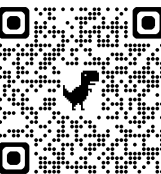




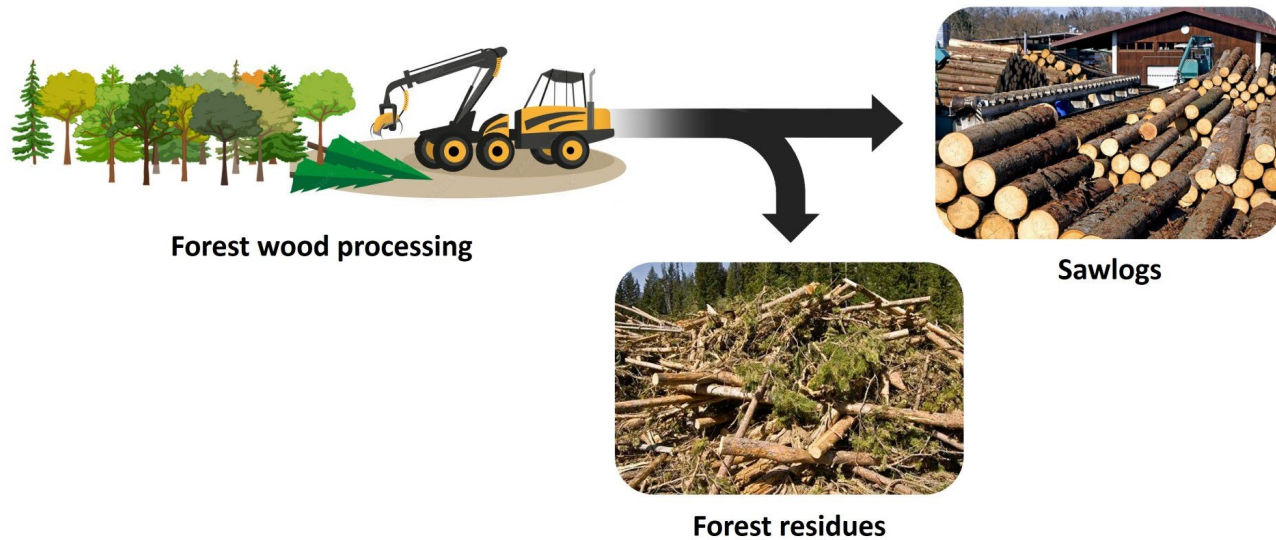
Comprehensive Utilization of Forest Residue Biomass for Fermentative Bioproducts and Solid Biofuels

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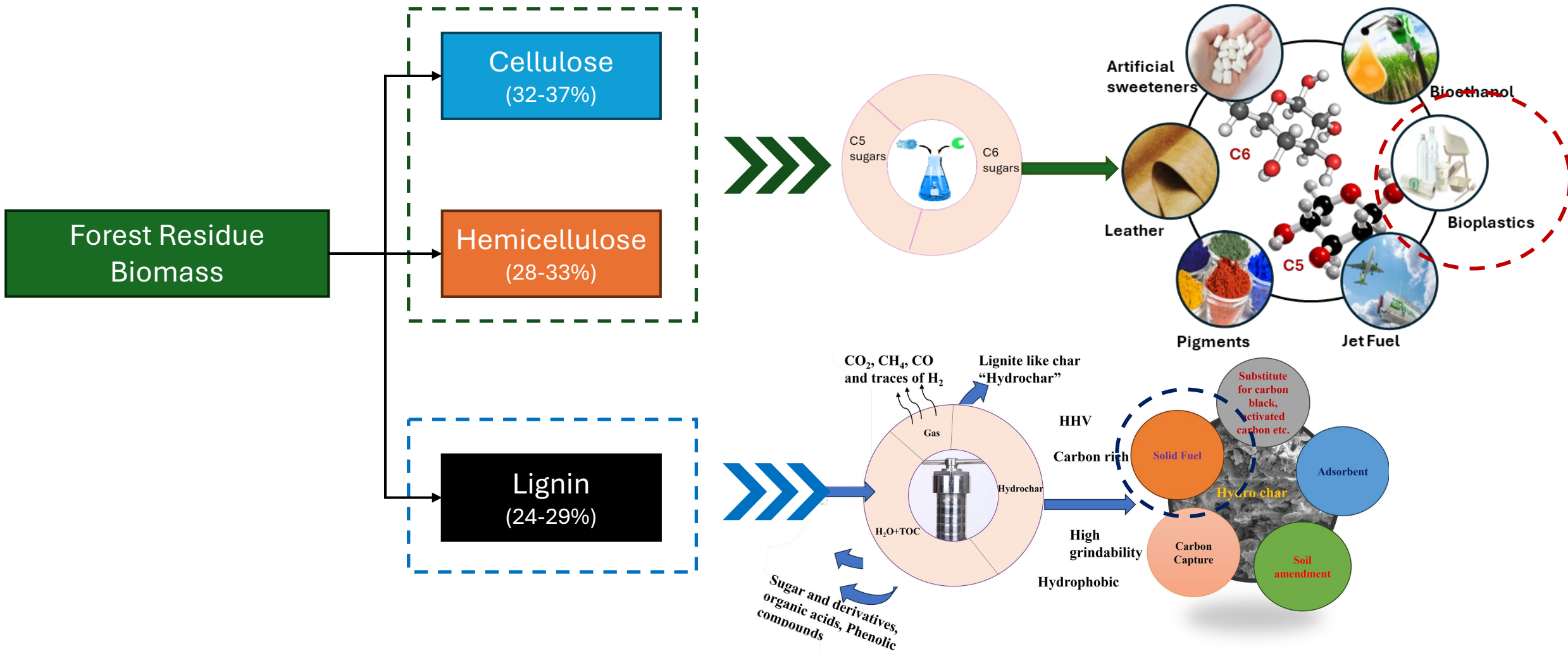
Forest Residue Biomass (FRB)



