ESI: Lignocellulosic biomass valorisation: A review of feedstocks, processes and potential value chains, and their implications for the decision-making process

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SUPPLEMENTARY DATA

Table S1 Composition lignocellulosic biomass for grasses (lower and upper limits of the ranges for each subtype are determined by the average of the minimum and maximum values found in the literature)

		Cellulose		Hemicellulose		Lignin	
	References	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Giant Reed (Arundo donax)	1	36 %	40 %	29 %	42 %	17 %	19%
Corn stalk	1, 2	34 %	40 %	17 %	42 %	7 %	14 %
Corn cob	2-4	34 %	45 %	31.9 %	39 %	6 %	15 %
Corn stover	3-6	35 %	40 %	21 %	26 %	7 %	19%
Corn leaves	3	27 %	27 %	13 %	13 %	15 %	15 %
Switch grass	2-4, 6, 7	5 %	45 %	23 %	50 %	6 %	40 %
Pennisetum	1	41 %	42 %	22 %	23 %	17 %	19 %
Silvergrass	1	43 %	44 %	26 %	29 %	17 %	18 %
Wheat straw	2-4, 6, 7	9 %	39 %	22 %	50 %	12 %	26 %
Wheat bran	2	9 %	12 %	39 %	39 %	3 %	5 %
Barley straw	2, 3	31 %	41 %	22%	38 %	6 %	19 %
Barley husk	2	39 %	39 %	12 %	12 %	22 %	22 %
Canola straw	2	44 %	44 %	6 %	6 %	15 %	15 %
Oat straw	2, 3	31 %	39 %	23 %	38 %	4 %	24 %
Rice husk	2, 3	17 %	35 %	18 %	38 %	20 %	31 %

Rice straw	2-4	20 %	40 %	19 %	50 %	2 %	18 %
Rice bran	2	34 %	34 %	28 %	28 %	25 %	25 %
Rye straw	2, 3	33 %	38 %	27 %	31 %	16 %	31 %
Rye bran	2	5 %	6 %			4 %	4 %
Soybean stalks	2	35 %	35 %	25 %	25 %	20 %	20 %
Soybean straw	2	52 %	52 %	10 %	10 %	10 %	10 %
Spelt straw	2	38 %	38 %	24 %	24 %	15 %	15 %
Sunflower stalks	2	39 %	42 %	30 %	34 %	13 %	18 %
Bamboo	3	40 %	40 %	19 %	19 %	21 %	21 %
Miscantus	3	38 %	40 %	18 %	24 %	24 %	25 %

Table S2 Composition lignocellulosic biomass for softwoods (lower and upper limits of the ranges for each subtype are determined by the average of the minimum and maximum values found in the literature)

		Cellulose		Hemicellulose		Lignin	
	References	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Pine wood	3, 5, 8, 9	38 %	50 %	19 %	22 %	21 %	29 %
P. Armandii Franch	3	48 %	48 %	18 %	18 %	24 %	24 %
Spruce	3	43 %	43 %	29 %	29 %	28 %	28 %
Japanese Cedar	3	39 %	39 %	23 %	23 %	34 %	34 %
Fir	3	45 %	45 %	22 %	22 %	30 %	30 %

Table S3 Composition lignocellulosic biomass for hardwoods (lower and upper limits of the ranges for each subtype are determined by the average of the minimum and maximum values found in the literature)

		Cellulose		Hemicellulose		Lignin	
	References	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Maple (Acer Rubrum)	7	43 %	43 %	17 %	17 %	25 %	25 %
Sweetgum (Liquidambar Styraciflua)	7	40 %	40 %	19 %	19 %	25 %	25 %
Eucalyptus (Eucalyptus Nitens)	5, 7	44 %	48 %	11 %	17 %	25 %	29 %
Poplar	3, 8, 9	40 %	49 %	17 %	24 %	15 %	28 %
Vineyard	8	34 %	34 %	18 %	18 %	25 %	25 %
Beech	3	45 %	45 %	30 %	30 %	20 %	20 %
Aspen	3	53 %	53 %	22 %	22 %	20 %	20 %
Cherry wood	3	46 %	46 %	29 %	29 %	18 %	18 %
Willow	3	42 %	42 %	17 %	17 %	29 %	29 %
Birch (Betula Pendula)	10	44 %	44 %	29 %	29 %		

