Supporting Information for:

Forest residue harvest optimization: Spanning the bridge between plant biology and biorefinery performance

Alison J. Shapiro,[1#] Robyn C. O'Halloran,[2#] Devin Tavares,[1#] Dat Huynh,[1] Seulki Han,[1] Ruofan Shi,[1] Yagya Gupta,[1,3] Robert O'Dea,[4] Sara Haney,[5] Yuichiro Otsuka,[6] Sunitha Sadula,[3] Dionisios G. Vlachos,[1,3] Marianthi Ierapetritou,[1] Delphis F. Levia,[2,7,8*] and Thomas H. Epps, III[1,9,10*]

[1]Dept. of Chemical & Biomolecular Engineering, University of Delaware, Newark, DE, 19716 USA
[2]Dept. of Civil, Construction, and Environmental Engineering, University of Delaware, Newark, DE, 19716 USA
[3]Catalysis Center for Energy Innovation, RAPID Manufacturing Institute & Delaware Energy Institute, University of Delaware, Newark, DE, 19716 USA
[4]Center for Plastics Innovation (CPI), University of Delaware, Newark, DE, 19716 USA
[5]Dept. of Chemistry & Biochemistry, University of Delaware, Newark, DE, 19716 USA
[6]Dept. of Forest Resource Chemistry, Forestry and Forest Products Research Institute, Tsukuba, Ibaraki 305-8687, Japan
[7]Dept. of Geography & Spatial Sciences, University of Delaware, Newark, DE, 19716 USA
[8]Dept. of Plant & Soil Sciences, University of Delaware, Newark, DE, 19716 USA
[9]Dept. of Materials Science & Engineering, University of Delaware, Newark, DE, 19716, USA
[10]Center for Research in Soft matter and Polymers (CRiSP), University of Delaware, Newark, DE, 19716 USA

[#]These authors contributed equally to this work.
*Corresponding authors: thepps@udel.edu, dlevia@udel.edu

Table of Contents:

Section 1. Compositional data for bark, twigs/branchlets, and foliage

Section 2. Statistical analysis and additional figures

Section 3. ASPEN biorefinery model inputs

Section 4. Techno-economic assessment (TEA)

Section 5. Life cycle analysis (LCA)

References

Section 1. Compositional data for bark, twigs/branchlets, and foliage

Table S1. Average data for glucan, xylan, total structural carbohydrates, moisture, and extractives content of each component by phenophase and species. Reported as mean ± standard deviation.

American beech															
	Bark					**Twigs/Branchlets**					**Foliage**				
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)
Emergence	6.2 ± 0.5	17.2 ± 0.7	23.4 ± 1.2	3.4	13.6	4.5 ± 0.0	10.7 ± 0.5	15.2 ± 0.5	6.6	13.2	6.1 ± 2.4	7.2 ± 3.1	13.3 ± 5.5	9.0	40.2
Leafed	7.6 ± 0.2	2.5 ± 0.7	10.1 ± 0.9	4.8	15.2	3.6 ± 1.1	22.9 ± 3.4	26.4 ± 4.4	8.8	10.1	9.4 ± 3.5	19.2 ± 1.0	28.6 ± 4.5	11.1	19.7
Senescence	4.7 ± 0.7	2.8 ± 0.7	7.5 ± 1.4	2.0	12.4	5.2 ± 0.6	11.7 ± 0.8	16.9 ± 1.4	7.2	13.7	4.6 ± 0.6	11.8 ± 0.5	16.4 ± 1.1	9.6	24.5
Leafless†	8.4 ± 1.9	18.6 ± 2.7	27.0 ± 4.6	4.3	12.9	17.4 ± 0.2	22.1 ± 0.7	39.6 ± 0.9	8.2	16.8	x	x	x	x	x
sweet birch															
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)
Emergence	8.9 ± 0.1	6.5 ± 0.4	15.4 ± 0.3	4.4	9.7	5.4 ± 1.0	11.1 ± 3.1	16.5 ± 4.0	8.2	10.7	5.5 ± 0.1	9.2 ± 0.5	14.7 ± 0.0	4.9	11.6
Leafed	5.8 ± 1.3	10.5 ± 0.5	16.3 ± 1.8	1.6	9.5	4.4 ± 0.9	23.8 ± 1.2	28.2 ± 2.0	8.5	12.0	4.9 ± 0.4	18.2 ± 0.1	23.1 ± 0.3	1.7	31.2
Senescence	4.5 ± 0.6	10.3 ± 1.5	14.8 ± 2.0	4.3	8.8	9.8 ± 2.0	21.1 ± 1.8	30.9 ± 3.8	2.4	18.2	5.6 ± 0.3	9.3 ± 0.5	14.8 ± 0.8	8.7	40.5
Leafless†	7.1 ± 0.8	12.5 ± 0.9	19.6 ± 0.1	2.7	7.5	4.5 ± 0.2	11.3 ± 0.0	15.7 ± 0.1	6.8	23.3	x	x	x	x	x
yellow poplar															
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total * (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)
Emergence	9.4 ± 1.1	9.6 ± 0.1	19.0 ± 1.0	7.9	12.5	10.5 ± 0.6	20.9 ± 0.0	31.4 ± 0.7	8.5	17.1	5.8 ± 0.9	6.1 ± 0.3	11.9 ± 1.2	6.7	37.6
Leafed	11.5 ± 0.4	10.1 ± 0.5	21.6 ± 0.1	7.2	14.9	8.9 ± 1.6	25.3 ± 2.3	34.2 ± 3.9	2.4	15.8	8.8 ± 1.2	12.9 ± 1.8	21.7 ± 0.5	9.6	37.8
Senescence	5.0 ± 0.2	8.0 ± 1.0	13.0 ± 0.8	4.2	9.1	14.5 ± 0.9	29.2 ± 2.0	43.8 ± 1.1	8.3	18.5	4.7 ± 1.8	14.2 ± 1.6	18.8 ± 3.5	9.9	39.3
Leafless†	10.3 ± 0.7	11.2 ± 1.2	21.6 ± 1.9	1.8	7.8	12.6 ± 0.4	25.7 ± 0.6	38.3 ± 0.2	7.6	20.3	x	x	x	x	x
pitch pine															
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Moisture (wt%)	Extractives (wt%)
Emergence	5.9 ± 0.3	2.2 ± 0.0	8.0 ± 0.3	5.3	10.1	8.5 ± 1.4	8.4 ± 2.1	17.0 ± 3.5	9.3	30.8	13.3 ± 0.8	8.6 ± 0.5	21.8 ± 1.3	9.3	34.2
Leafed - Spring/ Summer	11.5 ± 1.2	5.4 ± 0.3	16.9 ± 1.5	7.7	15.0	8.4 ± 0.3	15.4 ± 0.4	23.8 ± 0.7	2.4	25.2	25.8 ± 0.2	19.8 ± 0.5	45.5 ± 0.7	1.8	23.8
Senescence	8.1 ± 0.0	2.5 ± 0.8	10.6 ± 0.8	7.4	10.3	9.5 ± 0.5	9.9 ± 0.4	19.4 ± 0.9	7.8	26.9	5.9 ± 0.5	7.9 ± 0.9	13.8 ± 1.4	8.5	32.2
Leafed- Winter	9.9 ± 1.1	4.2 ± 0.5	14.1 ± 1.6	3.6	11.3	2.0 ± 0.5	9.1 ± 0.2	11.1 ± 0.3	9.0	28.3	5.3 ± 0.0	14.6 ± 0.4	19.9 ± 0.8	6.4	36.5

*Total = sum of glucan and xylan content.

†Deciduous species do not have foliage during the leafless phenophase.

Table S2. Median and quartile (Q1, Q3) data for glucan, xylan, total structural carbohydrates, moisture, and extractives content of each component by phenophase and species. Reported as median (Q1, Q3).

