



ALDER
RENEWABLES

A Predictive Framework for Thermal Instability in Pyrolysis Oils

TCBiomass+2026

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Refinery Integration Requires a Stable Liquid Intermediate

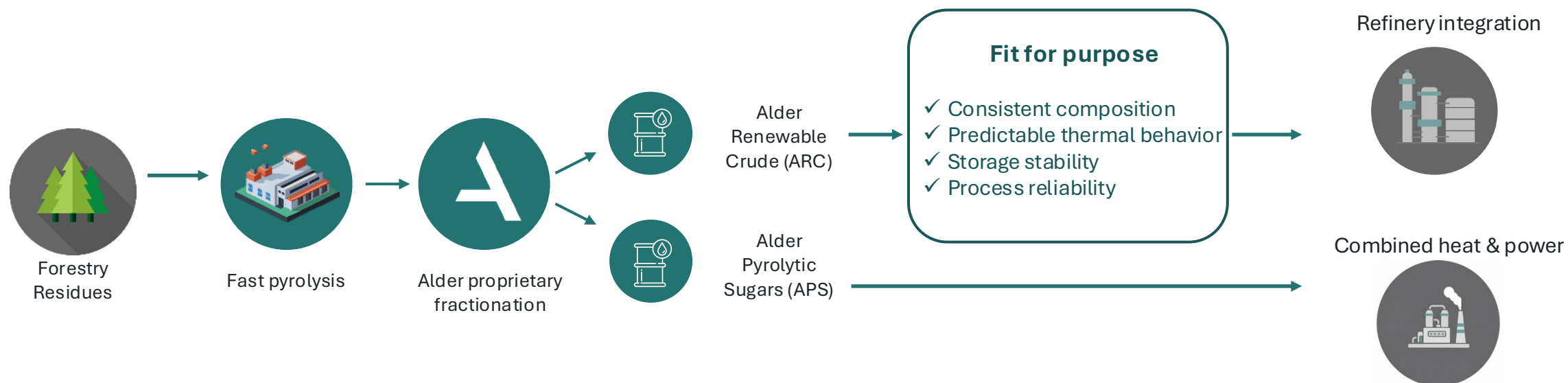
Alder fractionation separates variable pyrolysis oil into ARC for refinery integration and APS for heat and power.

① Variable feed quality

② Alder Technology

③ Biocrude Quality Window

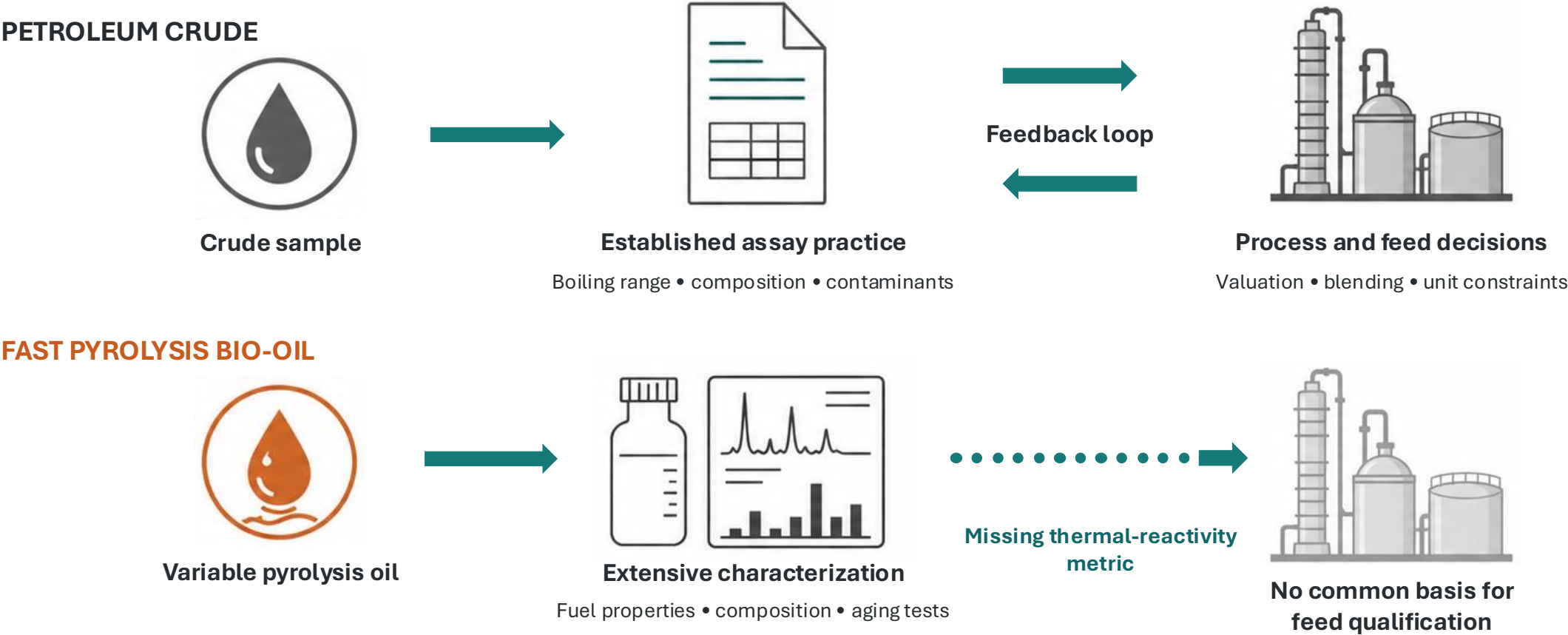
④ End-use applications



Can ARC deliver predictable, refinery-relevant thermal behavior across variable pyrolysis oils?

Pyrolysis Bio-Oil Lacks an Established Refinery Assay Framework

Standard methods characterize composition and fuel quality, but no broadly adopted metric connects thermal reactivity to refinery feed decisions.

