Hawaiʻi Natural Energy Institute Research Highlights

Alternative Fuels

Novel Biocarbons

<u>Objective and Significance</u>: Biomass can be a renewable resource to produce energy, fuels, chemicals, and materials. The goal of this project is to develop processes to 1) produce biochars and biocarbons from biomass feedstocks and 2) control and tune their properties by selection of biomass feedstocks and process conditions.

<u>Background</u>: Slow pyrolysis is a thermochemical process that converts biomass into solid carbonaceous materials. The maximum temperature used during slow pyrolysis will dictate the extent to which the material is carbonized. Low temperature slow pyrolysis (200-500°C) results in the formation of biochar. High temperature slow pyrolysis (900-1200°C) produces biocarbon. The pyrolysis temperature is the dominant process parameter to control critical properties (e.g. volatile matter, carbon and fixed carbon contents, reactivity, surface area, density, tensile/compressive strength, grindability, etc.). One limitation to improving biochar/biocarbon properties is that biomass carbonization proceeds via a charring mechanism (no molten phase). The lack of a molten phase during carbonization limits the capacity to engineer critical material properties.

Biochar and biocarbon have numerous applications including fuel for cooking, adsorbents for air/water purification, a carbon sequestering soil amendment, and a carbon neutral coal/coke replacement in industrial applications. All are applicable in Hawaiʻi and can be produced from low value biomass materials.

<u>Project Status/Results</u>: Research at HNEI has identified certain constant-volume/pressurized reaction conditions that result in the formation of biochar with drastically altered morphology compared to the parent biomass. This unique biochar experiences a transient plastic phase (TPP) during carbonization, representing a new biomass carbonization pathway. The underlying mechanisms of TPP formation and utility are still being explored.

The current research effort uses parametric research design to independently study the effects of pressure, temperature, water content, reactant gas, biomass type, biomass particle size, and metal impregnation on the formation of TPP biochar. In addition to standard analytical tools (proximate analysis, true density, ultimate analysis), powder compaction experiments have been developed to characterize material plasticity and mechanical strength. These fundamental insights have been leveraged to increase biocarbon mechanical strength, a critical bottleneck for commercial applications.

Experimental results demonstrate that TPP formation proceeds through a molten phase. Elevated pressure serves to keep water in the condensed phase, inhibiting condensation reactions and enabling molten phase formation. TPP formation conditions were identified for a range of biomass types, including hardwoods, softwoods, and herbaceous materials.

Results from powder compaction experiments show that TPP biochar has increased plasticity along with a reduced glass transition temperature. Experiments comparing the mechanical strength of TPP and standard biocarbon materials show the TPP material is 10 times stronger, and twice as dense. Efforts to maximize the mechanical strength of TPP biocarbon achieved another 10x improvement, the strongest biocarbon material reported in the scientific literature (Figure 1). These mechanical properties exceed values required for numerous industrial applications.

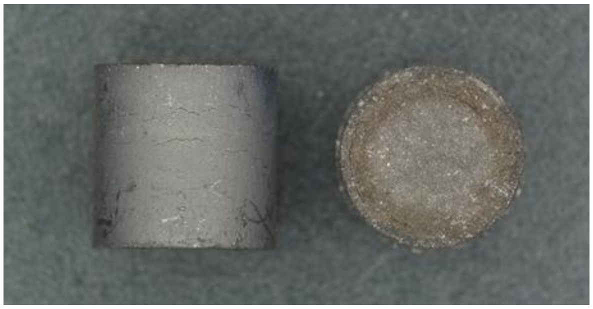

Figure 1. Biocarbon pellets produced from TPP biochar.

This novel production pathway overcomes technical barriers limiting biomass utilization as feedstock for biocarbons that can displace fossil carbon products. Potential applications include metallurgical reductants, binders, electrodes, or high value specialty materials. Two patent applications have been filed to protect this intellectual property and licensing opportunities are available. Current activities focus on developing experimental results to inform process design and to demonstrate the technology at large scales.

To date, this project has produced the following five publications:

- 2025, R.L. Johnson, et al., **Investigation into the role of feedstock in the carbonization of transient plastic phase biochar**, *Energy & Fuels*. In review.
- 2025, K. Castillo, et al., **Experimental optimization of pellet tensile strength from spruce biochar produced at elevated pressure**, *Energy & Fuels*, Vol. 39, Issue 3, pp. 1668-1678.
- 2024, B. Babinszki, et al., **Volatile matter characterization of birch biochar produced under pressurized conditions**, *Journal of Thermal Analysis and Calorimetry*, Vol. 149, pp. 10915-10926. (Open Access: **PDF**)
- 2023, R.L. Johnson, et al., **Biocarbon production via plasticized biochar: role of feedstock, water content, catalysts, and reaction time**, *Energy & Fuels*, Vol. 37, Issue 20, pp. 15808-15821.
- 2023, R.L. Johnson, et al., **Use of plasticized biochar intermediate for producing biocarbons with improved mechanical properties,** *ACS Sustainable Chemistry & Engineering*, Vol. 11, Issue 15, pp. 5845-5857.

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