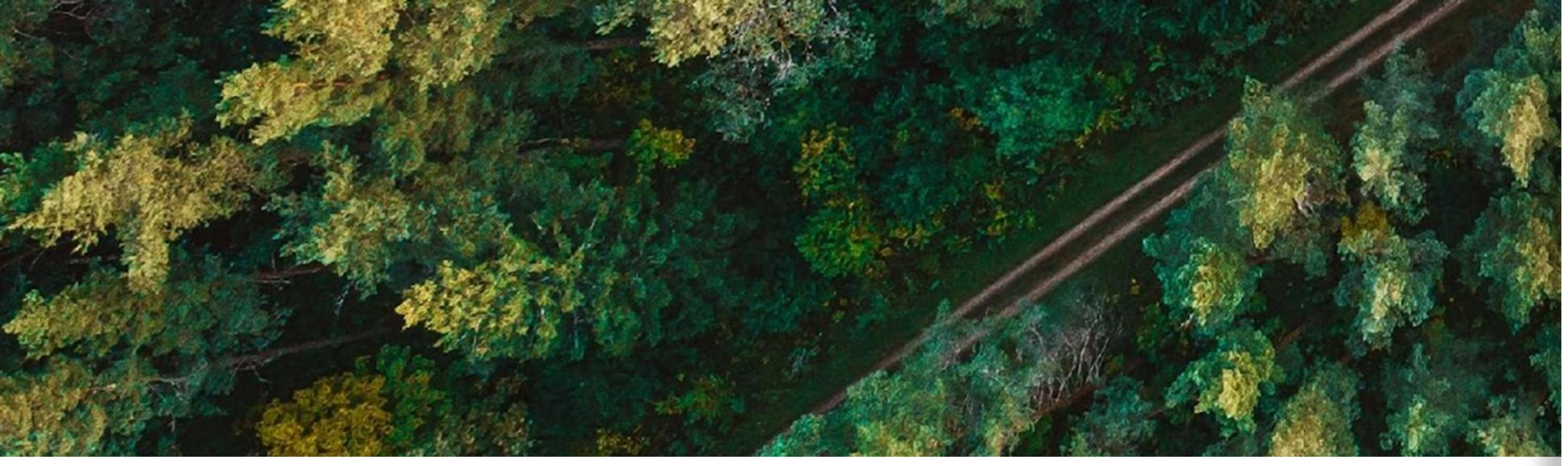

Pine Bark as a Renewable Feedstock for the Production of Rigid Polyurethane Foam

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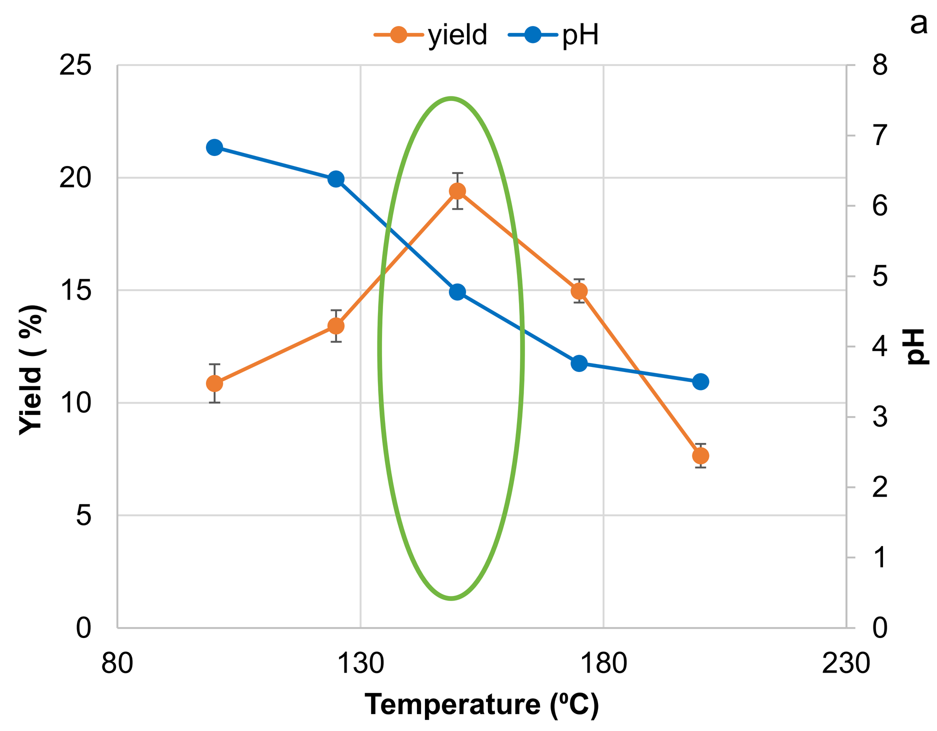
Introduction & Objectives