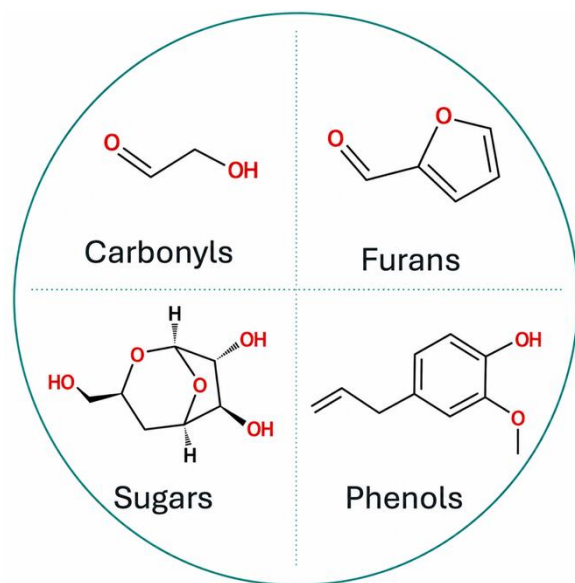


Needed metric: molecular growth under controlled thermal exposure

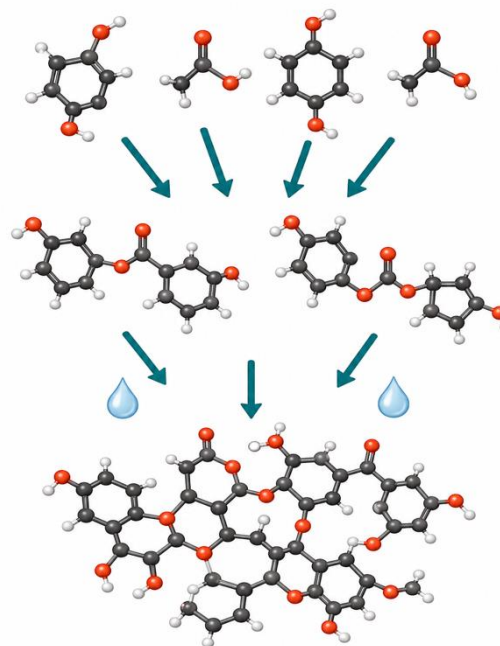
Thermal Instability Drives Molecular Growth and Phase Separation

A standardized method must quantify molecular growth even after phase separation.

Reactive oxygenates



Condensation and molecular growth



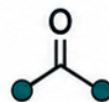
Phase separation and solids formation



How do we
quantify thermal
instability?



Viscosity
Bulk-property response



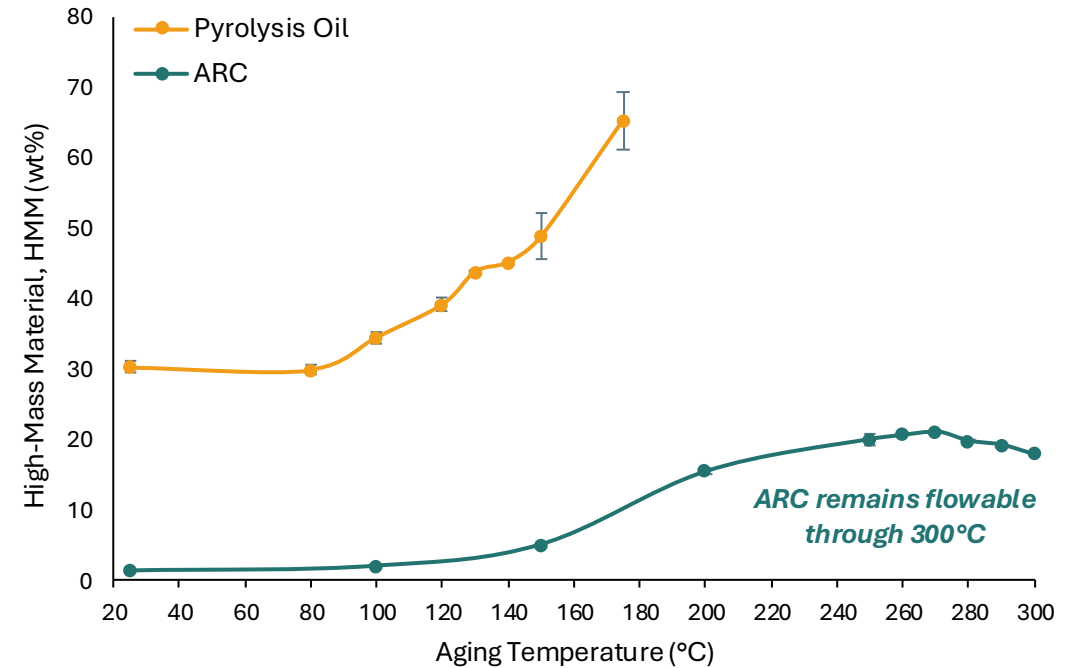
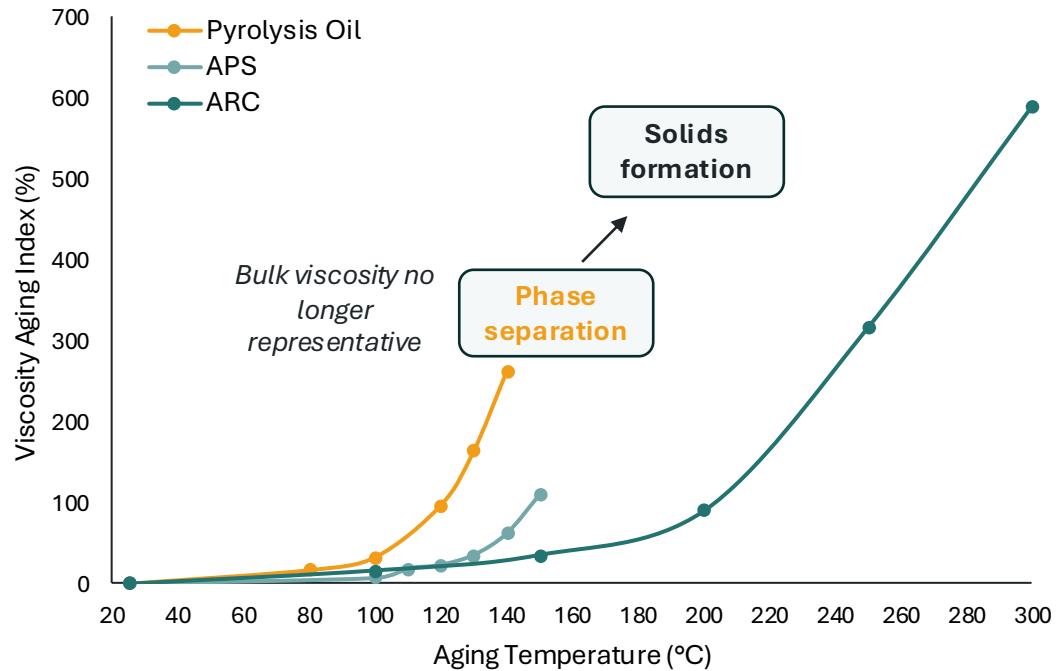
Carbonyl loss
Reactant-consumption indicator



