



Integrating Renewable Carbon into Refining Assets: Pilot-Scale Insights into Carbon Fate during Biomass Pyrolysis Oil Upgrading

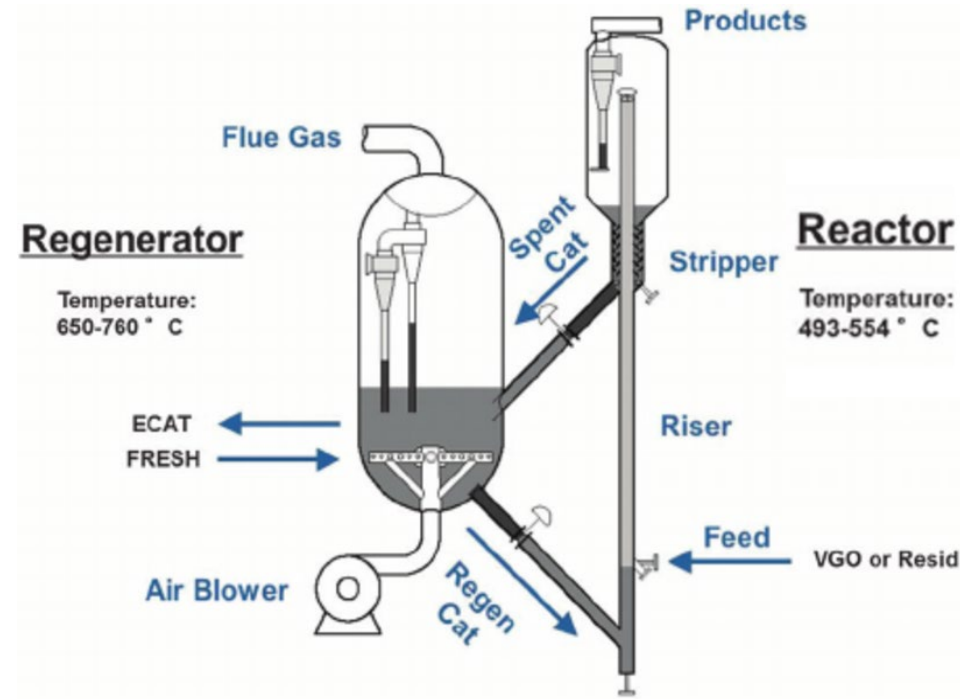
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FCC co-processing is a near-term route to integrate renewable carbon into existing refinery assets



Riser Reactor

Regenerator

Product Separation Column

Microspherical
FCC Catalyst



FCC catalyst enables tunable carbon conversion

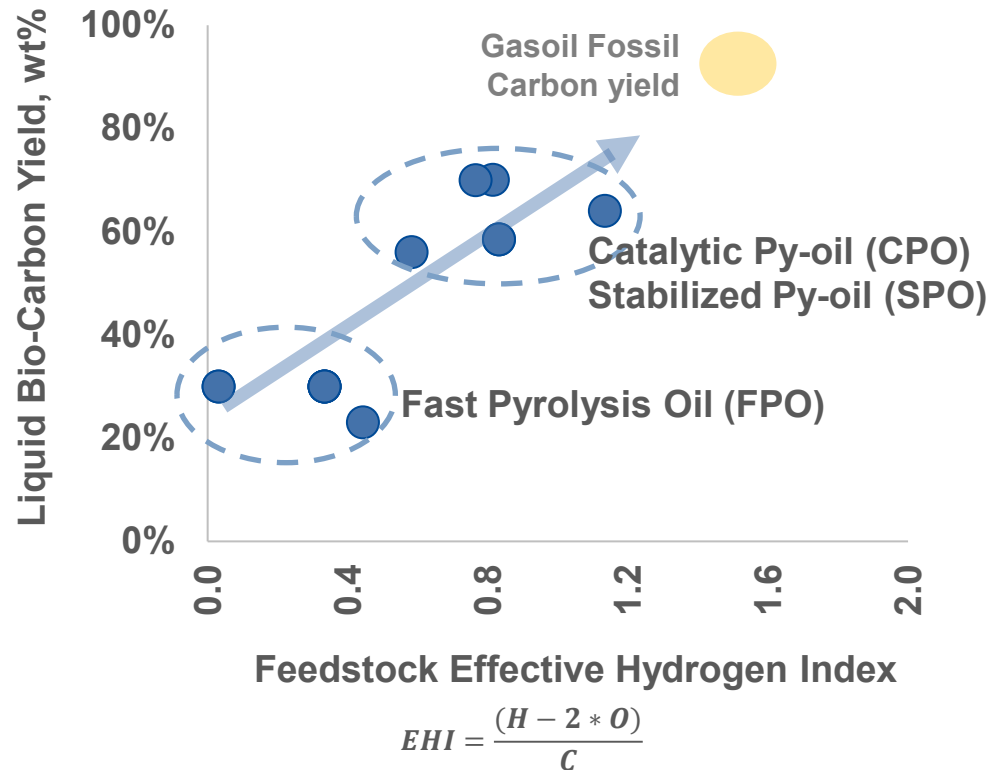
- Zeolite and matrix cracking functions
- Product selectivity control
- Opportunity to influence renewable-carbon fate