Bark															
	American beech			**sweet birch**			**yellow poplar**			**pitch pine‡**			**All Species**		
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt.%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)
Emergence	6.2 (7.7, 8.1)	17.2 (20.9, 23.9)	23.4 (28.7, 32.0)	8.9 (10.1, 10.3)	6.5 (8.0, 8.2)	15.4 (18.3, 18.3)	9.4 (10.8, 12.2)	9.6 (12.8, 14.3)	19.0 (23.6, 26.5)	5.9 (7.1, 7.4)	2.2 (3.6, 3.6)	8.0 (10.7, 11.1)	9.0 (7.6, 12.2)	11.5 (4.7, 18.4)	22.7 (13.0, 27.7)
Leafed	7.6 (3.9, 3.9)	2.5 (3.1, 3.3)	10.1 (7.0, 7.2)	5.8 (7.1, 9.2)	10.5 (12.4, 14.6)	16.3 (19.6, 23.8)	11.5 (13.2, 13.9)	10.1 (10.5, 10.6)	21.6 (23.8, 24.4)	11.5 (11.9, 13.0)	5.4 (6.2, 6.9)	16.9 (18.1, 19.9)	11.5 (5.5, 13.3)	9.0 (4.4, 14.4)	22.1 (10.7, 25.3)
Senescence	4.7 (6.2, 6.4)	2.8 (3.5, 4.2)	7.5 (9.7, 10.6)	4.5 (5.0, 5.2)	10.3 (13.2, 13.3)	14.8 (18.2, 18.5)	5.0 (7.1, 7.2)	8.0 (8.4, 9.4)	13.0 (15.5, 16.6)	8.1 (9.2, 9.6)	2.5 (3.1, 3.7)	10.6 (12.3, 13.3)	6.8 (5.3, 8.5)	6.2 (3.2, 11.9)	13.4 (11.2, 17.3)
Leafless†	8.4 (11.2, 12.1)	18.6 (21.6, 22.6)	27.0 (32.6, 34.7)	7.1 (5.7, 6.4)	12.5 (13.2, 16.1)	19.6 (18.9, 22.5)	10.3 (11.8, 12.4)	11.2 (15.8, 16.5)	21.6 (27.6, 28.9)	9.9 (10.0, 11.3)	4.2 (4.5, 5.3)	14.1 (14.6, 16.6)	12.2 (8.1, 12.7)	17.2 (8.4, 21.7)	27.0 (19.3, 34.2)
All Phenophases	7.0 (4.5, 11.3)	12.0 (3.7, 22.2)	19.0 (8.2, 33.5)	8.5 (5.4, 10.4)	14.5 (9.3, 17.0)	21.3 (18.2, 25.5)	12.8 (8.5, 12.9)	12.9 (8.6, 16.4)	25.7 (17.1, 29.2)	10.5 (7.9, 13.1)	4.6 (3.0, 6.9)	14.7 (11.4, 20.0)	9.6 (6.9, 12.7)	9.3 (4.8, 16.6)	19.5 (12.5, 26.7)
Twigs/branchlets															
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt.%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)
Emergence	4.5 (3.4, 3.6)	10.7 (35.1, 38.6)	15.2 (38.5, 42.1)	5.4 (22.8, 26.3)	11.1 (27.6, 28.5)	16.5 (50.3, 54.8)	10.5 (12.4, 12.9)	20.9 (26.2, 27.1)	31.4 (38.6, 40.0)	8.5 (2.7, 4.7)	8.4 (13.8, 15.7)	17.0 (16.5, 20.3)	7.7 (2.2, 18.8)	26.4 (16.0, 31.8)	37.3 (20.1, 45.6)
Leafed	3.6 (3.5, 4.1)	22.9 (24.2, 26.2)	26.4 (27.6, 30.3)	4.4 (4.6, 5.3)	23.8 (26.7, 28.4)	28.2 (31.4, 33.7)	8.9 (9.9, 11.2)	25.3 (30.5, 32.4)	34.2 (40.4, 43.7)	8.4 (5.8, 6.3)	15.4 (17.3, 17.3)	23.8 (23.1, 23.6)	6.1 (3.7, 8.6)	26.2 (18.8, 29.4)	30.6 (24.5, 37.8)
Senescence	5.2 (23.4, 24.1)	11.7 (20.2, 23.4)	16.9 (44.2, 46.8)	9.8 (11.1, 12.9)	21.1 (27.2, 28.8)	30.9 (37.3, 41.7)	14.5 (17.6, 18.4)	29.2 (35.5, 36.0)	43.8 (53.6, 54.0)	9.5 (18.0, 19.1)	9.9 (13.2, 13.9)	19.4 (31.1, 33.1)	18.4 (14.6, 23.2)	24.1 (15.4, 34.6)	43.2 (36.3, 50.9)
Leafless†	17.4 (20.8, 21.0)	22.1 (29.2, 29.3)	39.6 (50.0, 50.3)	4.5 (31.3, 35.0)	11.3 (21.2, 21.2)	15.7 (52.4, 56.2)	12.6 (15.6, 16.0)	25.7 (34.2, 34.6)	38.3 (49.8, 50.6)	2.0 (2.5, 3.0)	9.1 (12.8, 12.8)	11.1 (15.2, 15.8)	18.6 (6.5, 27.3)	25.2 (14.9, 33.5)	50.5 (24.7, 50.9)
All Phenophases	12.2 (3.2, 23.6)	26.3 (19.7, 32.3)	39.8 (28.9, 48.5)	17.4 (7.7, 27.3)	28.1 (22.7, 29.5)	45.7 (37.0, 50.0)	14.1 (10.0, 16.9)	32.2 (26.7, 35.9)	44.9 (38.1, 52.8)	4.9 (2.2, 16.4)	13.6 (12.8, 16.6)	20.0 (14.9, 31.5)	12.9 (4.0, 20.7)	26.4 (17.6, 29.6)	38.3 (28.2, 49.8)
Foliage															
Phenophase	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)
Emergence	6.1 (8.4, 10.9)	7.2 (10.2, 12.2)	13.3 (20.6, 21.1)	5.5 (22.7, 22.8)	9.2 (9.0, 9.3)	14.7 (31.7, 32.0)	5.8 (8.8, 9.8)	6.1 (9.3, 10.5)	11.9 (19.1, 19.3)	13.3 (13.8, 14.4)	8.6 (20.0, 20.6)	21.8 (34.3, 34.3)	12.8 (10.8, 20.5)	9.0 (8.7, 18.0)	26.5 (19.6, 33.7)
Leafed	9.4 (6.0, 9.0)	19.2 (23.6, 24.8)	28.6 (29.6, 33.8)	4.9 (4.7, 5.0)	18.2 (18.2, 18.3)	23.1 (23.0, 23.2)	8.8 (13.3, 14.4)	12.9 (17.2, 18.1)	21.7 (30.5, 32.4)	25.8 (33.7, 33.9)	19.8 (26.8, 27.2)	45.5 (60.5, 61.1)	9.7 (4.6, 29.2)	20.7 (18.3, 26.3)	30.4 (24.0, 54.4)
Senescence	4.6 (20.3, 22.5)	11.8 (23.4, 25.2)	16.4 (45.5, 45.9)	5.6 (7.5, 8.4)	9.3 (8.1, 8.7)	14.8 (16.2, 16.5)	4.7 (6.9, 8.8)	14.2 (22.2, 23.7)	18.8 (29.1, 32.5)	5.9 (7.6, 7.9)	7.9 (5.4, 6.1)	13.8 (13.4, 13.8)	9.0 (7.3, 16.8)	16.7 (6.1, 25.7)	25.1 (13.9, 42.6)
Leafless†	x	x	x	x	x	x	x	x	x	5.3 (8.2, 8.6)	14.6 (23.3, 23.8)	19.9 (31.4, 32.4)	8.4 (8.2, 8.6)	23.5 (23.3, 23.8)	31.9 (31.4, 32.4)

All Phenophases	12.1 (4.5, 19.2)	23.0 (9.2, 26.2)	27.5 (21.3, 45.4)	7.0 (4.6, 22.8)	9.0 (8.8, 18.3)	22.9 (16.1, 31.6)	10.4 (9.8, 14.9)	18.5 (8.7, 24.4)	33.3 (19.1, 34.2)	10.8 (8.0, 28.9)	22.0 (9.0, 26.3)	32.7 (17.7, 54.7)	10.4 (7.5, 17.0)	18.5 (8.9, 23.7)	31.0 (20.2, 34.3)

‡ Phenophases for pitch pine are emergence, leafed-spring/summer, senescence, and leafed-winter.

*Total = sum of glucan and xylan content.

†Deciduous species do not have foliage during the leafless phenophase.

Section 2. Statistical analysis and additional figures

Table S3. Shapiro-Wilk test for normality *p*-values with the Wilk's test statistic (W) for glucan, xylan, and total structural carbohydrates (wt%) for all components, species, and phenophases. Reported as *p*-value (Wilk's test statistic).