High-mass material (HMM)
Reaction-product metric

HMM Quantifies Thermal Instability Beyond the Limits of Viscosity

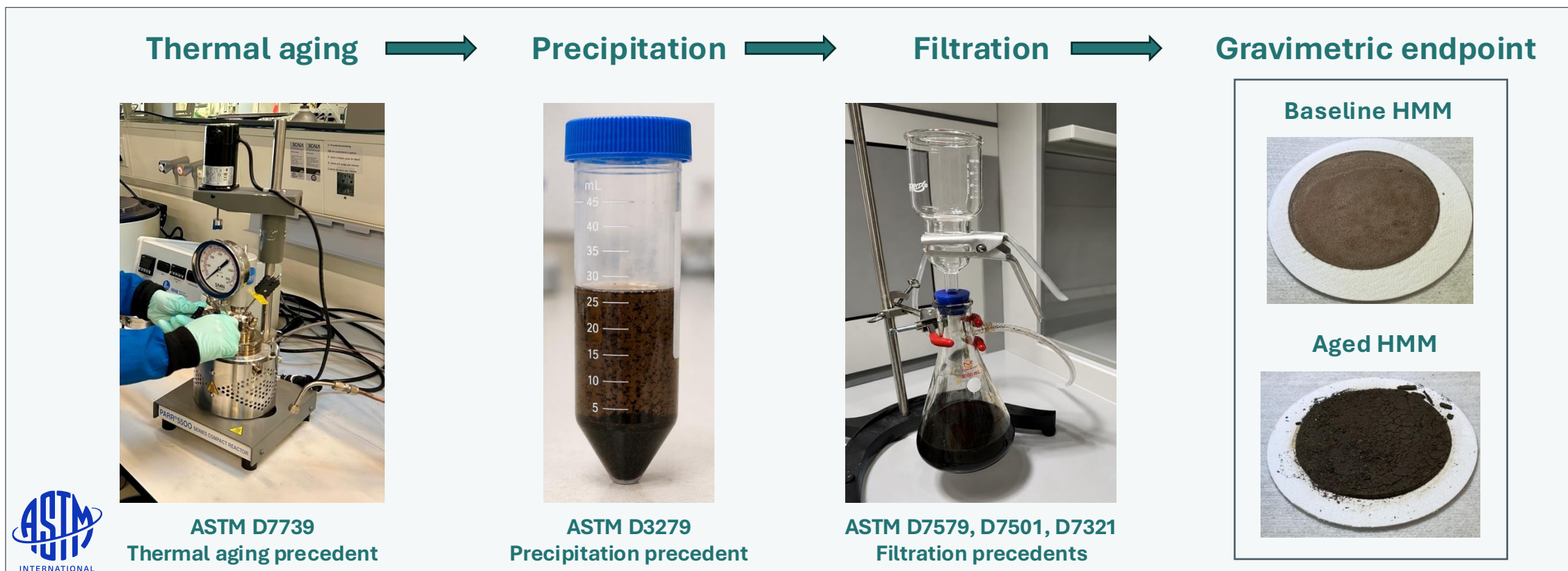
Across the same aging-temperature series, ARC forms substantially less HMM than conventional fast pyrolysis oil and remains flowable through 300°C.



- **A comparable endpoint across the full response:** HMM remains quantifiable through phase separation and solids formation, when bulk viscosity no longer represents the sample.
- **Alder products show lower thermal reactivity:** ARC and APS exhibit less viscosity growth than whole pyrolysis oil, consistent with separating lignin- and sugar-derived components that otherwise cross-react.