- Co-processing bio-oil inherently redistributes renewable carbon among products, gas, and coke

When renewable carbon enters an existing refinery asset, where does it physically go? How can renewable-carbon claims be assigned?

Renewable-carbon fate begins with feed pretreatment

Higher feed hydrogen content
increases liquid bio-carbon yield

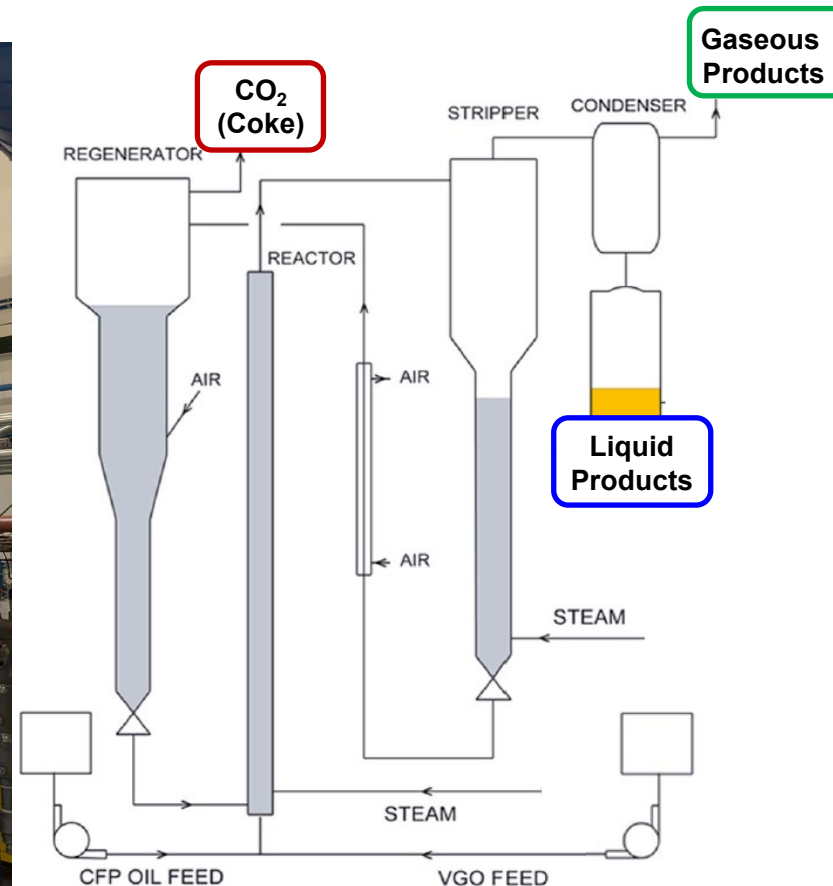


- Oxygen-rich feeds naturally promote coke and gas formation
- Feed effective hydrogen content governs upgradability
- Higher feed hydrogen content shifts bio-carbon from coke to liquid products
- Pretreatment establishes the ceiling for renewable-carbon utilization

Pretreatment determines what's possible. Catalyst selection determines how close you get to that limit.

