

BIOCARBON PELLET BINDER PERFORMANCE TESTING

Evaluating bio-oil and FeO-hybrid binders for adhesion, wettability, thermal curing, and pelletization performance in low-carbon steelmaking.

Adhesion Testing	Contact Angle Analysis	Python Image Processing	Hydraulic Press	Thermal Curing	Clean Steel Decarbonization
4 Bio-oil candidates	32% Strength gain (hybrid)	120+ Drop-shape frames	3 Test campaigns		

CONTEXT

Why this work matters

Biocarbon is a renewable alternative to fossil nut coke in blast-furnace steelmaking, but turning it into durable, transport-ready pellets requires binders that can handle industrial curing, handling, and moisture exposure without falling apart. The Metallurgical Fuels Research Group at CanmetENERGY Ottawa was evaluating bio-derived binder candidates to support a broader research program on decarbonizing the steelmaking supply chain.

I joined the group as a co-op student from May to August 2025, working under researchers Kun Liu and Xianai Huang. My primary contribution was generating the laboratory data that Xianai needed for a research paper on biologically derived binders. That meant running adhesion tests, wettability experiments, and pellet fabrication trials across four bio-oil candidates and a set of FeO-hybrid formulations, and building Python workflows to process the resulting video and image data.

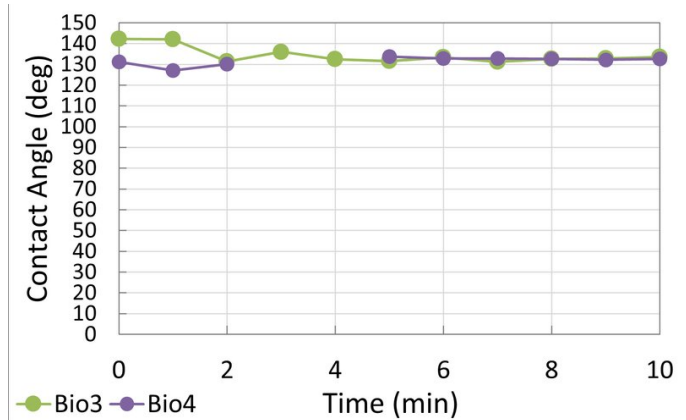
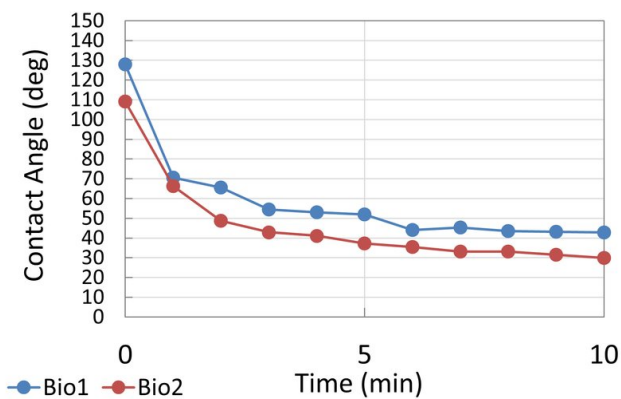


Fig. 1 — Sessile-drop contact angle vs. time for all four bio-oil candidates. Left: Bio1 and Bio2 show rapid spreading from 110–130° down to ~30–45° within 10 minutes. Right: Bio3 and Bio4 remain hydrophobic, holding steady above 130° throughout — indicating poor surface affinity with biocarbon.

ADHESION TESTING

Pull-off strength across curing conditions

Adhesion was measured using a mechanical dolly pull-off protocol. Substrates were surface-prepared consistently across all samples, and cure schedules and replicates were controlled to allow statistical comparison between candidates. I ran three test campaigns covering Bio-oils 1 through 4 and FeO-hybrid formulations.

Campaign 1: room-temperature curing out to 5 weeks

Samples were cured at ambient temperature and pull-off strength was measured at intervals over five weeks. This established the baseline behavior of each bio-oil without thermal activation and showed how strength developed over time for candidates that rely on ambient curing mechanisms.

Campaign 2: rapid thermal cure at 170°C for 1.5 hours

All four bio-oils and the FeO hybrids were thermally cured at 170°C and tested immediately after. Heat exposure produced a marked increase in adhesion across all bio-oil candidates compared to room-temperature curing. FeO hybrids maintained strong bonding across the tested loading range of 10 to 40 percent FeO.

Campaign 3: multi-temperature assessment from 70 to 200°C

Candidates were cured across a range of temperatures to map how adhesion developed with heat input. This informed oven setpoints and ramp rates for future scale-up work, identifying the temperature range where adhesion gain plateaus relative to the risk of volatile loss.

For each test I logged whether failure was adhesive (at the binder-substrate interface) or cohesive (within the binder itself), inspected pull surfaces for residue transfer, and captured photographic evidence for traceability.

