Electronic Supplementary Information
for
Evaluating landfill leachate treatment by organic municipal solid waste-derived biochar

Table S1. Measurements of each dry feedstock's elemental composition, which includes carbon (C), hydrogen (H), nitrogen (N), and ash; each of these was used to calculate oxygen (O) and the hydrogen to carbon (H/C), oxygen to carbon (O/C), and oxygen plus nitrogen to carbon (O+N/C) ratios. All are percent by mass. Note: * denotes that lignin and cellulose composition were based on typical feedstock compositions as found in the referenced literature.

	C %	H %	N %	Ash %	O %	H/C %	O/C %	O+N/C %	Lignin* %	Cellulose* %
Paper	54	7.5	0.5	18	21	166	29	29	0 to 15 [1,2]	62 to 99 [1,3]
Pine needles	49	7.0	1.5	3.8	39	170	59	62	20 to 33 [4,5]	30 to 39 [4,6]
Grass	44	5.5	1.0	11	38	149	65	67	4.0 to 30 [1,7]	25 to 50 [1,7,8]
Wood	49	6.0	1.0	0.25	43	143	64	66	29 to 35 [8,9]	38 to 44 [8,9]
Peanut	48	5.4	1.7	28	17	134	27	30	30 to 40 [1,10]	25 to 45 [1,10]
Orange	50	6.4	0.9	3.2	40	153	60	62	0.6 to 6.9 [11–13]	13 to 34 [11–13]
Coffee	57	7.6	2.1	2.0	31	159	41	44	18 to 26 [14,15]	12 to 23 [14,15]

Table S2. Synthetic leachate recipe.

Compound	Chemical formula	Units	Quantity
VOCs			
Nitrobenzene	$C_6H_5NO_2$.	mg/L	0.03
2,4 Dichlorophenoxyacetic acid	$C_8H_6Cl_2O_3$	mg/L	0.03
VFAs			
Acetic acid	CH_3COOH	mL/L	2.4
Propionic acid	$C_3H_6O_2$	mL/L	1.714
Butyric acid	$C_4H_8O_2$	mL/L	0.343
Inorganic compounds			
Ammonium bicarbonate	NH_4HCO_3	mg/L	2440
Calcium chloride	$CaCl_2*2H_20$	mg/L	3350
Dipotassium phosphate	K_2HPO_4	mg/L	30
Magnesium chloride	$MgCl_2*6H_2O$	mg/L	3115
Magnesium sulfate	$MgSO_4$	mg/L	156.3
Potassium biocarbonate	$KHCO_3$	mg/L	312
Potassium carbonate	K_2CO_3	mg/L	325
Sodium bicarbonate	$NaHCO_3$	mg/L	3015
Sodium nitrate	$NaNO_3$	mg/L	50
Urea	$CO(NH_2)_2$	mg/L	695
Metals			
Aluminum sulfate	$Al_2(SO_4)_3*16H_20$	µg/L	30
Ammonium molybdate hydrated	$(NH_4)6Mo_7O_{24}*4H_2O$	µg/L	50
Boric acid	H_3BO_3	µg/L	50
Cobalt sulfate	$CoSO_4*7H_2O$	µg/L	150
Copper sulfate hydrated	$CuSO_4*5H_2O$	µg/L	40
Ferrous sulfate hydrated	$FeSO_4*7H_20$	µg/L	3659
Manganese sulfate	$MnSO_4*H_2O$	µg/L	305
Nickel sulfate	$NiSO_4*6H_2O$	µg/L	500
Sulfuric acid	96% H_2SO_4	µL/L	1
Zinc sulfate	$ZnSO_4*7H_2O$	µg/L	50