	Bark			**Twigs/Branchlets**		
	Glucan (wt%)	Xylan (wt%)	Total‡ (wt%)	Glucan (wt%)	Xylan (wt%)	Total‡ (wt%)
American beech	0.57 (0.94)	0.02* (0.78)	0.04* (0.82)	<0.01* (0.75)	0.94 (0.98)	0.35 (0.91)
sweet birch	0.04* (0.81)	0.77 (0.96)	<0.01* (0.73)	0.56 (0.93)	0.09 (0.85)	0.62 (0.94)
pitch pine	0.91 (0.97	0.62 (0.94)	0.43 (0.92)	0.02* (0.79)	0.01* (0.76)	0.37 (0.91)
yellow poplar	0.15 (0.87)	0.554 (0.93)	0.60 (0.94)	0.93 (0.97)	0.21 (0.88)	0.27 (0.90)
Emergence	0.43 (0.92)	0.54 (0.93)	0.72 (0.95)	0.22 (0.89)	0.98 (0.95)	0.76 (0.96)
Leafed	0.14 (0.87)	0.66 (0.95)	0.15 (0.87)	0.30 (0.90)	0.46 (0.92)	0.70 (0.95)
Leafless†	0.14 (0.87)	0.55 (0.93)	0.15 (0.95)	0.71 (0.95)	0.43 (0.89)	<0.01* (0.67)
Senescence	0.94 (0.14)	0.15 (0.87)	0.57 (0.94)	0.90 (0.97)	0.53 (0.93)	0.65 (0.94)
All Seasons/ Phenophases	0.28 (0.96)	0.04* (0.93)	0.48 (0.97)	0.04* (0.93)	0.13 (0.95)	0.16 (0.95)
	Foliage			**All components**		
	Glucan (wt%)	Xylan (wt%)	Total‡ (wt%)	Glucan (wt%)	Xylan (wt%)	Total‡ (wt%)
American beech	0.71 (0.95)	0.15 (0.85)	0.24 (0.88)	<0.01* (0.85)	0.07 (0.92)	0.13 (0.93)
sweet birch	0.03* (0.77)	0.02* (0.74)	0.25 (0.87)	<0.01* (0.81)	0.03* (0.90)	0.01* (0.86)
pitch pine	0.03* (0.77)	0.05* (0.82)	0.15 (0.87)	<0.01* (0.80)	0.05* (0.92)	0.0004* (0.81)
yellow poplar	0.01* (0.73)	0.81 (0.96)	0.24 (0.87)	0.98 (0.99)	0.03* (0.90)	0.20 (0.94)
Emergence	0.20 (0.82)	0.02* (0.78)	0.02* (0.78)	0.04* (0.91)	0.14 (0.94)	0.44 (0.96)
Leafed	0.03* (0.79)	0.12 (0.86)	0.03* (0.80)	<0.01* (0.73)	0.36 (0.96)	0.03* (0.91)
Leafless	-	-	-	0.05* (0.90)	0.82 (0.97)	0.07 (0.90)
Senescence	0.01* (0.77)	0.06 (0.83)	0.08 (0.84)	0.01* (0.86)	0.07 (0.92)	0.01* (0.88)
All Seasons/ Phenophases	<0.01* (0.83)	0.03* (0.91)	0.02* (0.91)	<0.01* (0.88)	0.02* (0.97)	0.01* (0.96)

‡Total = sum of glucan and xylan content.

*Indicates that the sample failed the normality test and is non-normal.

†Deciduous species do not have foliage during the leafless phenophase.

Table S4. Bartlett's test for homoscedasticity *p*-values with the Bartlett's test statistic for glucan, xylan, and total structural carbohydrates (wt%) for all components, species, and phenophases. Reported as *p*-value (Bartlett's test statistic).

	Bark			**Twigs/Branchlets**		
	Glucan (wt%)	Xylan (wt%)	Total† (wt%)	Glucan (wt%)	Xylan (wt%)	Total† (wt%)
Phenophases	0.07 (6.94)	0.33 (3.45)	0.19 (1.71)	<0.01* (13.56)	0.68 (1.51)	0.16 (5.19)
Species	0.86 (0.76)	<0.01* (24.27)	<0.01* (17.05)	0.02* (10.23)	0.04 (8.39)	0.64 (1.71)

	Foliage			**All Components**		
	Glucan (wt%)	Xylan (wt%)	Total† (wt%)	Glucan (wt%)	Xylan (wt%)	Total† (wt%)
Phenophases	0.11 (4.37)	<0.01* (7.10)	0.27 (1.40)	0.38 (3.06)	0.82 (0.94)	0.67 (1.56)
Species	0.09 (6.60)	0.62 (1.80)	0.07 (7.10)	<0.01 (20.00)	0.46 (2.61)	0.91 (0.57)
All Seasons/ Phenophases	-	-	-	<0.01* (33.91)	0.54 (1.22)	0.02* (8.45)

†Total = sum of glucan and xylan content.

*Indicates that the sample failed the homoscedasticity test and is heteroscedastic.

Table S5. Normality, homoscedasticity results, and the ANOVA test that were chosen for each sample.

Normality, Homoscedasticity, and ANOVA Test						
	Bark			**Twigs/Branchlets**		
	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)
Phenophases	Normal, Homoscedastic, Ordinary	Normal, Homoscedastic, Ordinary	Normal, Homoscedastic, Ordinary	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Homoscedastic, Kruskal-Wallis
Species	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Normal, Homoscedastic, Ordinary
	Foliage			**All Components**		
	Glucan (wt%)	Xylan (wt%)	Total* (wt%)	Glucan (wt%)	Xylan (wt%)	Total* (wt%)
Phenophases	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Normal, Homoscedastic, Ordinary	Non-normal, Homoscedastic, Kruskal-Wallis
Species	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis	Normal, Homoscedastic, Ordinary	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Homoscedastic, Kruskal-Wallis
All Seasons/ Phenophases	-	-	-	Non-normal, Heteroscedastic, Kruskal-Wallis	Non-normal, Homoscedastic, Kruskal-Wallis	Non-normal, Heteroscedastic, Kruskal-Wallis

*Total = sum of glucan and xylan content.