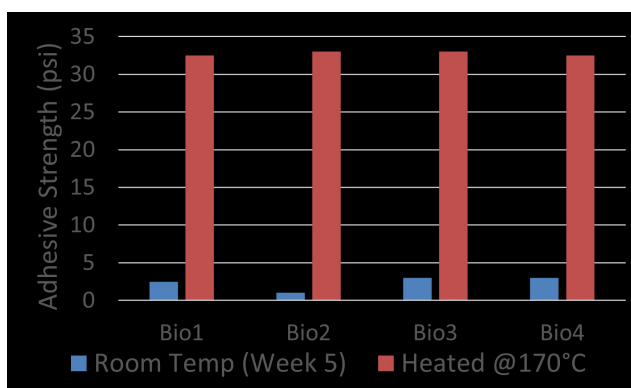


Fig. 2 — Left: adhesion strength (psi) for Bio-oils 1–4 at room temperature (Week 5, blue) vs. thermally cured at 170°C (red). Thermal curing produced roughly 10–30x strength gain across all candidates. Right: post-pull dolly plates from FeO hybrid tests at 10, 20, 30, and 40% FeO

loading, showing cohesive failure and residual film transfer indicating robust interfacial adhesion.

WETTABILITY ANALYSIS

Sessile-drop contact angle over time

For each binder I recorded a 10-minute droplet video immediately after depositing the sample on the biocarbon substrate. The contact angle at each frame was measured using specialized contact-angle software available at CanmetENERGY. I personally operated the software and extracted the angle-versus-time data for all candidates.

Before measurement, raw video needed preprocessing — the footage included long heat-up phases and the droplet region was small relative to the full frame. I built three Python scripts to handle this: one to speed up droplet cycles for review, one to crop and focus on the droplet region, and one to trim videos to the relevant reaction window. This made batch processing of 120+ frames consistent and repeatable across all candidates.

The contact angle data separated candidates into two clear behavioral groups. Bio-oils 1 and 2 showed rapid spreading, with contact angles dropping sharply in the first two minutes and stabilizing at low values. Bio-oils 3 and 4 were more hydrophobic, maintaining higher angles with slower decay. FeO hybrids showed time-dependent wetting that stabilized at low angles, supporting particle bridging and film formation at the binder-substrate interface.

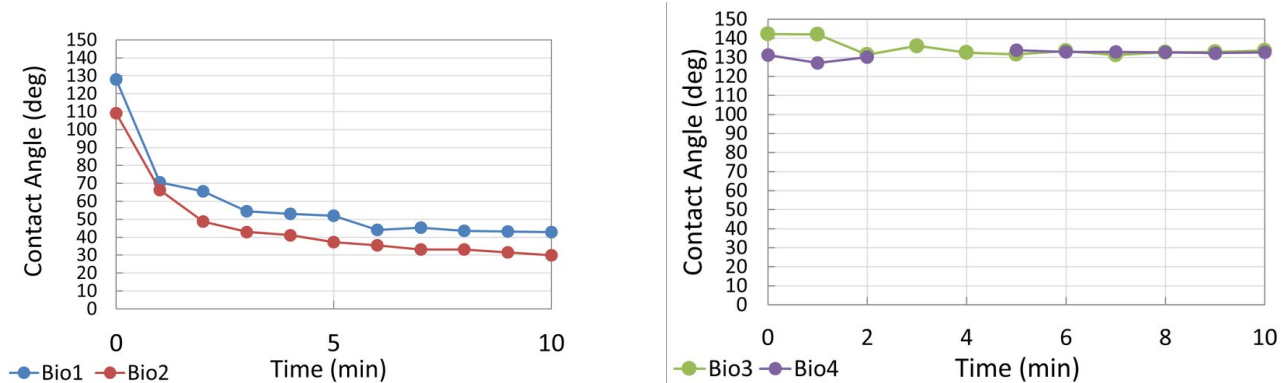


Fig. 3 — Contact angle decay profiles used for candidate ranking. Left: Bio1 and Bio2 — rapid spreading group, final angles 30–45°. Right: Bio3 and Bio4 — hydrophobic group, stable above 130° with negligible decay. Lower final angle indicates better wetting and binder-substrate contact area.

THERMAL BEHAVIOR

TGA weight-loss and curing window

TGA-derived weight-loss trends were reviewed to understand how each candidate behaved under heat — specifically where volatiles were released, where binder activation occurred, and at what temperature the material started to degrade. This informed the curing parameters used in Campaign 3 and the pellet fabrication trials.

One candidate showed higher mass loss at elevated temperatures, which meant its curing window had to stay below a threshold to avoid burning off material before the binder fully activated. Another candidate was more thermally stable across the tested range, giving it a wider usable window. These differences in volatility directly affected which ramp rates and hold times were selected for each candidate in subsequent trials.