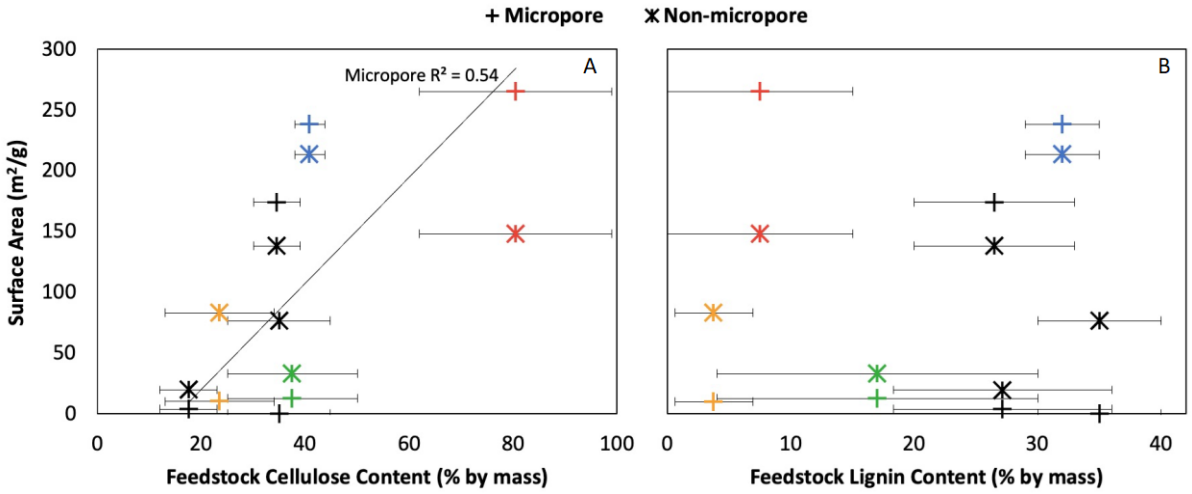

Figure S1. Measured biochar micropore (plus sign) and non-micropore (star) surface areas as a function of feedstock A) cellulose and B) lignin contents for each biochar (color based on feedstock). The lignin and cellulose content's error bars represent the range found in literature (Table S1), and the marker is the midpoint of that range. Despite that future research has found that lignin and cellulose can contribute to biochar structure,[65,66] there were no correlations with the estimated lignin contents (possibly due to the large ranges of possible values for each feedstock) and only weak correlations with the estimated cellulose contents.

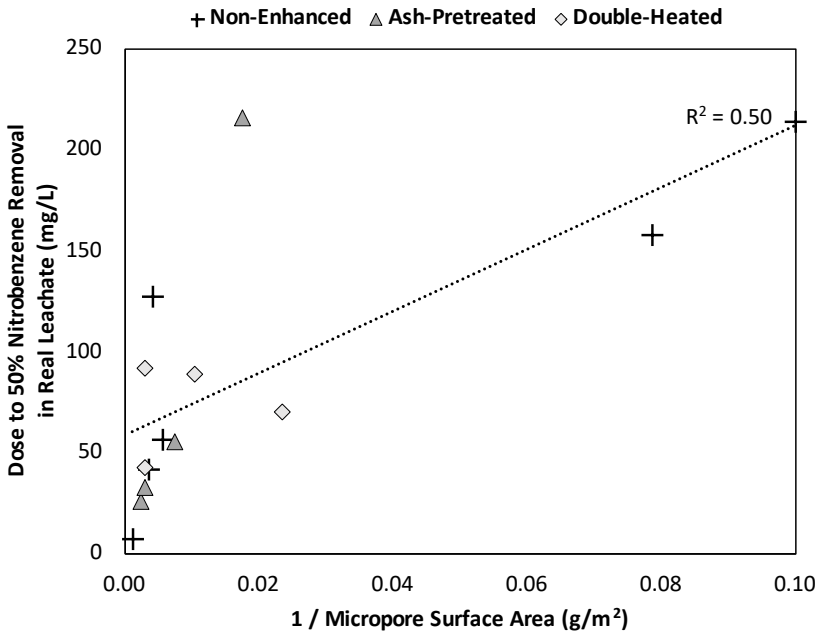

Figure S2. Dose to 50% nitrobenzene removal in real leachate as a function of the reciprocal of biochar micropore surface area. All biochars were included except peanut biochar because it did not have micropore surface area. Micropore surface area had a potential correlation with nitrobenzene removal.

