Waste biorefinery technologies for accelerating sustainable energy processes

Lignocellulosic Biomass and Residues as Potential Substrates for the Industrial Biotechnology

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10. May 2022

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

History

- 1927 Experimental farm of the Agricultural University Berlin
- 1933 Independent research center on agricultural mechanization
- 1952 Central institute of agricultural engineering of East Germany
- 1992 Reestablished after the reunification of Germany

Today:

Leibniz Institute for Agricultural Engineering and Bioeconomy

- member of the Leibniz Association

Research Program „Material & energetic use of biomass

Coordination: Dr. Joachim Venus

Consideration of the entire value chain – System‘s approach

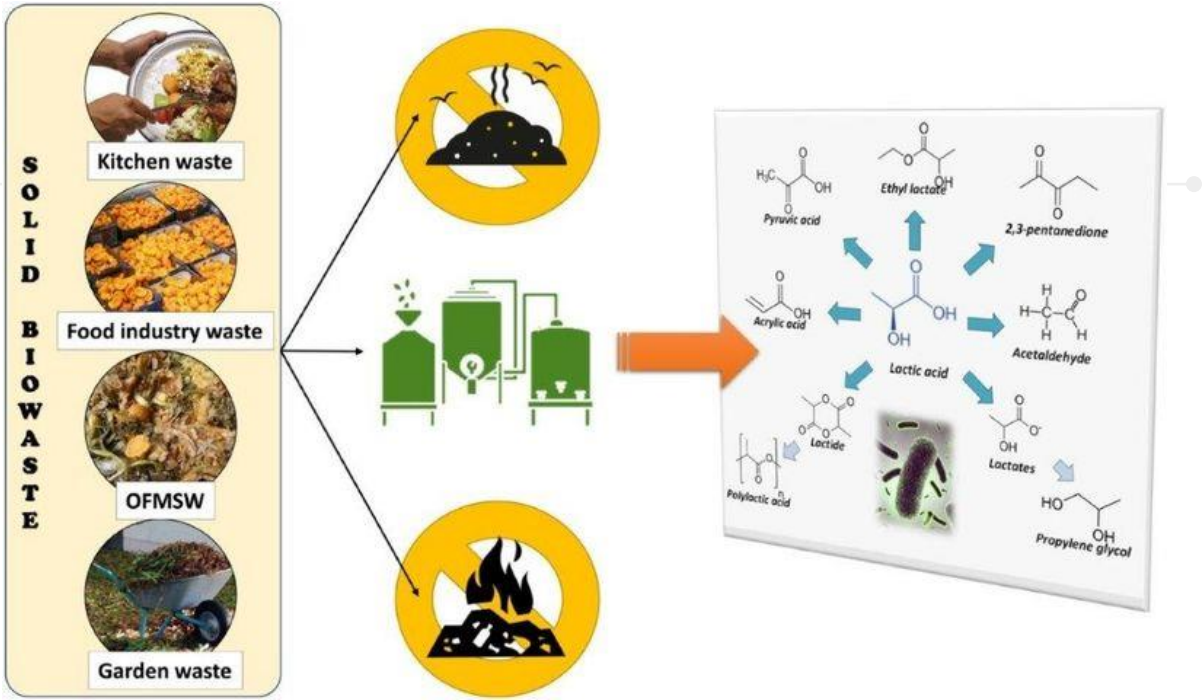
Biomass provision
(Cultivation, harvest, storage… e.g. short rotation wood, hemp)

Chemicals & Materials
➲ biotechnological products

Energetic use
(Biogas, wood pellets, biochar)

Valorization of residues, sidestreams etc.

Biotechnological production of chemicals
(e.g. LA as monomer for PLA)



López Gómez, J.P.; Latorre-Sánchez, M.; Unger, P.; Schneider, R.; Lozano, C.C.; Venus, J.: Assessing the organic fraction of municipal solid wastes for the production of lactic acid, Biochemical Engineering Journal 150 (2019), 107251, https://doi.org/10.1016/j.bej.2019.107251
López Gómez, J.P.; Unger, P.; Schneider, R.; Venus, J.: From Upstream to Purification: Production of Lactic Acid from the Organic Fraction of Municipal Solid Waste. Waste Biomass Valor 11 (2020) 10, 5247–5254, https://doi.org/10.1007/s12649-020-00992-9