Pilot-scale FCC experiments tracked renewable carbon across all major product streams

NLR Pilot Circulating Riser Reactor



Gaseous Products

- Gas GC
- [Radiocarbon ¹⁴C analysis](#)
- Oxygenate Analysis

Liquid Products

- Simulated Distillation
- [Radiocarbon ¹⁴C analysis](#)
- [Physical Distillation](#)
- Oxygenate Analysis
- Hydrocarbon Analysis

Coke

- Mass Yield (CO₂ NDIR)
- [Radiocarbon ¹⁴C analysis](#)

Radiocarbon analysis was applied to every major carbon-containing product stream, enabling complete renewable-carbon accounting.

Commercially relevant feedstocks and FCC catalysts were selected to evaluate renewable-carbon fate

Feedstocks



Stabilized Filtered Pinewood
Pyrolysis Oil (SPO)



Co-processing blend
10% SPO + 90% Vacuum Gasoil

	SPO	Gasoil
C, wt%	53	86
H, wt%	9	13
O, wt%	39	0
EHl	0.83	1.74
CCR*	10.5	0.5

*Conradson Carbon Residue, wt%

- Stabilization reduces reactive oxygenate species
- SPO remains hydrogen deficient relative to gasoil
- High CCR indicates greater coke-forming tendency