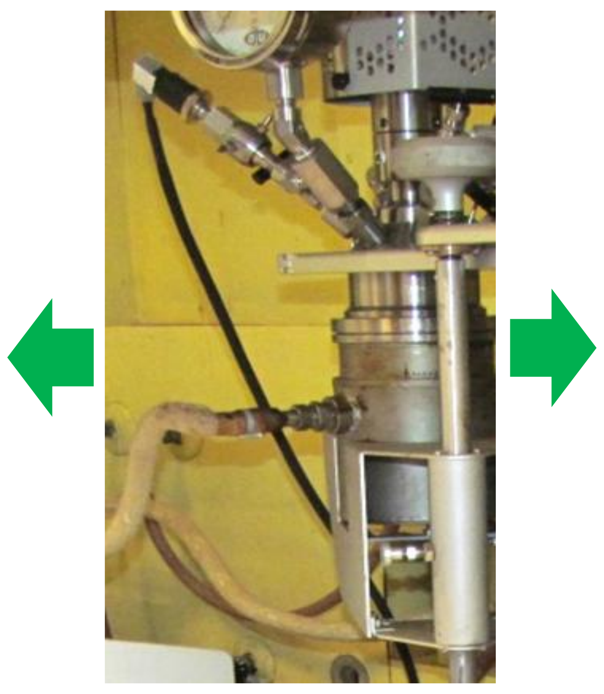
The Challenge: A Reliance on Fossil-Fuel Plastics

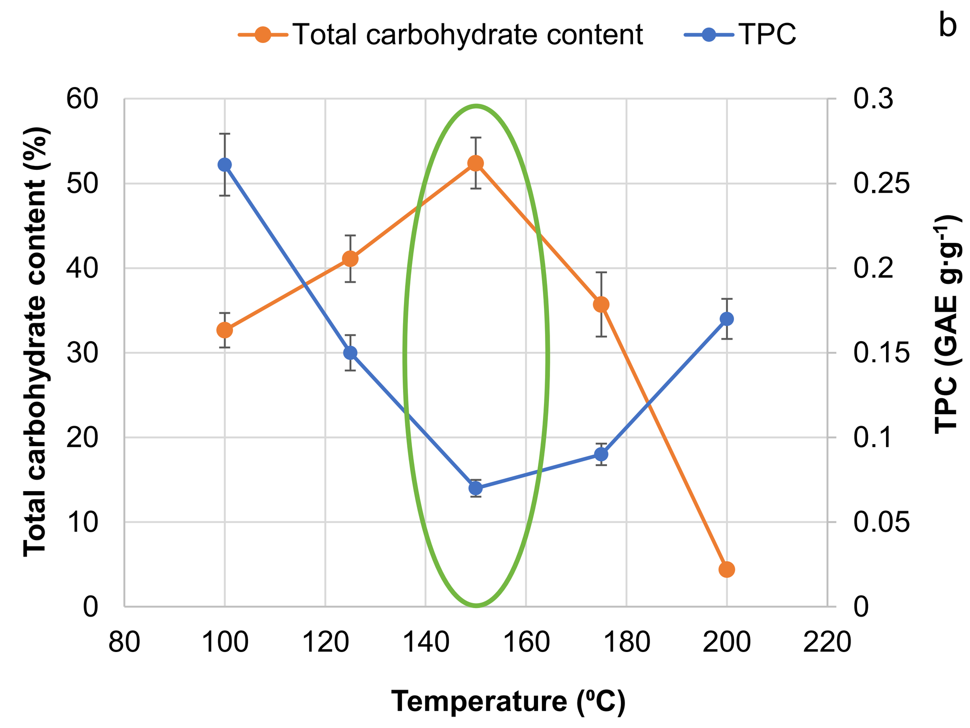
This study evaluates pine bark—an abundant and underexploited forestry by-product (300–400 million m³ globally/year)—as a complete renewable resource for rigid polyurethane (PUR) foam production.

