biorefining processes because is not a residue, rather it is a part of the banana plant used for planting.

5.4 Coconut Residues

- Both coconut husks and coirs have sufficient amounts of lignocellulosic sugars to justify their processing in hydrolysis biorefining technologies.

- The compositions of the coir samples that were analysed tended to show more variation than those of the husks samples analysed.

- The low ash content in coconut samples, is a good parameter, since the high ash content affects the acid hydrolysis increasing the acid consumption and causes problems with corrosion during incineration if a high content of alkali metals are present. Ash also retards the enzymatic hydrolysis, since the ash cations would transfer into the solution and affect the cellulase activity.

- Overall, the results showed that the production of ethanol, levulinic acid, and other bio-products from agricultural residues such as coconut husk and fibres is promising.

5.5 Coffee Residues

- Coffee production requires an elevated degree of processing know-how and produces large amounts of by-products, such as coffee husks, which have limited applications such as fertilizer, livestock feed, compost and such others.

- Biotechnological applications in the field of industrial residues management promote sustainable development of a country's economy, with production of by-products, via chemical and biotechnological processes. With the background of high crop production in the upcoming years, there is an imperative need to counterpart this production with some utilization and industrial application of coffee by-products.

- Coffee is one of the most important products, its subsequent processes such as cultivation, processing, trading, transportation, and marketing, provide employment and is a huge business worldwide. With the high crop production projected in the future, there is a vital need to counterpart this production with proper utilization and industrial application of coffee by-products.

- From the coffee fractions analysed, only the husks have sufficient amounts of lignocellulosic sugars to justify their processing in hydrolysis biorefineries.

- Also, the coffee husks present a large range of variation for all parameters due to the husks coming from different locations and different crop varieties.

- The leaves presented very low sugars content, not enough for use in biorefineries.

- The bean is not a resource that can practically be used in biorefining since it is used in industry for coffee production.