- Across the Northern Forest region, forests and the forest industry are cornerstones of rural communities.
- Maintaining consistent and reliable markets for low-grade forest residuals has become an increasingly visible challenge.
- These residuals need to hold sufficient value to make the entire process of harvesting, processing, and delivery economically viable
- Within this context, efficient utilization of FRB generated from harvesting operations is a key solution addressing both global imperatives and regional priorities
- Availability of FRB in US makes it one of the most economically viable feedstocks available

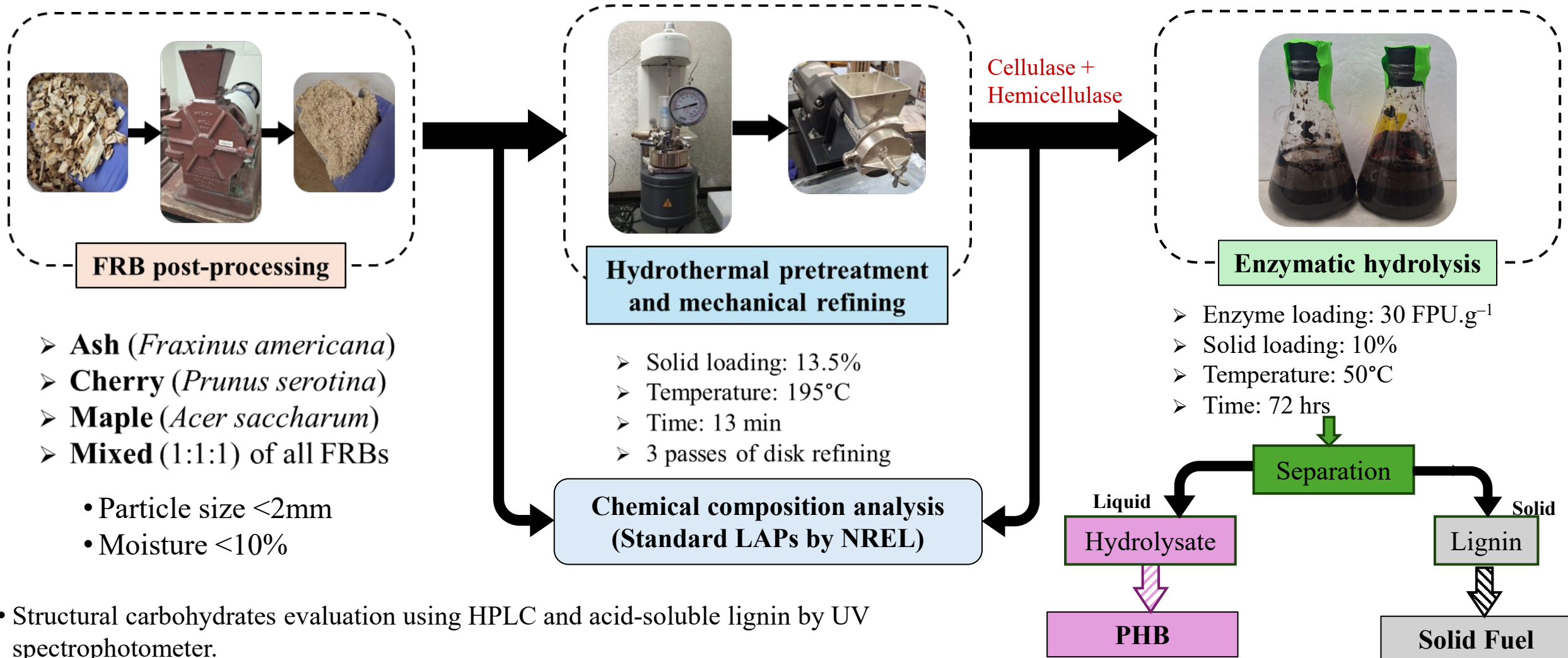
Biorefinery Approach

Objective: Complete utilization of Forest Residue Biomass for maximum revenue generation