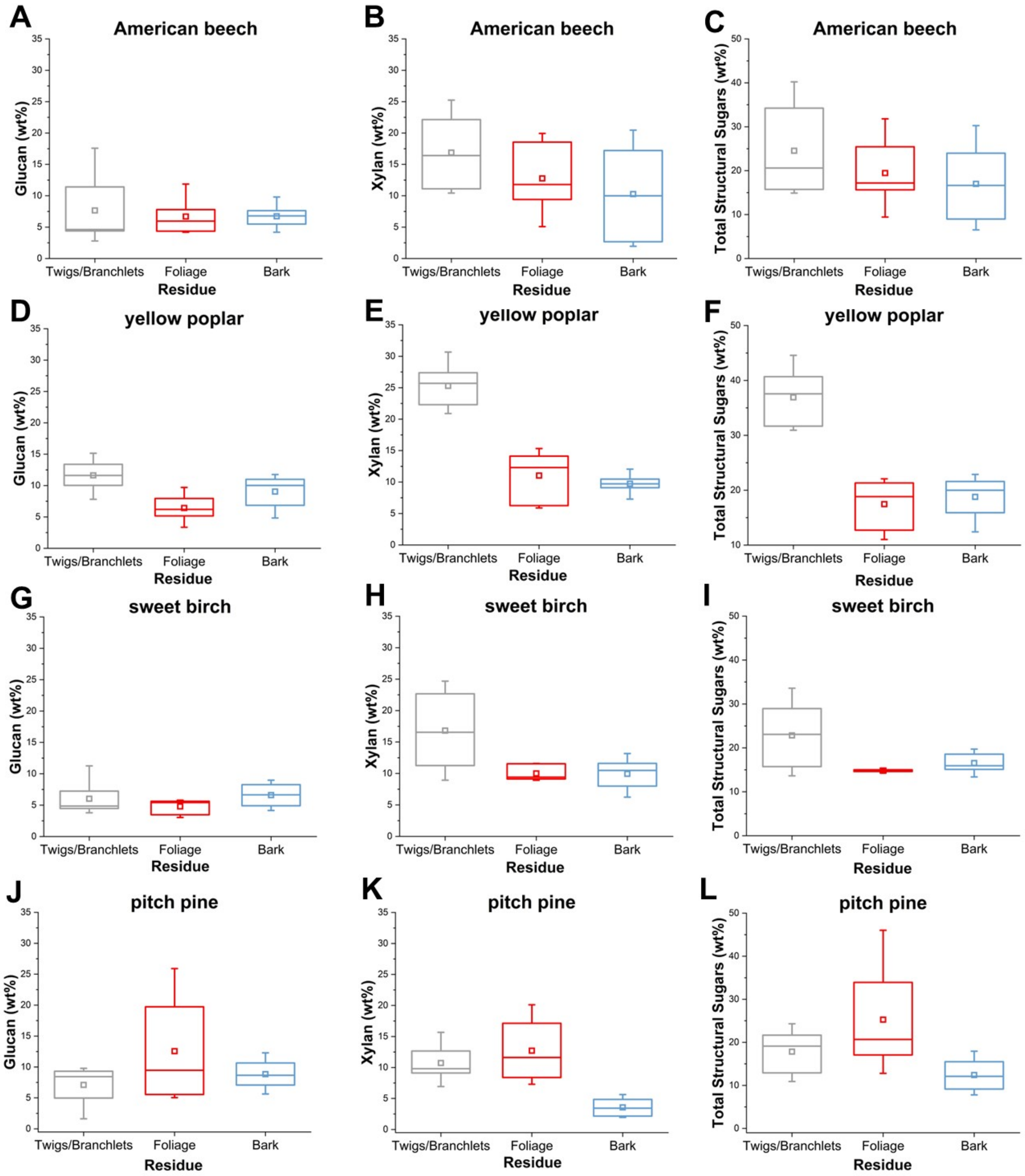

Fig. S1. Structural carbohydrates grouped by species and residue type. A-C) American beech, D-F) yellow poplar, G-I) sweet birch, and J-L) pitch pine glucan, xylan, and total structural sugars for twigs/branchlets, foliage, and bark. Total structural sugars are the sum of glucan and xylan. The box indicates the interquartile range of the data, spanning from the first to the third quartile. The whiskers indicate the minimum and maximum data points, the square within the box denotes the mean, and the horizontal line inside represents the median (50th percentile). *n* = 12 for all tree parts, except for hardwood foliage, for which *n* = 10. Values are reported on a dry, extractive-free basis.

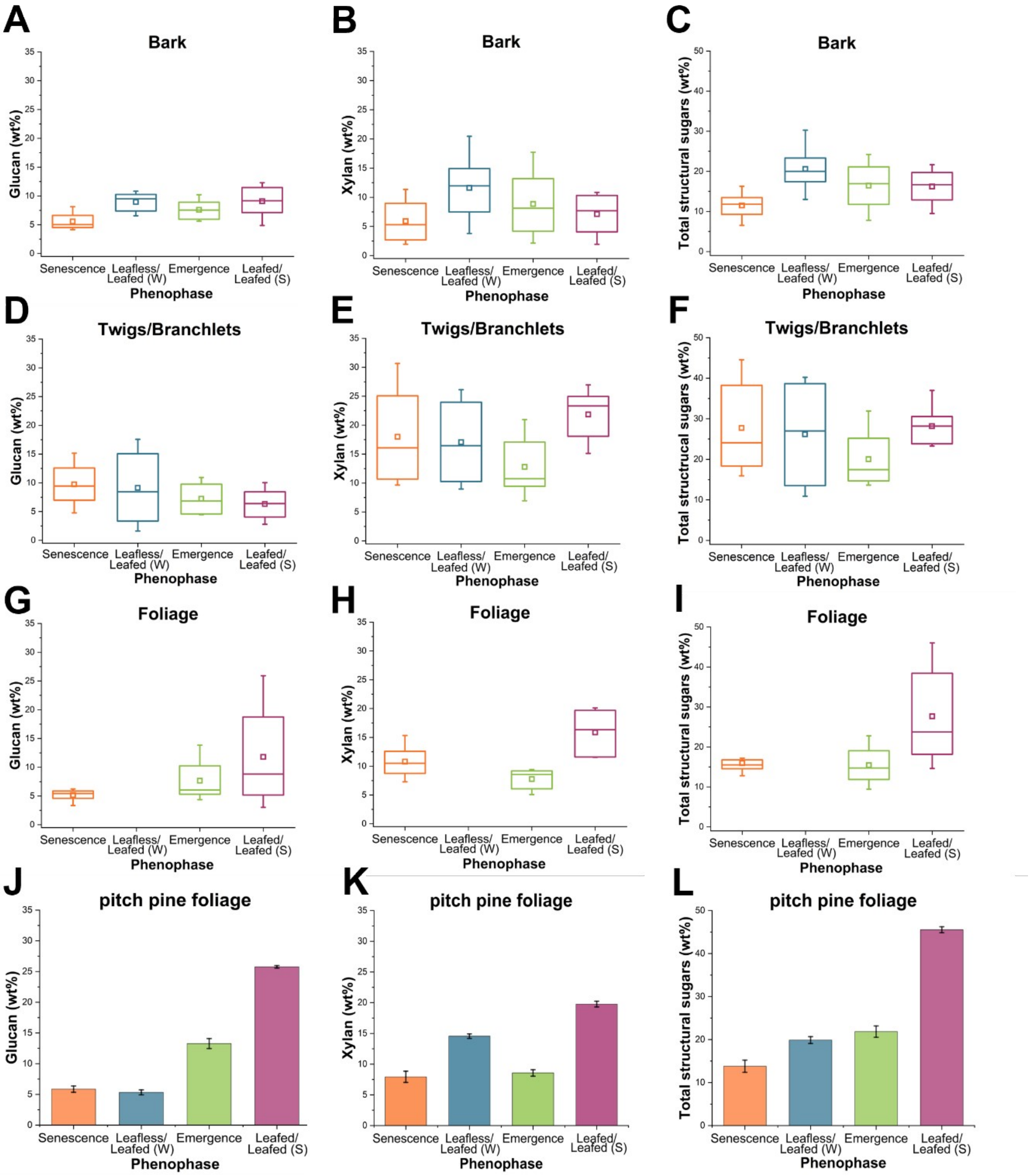

Fig. S2. Structural carbohydrates grouped by phenophase and residue type. A-C) bark glucan, xylan, and total structural sugars, D-F) twigs/branchlets glucan, xylan, and total structural sugars, G-I) foliage glucan, xylan, and total structural sugars for all hardwood species. Note: hardwood species do not have foliage during the leafless phenophase. J-L) glucan, xylan, and total structural sugars for pitch pine foliage. For A-I, *n* = 8, and for J-L, error bars are the standard deviation between replicates (*n* = 2). Total structural sugars are the sum of glucan and xylan. The box indicates the interquartile range of the data, spanning from the first to the third quartile. The whiskers indicate the minimum and maximum data points, the square within the box denotes the mean, and the horizontal line inside represents the median (50th percentile). Values are reported on a dry, extractive-free basis.