Catalysts



Microspherical Fluidized Cracking Catalyst



Catalyst A

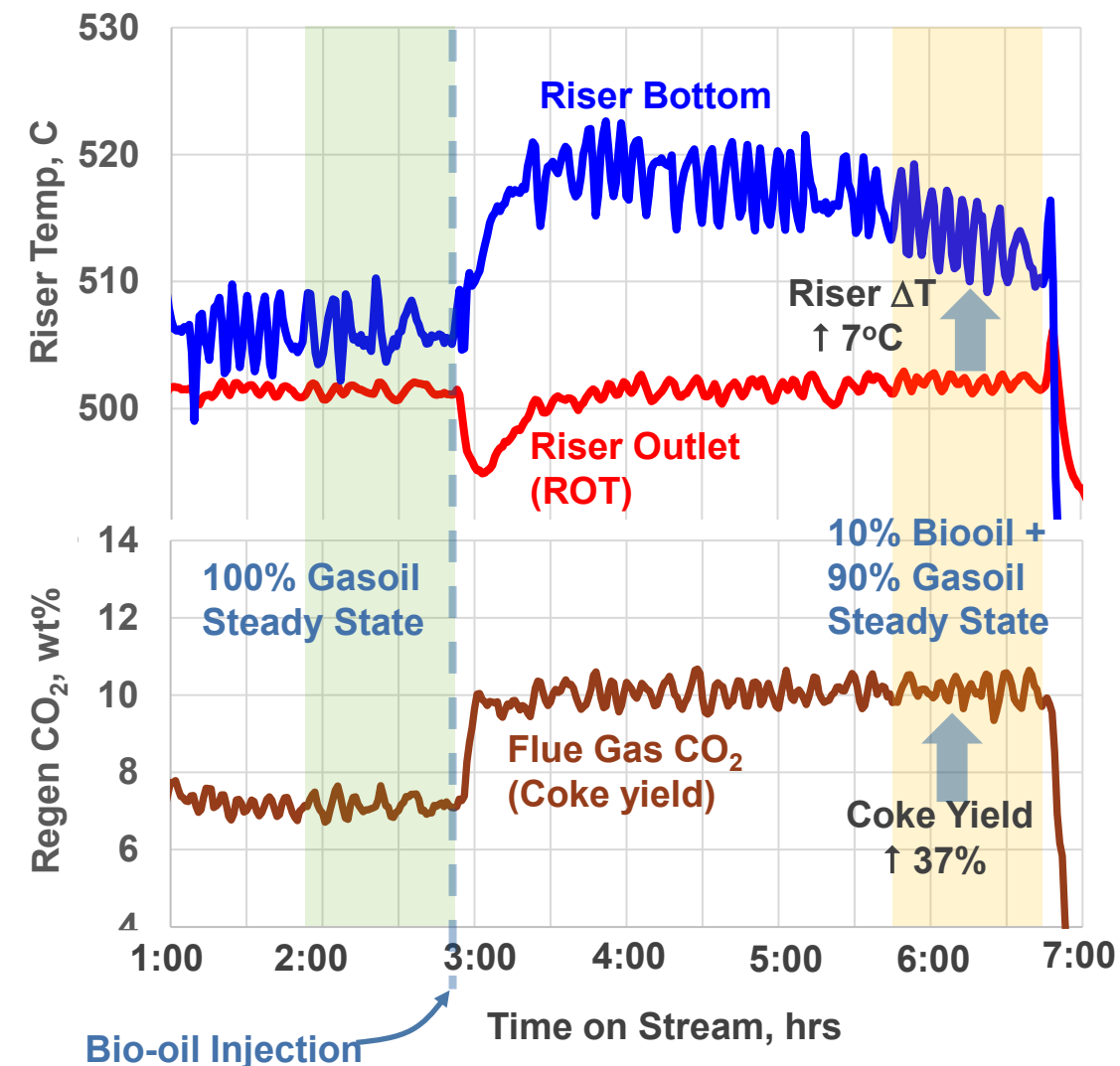
High activity
Max Gasoline Catalyst

Catalyst B

Moderated activity
Max Distillate Catalyst

Even low levels of bio-oil materially impact FCC operation and riser chemistry

Catalyst B: Max Distillate Catalyst
Constant ROT = 502°C & Cat/Oil = 6.8



- **Addition of 10 wt% bio-oil immediately alters FCC operation**

Operating conditions were adjusted to maintain constant Cat/Oil and ROT

- **Coke yield increases by 37%**

Higher CO₂ in Regenerator Flue Gas

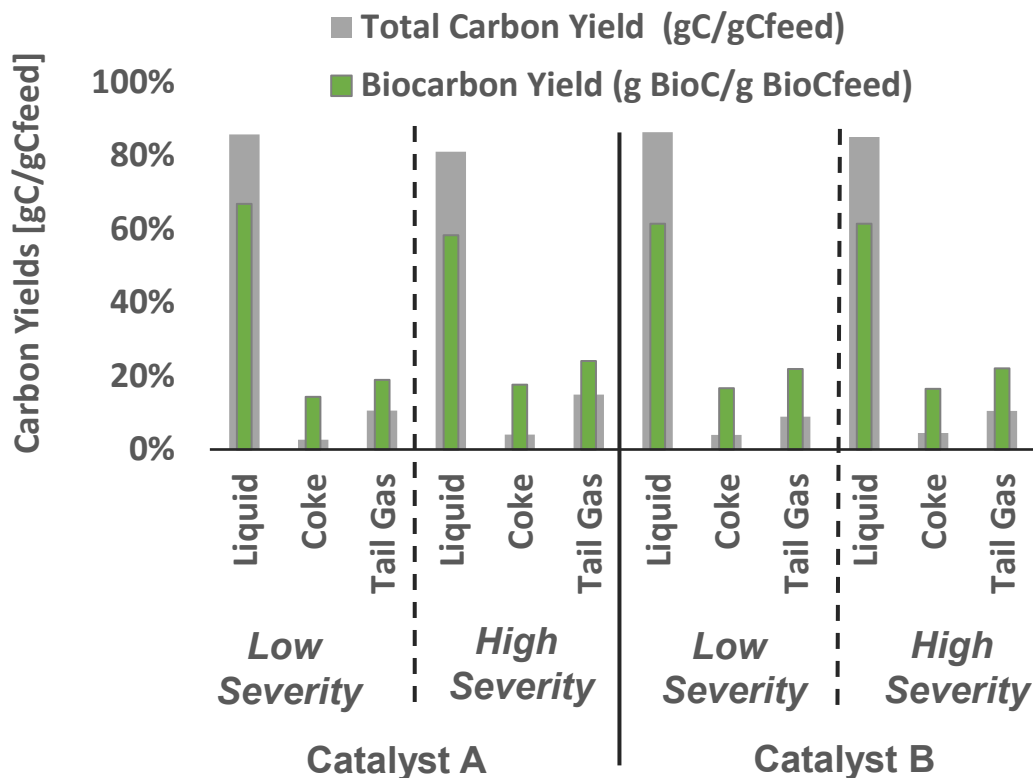
- **Bio-oil cracking reactions are more endothermic than gasoil cracking**