(Different) Composition & Behaviour of (lignocellulosic) Biomass

The contents of cellulose, hemicellulose, and lignin in various types of lignocellulosic biomass (% dry weight).[a]

Lignocellulosic materials	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Algae (green)	20–40	20–50	NA[b]
Aspen hardwood	51	29	16
Birch Hardwood	40	39	21
Chemical pulps	60–80	20–30	2–10
Coastal Bermuda grass	25	35.7	6.4
Corn cobs	45	35	15
Cornstalks	39–47	26–31	3–5
Cotton seed hairs	80–95	5–20	0
Cotton, flax, etc.	80–95	5–20	NA[b]
Grasses	25–40	25–50	10–30
Hardwood	45 ± 2	30 ± 5	20 ± 4
Hardwood barks	22–40	20–38	30–55
Hardwood stems	40–55	24–40	18–25
Leaves	15–20	80–85	0
Newspaper	40–55	25–40	18–30
Nut shells	25–30	25–30	30–40
Paper	85–99	0	0–15
Pine softwood	44	26	29
Primary wastewater solids	8–15	NA[b]	24–29
Softwood	42 ± 2	27 ± 2	28 ± 3
Softwood barks	18–38	15–33	30–60
Softwood stems	45–50	25–35	25–35
Solid cattle manure	1.6–4.7	1.4–3.3	2.7–5.7
Sorted refuse	60	20	20
Spruce softwood	43	26	29
Swine waste	6.0	28	NA[b]
Switch grass	45	31.4	12.0
Waste papers from chemical pulps	60–70	10–20	5–10
Wheat straw	37–41	27–32	13–15
Willow Hardwood	37	23	21

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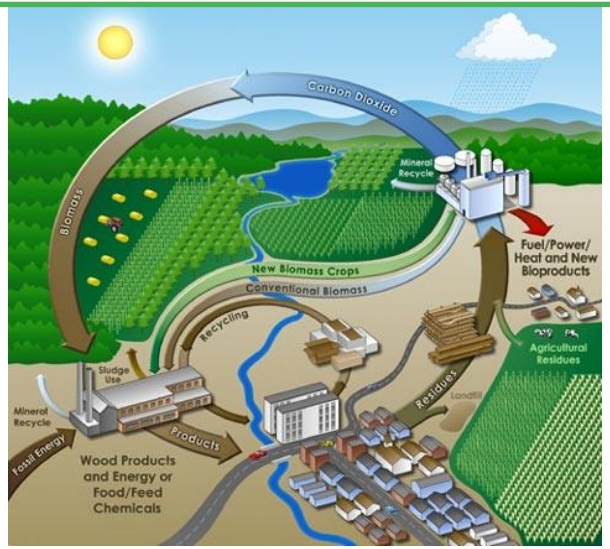
Journal of Biotechnology 156 (2011) 286– 301

Percent dry weight composition of lignocellulosic feedstocks

Feedstock	Glucan (cellulose)	Xylan (hemicellulose)	Lignin
Corn stover[a]	37.5	22.4	17.6
Corn fiber[b,c]	14.28	16.8	8.4
Pine wood[d]	46.4	8.8	29.4
Popular[d]	49.9	17.4	18.1
Wheat straw[d]	38.2	21.2	23.4
Switch grass[d]	31.0	20.4	17.6
Office paper[d]	68.6	12.4	11.3



Composition of representative lignocellulosic feedstocks.