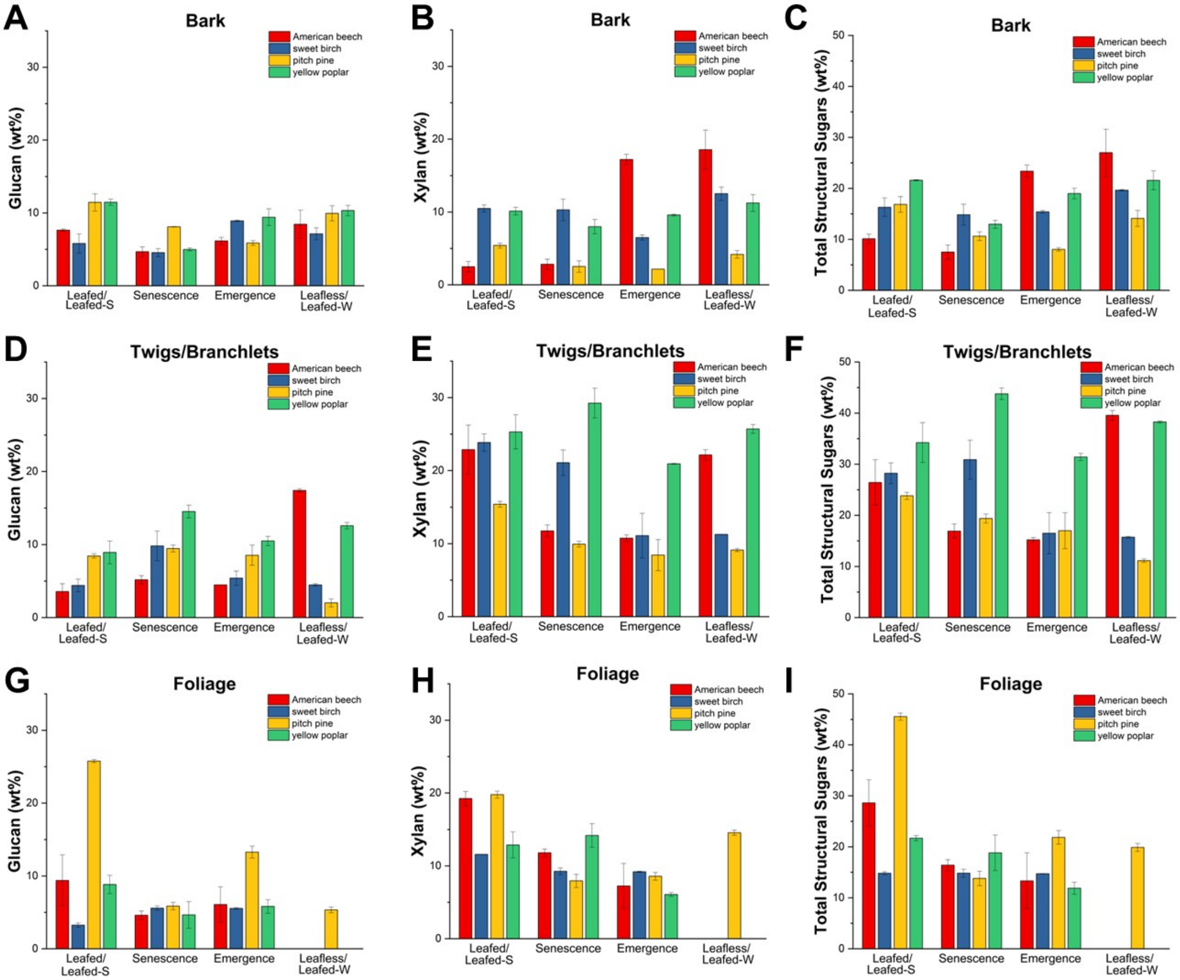

Fig. S3. Individual structural carbohydrates for each species, phenophase, and tree part. A-C) bark glucan, xylan, and total structural sugars, D-F) twigs/branchlets glucan, xylan, and total structural sugars, G-I) foliage glucan, xylan, and total structural sugars. Leafed-S and leafed-W are leafed-spring/summer and leafed-winter, respectively. Values are reported as mean ± standard deviation of replicates (*n* = 2). Values are reported on a dry, extractive-free basis.

Section 3. ASPEN biorefinery model inputs

Table S6. ASPEN biorefinery flowsheet inputs. Reported as fractions normalized to one.

Phenophase	Species	Tree Part	Extractives (wt%)	Lignin† (wt%)	Cellulose (wt%)	Hemicellulose (wt%)	Ash (wt%)	RCF Yield*† (wt%, lignin basis)
Leafless	American beech	Bark	12.9	52.5	10.0	21.9	2.7	7.8
Leafed-Winter	pitch pine	Bark	11.3	71.0	12.4	5.2	0.1	4.9
Leafless	yellow poplar	Bark	7.8	66.4	12.2	13.3	0.4	6.3
Leafless	sweet birch	Bark	7.5	69.9	7.8	13.8	1.0	6.7
Leafed	American beech	Bark	15.2	63.7	8.2	2.7	10.2	15.6
Senescence	American beech	Bark	12.4	67.8	7.0	4.3	8.6	4.8
Emergence	American beech	Bark	13.6	54.9	8.0	22.3	1.2	8.8
Leafed	American beech	Twigs/ Branchlets	10.1	53.5	4.7	30.4	1.3	18.3
Leafed	American beech	Foliage	19.7	47.9	9.6	19.8	3.0	9.1

†Values sourced from previous work.(1)
*(RCF) reductive catalytic fractionation.

Section 4. Techno-economic assessment (TEA)

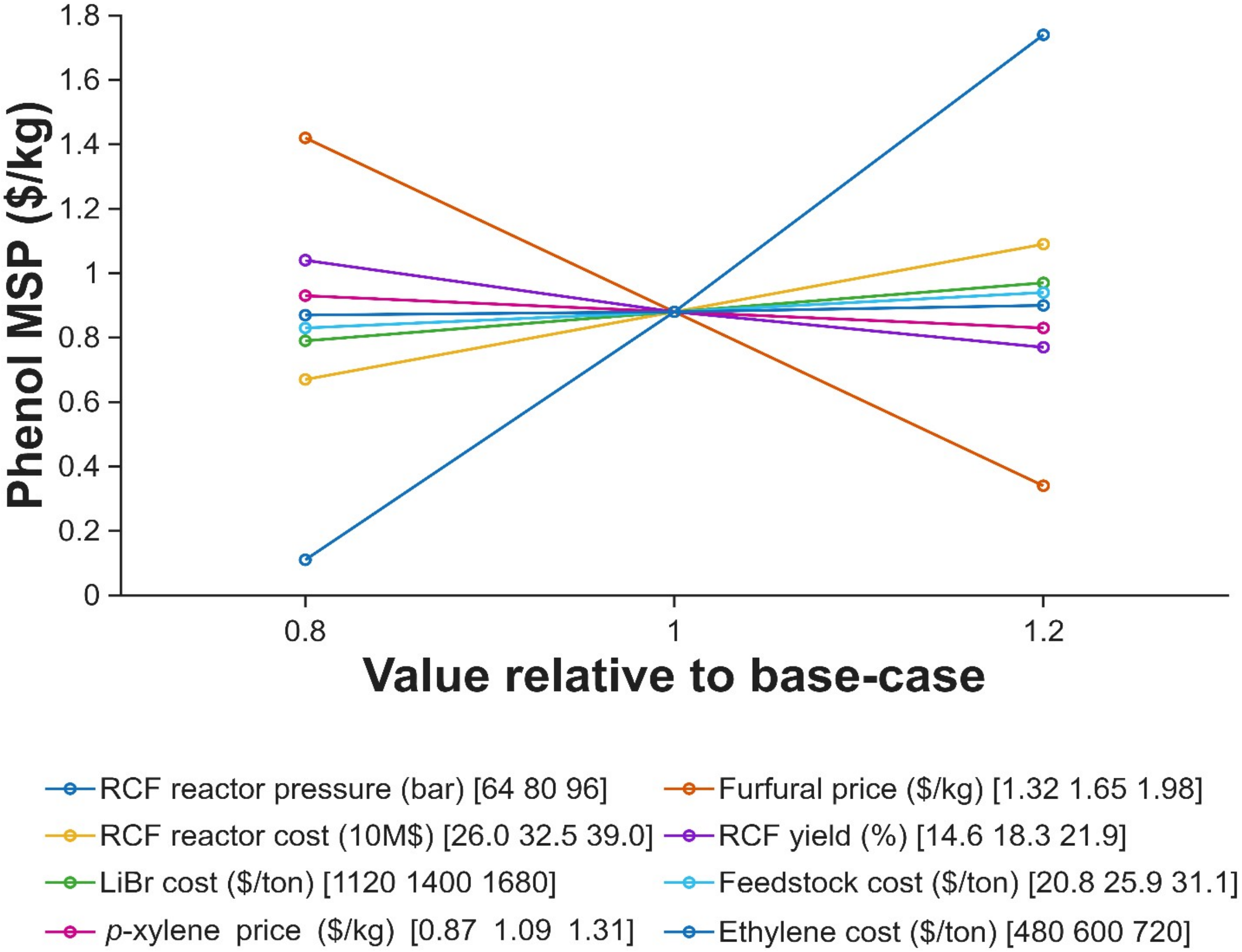

Fig. S4. Sensitivity analysis for the American beech twigs/branchlets leafed case with ±20% variation in key process and economic parameters. The numbers in brackets represent the lower, base-case, and upper values used for the ±20% variation of each parameter.

4.1 Biomass price estimation

A heating value (HV)-based approach was applied to estimate the price of the individual parts of each tree species. This method assumes that the economic value of biomass varies by its energy content, represented by its heating value. The price of a given biomass part *i* was estimated relative to a reference material as follows in Eq. S1:

$$P_i = P_{ref}\frac{HV_i}{HV_{ref}} \qquad \text{Eq. S1}$$

in which P_i is the estimated price of part *i*, P_{ref} is the reference price, HV_i and HV_{ref} are the heating values (high or low heating value) of the biomass part and the reference material, respectively.