HMM Draws on Familiar ASTM Methods for Practical Stability Screening

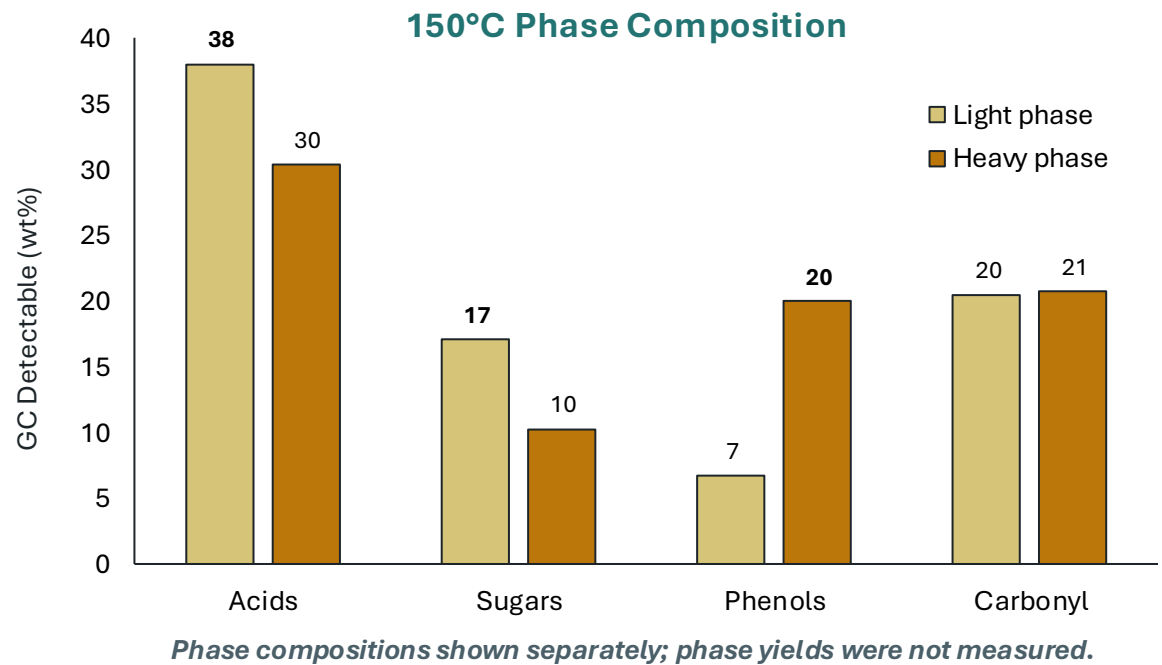
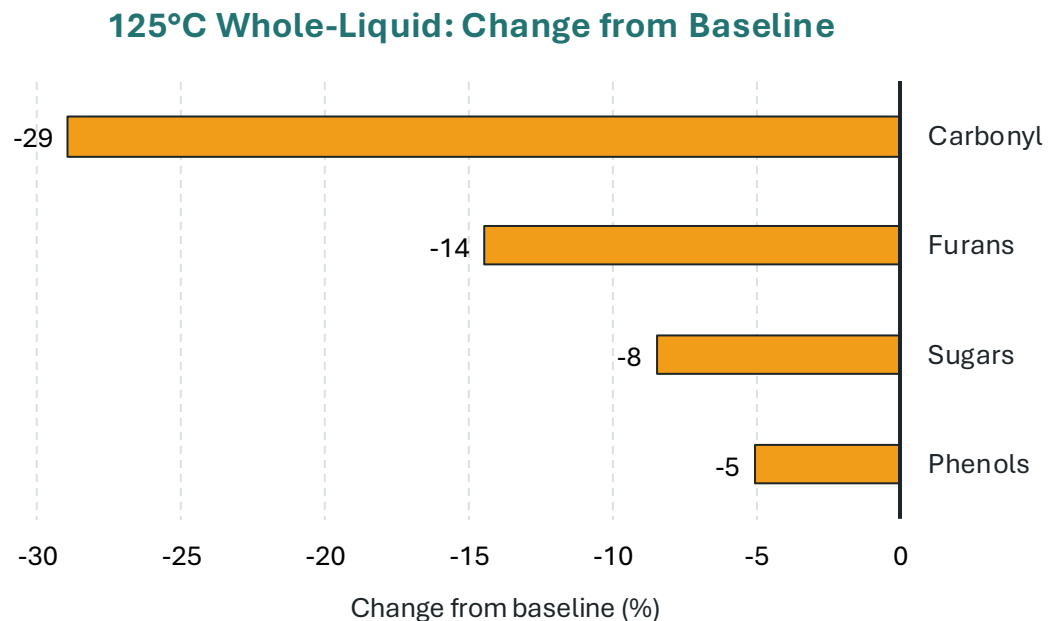
Thermal aging, precipitation, filtration, and gravimetric analysis provide a comparable HMM endpoint across oils.



- **Familiar operations, new endpoint:** Established thermal-aging and insolubles procedures are combined to quantify reaction-product formation.
- **Designed for routine use:** Common laboratory equipment enables comparisons across oils and controlled aging conditions.

Pyrolysis Oil Thermal Aging Drives Reaction and Phase Separation

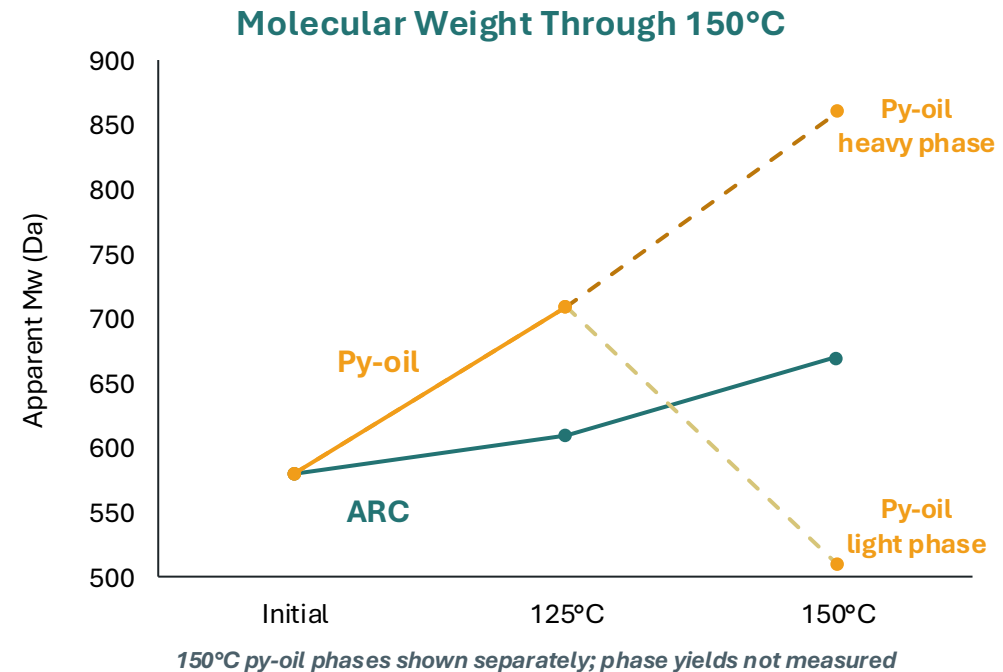
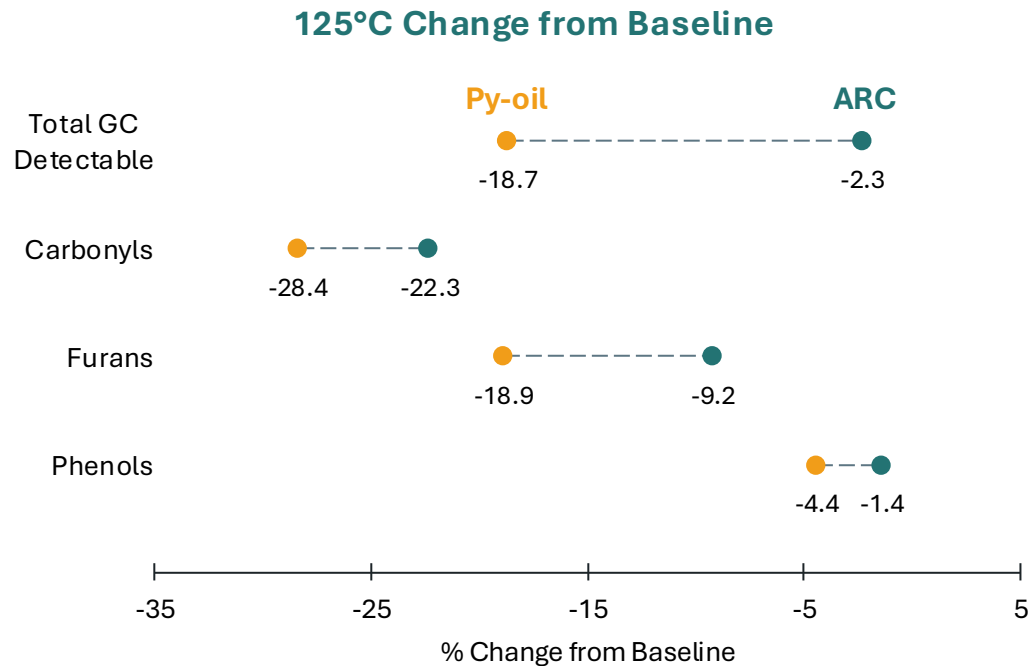
Quantitative whole-liquid and phase-specific analysis distinguishes chemical conversion from phase redistribution (GC–MS/Polyarc–FID).