Table S4 Composition lignocellulosic biomass for secondary streams (lower and upper limits of the ranges for each subtype are determined by the average of the minimum and maximum values found in the literature)

		Cellulose		Hemicellulose		Lignin	
	References	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Sugarcane bagasse	2-4, 7	37 %	48 %	19 %	30 %	19 %	42 %
Sweet sorghum bagasse	3, 4	34 %	45 %	18 %	27 %	14 %	21 %
Sugar beet pulp	2	22 %	22 %	30 %	30 %	4 %	4 %
Apple pomace	2	48 %	48 %	28 %	28 %	15 %	22 %
Grape pomace	2	9 %	15 %	4 %	10 %	12 %	41 %
Brewer’s spent grain	2	12 %	40 %	28 %	40 %	12 %	28 %
Flax oil cake	2	8 %	8 %	5 %	5 %	6 %	6 %
Hemp oil cake	2	23 %	23 %	14 %	14 %	17 %	17 %

Hull-less pumpkin oil cake	2	4 %	4 %	7 %	7 %	1 %	1 %
Olive mill waste	2	25 %	34 %	13 %	16 %	13 %	16 %
Rapseed cake	2	16 %	16 %	13 %	13 %	7 %	7 %
Hazelnut shell	3	25 %	25 %	28 %	28 %	42 %	42 %
Palm oil shell	11	22 %	22 %	24 %	24 %	54 %	54 %
Jatropha Curcas shell	11	61 %	61 %	18 %	18 %	21 %	21 %

REFERENCES

1. L. Kou, Y. Song, X. Zhang and T. Tan, *Bioresource Technology*, 2017, **241**, 424-429.
2. M. Tišma, M. Bucić-Kojić and M. Planinić, *Chemical and Biochemical Engineering Quarterly*, 2021, **35**, 139-156.
3. M. Tayyab, A. Noman, W. Islam, S. Waheed, Y. Arafat, F. Ali, M. Zaynab, S. Lin, H. Zhang and W. Lin, *Appl. Ecol. Environ. Res*, 2018, **16**, 225-249.
4. Z. Anwar, M. Gulfraz and M. Irshad, *Journal of Radiation Research and Applied Sciences*, 2014, **7**, 163-173.
5. E. W. Qian, in *Research Approaches to Sustainable Biomass Systems*, eds. S. Tojo and T. Hirasawa, Academic Press, Boston, 2014, DOI: https://doi.org/10.1016/B978-0-12-404609-2.00007-6, pp. 181-204.
6. J. N. Putro, F. E. Soetaredjo, S.-Y. Lin, Y.-H. Ju and S. Ismadji, *RSC advances*, 2016, **6**, 46834-46852.
7. W. Geng, R. Narron, X. Jiang, J. J. Pawlak, H.-m. Chang, S. Park, H. Jameel and R. A. Venditti, *Cellulose*, 2019, **26**, 3219-3230.
8. C. K. Nitsos, T. Choli-Papadopoulou, K. A. Matis and K. S. Triantafyllidis, *ACS Sustainable Chemistry & Engineering*, 2016, **4**, 4529-4544.
9. H. Wang, J. Male and Y. Wang, *ACS Catalysis*, 2013, **3**, 1047-1070.
10. P. Das, Itä-Suomen yliopisto, 2019.
11. C. Gutiérrez-Antonio, A. G. Romero-Izquierdo, F. I. Gómez-Castro and S. Hernández, in *Production Processes of Renewable Aviation Fuel*, eds. C. Gutiérrez-Antonio, A. G. Romero-Izquierdo, F. I. Gómez-Castro and S. Hernández, Elsevier, 2021, DOI: https://doi.org/10.1016/B978-0-12-819719-6.00005-5, pp. 129-169.