Steady-state riser ΔT approximately doubles

Even a 10 wt% SPO biooil materially changes FCC operation

Renewable carbon is retained primarily in liquid products across a range of FCC conditions

Carbon distribution varies incrementally as catalyst and operating conditions change

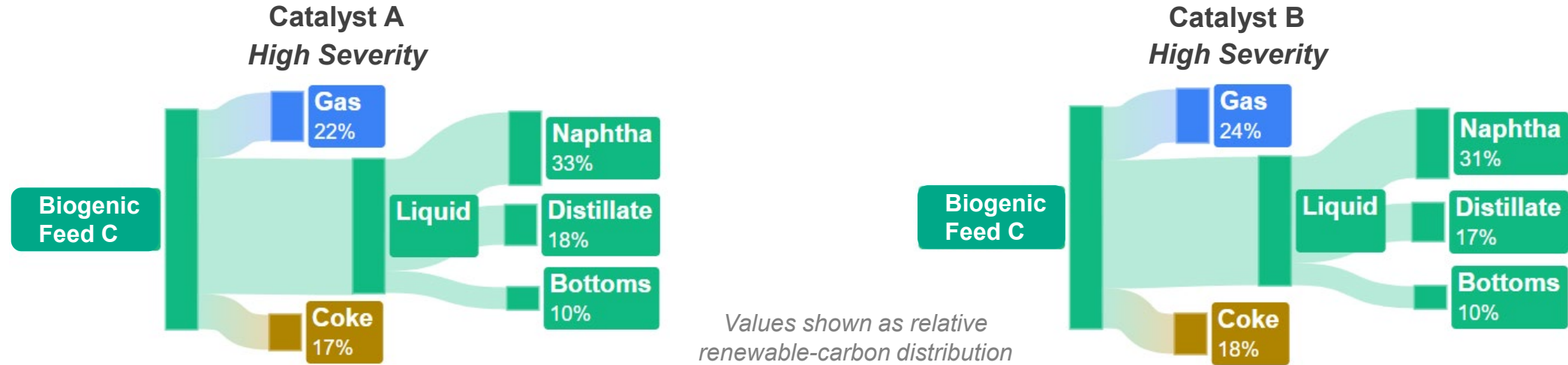


- Liquid products remain the dominant destination for renewable carbon under all conditions tested
- Catalyst and severity shift renewable-carbon distribution between liquids, gas, and coke
- Renewable-carbon utilization can be improved by managing these shifts

Liquid products are the primary destination for renewable carbon, although gas and coke remain important carbon sinks

Physical distillation and radiocarbon analysis reveal where renewable carbon resides within FCC liquid products

Physical distillation enabled direct measurement of renewable carbon within FCC liquid products



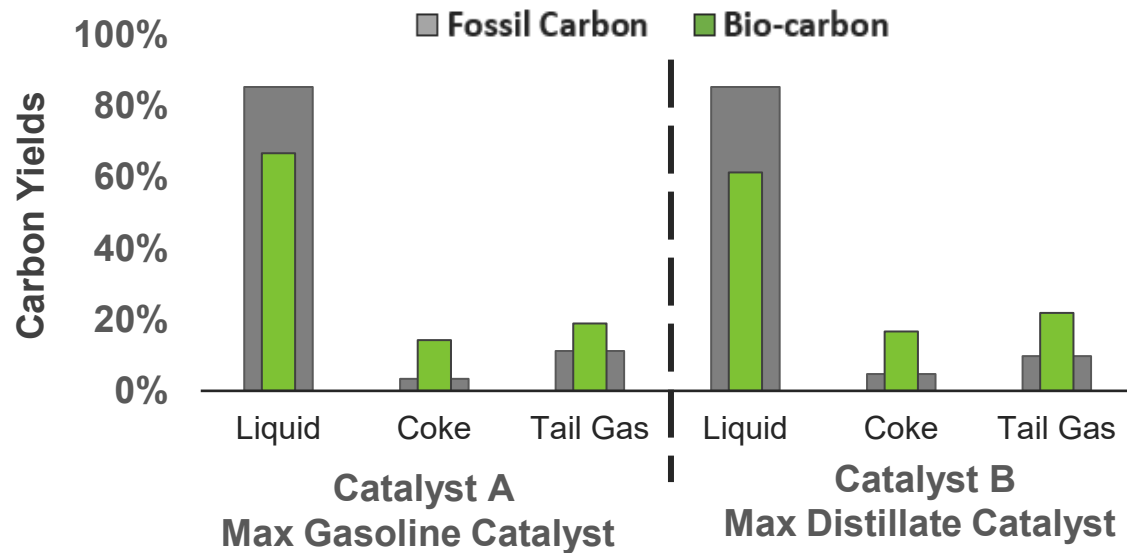
- Physical distillation enabled product-level renewable-carbon measurements
- Renewable carbon preferentially concentrates in naphtha-range products
- Carbon-fate trends remain similar despite differences in catalyst selectivity