- **Chemical conversion dominates at 125°C:** Carbonyls and furans decline substantially, while sugars and phenols change much less.
- **Phase compositions diverge at 150°C:** The heavy phase contains a higher proportion of phenols, while the light phase contains higher proportions of acids and sugars.

Carbonyl Loss Alone Does Not Capture High-Temperature Aging

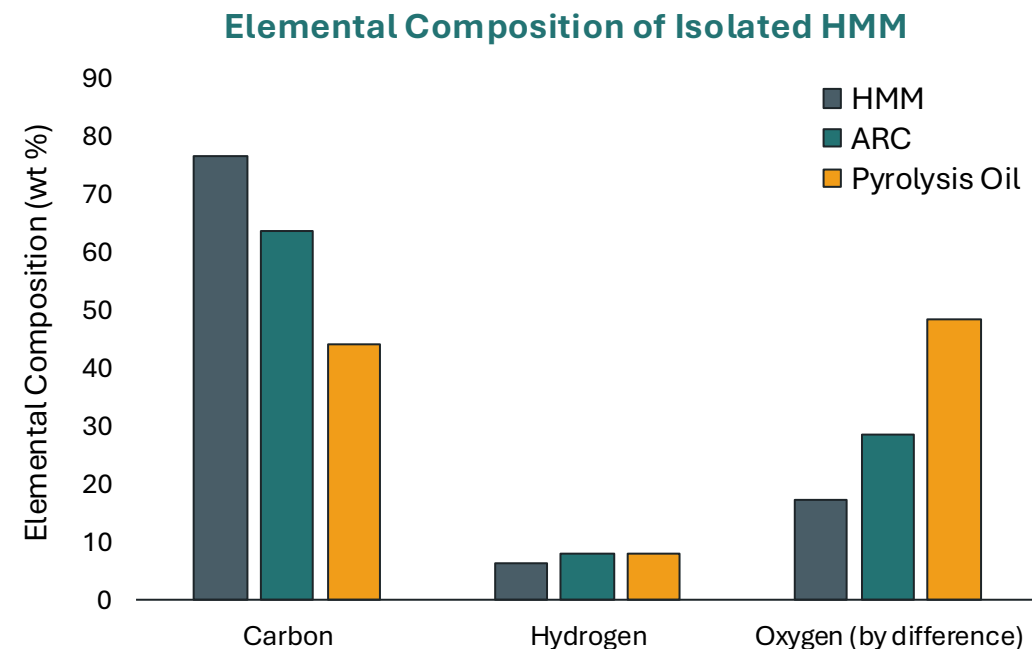
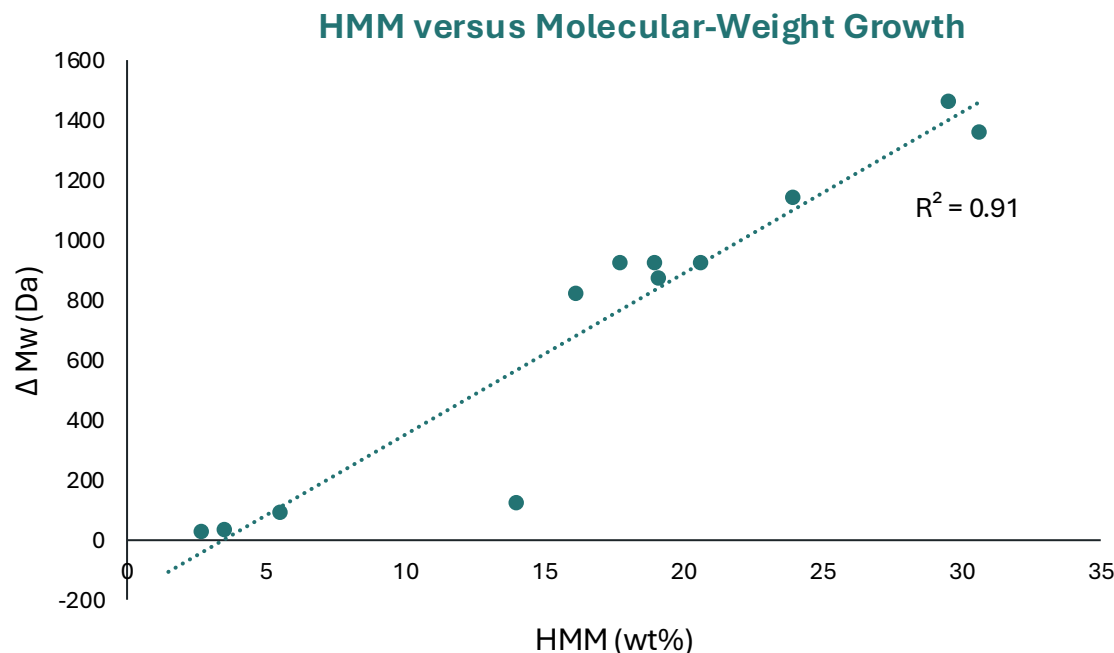
At 125–150°C, apparent molecular-weight growth and phase separation reveal aging that carbonyl tracking alone cannot resolve (GPC).