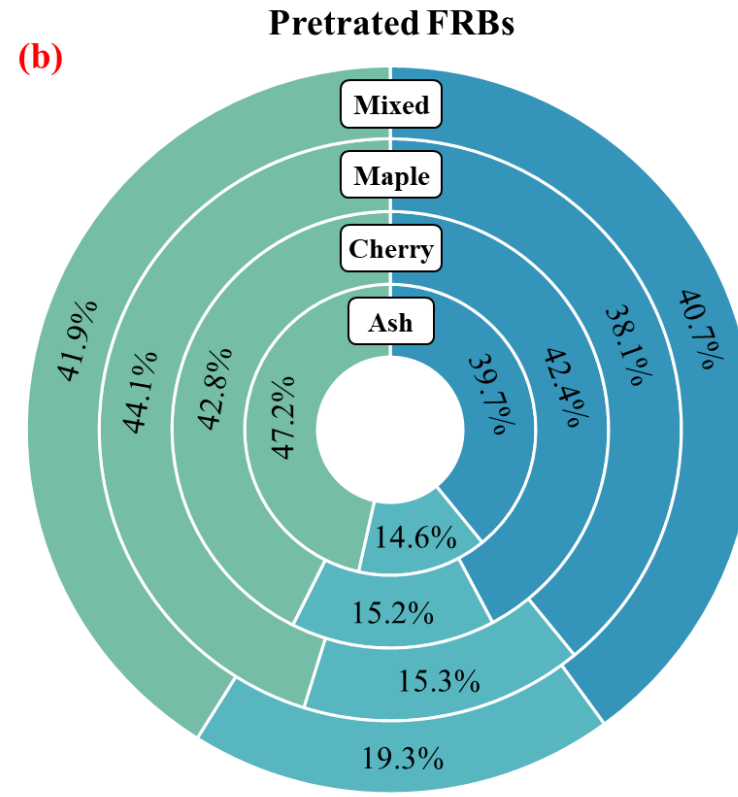
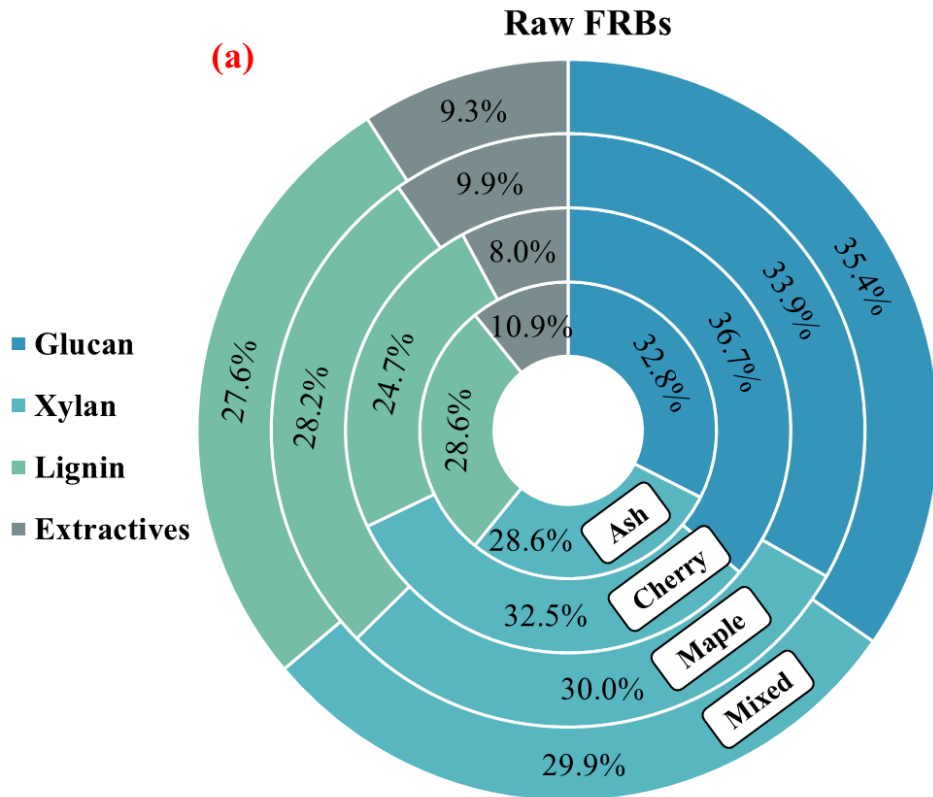
Feedstock Flexible Biorefineries

Objective 1: Potential of mixed FRB for production of bio-products, offering insights for more reliable, feedstock-flexible biorefineries