Objectives:

1. Optimize a scalable, pressurized water extraction method to isolate carbohydrate-rich, reactive extractives from pine bark.
2. Synthesize bio-polyols using a "green" oxypropylation agent, propylene carbonate (PC), as a safe, non-flammable alternative to hazardous propylene oxide (PO).
3. Formulate bio-polyol-based rigid PUR foams and evaluate their mechanical, thermal isolation, and fire safety performance against a commercial reference.
4. Investigate the use of the residual extracted bark as a circular-economy bio-filler, valorizing the entire biomass stream.



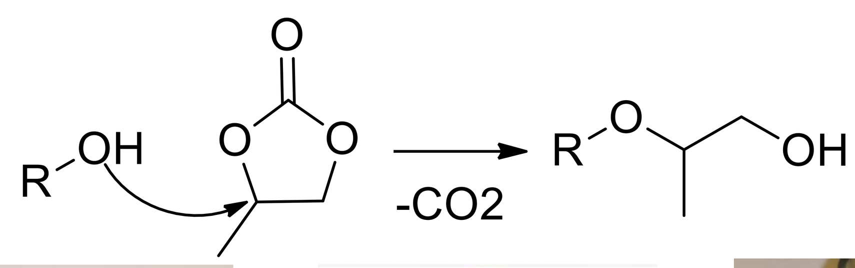


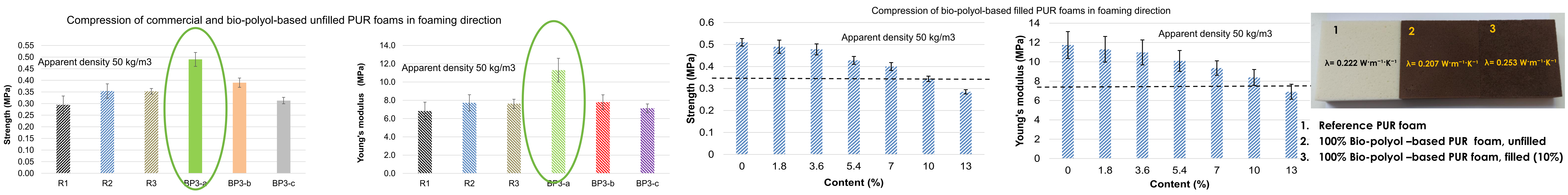


Ground pine bark was processed in a Parr reactor using only deionized water. Optimal Conditions: 150 °C for 0.5 hours. This temperature was a "sweet spot": lower temperatures had lower extractives yield, while higher temperatures degraded them, reducing yield.

The extractives were liquefied into polyols by reacting them with propylene carbonate (PC) with varying PC/OH ratios from 1 to 5.