- **A molecular-growth endpoint is needed:** Carbonyl measurements track selective conversion but do not correlate with higher-mass product formation.
- **Molecular growth captures the higher-temperature response:** Through 150°C, ARC remains single-phase as its apparent molecular weight increases, while pyrolysis oil separates into light and heavy phases.

HMM Links Thermal Conversion to Molecular Growth

GPC correlation and elemental composition support HMM as a carbon-rich, oxygen-poor reaction product.

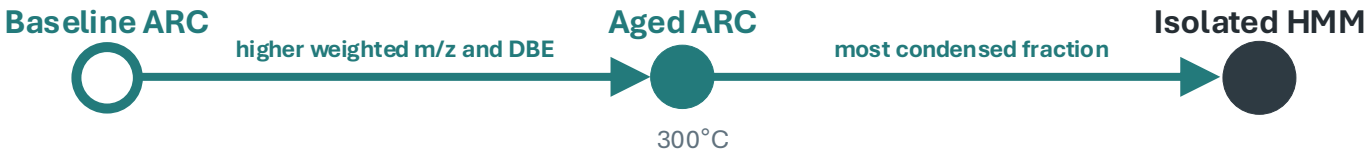


- **HMM provides a practical molecular-growth proxy:** HMM tracks GPC-measured apparent molecular-weight growth across aged samples ($R^2 = 0.91$).
- **Composition supports chemical transformation:** Isolated HMM is carbon-rich and oxygen-poor relative to ARC and pyrolysis oil, consistent with reaction rather than simple concentration of pre-existing heavy components.

High-Resolution MS Confirms Molecular Growth During ARC Aging

At 300°C, the detected molecular population shifts toward higher mass and unsaturation, with isolated HMM defining the most condensed endpoint.

Aging trajectory at 300°C



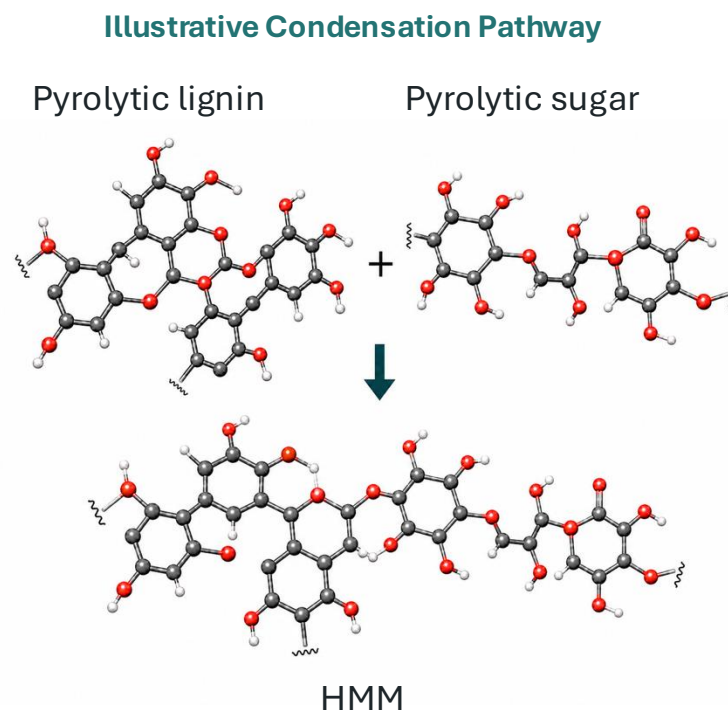
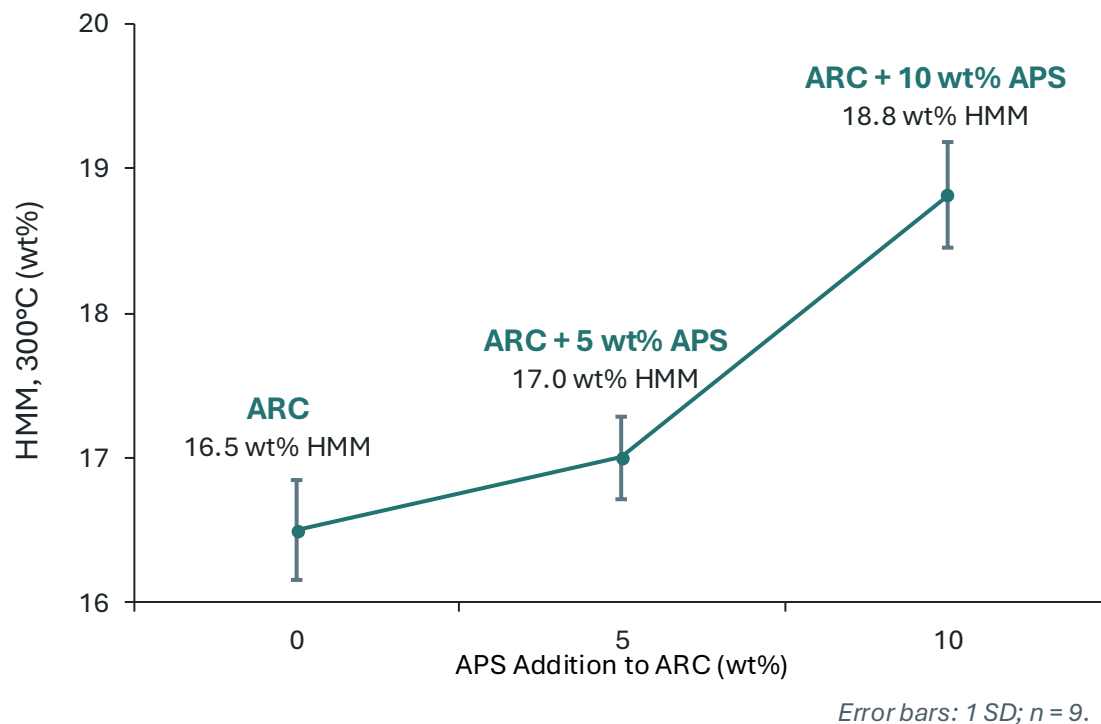
FT-ICR-MS <i>intensity-weighted</i>	Weighted m/z	621	643	701	} higher mass and unsaturation
	Weighted DBE	19.4	20.3	24.8	
CHN analysis <i>bulk molar ratios</i>	H/C	1.55	1.43	1.07	} lower H/C and O/C
	O/C	0.35	0.30	0.16	