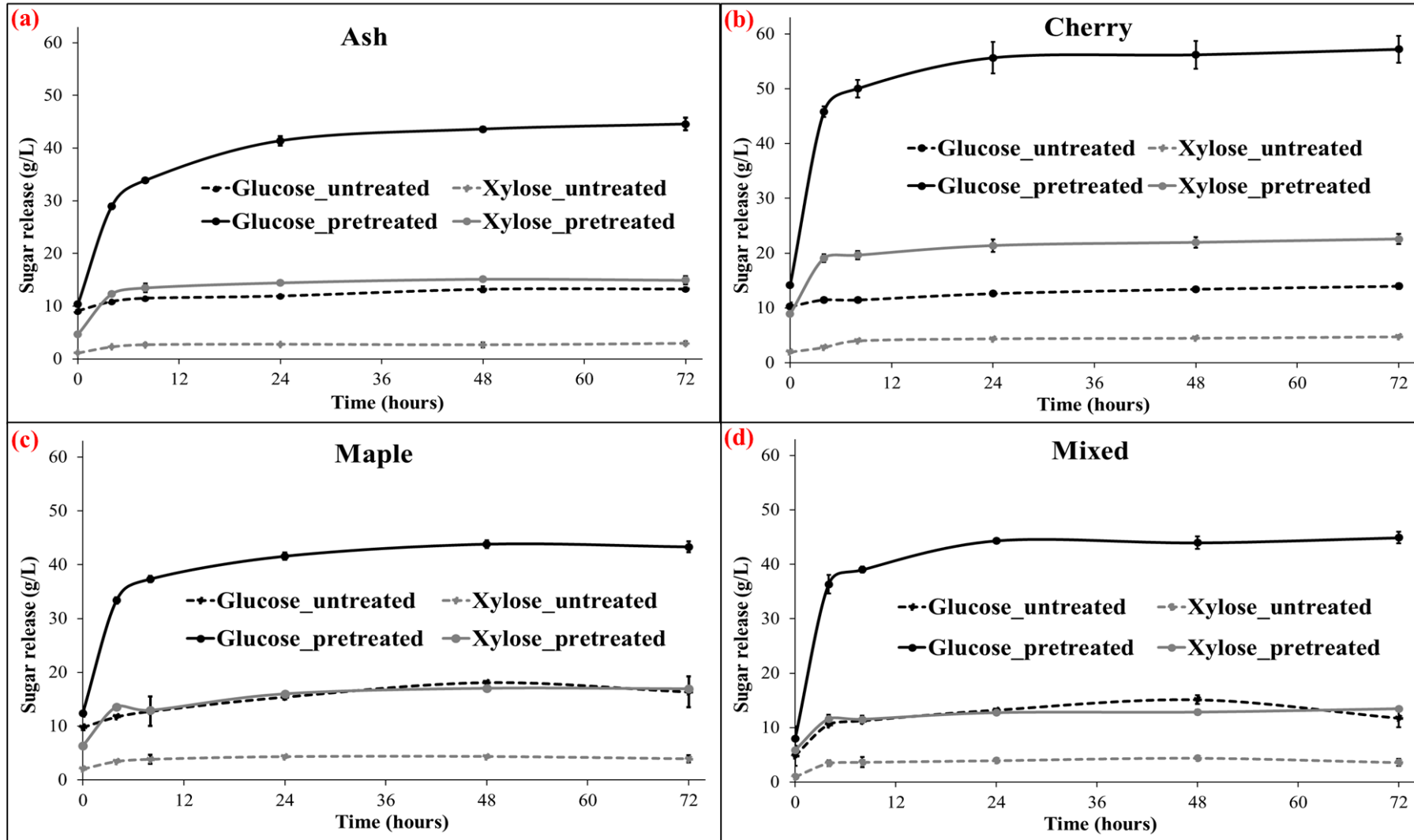
- Structural carbohydrates evaluation using HPLC and acid-soluble lignin by UV spectrophotometer.
- Total lignin = acid-soluble lignin + acid-insoluble lignin.

Composition of (a) raw (untreated) and (b) pretreated FRBs



- Hardwood residues showed variation in composition, with glucan ranging from 32.8–36.7% and xylan from 28.6–32.5%.
- Pretreatment increased glucan by 5.4–9.6% and lignin by 13.2–18.6%, while reducing xylan by 36–53%, showing effective hemicellulose solubilization.
- Ash exhibited the highest glucan enrichment (+6.9%), followed by cherry (+5.7%) and maple (+4.3%).
- The 1:1:1 mixed feedstock showed a balanced profile with 40.7% glucan and 19.3% xylan, suggesting strong potential for co-product generation from glucose and xylose.

Hydrolysis profile of untreated and pretreated FRBs



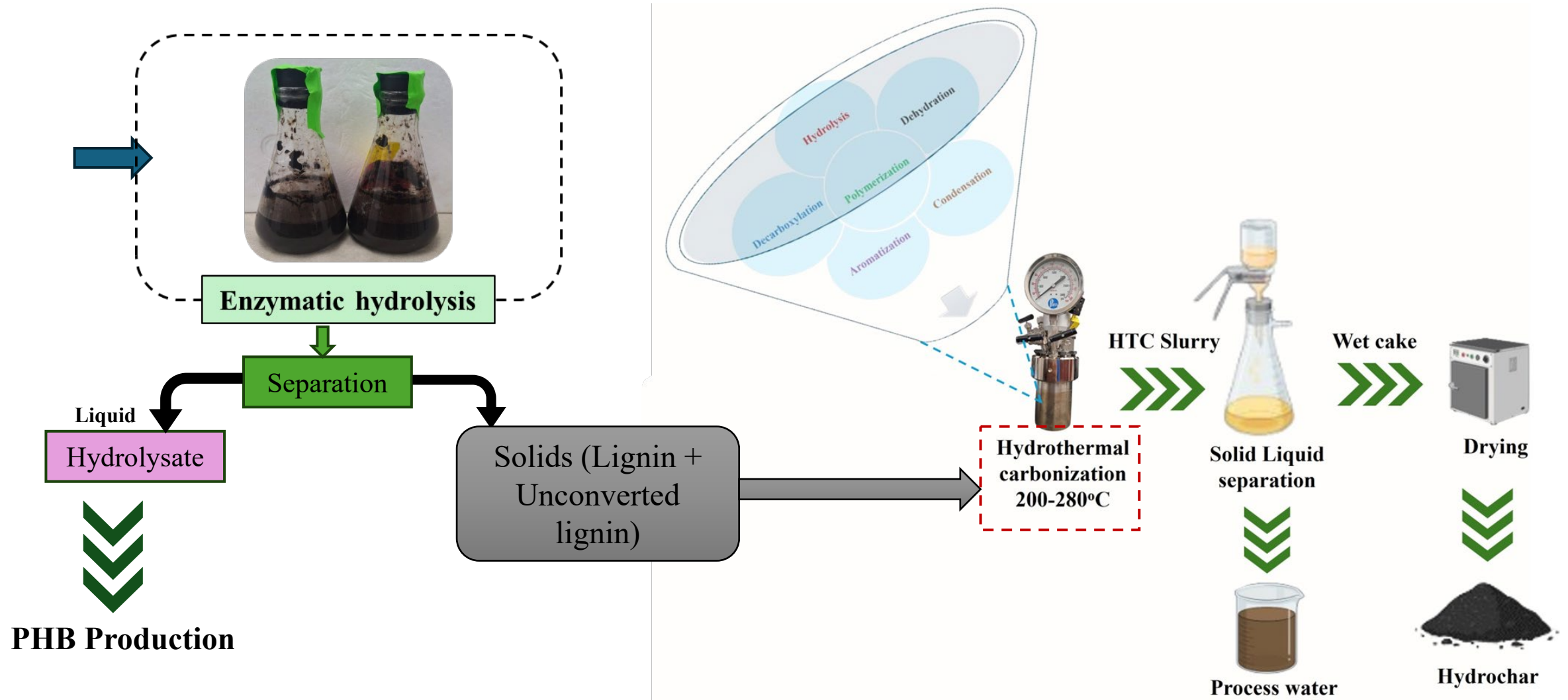
- Pretreatment enhanced substrate availability
 - Increased glucose release by 2.6–4.1 fold
 - Increased xylose release by 3.7–5.1 fold.
- The highest glucose and xylose release rates were observed within the first 24 hrs, after which no significant increase was detected.