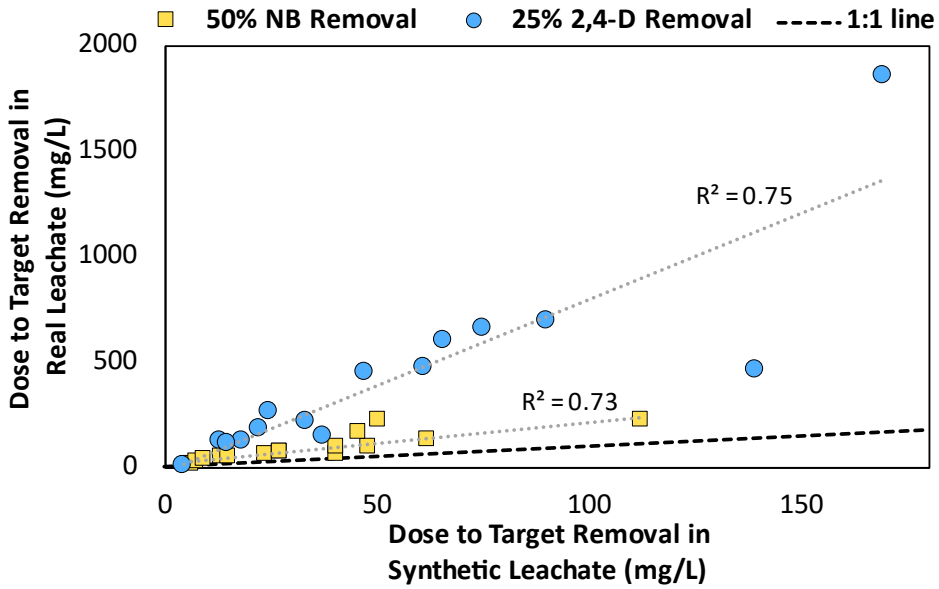

Figure S3. Doses to 50% nitrobenzene (NB) and to 25% 2,4-D removal in real leachate versus synthetic leachate; both removal trendline slopes are greater than one, suggesting that the real leachate had more competitive effects than the synthetic leachate.

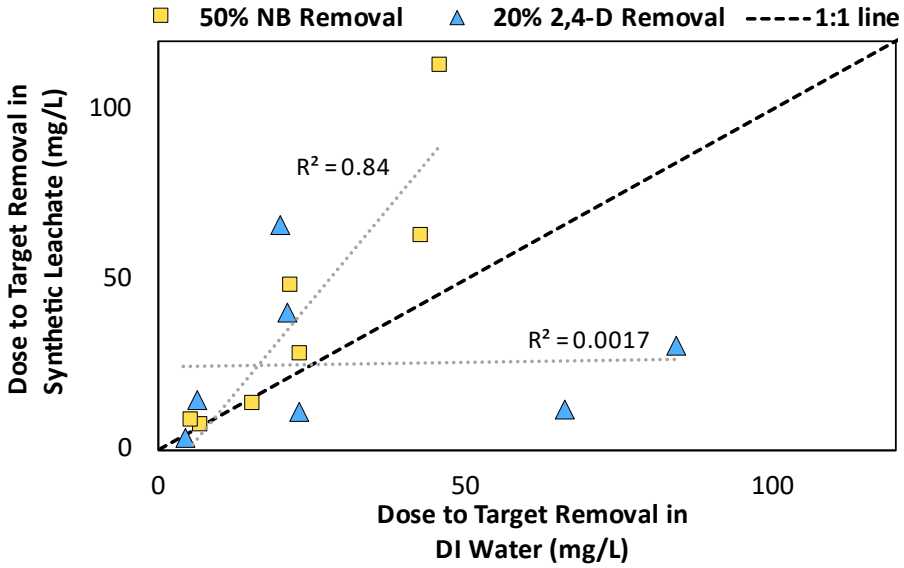

Figure S4. Doses to 50% nitrobenzene (NB) and to 20% 2,4-D removal in synthetic leachate versus deionized (DI) water; the largest, common 2,4-D removal dose in DI water was 20%. Biochar doses in synthetic leachate were similar to those in water without any DOM (i.e., DI water).