Feedstocks	Carbohydrate composition (% dry wt)			References
	Cellulose	Hemicellulose	Lignin	
Barley hull	34	36	19	[12]
Barley straw	36–43	24–33	6.3–9.8	[13,14]
Bamboo	49–50	18–20	23	[15,16]
Banana waste	13	15	14	[17]
Corn cob	32.3–45.6	39.8	6.7–13.9	[18,19]
Corn stover	35.1–39.5	20.7–24.6	11.0–19.1	[20]
Cotton	85–95	5–15	0	[21]
Cotton stalk	31	11	30	[22]
Coffee pulp	33.7–36.9	44.2–47.5	15.6–19.1	[23]
Douglas fir	35–48	20–22	15–21	[24]
Eucalyptus	45–51	11–18	29	[16,25]
Hardwood stems	40–55	24–40	18–25	[26,27]
Rice straw	29.2–34.7	23–25.9	17–19	[28,29]
Rice husk	28.7–35.6	11.96–29.3	15.4–20	[30,31]
Wheat straw	35–39	22–30	12–16	[29,32]
Wheat bran	10.5–14.8	35.5–39.2	8.3–12.5	[33]
Grasses	25–40	25–50	10–30	[34,35]
Newspaper	40–55	24–39	18–30	[26]
Sugarcane bagasse	25–45	28–32	15–25	[16,36]
Sugarcane tops	35	32	14	[37]
Pine	42–49	13–25	23–29	[25]
Poplar wood	45–51	25–28	10–21	[38]
Olive tree biomass	25.2	15.8	19.1	[39]
Jute fibres	45–53	18–21	21–26	[40]
Switchgrass	35–40	25–30	15–20	[26]
Grasses	25–40	25–50	10–30	[26,27]
Winter rye	29–30	22–26	16.1	[41]
Oilseed rape	27.3	20.5	14.2	[41]
Softwood stem	45–50	24–40	18–25	[26,27]
Oat straw	31–35	20–26	10–15	[14]
Nut shells	25–30	22–28	30–40	[42]
Sorghum straw	32–35	24–27	15–21	[43,44]
Tamarind kernel powder	10–15	55–65	–	[45]
Water hyacinth	18.2–22.1	48.7–50.1	3.5–5.4	[46,47]

V. Menon, M. Rao
Progress in Energy and Combustion Science 38 (2012) 522-550

Renewable Resources Angew. Chem. Int. Ed. 2011, 50, 10502 – 10509 DOI: 10.1002/anie.201102117

Beyond Petrochemicals: The Renewable Chemicals Industry**

*P. N. R. Vennestrøm, C. M. Osmundsen, C. H. Christensen, and Esben Taarning**

Chemical	Market type	Market size (Mty^{-1})[a]	Major player(s)	Feedstock
acetic acid	existing	9.0	–	ethanol
acrylic acid	existing	4.2	Arkema, Cargill/Novozymes	glycerol or glucose
C_4 diacids	emerging	(0.1–0.5)	BASF/Purac/CSM, Myriant	glucose
epichlorohydrin	existing	1.0	Solvay, DOW	glycerol
ethanol	exisiting	60	Cosan, Abengoa Bioenergy, ADM	glucose
ethylene	existing	110	Braskem, DOW/Crystalsev, Borealis	ethanol
ethylene glycol	existing	20	India Glycols, Dacheng Industrial	glucose or xylitol
glycerol	existing	1.5	ADM, P&G, Cargill	vegetable oil
5-hydroxymethylfurfural	emerging	–	–	glucose/ fructose
3-hydroxypropionic acid	emerging	(≥0.5)	Novozymes/Cargill	glucose
isoprene	existing/ emerging	0.1 (0.1–0.5)	Danisco/Goodyear	glucose
lactic acid	existing/ emerging	0.3 (0.3–0.5)	Cargill, Purac/Arkema, ADM, Galactic	glucose
levulinic acid	emerging	(≥0.5)	Segetis, Maine Bioproducts, Le Calorie	glucose
oleochemicals	existing	10–15	Emery, Croda, BASF, Vantage Oleochemicals	vegetable oil/fat
1,3-propanediol	emerging	(0.1–0.5)	Dupont/Tate & Lyle	glucose
propylene	existing	80	Braskem/Novozymes	glucose
propylene glycol	existing/ emerging	1.4 (≥2.0)	ADM, Cargill/Ashland, Senergy, Dacheng Industrial	glycerol or sorbitol
polyhydroxyalkanoate	emerging	(0.1–0.5)	Metabolix/ADM	glucose

[a] Market size of an existing market is given as its current size including production from fossil resources; for emerging markets the expected market size is reported in parenthesis.