As a baseline for the price estimation, we used literature data for wood residues with 15 wt% moisture content (air-dry condition). This reference is commonly reported in the literature and provides both an average low heating value (LHV) of 16.0 MJ/kg and a global average price of \$2.0/GJ (~\$30/ton).(2) These values were used solely as the benchmark for applying the HV-based scaling in Eqn. S1. The LHVs for different species and parts were collected from literature, and their corresponding prices were estimated relative to this reference, as shown in Table S7.(3, 4) It should be noted that oak-derived LHVs from sessile oak (*Quercus petraea*) were used for the American beech samples, as American beech and oak are chemically and structurally similar temperate hardwoods.(5)

Table S7. Low heating value and estimated biomass price for each tree species and part.(3, 4)

Species	Tree Part	LHV (MJ/kg)	Price ($/ton)
American beech	Bark	13.51	25.34
	Twigs/Branchlets	12.98	24.34
	Foliage	12.33	23.12
sweet birch	Bark	13.89	26.05
pitch pine	Bark	13.46	25.25
yellow poplar	Bark	12.08	22.65

4.2 RCF reactor cost estimation

Capital cost for the deconstruction reactor was estimated by approximating it with 232 pressure vessels.(6) The design basis assumes an operating pressure of 80 bar with a 10% safety margin and a residence time of 6 h. A length-to-diameter ratio of 1:5 was used for individual pressure vessels. The internal diameter value was estimated by the total production volumetric flow rate of the reactor.

The pressure vessels consist of an ASTM A515 Grade 60 carbon-steel shell with a thin 316L lining for corrosion resistance. The minimum thickness of individual pressure vessels was based on the hoop stress (Eq. S2) and the longitudinal stress (Eq. S3) equations. A 2:1 ellipsoidal head was considered in the design with a thickness defined by Eq. S4:(6)

$$t_h = \frac{P_i D_i}{2SE - 1.2P_i} \qquad \text{Eq. S2}$$

$$t_l = \frac{P_i D_i}{4SE - 0.8P_i} \qquad \text{Eq. S3}$$

$$t_{head} = \frac{P_i D_i}{2SE - 0.2P_i} \qquad \text{Eq. S4}$$

in which S is the maximum allowable stress for carbon steel (17.1 ksi at 500 °F), E is the welded joint efficiency, which was assumed to be 0.85, D_i represents the internal diameter, and P_i is the internal operating pressure with a 10% safety margin.

The mass of the pressure vessel is calculated by the shell mass (Eq. S5) and the 316L lining mass (Eq. S6). The maximum weight per pressure vessel should not exceed 250,000 kg.

$$M_{cs} = A_{cyl}t_{cyl}\rho_{cs} + 2A_{head}t_{head}\rho_{cs} \qquad \text{Eq. S5}$$

$$M_{lin} = (A_{cyl} + 2A_{head})t_{lin}\rho_{ss} \qquad \text{Eq. S6}$$

in which ρ_{ss} is the density of 304/316L stainless steel with a value of 8,000 kg/m^3, ρ_{cs} is the density of carbon steel with a value of 7,850 kg/m^3, A_{cyl} is the area of the pressure vessel cylinder, A_{head} represents the area of the ellipsoidal head, t_{lin} is the lining thickness, which is assumed to be 3 mm, and t_{cyl} is the required wall thickness.

The Towler & Sinnott formula (Eq. S7) was used to calculate the cost of each pressure vessel, and the total capital cost of the reactor is calculated by Eq. S8. The 316 L lining mass is small compared to the shell mass.(6)

$$C_{each} = \left(a + bM_{cs}^{n}\right) + C_{316L}M_{lin} \qquad \text{Eq. S7}$$

$$C_{total} = C_{each}n_{reactor} \qquad \text{Eq. S8}$$

For ASTM A515 Grade 60 carbon-steel: *a* = 11,600, *b* = 34, and *n* = 0.85.

4.3 TEA and sensitivity analysis

Table S8. Detailed annualized capital and operating costs for all biomass cases ($M/yr).

		American beech Bark Emerg.	**American beech Bark Leafed**	**American beech Bark Leafless**	**American beech Bark Senes.**	**American beech Foliage Leafed**	**American beech Twigs/ Branchlets Leafed**	**sweet birch Bark Leafless**	**pitch pine Bark Leafed-Winter**	**yellow poplar Bark Leafless**
Capital cost	Purchased equipment	43.29	44.59	43.10	42.22	43.04	44.92	43.37	42.37	43.24
	Other*	7.31	7.40	7.36	7.34	7.15	7.66	7.45	7.39	7.24
	G&A* overhead	0.31	0.32	0.32	0.32	0.31	0.33	0.35	0.32	0.31
	Contract fee	0.42	0.42	0.42	0.42	0.41	0.43	0.44	0.42	0.41
	Contingencies	2.19	2.26	2.23	2.24	2.16	2.33	2.41	2.22	2.20
Operating cost	Raw material	32.52	30.95	32.75	31.54	31.58	30.38	32.23	33.84	32.67
	Utilities used	45.55	47.27	45.01	43.70	44.69	50.59	44.31	44.26	45.69
	Other	4.11	3.98	3.93	3.81	3.71	4.06	4.09	4.02	3.82
	Utilities produced	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03
Revenue	Phenol	22.50	41.78	19.54	16.14	20.61	41.19	21.90	17.05	19.88
	Furfural	93.20	9.76	79.32	15.41	71.53	99.17	49.91	18.73	48.08
	p-xylene	20.54	18.11	22.04	15.53	21.29	9.09	17.31	27.30	26.97

*G&A overhead: general and administrative overhead; Other: direct field costs (*e.g.,* piping, electrical, civil, instrumentation, foundations, site preparation); Emerg.: Emergence; Senes.: Senescence.

Section 5. Life cycle analysis (LCA)

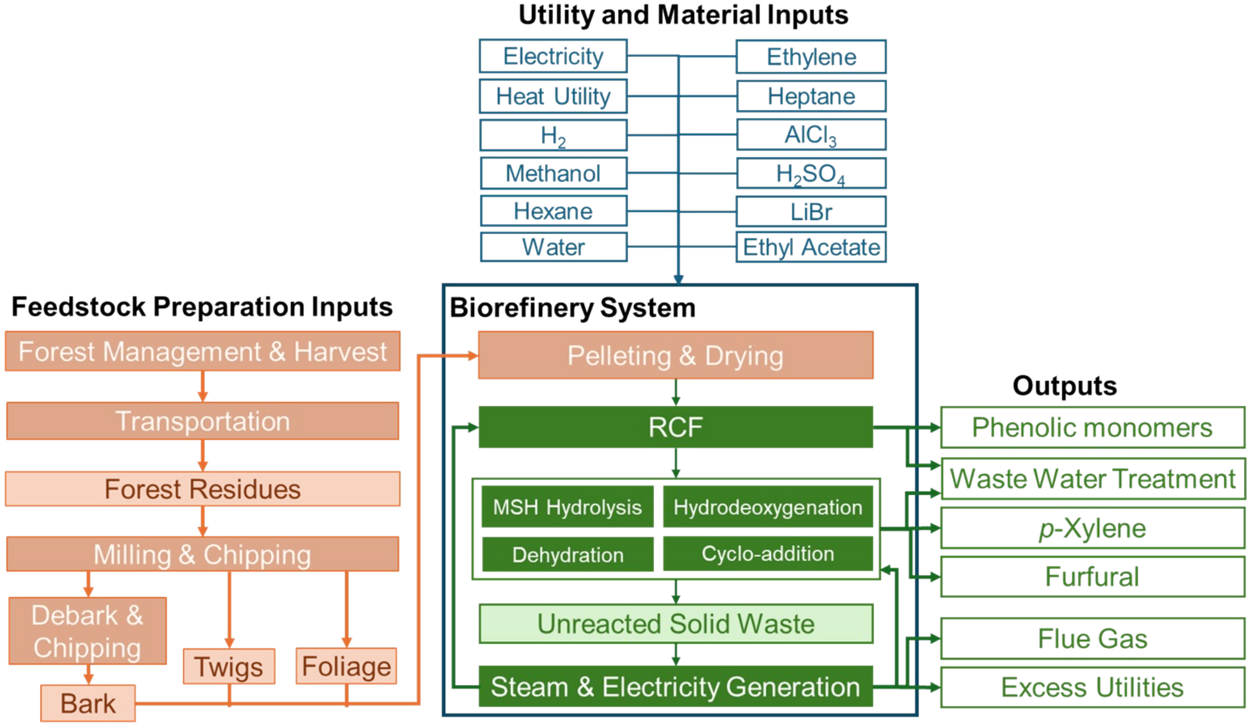

Fig. S5. System boundaries for the LCA, including feedstock preparation inputs, utility and material inputs, biorefinery system, and outputs.