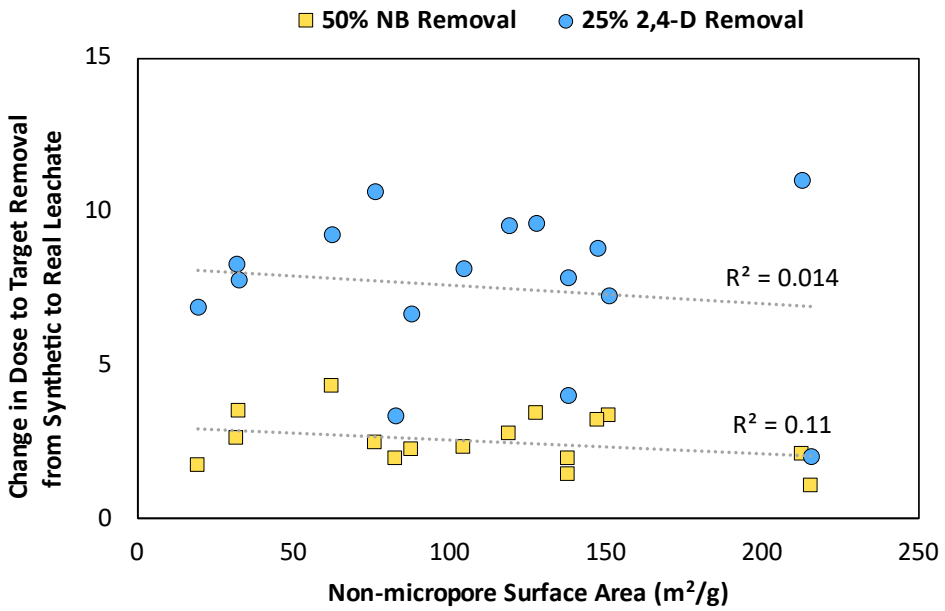

Figure S5. Factor change in dose to 25% 2,4-D and to 50% nitrobenzene (NB) removal required from synthetic to real leachate background matrices as a function of non-micropore surface area for each biochar. No trend exists for either OMP, suggesting that non-VFA DOM is not being accommodated by increasing non-micropore surface area.

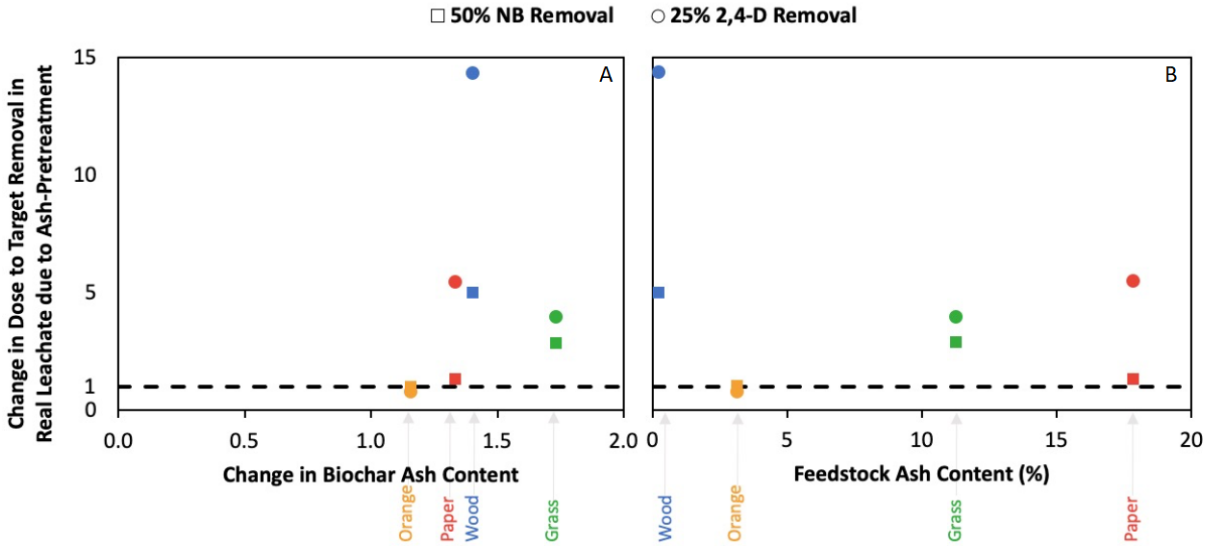

Figure S6. Factor change in dose to 25% 2,4-D and to 50% nitrobenzene (NB) removal in real leachate as impacted by the ash-pretreatment enhancement; dose change is graphed as a function of A) factor change in biochar ash content (enhanced biochar ash content relative to the untreated biochar of the same feedstock), and B) feedstock ash content. Biochar performance generally improved if the biochar ash content increased after the enhancement, but that improvement was not correlated with the feedstock ash content.

References

(1) Khalid, K. A.; Ahmad, A. A.; Yong, T. L.-K. Lignin Extraction from Lignocellulosic Biomass Using Sub- and Supercritical Fluid Technology as Precursor for Carbon Fiber Production. *J. Japan Inst. Energy* **2017**, *96* (8), 255–260. https://doi.org/10.3775/jie.96.255.

(2) Alaboudi, K. A.; Ahmed, B.; Brodie, G. Effect of Biochar on Pb, Cd and Cr Availability and Maize Growth in Artificial Contaminated Soil. *Ann. Agric. Sci.* **2019**, *64* (1), 95–102. https://doi.org/10.1016/j.aoas.2019.04.002.

