

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

Britt Segers,^a Philippe Nimmegeers,^{a,b,c} Marc Spiller,^{d,e,f} Giorgio Tofani,^g Edita Jasiukaitytė-Grojddek,^g Elina Dace,^{h,i} Timo Kikas,^j Jorge M. Marchetti,^k Milena Rajić,^l Güray Yildiz^m and Pieter Billen^{*a,e}

^aIntelligence in Processes, Advanced Catalysts and Solvents (iPRACS), Faculty of Applied Engineering, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium.

^bEnvironmental Economics (EnvEcon), Department of Engineering Management, Faculty of Business and Economics, University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium.

^cFlanders Make@UAntwerp, 2000 Antwerp, Belgium.

^dBiobased Sustainability Engineering (SUSTAIN), Department of Bioscience Engineering, University of Antwerp, 2020 Antwerpen, Belgium.

^eCentre for Advanced Process Technology for Urban Resource Recovery (CAPTURE), Frieda Saeystraat 1, 9052 Gent, Belgium.

^fVITO WaterClimateHub, Wetenschapspark 1, 8400 Oostende, Belgium.

^gDepartment of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Hajdrihova 19, 1000 Ljubljana, Slovenia.

^hBaltic Studies Centre, Kokneses prospekts 26-2, Riga LV-1014, Latvia.

ⁱInstitute of Microbiology and Biotechnology, University of Latvia, Jelgavas iela 1, Riga, LV-1004, Latvia B

^jBiosystems Engineering, Institute of Forestry and Engineering, Estonian University of Life Sciences, Kreutzwaldi 56, Tartu, 51014, Estonia.

^kFaculty of Science and Technology, Norwegian University of Life Sciences, Drøbakveien 31, 1432 Ås, Norway.

^lDepartment of Management in Mechanical Engineering, Faculty of Mechanical Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

^mDepartment of Materials Engineering and Production, Faculty of Mechanical Engineering, Bialystok University of Technology, Wiejska 45C, 15-351 Białystok, Poland.

*Corresponding Author at: ¹Intelligence in Processes, Advanced Catalysts and Solvents (iPRACS), Faculty of Applied Engineering, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium.

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)

	References	Cellulose		Hemicellulose		Lignin	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Giant Reed (<i>Arundo donax</i>)	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)

	References	Cellulose		Hemicellulose		Lignin	
		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)

	References	Cellulose		Hemicellulose		Lignin	
		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)

	References	Cellulose		Hemicellulose		Lignin	
		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 %
Rapeseed 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.