Table S9. LCA inputs and outputs of biorefinery operations using 1000 kg of American beech bark in the emergence phenophase.

Process	Input/Output		Unit	Amount
RCF	Input	Hydrogen	kg	0.53
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	87.23
		Steam	kJ	7,337,000
		Hot oil	kJ	8,561,000
		Electricity	kWh	39.61
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	104.5
		Phenol	kg	44.8
MSH*	Input	Ethylene	kg	11.58
		Heptane	kg	0.01
		$AlCl_3$	kg	1.54

		Ethyl acetate	kg	0.00
		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.15
		Tap water	kg	74.05
		Hydrogen	kg	2.61
		Hot oil	kJ	137,500
		Steam	kJ	13,850,000
		Electricity	kWh	15.88
	Output	Furfural	kg	125.8
		Wastewater	kg	140.2
		p-xylene	kg	41.9
Electricity & Steam	Input	Tap water	kg	642.3
	Output	Electricity	kWh	-888.7
		Steam	kJ	23,720,000
		Combustion	kg	1770
Growth	Input	Carbon sequestration	kg	-1634

*(MSH) molten salt hydrolysis.

Table S10. LCA inputs and outputs of biorefinery operations using 1000 kg of American beech bark in the leafed phenophase.

Process	Input/Output		Unit	Amount
RCF	Input	Hydrogen	kg	1.09
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	72.10
		Steam	kJ	8,579,000
		Hot oil	kJ	8,873,000
		Electricity	kWh	40.55
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	109.9
		Phenol	kg	83.2
MSH	Input	Ethylene	kg	10.37
		Heptane	kg	0.01
		$AlCl_3$	kg	0.44
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.22
		Lithium bromide	kg	25.7
		Tap water	kg	106.8
		Hydrogen	kg	2.21
		Hot oil	kJ	52,060
		Steam	kJ	13,020,000
		Electricity	kWh	17.78
	Output	Furfural	kg	13.2
		Wastewater	kg	127.2
		p-xylene	kg	37.2
Electricity & Steam	Input	Tap water	kg	598.5
	Output	Electricity	kWh	-828.2
		Steam	kJ	22,110,000
		Combustion	kg	1644
Growth	Input	Carbon sequestration	kg	-1627

Table S11. LCA inputs and outputs of biorefinery operations using 1000 kg of American beech bark in the leafless phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	0.45
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	84.19
		Steam	kJ	7,226,000
		Hot oil	kJ	8,521,000
		Electricity	kWh	38.85
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	103.8
		Phenol	kg	38.9
MSH	Input	Ethylene	kg	12.53
		Heptane	kg	0.01
		$AlCl_3$	kg	1.38
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.32
		Tap water	kg	80.96
		Hydrogen	kg	2.68
		Hot oil	kJ	117,200
		Steam	kJ	13,510,000
		Electricity	kWh	16.60
	Output	Furfural	kg	107.5
		Wastewater	kg	139.6
		p-xylene	kg	45.2
Electricity & Steam	Input	Tap water	kg	529.5
	Output	Electricity	kWh	-732.7
		Steam	kJ	19,560,000
		Combustion	kg	1483
Growth	Input	Carbon sequestration	kg	-1636

Table S12. LCA inputs and outputs of biorefinery operations using 1000 kg of American beech bark in the senescence phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	0.36
		Hexane	kg	0.45
		Methanol	kg	0.55
		Tap water	kg	62.13
		Steam	kJ	6,680,000
		Hot oil	kJ	8,490,000
		Electricity	kWh	38.89
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	103.5
		Phenol	kg	32.2
MSH	Input	Ethylene	kg	8.89
		Heptane	kg	0.02
		$AlCl_3$	kg	0.47
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.59
		Tap water	kg	115.0
		Hydrogen	kg	1.89
		Hot oil	kJ	49,400
		Steam	kJ	1,307,000
		Electricity	kWh	17.10
	Output	Furfural	kg	20.9
		Wastewater	kg	131.9
		p-xylene	kg	31.9
Electricity & Steam	Input	Tap water	kg	579.5
	Output	Electricity	kWh	-802.0
		Steam	kJ	21,410,000
		Combustion	kg	1595
Growth	Input	Carbon sequestration	kg	-1675

Table S13. LCA inputs and outputs of biorefinery operations using 1000 kg of American beech foliage in the leafed phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	0.48
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	80.90
		Steam	kJ	7,264,000
		Hot oil	kJ	8,540,000
		Electricity	kWh	38.59
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	104.0
		Phenol	kg	41.1
MSH	Input	Ethylene	kg	12.08
		Heptane	kg	0.01
		$AlCl_3$	kg	1.27
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.24
		Tap water	kg	84.56
		Hydrogen	kg	2.59
		Hot oil	kJ	109,300
		Steam	kJ	13,210,000
		Electricity	kWh	15.72
	Output	Furfural	kg	97.0
		Wastewater	kg	138.2
		p-xylene	kg	43.7
Electricity & Steam	Input	Tap water	kg	625.3
	Output	Electricity	kWh	-865.2
		Steam	kJ	23,100,000
		Combustion	kg	1729
Growth	Input	Carbon sequestration	kg	-1558

Table S14. LCA inputs and outputs of biorefinery operations using 1000 kg of American beech twigs/branchlets in the leafed phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	1.08
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	901.9
		Steam	kJ	8,550,000
		Hot oil	kJ	8,879,000
		Electricity	kWh	39.25
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	109.9
		Phenol	kg	82.1
MSH	Input	Ethylene	kg	9.16
		Heptane	kg	0.04
		$AlCl_3$	kg	1.54
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.22
		Lithium bromide	kg	25.81
		Tap water	kg	67.49
		Hydrogen	kg	1.80
		Hot oil	kJ	1,018,000
		Steam	kJ	15,010,000
		Electricity	kWh	19.20
	Output	Furfural	kg	134.9
		Wastewater	kg	136.5
		p-xylene	kg	19.1
Electricity & Steam	Input	Tap water	kg	568.7
	Output	Electricity	kWh	-787.0
		Steam	kJ	21,010,000
		Combustion	kg	1591
Growth	Input	Carbon sequestration	kg	-1519

Table S15. LCA inputs and outputs of biorefinery operations using 1000 kg of sweet birch bark in the leafless phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	0.52
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	71.49
		Steam	kJ	7,310,000
		Hot oil	kJ	8,420,000
		Electricity	kWh	39.49
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	104.3
		Phenol	kg	43.6
MSH	Input	Ethylene	kg	10.74
		Heptane	kg	0.06
		$AlCl_3$	kg	0.93
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.15
		Tap water	kg	96.33
		Hydrogen	kg	2.11
		Hot oil	kJ	87,240
		Steam	kJ	13,230,000
		Electricity	kWh	15.24
	Output	Furfural	kg	67.7
		Wastewater	kg	132.8
		p-xylene	kg	35.5
Electricity & Steam	Input	Tap water	kg	554.5
	Output	Electricity	kWh	-767.3
		Steam	kJ	20,480,000
		Combustion	kg	1571
Growth	Input	Carbon sequestration	kg	-1713

Table S16. LCA inputs and outputs of biorefinery operations using 1000 kg of pitch pine bark in the leafed-winter phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	0.38
		Hexane	kg	0.45
		Methanol	kg	0.21
		Tap water	kg	103.2
		Steam	kJ	6,256,000
		Hot oil	kJ	8,499,000
		Electricity	kWh	38.19
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	103.4
		Phenol	kg	34.0
MSH	Input	Ethylene	kg	16.11
		Heptane	kg	0.06
		$AlCl_3$	kg	0.72
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.49
		Tap water	kg	105.5
		Hydrogen	kg	3.33
		Hot oil	kJ	80,090
		Steam	kJ	13,750,000
		Electricity	kWh	18.38
	Output	Furfural	kg	25.6
		Wastewater	kg	145.0
		p-xylene	kg	56.0
Electricity & Steam	Input	Tap water	kg	472.0
	Output	Electricity	kWh	-653.7
		Steam	kJ	17,450,000
		Combustion	kg	1324
Growth	Input	Carbon sequestration	kg	-1941

Table S17. LCA inputs and outputs of biorefinery operations using 1000 kg of yellow poplar bark in the leafless phenophase.