Potential of hardwood residues from US to fulfil global demand of fermentative products

Biochemical	Theoretical yield (g/g glucose)	Theoretical yield (g/g xylose)	Total production (g/100 g biomass) (assuming 85% C6 conversion and 30% C5 conversion)	Current global production (×1000 MT/yr)	Expected production in next 10 years (×1000 MT/yr)	Additional biochemical required (×1000 MT/yr)	Amount of hardwood residues required to fulfill total expected demand after 10 years (×1000 MT/yr)	% of demand fulfilled by hardwood residues from US
Acetic acid	0.64	0.76	24.35 - 27.35	17207	30153.36	12946.14	123826.20 - 110256.08	12%
Adipic acid	0.52	-	14.48 - 16.20	4350	6639.95	2289.95	45856.29 - 40977.96	33%
Butanediol	0.51	0.50	18.50 - 20.76	3665	5935.87	2270.87	32090.29 - 28587.18	48%
Butanol	0.41	0.49	15.63 - 17.55	6400	9036.56	2636.56	57826.79 - 51488.69	27%
Butyric acid	0.49	0.49	17.85 - 20.04	140	194.26	54.26	1088.03 - 969.21	>100%
Citric acid	1.07	-	29.80 - 33.34	2810	4199.66	1389.66	14095.06 - 12595.59	>100%
Ethanol	0.51	0.51	18.58 - 20.86	46245	111504.18	65259.18	600021.01 - 534496.17	3%
Formic acid	0.72	0.79	26.84 - 30.13	1100	1614.23	514.23	6015.00 - 5356.91	>100%
Glycerol	0.51	-	14.20 - 15.89	4442	7515.96	3073.96	52923.88 - 47293.68	29%
Isobutanol	0.41	0.41	14.94 - 16.77	650	1063.83	413.83	7120.91 - 6343.28	>100%
Itaconic acid	0.50	0.72	20.11 - 22.60	52	76.97	24.97	382.77 - 340.64	>100%
Lactic acid	0.90	0.60	30.22 - 33.89	1810	3765.31	1955.31	12461.08 - 11109.97	>100%
Propionic acid	0.55	-	15.32 - 17.14	400	532.37	132.37	3476.07 - 3106.27	>100%
Succinic acid	0.70	0.60	24.65 - 27.66	308	556.81	248.81	2259.09 - 2013.11	>100%
Xylitol	-	0.85	7.30 - 8.28	150	326.85	176.85	4475.43 - 3946.32	>100%