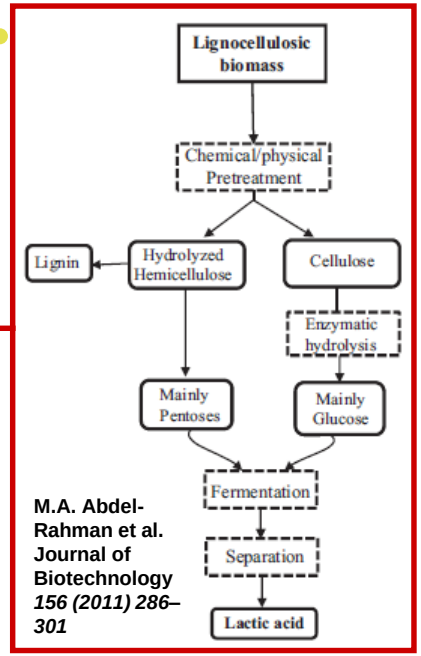


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Table 1: Overview of chemicals that are currently produced, or could be produced, from biomass together with their respective market type, size of the market, and potential biomass feedstock. Major players involved are also given.

The processes for producing chemicals from biomass/residues include the following 4 main steps:

(1) **Pretreatment - breaking down the structure of the feedstock matrix**

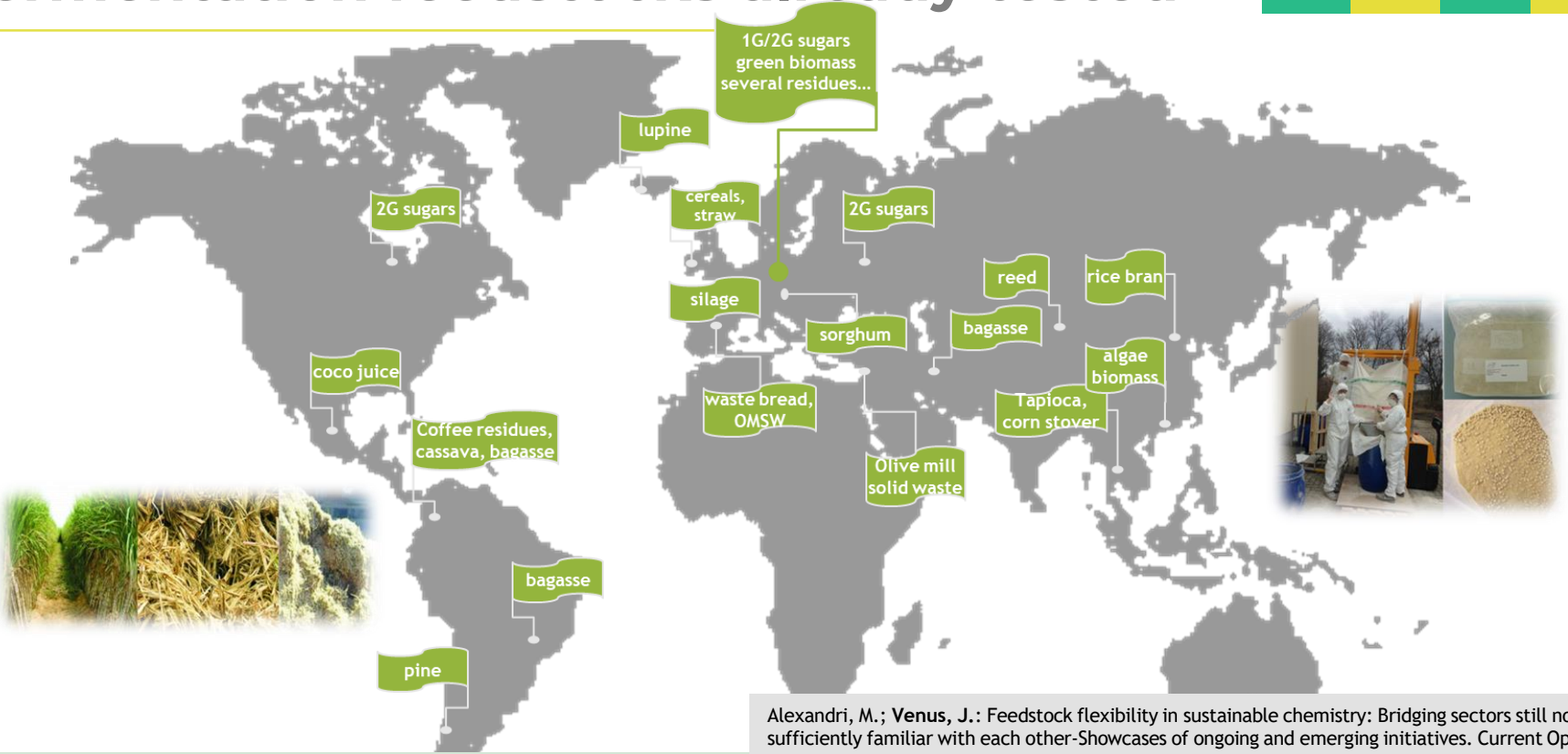
(2) Enzymatic hydrolysis - depolymerizing biopolymers like starch, cellulose etc. to fermentative sugars, such as glucose (C6) and xylose (C5), by means of hydrolytic enzymes