Process	**Input/Output**		**Unit**	**Amount**
RCF	Input	Hydrogen	kg	0.46
		Hexane	kg	0.45
		Methanol	kg	0.00
		Tap water	kg	114.3
		Steam	kJ	7,236,000
		Hot oil	kJ	8,435,000
		Electricity	kWh	39.13
		Biomass pretreatment	kg	1000
	Output	Wastewater	kg	103.9
		Phenol	kg	39.6
MSH	Input	Ethylene	kg	16.11
		Heptane	kg	0.06
		$AlCl_3$	kg	1.06
		Ethyl acetate	kg	0.00

		Sulfuric acid	kg	0.23
		Lithium bromide	kg	27.29
		Tap water	kg	91.68
		Hydrogen	kg	3.29
		Hot oil	kJ	116,400
		Steam	kJ	14,270,000
		Electricity	kWh	18.61
	Output	Furfural	kg	65.2
		Wastewater	kg	144.2
		p-xylene	kg	55.4
Electricity & Steam	Input	Tap water	kg	517.2
	Output	Electricity	kWh	-715.7
		Steam	kJ	19,110,000
		Combustion	kg	1454
Growth	Input	Carbon sequestration	kg	-1736

Table S18. Carbon content for each sample.

Sample	**Carbon Content (%)**
American beech bark emergence(7)	48.1
American beech bark leafed(7)	48.1
American beech bark leafless(7)	48.1
American beech bark senescence(7)	48.1
American beech foliage leafed(7)	48.1
American beech twigs/branchlets leafed(7)	47.3
sweet birch bark leafless(8)	49.5
pitch pine bark leafed-winter(8)	52.5
yellow poplar bark leafless(9)	48.2

The reference carbon content was obtained for each species as an aggregated value. A conversion factor is calculated to convert from aggregated value carbon content, which we assume to be the stem of the tree, to either the bark, foliage, or twigs carbon content. The conversion is defined in Eq. S9:

$$C_{tissue} = C_{base} + \Delta C_{tissue-base} \quad \text{Eq S9.}$$

in which C_{tissue} is the plant tissue carbon content, C_{base} is the aggregated carbon content, and $\Delta C_{tissue-base}$ is the conversion factor. To determine the conversion factor, the average values for the carbon contents of the foliage, branch, bark, and stem were used from Zhang *et al.* and Herrero de Aza *et al*. The conversion factors to bark, foliage, and twigs/branchlets are 1.5, 1.5, and 0.65, respectively. It is assumed that the carbon content of the bark of the tree is constant with phenophase according to tree physiology. Research suggests that the non-structural carbohydrates in branchlets account for 90% of the carbon investment in foliage, which reinforces this point.(10-12) A sensitivity analysis was conducted on the tissue-specific carbon contents to assess the impact of uncertainty in carbon content.

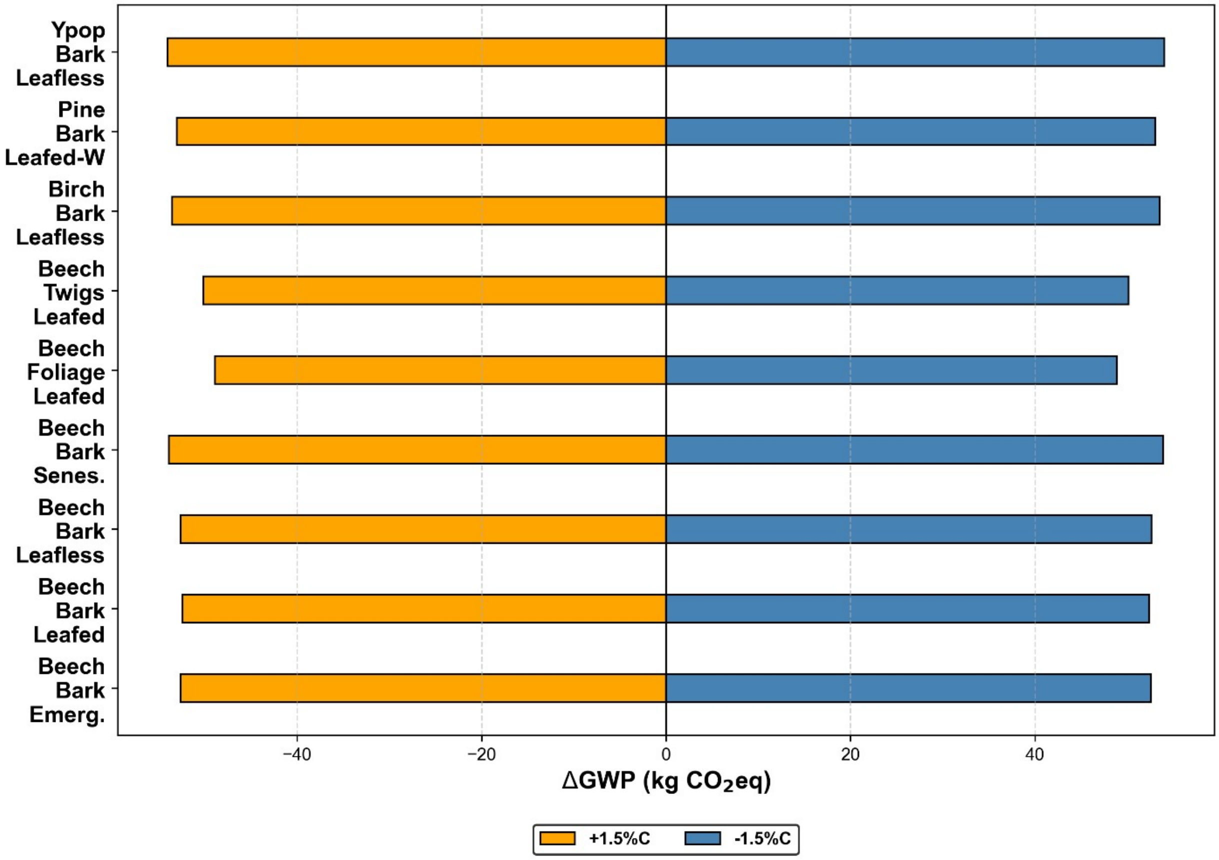

Fig. S5. A sensitivity analysis on the global warming potential (GWP) on the basis of varying the carbon content in each species by 1.5%. Ypop: yellow poplar.

References

1. O'Halloran RC, Shapiro AJ, Gupta Y, Long A, Haney SG, Otsuka Y, et al. Following forest cues for the harvest optimization of tomorrow's biofeedstocks. Green Chem. 2026;28(2):827-38.
2. Labriet M. Biomass Production and Logistics. IEA Energy Technology Network; 2013.
3. Saletnik B, Saletnik A, Zaguła G, Bajcar M, Puchalski C. Oak biomass in the form of wood, bark, brushwood, leaves and acorns in the production process of multifunctional biochar. Molecules. 2022;27(21):7191.
4. Vasileios F, Ioannis, P., Nikolaos, S., Ioannis, E., Kostas, T. Analysis of logging forest residues as an energy source. Journal of Agricultural Informatics,. 2018;9(1):14-25.
5. Szczepkowski A, Nicewicz D, Koczoń P. The relationship between tree health and chemical composition of beech (Fagus sylvatica L.) and oak (Quercus robur L.) wood of Polish provenances. Acta Scientiarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria. 2007;6(3):77-88.
6. Towler G, Sinnott R. Chemical Engineering Design Principles, Practice and Economics of Plant and Process Design. 3rd ed: Elsevier; 2021.
7. Lamlom SH, Savidge RA. A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass Bioenergy. 2003;25(4):381-8.
8. Aalde H, Gonzalez P, Gytarsky M, Krug T, Kurz WA, Ogle S, et al. IPCC Guidelines for National Greenhouse Gas Inventories. IPCC; 2006.
9. Luo Y, O'Dea RM, Gupta Y, Chang J, Sadula S, Soh LP, et al. A life cycle greenhouse gas model of a yellow poplar forest residue reductive catalytic fractionation biorefinery. Environ Eng Sci. 2022;39(10):821-33.
10. Zhang Q, Wang C, Wang X, Quan X. Carbon concentration variability of 10 Chinese temperate tree species. Forest Ecology and Management. 2009;258(5):722-7.
11. Herrero de Aza C, Turrión MB, Pando V, Bravo F. Carbon in heartwood, sapwood and bark along the stem profile in three Mediterranean Pinus species. Annals of Forest Science. 2011;68(6):1067.
12. Klein T, Vitasse Y, Hoch G. Coordination between growth, phenology and carbon storage in three coexisting deciduous tree species in a temperate forest. Tree Physiology. 2016;36(7):847-55.