(3) Loelovich, M. Waste Paper as Promising Feedstock for Production of Biofuel. *J. Sci. Res. Reports* **2014**, *3* (7), 905–916. https://doi.org/10.9734/jsrr/2014/8025.

(4) Font, R.; Conesa, J. A.; Moltó, J.; Muñoz, M. Kinetics of Pyrolysis and Combustion of Pine Needles and Cones. *J. Anal. Appl. Pyrolysis* **2009**, *85* (1–2), 276–286. https://doi.org/10.1016/j.jaap.2008.11.015.

(5) Singha, A. S.; Thakur, V. K. Study of Mechanical Properties of Urea-Formaldehyde Thermosets Reinforced by Pine Needle Powder. *BioResources* **2009**, *4* (1), 292–308. https://doi.org/10.15376/biores.4.1.292-308.

(6) Xiao, S.; Gao, R.; Lu, Y.; Li, J.; Sun, Q. Fabrication and Characterization of Nanofibrillated Cellulose and Its Aerogels from Natural Pine Needles. *Carbohydr. Polym.* **2015**, *119*, 202–209. https://doi.org/10.1016/j.carbpol.2014.11.041.

(7) Ciepiela, G. A.; Godlewska, A. The Effect of Growth Regulator on Structural and Non-Structural Carbohydrates and Lignin Content in Selected Grass Species and Cultivars. *J. Ecol. Eng.* **2015**, *16* (3), 189–197. https://doi.org/10.12911/22998993/2955.

(8) Hernández-Beltrán, J. U.; Hernández-De Lira, I. O.; Cruz-Santos, M. M.; Saucedo-Luevanos, A.; Hernández-Terán, F.; Balagurusamy, N. Insight into Pretreatment Methods of Lignocellulosic Biomass to Increase Biogas Yield: Current State, Challenges, and Opportunities. *Appl. Sci.* **2019**, *9* (18). https://doi.org/10.3390/app9183721.

(9) Darmawan, S.; Wistara, N. J.; Pari, G.; Maddu, A.; Syafii, W. Characterization of Lignocellulosic Biomass as Raw Material for the Production of Porous Carbon-Based Materials. *BioResources* **2016**, *11* (2), 3561–3574. https://doi.org/10.15376/biores.11.2.3561-3574.

(10) Sareena, C.; Sreejith, M. P.; Ramesan, M. T.; Purushothaman, E. Biodegradation Behaviour of Natural Rubber Composites Reinforced with Natural Resource Fillers - Monitoring by Soil Burial Test. *J. Reinf. Plast. Compos.* **2014**, *33* (5), 412–429. https://doi.org/10.1177/0731684413515954.

(11) Ververis, C.; Georghiou, K.; Danielidis, D.; Hatzinikolaou, D. G.; Santas, P.; Santas, R.; Corleti, V. Cellulose, Hemicelluloses, Lignin and Ash Content of Some Organic Materials and Their Suitability for Use as Paper Pulp Supplements. *Bioresour. Technol.* **2007**, *98* (2), 296–301. https://doi.org/10.1016/j.biortech.2006.01.007.

(12) Ahmadi, F.; Zamiri, M. J.; Khorvash, M.; Banihashemi, Z.; Bayat, A. R. Chemical Composition and Protein Enrichment of Orange Peels and Sugar Beet Pulp after Fermentation by Two Trichoderma Species. *Iran. J. Vet. Res.* **2015**, *16* (1), 25–30. https://doi.org/10.22099/ijvr.2015.2919.

(13) Rivas-Cantu, R. C.; Jones, K. D.; Mills, P. L. A Citrus Waste-Based Biorefinery as a Source of Renewable Energy: Technical Advances and Analysis of Engineering Challenges. *Waste Manag. Res.* **2013**, *31* (4), 413–420. https://doi.org/10.1177/0734242X13479432.

(14) Zarrinbakhsh, N.; Wang, T.; Rodriguez-Uribe, A.; Misra, M.; Mohanty, A. K. Characterization of Wastes and Coproducts from the Coffee Industry for Composite Material Production. *BioResources* **2016**, *11* (3), 7637–7653. https://doi.org/10.15376/biores.11.3.7637-7653.
(15) Ballesteros, L. F.; Teixeira, J. A.; Mussatto, S. I. Chemical, Functional, and Structural Properties of Spent Coffee Grounds and Coffee Silverskin. *Food Bioprocess Technol.* **2014**, *7* (12), 3493–3503. https://doi.org/10.1007/s11947-014-1349-z.