H/C and O/C are bulk molar ratios from CHN combustion analysis (oxygen by difference); weighted m/z and DBE are FT-ICR-MS intensity-weighted means.

- **Independent confirmation of molecular growth:** FT-ICR-MS shows weighted m/z increasing from baseline ARC to aged ARC and isolated HMM, corroborating the GPC–HMM relationship.
- **The trajectory is consistent with condensation:** Increasing DBE and declining bulk H/C and O/C place HMM at the most condensed, oxygen-poor endpoint.

Adding APS Back to ARC Reintroduces Thermal Instability

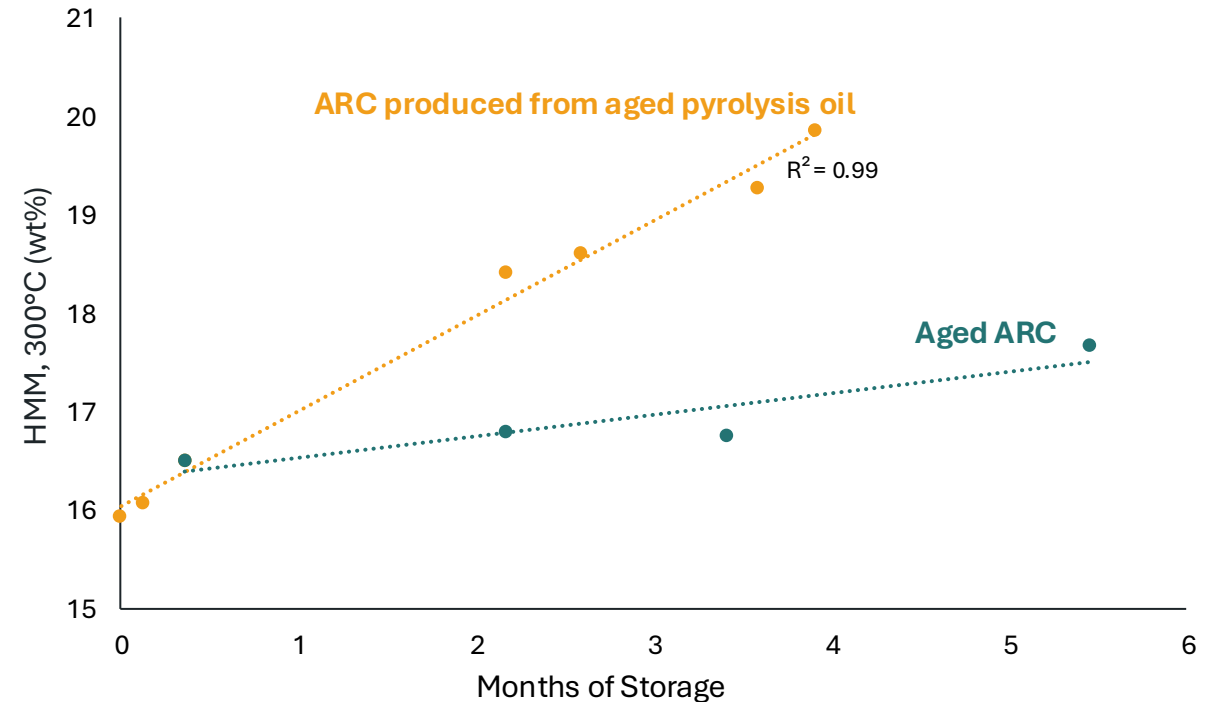
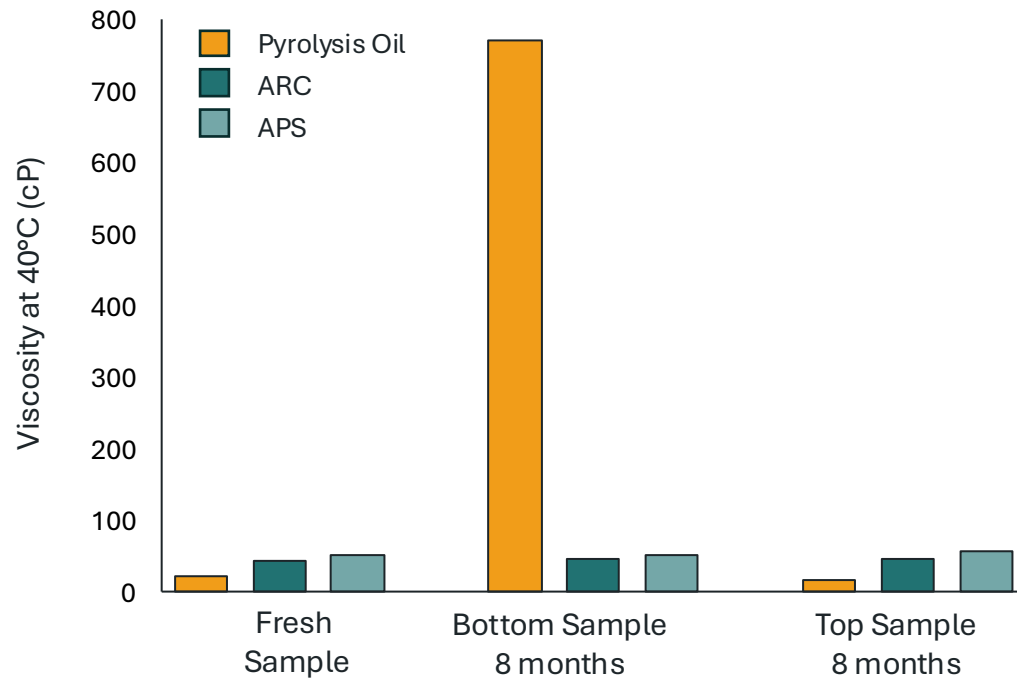
The response confirms separating sugar-rich and lignin-rich fractions is central to the stability benefit of Alder Technology.