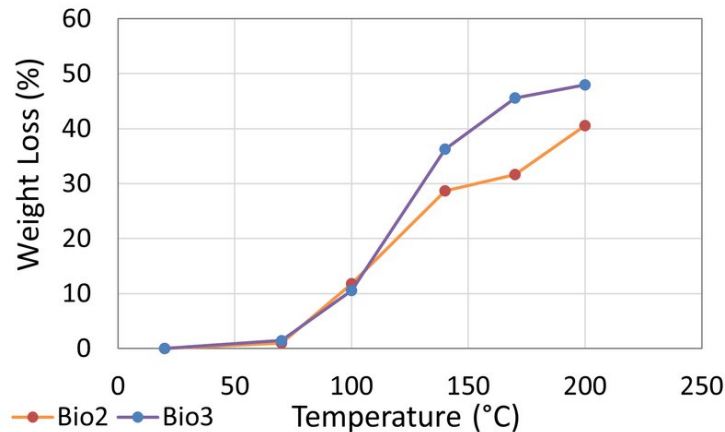


Fig. 4 — TGA weight-loss profiles for Bio2 and Bio3 across 20–210°C. Both candidates track closely up to 100°C, then diverge — Bio3 loses mass faster above 140°C (~36% vs ~29% at 140°C, ~48% vs ~40% at 200°C). This difference in volatile release informed the curing window selection: Bio2 tolerates higher temperatures without excessive material loss.

PELLET FABRICATION

Hydraulic pressing and FeO-hybrid formulations

Pellets were fabricated by pressing 0.7g samples at controlled pressure and curing at 140°C for 1.5 hours. FeO-hybrid formulations were prepared by blending a bio-oil binder with FeO powder at loadings from 10 to 40 percent by weight. All hybrid samples maintained visual integrity after curing and were advanced for scale-up consideration.

I documented press settings, mass balance, and visual pass/fail criteria for each batch. The goal was to establish a repeatable fabrication baseline that could be translated to roller-press production and used as the foundation for future compressive strength testing. The FeO hybrids were of particular interest because FeO is already present in steelmaking feedstocks — blending it into the binder could reduce the need for a separate binder additive at industrial scale.



Fig. 5 — Left: Carver laboratory hydraulic press used for pellet fabrication at controlled pressure. Right: two pressed biocarbon pellets (Bio4, 10% FeO loading) after thermal curing at 140°C — maintaining visual integrity and uniform geometry post-cure.

RESULTS

What the data showed

Thermal curing improved adhesion consistently across all four bio-oil candidates under controlled protocols. The strongest effect came from comparing room-temperature cured samples to FeO hybrids cured at 170°C — the hybrid formulations showed approximately 32% higher pull-off strength at comparable loading. FeO hybrids also maintained strong bonding across the full 10 to 40 percent loading range and showed no visual degradation after curing.

Wettability analysis established a clear ranking of candidates by surface affinity. The rapid-spreading group (Bio-oils 1 and 2) is more compatible with biocarbon substrates and a stronger starting point for pelletization. The hydrophobic group (Bio-oils 3 and 4) may need surface treatment or formulation changes to achieve comparable bonding.

The full workflow, from pressing and curing through adhesion measurement, contact-angle processing, and TGA review, is documented and ready for roller-press scale-up and compressive strength testing. The data collected contributed directly to the research paper being prepared by Xianai Huang on biologically derived binder systems for biocarbon pelletization.

RETROSPECTIVE

What I'd do differently

01 Automate angle extraction rather than measuring frames manually

Measuring contact angles frame by frame in the software was the most time-consuming part of the wettability work. Writing a Python script to automate droplet edge detection and angle extraction would have cut that time significantly and reduced the chance of measurement inconsistency across a large number of frames.

02 Run a paired surface roughness measurement alongside wettability

Some of the variation in contact angle between samples was likely due to differences in biocarbon substrate roughness rather than binder behavior alone. Adding a simple profilometry step before each test would have separated surface effects from material effects and made the wettability comparisons cleaner.

03 Include compressive strength testing in the fabrication phase

The pellet fabrication work stopped at visual integrity checks. Adding a compressive strength measurement for each batch would have given a quantitative mechanical baseline at this stage rather than leaving it for a future phase, and would have made the FeO-loading optimization more data-driven.

REFERENCE

Technical specifications

Organization	CanmetENERGY Ottawa — Natural Resources Canada
Division	Metallurgical Fuels Research Group
Role	Co-op student (R&D;)
Supervisors	Kun Liu, Xianai Huang
Duration	May 2025 to August 2025
Binder candidates	Bio-oils 1–4 (organic); FeO-hybrid formulations at 10–40% loading
Adhesion method	Mechanical dolly pull-off; controlled surface prep, cure schedules, replicates
Adhesion campaigns	3: room-temp (5 wk), rapid cure 170°C/1.5h, multi-temp 70–200°C
Strength result	~32% pull-off strength gain for FeO hybrids vs. room-temp cured bio-oil
Wettability method	Sessile-drop contact angle; 10-min videos; manual measurement + Python preprocessing
Python scripts	video_speed.py, screen_crop.py, video_crop.py
Frames processed	120+ drop-shape frames across all candidates
Pellet fabrication	0.7g pellets, hydraulic press, 140°C / 1.5h cure
Thermal analysis	TGA weight-loss review for curing envelope definition
Output	Lab dataset contributed to research paper on biologically derived binders (Xianai Huang, CanmetENERGY)