(3) Fermentation - metabolizing the sugars to lactic acid, generally by LAB

(4) **Separation and purification of lactic acid - purification of lactic acid to meet the standards of commercial applications**

Pilot plant facility for lactic acid fermentation at Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB Potsdam)

Fermentation feedstocks already tested



Alexandri, M.; **Venus, J.**: Feedstock flexibility in sustainable chemistry: Bridging sectors still not sufficiently familiar with each other-Showcases of ongoing and emerging initiatives. Current Opinion in Green and Sustainable Chemistry 8 (2017) 24-29, https://doi.org/10.1016/j.cogsc.2017.09.003

- *Starchy materials (cereals, industrial grade corn/potatoe starch, tapioca)*
- *Green biomass (alfalfa, grass juice, lupine, sweet sorghum, forage rye, silage, coco juice)*
- *Lignocellulosics (wood/straw hydrolysates, 2ndG sugars, bagasse, reed)*
- ***Residues & By-products (oilseed cake/meal, thick juice, molasses, whey, coffee residues, waste bread, waffle residues, algae biomass, fruit residues, rice bran, meat & bone meal, OMSW, AD digestates, corn stover…)***

Example coffee residues

Coffee mucilage

Bacillus coagulans

2 L Scale

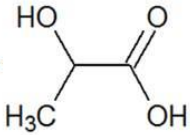
50 L Scale

Fermentation

Filtration
Softening
Electro-dialysis
Polishing
Distillation

Downstream

Poly(lactic acid)