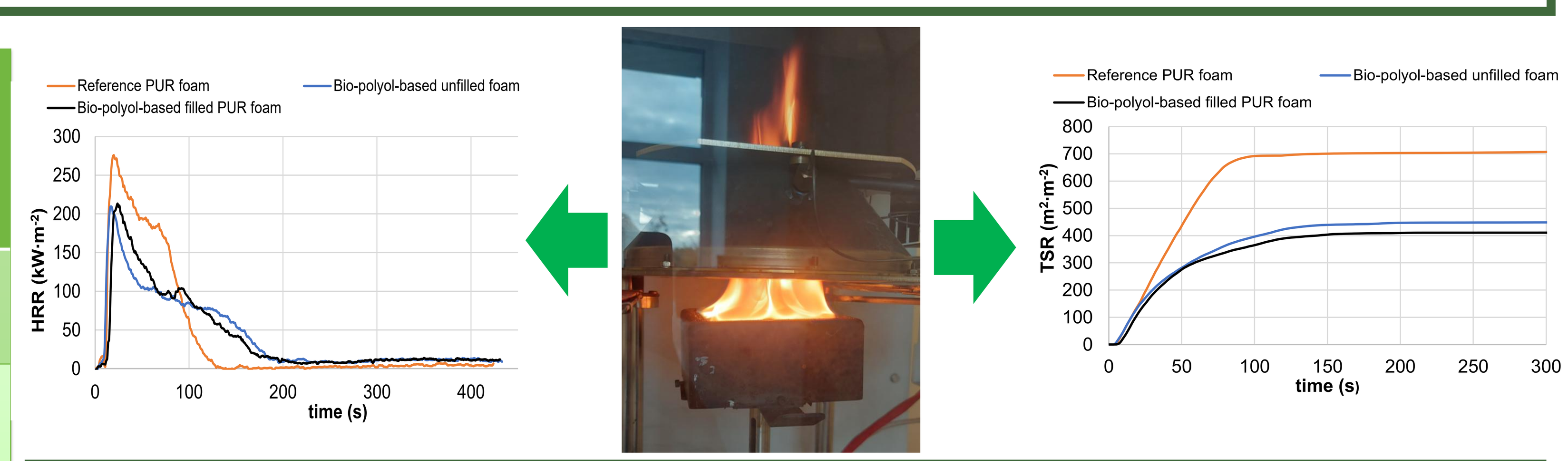
- **Optimal Formulation:** A **PC/OH molar ratio of 3**
  - This ratio was a critical engineering trade-off. Lower ratios (e.g., 2.0) resulted in extremely high viscosity (85 Pa·s), making foam processing difficult. Higher ratios (e.g., 5.0) reduced viscosity but also diluted the renewables content.
- **Output (Bio-Polyol BP3-a):** The optimal polyol (PC/OH=3) had ideal properties for PUR foam formulation:
  - **Viscosity:** 14.9 Pa·s (at 25 °C)
  - **OHV:** 527 mgKOH·g⁻¹
  - **Biomass Content:** 27%





The100% bio-polyol-based foams (BP3-a, BP3-b, BP3-c) were tested against a commercial reference foams based on Lupranol 3300 (R1), Lupranol 3422 (R2) and their combination (R3.). The PUR foam (BP3-a) based on the bio-polyol synthesized at PC/OH = 3 demonstrated the highest compressive strength and modulus—exceeding those of the commercial reference by 30–35% and also exhibited a 9% improvement in thermal insulation properties. The residual bark from extraction was successfully used as a natural filler in the bio-polyol-based foam, creating a full-valorization pathway. At up to **10 wt% filler**, the filled bio-foam's mechanical properties were *comparable to the commercial reference foam.*

Fire Safety Parameter *ISO 5660-1*	**Reference foam**	**100% Bio-polyol –based Foam, unfilled**	**100% Bio-polyol –based Foam, filled (10% filler)**
Peak Heat Release Rate (PHRR), kW·m⁻²	278±2	208±9	207±5
Max Avg. Rate of Heat (MARHE), kW·m⁻²	176±8	124±6	125±3
Total Smoke Release (TSR), m²·m⁻²	764±51	476±21	479±30
Average Mass Loss Rate, %·s⁻¹	0.66±0.04	0.44±0.04	0.43±0.05



The bio-polyol-based foam outperformed the reference in every key metric for fire hazard assessment, and the addition of filler did not negatively impact the superior fire performance of the bio-foam matrix.

Conclusions

1. Pressurized water extraction at 150 °C for 30 min is the optimal "green" method to produce high-yield (25%), carbohydrate-rich (57%) extractives from pine bark.
2. "Green" oxypropylation with propylene carbonate at a PC/OH ratio of 3 yields a bio-polyol with ideal processing viscosity (14.9 Pa·s) and high bio-content (27%).
3. The 100% bio-polyol-based foam is a superior product, demonstrating 30–35% higher compressive properties in the foaming direction and 9% better thermal insulation than the commercial reference.
4. Crucially, the bio-polyol-based foam exhibits significantly enhanced fire *safety according to ISO-5660-1*, with a 25% lower Peak Heat Release Rate and a 38% lower Total Smoke Release, attributed to its high char-forming tendency.
5. Pine bark is a promising, sustainable resource for the complex, full valorization of PUR foam, yielding both a high-performance bio-polyol and a viable natural filler.

Acknowledgments

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