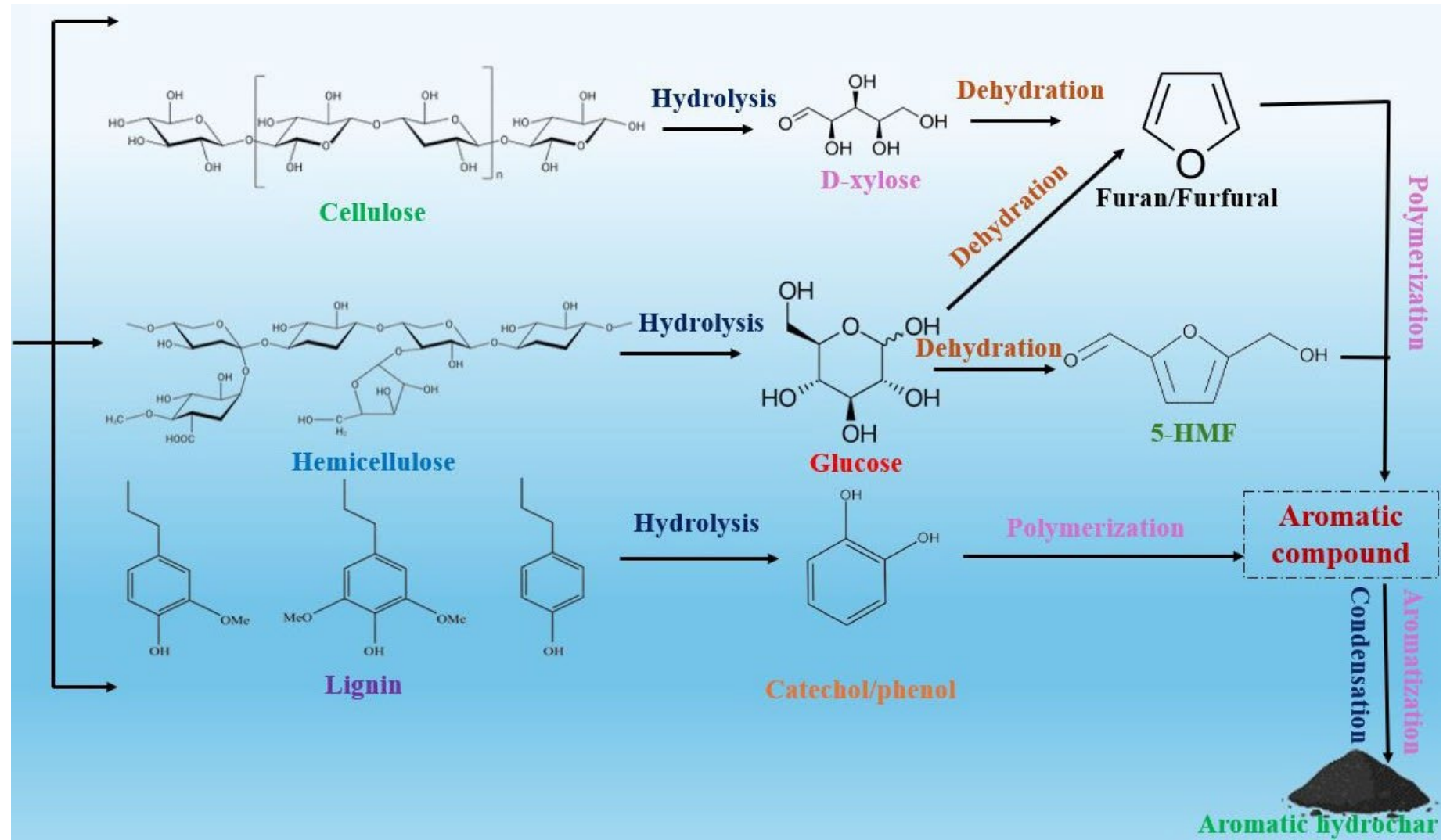
Lignin-rich Residue

Objective 2: Valorization of Lignin-rich Hydrolysis Residue



Lignin-rich Residue

HTC Mechanism



Results

Appearance of Hydrochar



LRR



LRR 200



LRR 220



LRR 240

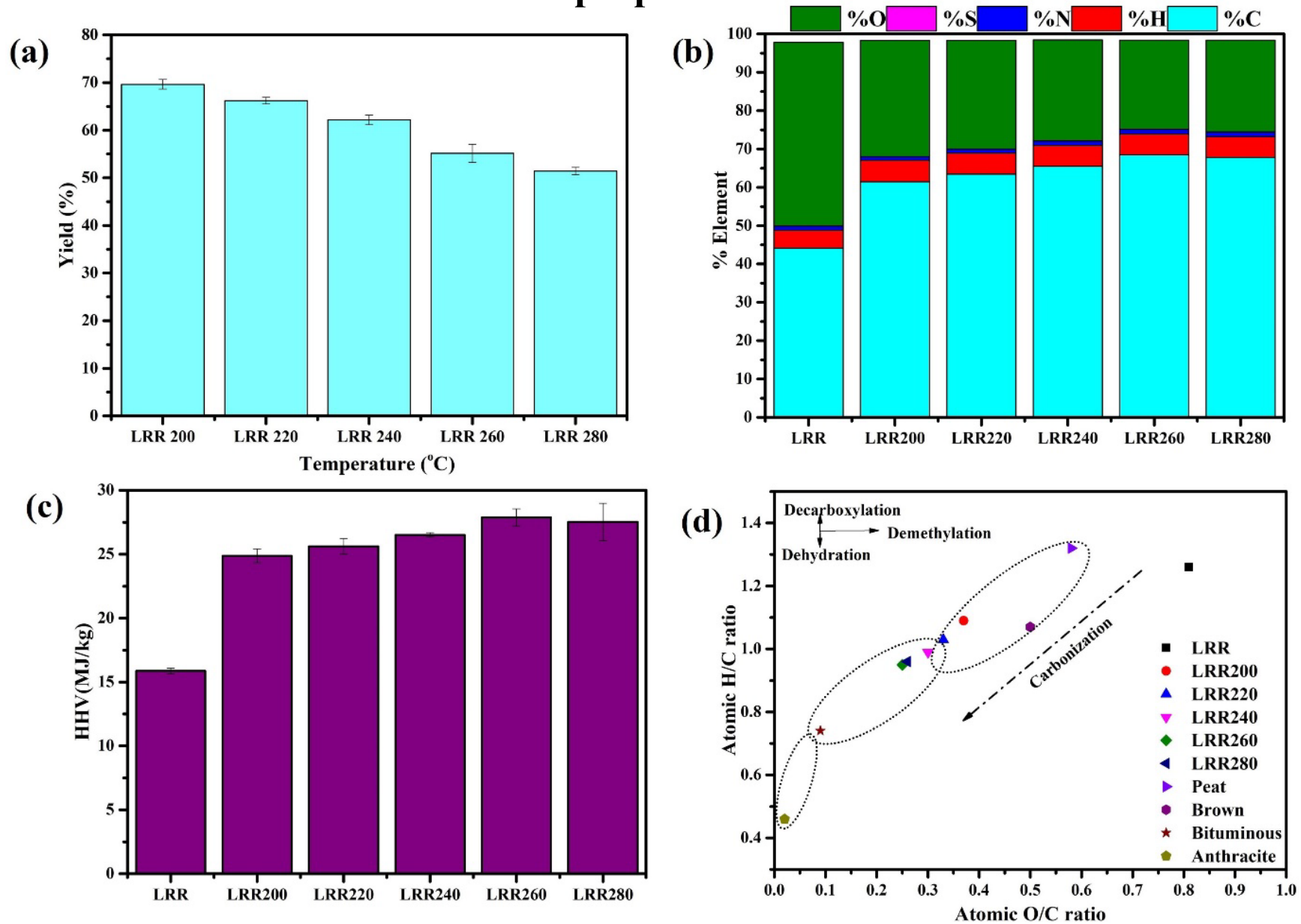


LRR 260



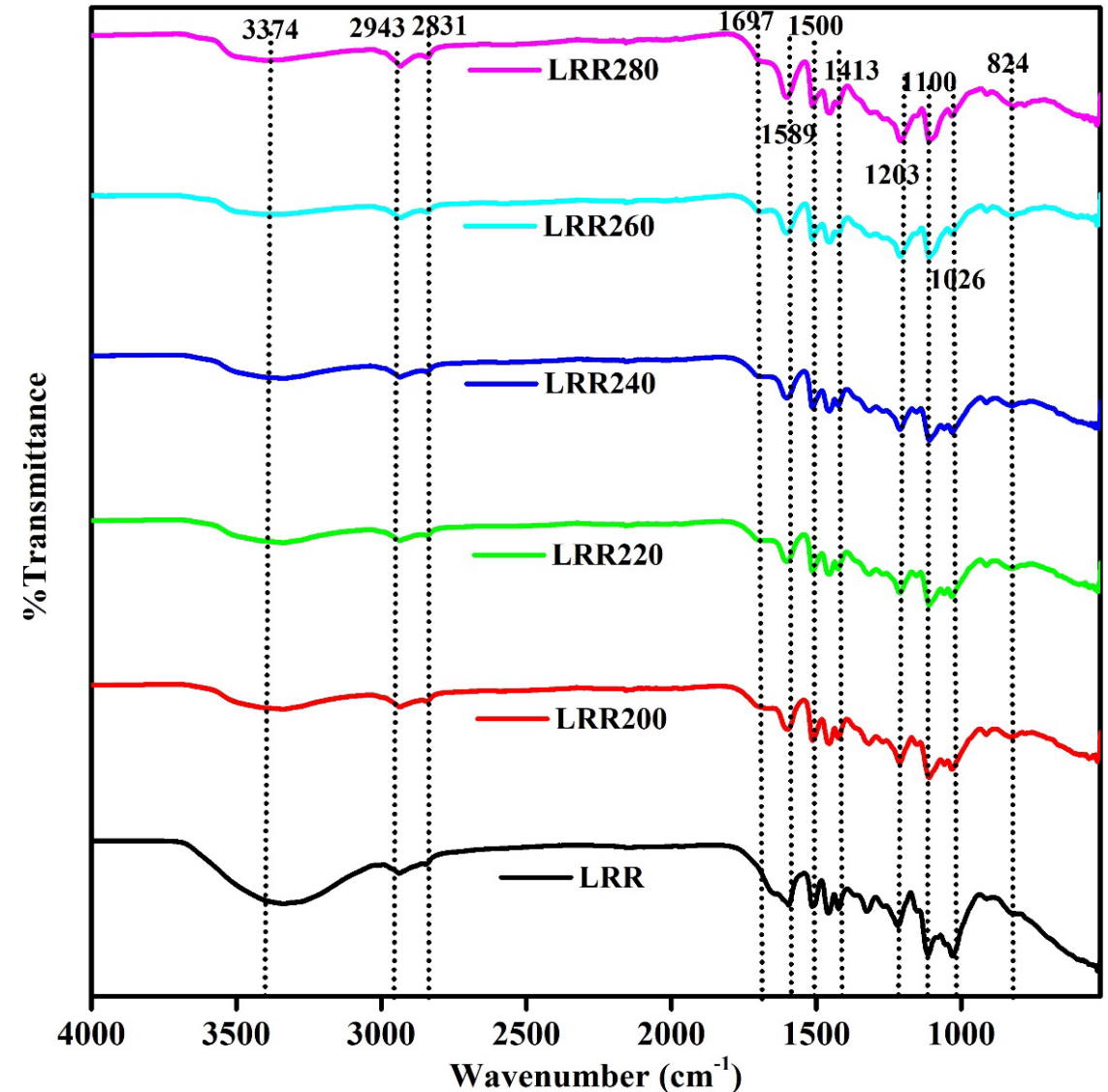
LRR 280

Fuel properties



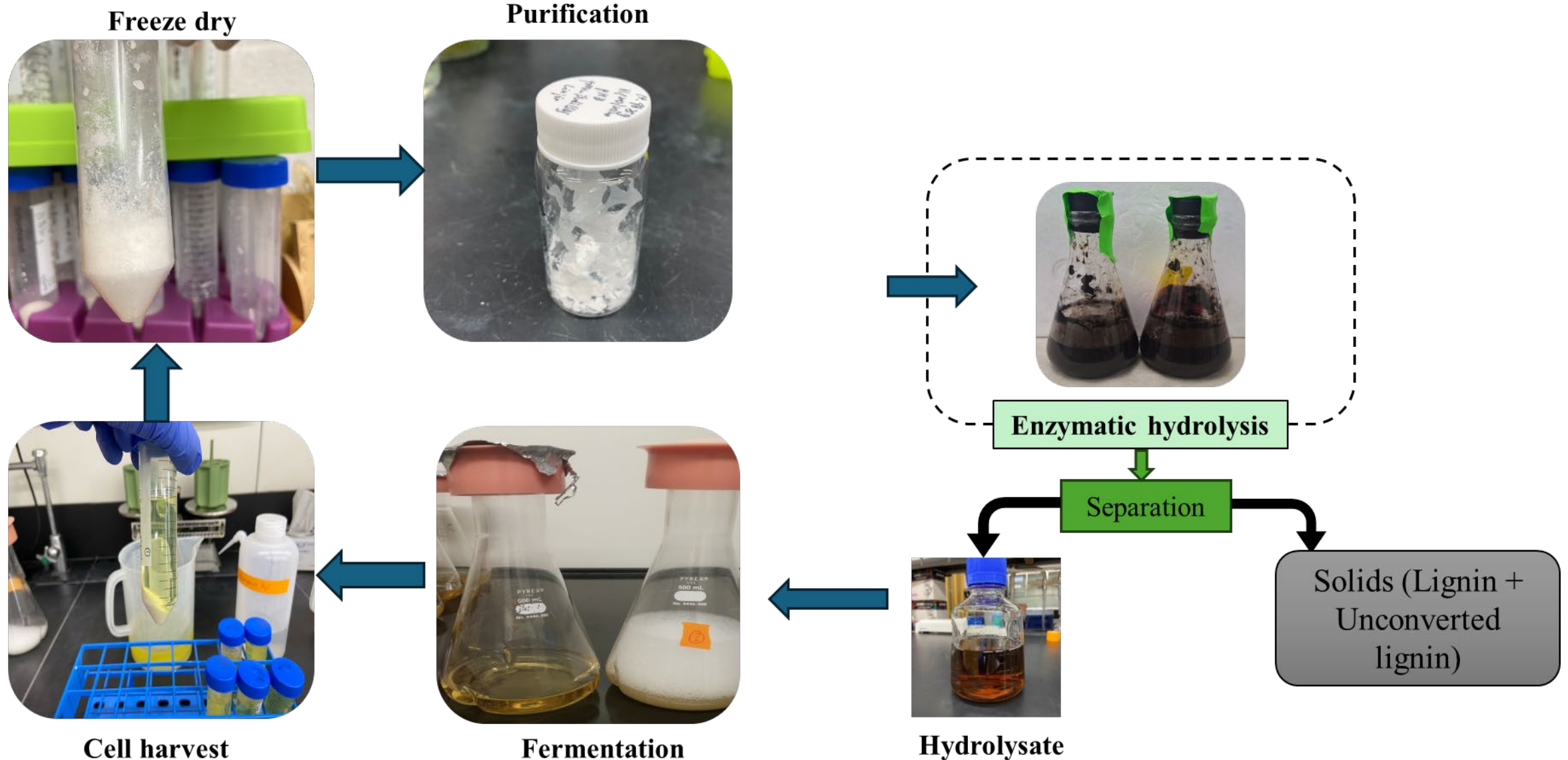
FTIR analysis

Absorption peaks (cm ⁻¹)	Functional groups
3374	O-H stretching vibrations of phenols, alcohols and carboxylic acids
2943, 2831	C-H stretching vibrations of the –CH ₂ and -CH ₃
1697	stretching vibration of C=O (for example, ketones, aldehydes, quinones, esters and carboxylic acids).
1589,1500	Stretching vibrations of C=O and C=C functional group
1413-824	vibration of the (C-OH) side groups in cellulose, the vibration of the (C-O-C) glycosidic bond in cellulose, and the stretching of the hemicellulose



Future Work

Objective 3: Optimization of PHB Production from FRB Hydrolysates



Conclusion

- FRB is a high potential feedstock for valorization into valuable products.
 - Amount of carbohydrates present in FRB can be converted to multitude of fermentative products.
 - Global demand of these fermentative products can be fulfilled by FRB produced only in the United States.
 - Mixed feedstock can be utilized equally well ensuring year-round supply for any biorefinery.
- Conventionally unused fraction, lignin, can also be utilized to improve biorefinery economics.
 - Hydrothermal carbonization (HTC) successfully converts LRR into energy-dense hydrochar.
 - This approach supports waste-to-energy strategies, highlighting the potential of LRR as a renewable, high-quality solid biofuel.

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