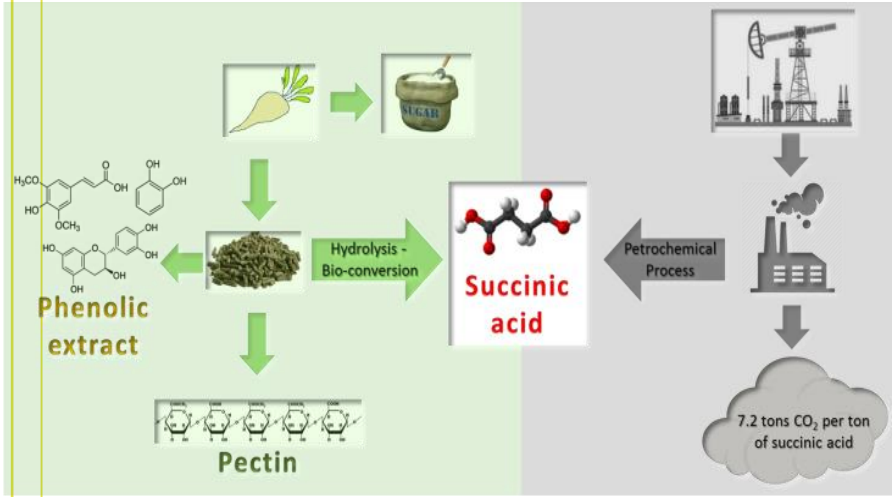
L(+)-lactic acid

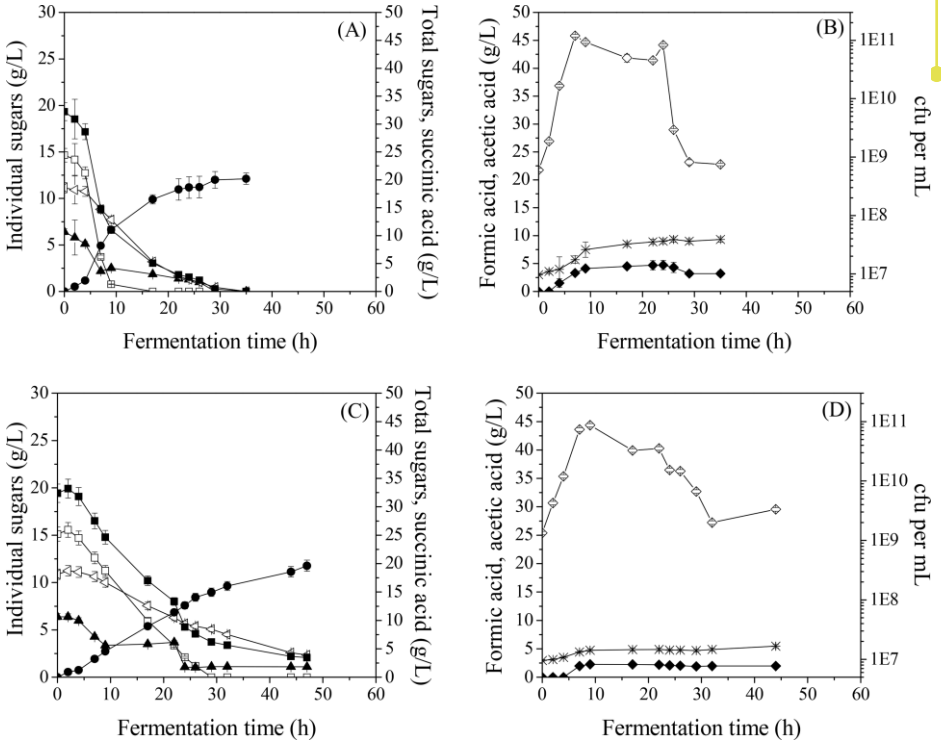
Bundesministerium für Bildung und Forschung

Pleissner, D.; Neu, A.-K.; Mehlmann, K.; Schneider, R.; Puerta-Quintero, G.I.; Venus, J.: Fermentative lactic acid production from coffee pulp hydrolysate using *Bacillus coagulans* at laboratory and pilot scales. Bioresource Technology 218 (2016) 167–173
Neu, A.-K.; Pleissner, D.; Mehlmann, K.; Schneider, R.; Puerta-Quintero, G.I.; Venus, J.: Fermenta-tive utilization of coffee mucilage using Bacillus coagulans and investigation of down-stream pro-cessing of fermentation broth for optically pure L(+)-lactic acid production. Bioresource Technology 211 (2016) 398–405

Example SBP

Biotechnological production of succinic acid





Batch fermentation of *A. succinogenes* using (A), (B) SBP hydrolysate supplemented with yeast extract and (C), (D) SBP hydrolysate alone. Glucose (□), xylose+fructose+galactose (▲), arabinose (◁) and total sugars (■), succinic acid (●), formic acid (♦) and acetic acid (✳), cfu per mL (◇)

Alexandri, M.; Schneider, R.; Papapostolou, H.; Ladakis, D.; Koutinas, A.; Venus, J.: Restructuring the conventional sugar beet industry into a novel biorefinery: Fractionation and bioconversion of sugar beet pulp into succinic acid and value-added co-products. ACS Sustainable Chem. Eng. 2019, 7, 7, 6569-6579

Previous/Current EU-BBI/H2020 projects

PERCAL - Chemical building blocks from versatile MSW biorefinery
07/2017 - 12/2020

- **BBI Project CAFIPLA** "Combining carboxylic acid production and fibre recovery as an innovative, cost effective and sustainable pre-treatment process for heterogeneous bio-waste" (BBI grant agreement Nº 887115) – **06/2020–05/2023**, https://cafipla.eu/
- **BBI Project BeonNAT** "Innovative value chains from tree & shrub species grown in marginal lands as a source of biomass for bio-based industries" (BBI grant agreement Nº 887917) – **07/2020–06/2025**, https://beonnat.eu/
- **EU Project BIOMAC** "European Sustainable BIObased nanoMAterials Community" (H2020 grant agreement Nº 952941) – **01/2021–12/2024**, https://www.biomac-oitb.eu

Thank you for your attention!

https://www.youtube.com/watch?v=JnkB0WRIO-o&t=57s

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