- **Controlled recombination reintroduces instability:** A 10 wt% APS spike increased HMM rating from 16.5 to 18.8 wt%.
- **Separation creates the stability advantage:** Alder Technology separates sugar-rich APS from lignin-rich ARC, suppressing cross-reactions that promote molecular growth in whole pyrolysis oil.

Pyrolysis Oil Storage Compromises Feed Handling and ARC Stability

Pyrolysis oil can phase-separate during extended storage, while ARC made from older oil forms progressively higher HMM.

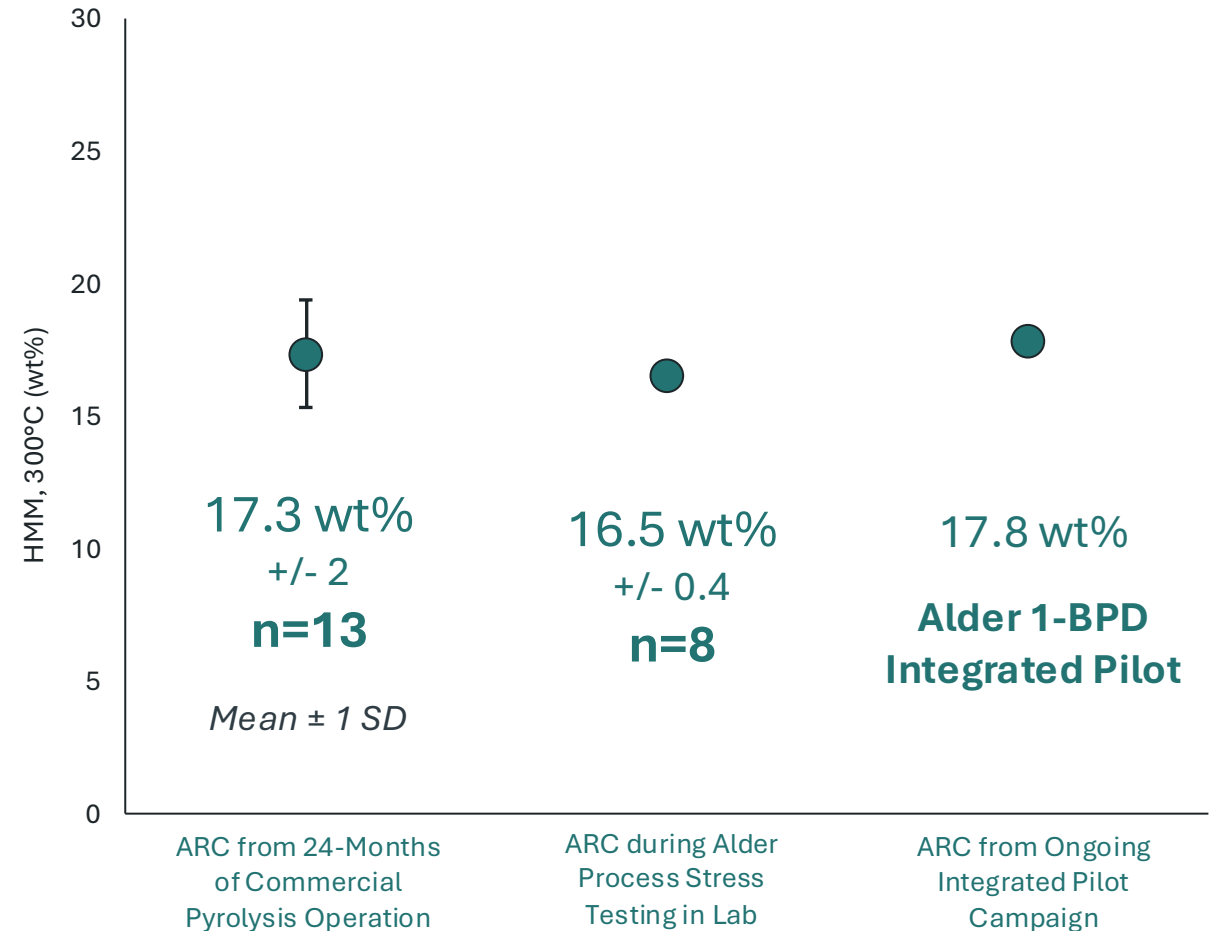


- **Poor feed shelf stability:** Extended storage can create a highly viscous pyrolysis-oil bottom layer; ARC and APS remain homogeneous with little viscosity change.
- **Feed age affects ARC stability:** Older pyrolysis oil yields ARC that forms more HMM; stored ARC changes comparatively little

HMM Closes the Feed-to-ARC Quality-Control Loop

Alder Technology limits process-driven HMM variability, allowing feed-dependent stability to be identified and managed.

- **Feed-quality sensitivity:** Thirteen oils from one commercial producer, collected over 24 months, showed HMM variability.
- **Process robustness:** Across stress-tested operating conditions, Alder Technology produced tightly clustered ARC HMM results from a single feed.
- **Actionable feedback:** HMM screening supports feed qualification, blending, and process decisions while returning stability feedback to pyrolysis production before upgrading.





Thank You

Questions and Discussion

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Crude Platform to Enable Feedstock Flexibility for Refinery Integration

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