Radiocarbon analysis transforms renewable carbon from an assumed quantity into a traceable, measurable flow through the FCC process

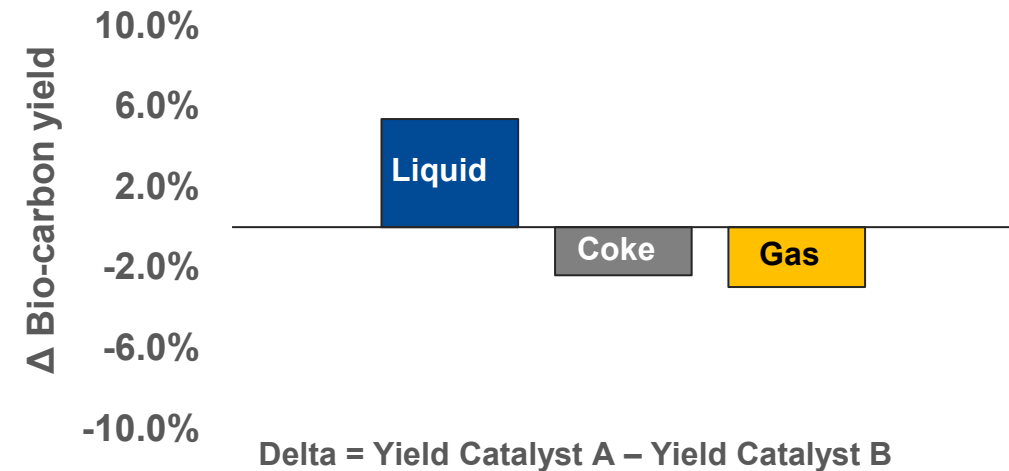
Catalyst selection can be leveraged to maximize renewable carbon utilization

Most renewable carbon remains in liquid products for both catalyst technologies

Low Severity Conditions



Catalyst selection measurably shifts renewable carbon between liquid, gas, and coke products



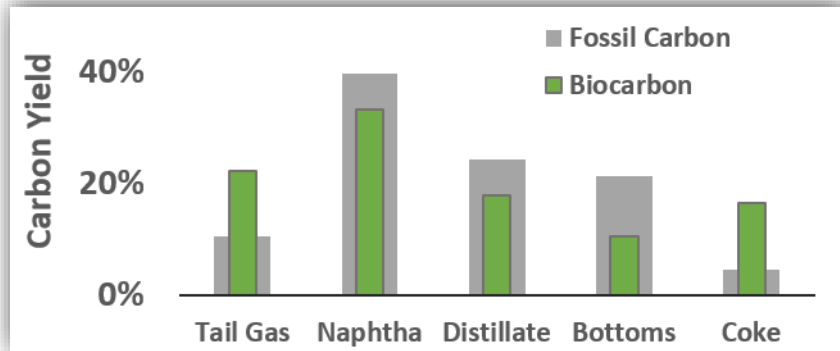
- Renewable carbon retention is an optimization variable, not a fixed outcome
- Product distribution depends on feed quality and catalyst chemistry

Catalyst selection provides a practical lever to influence where renewable carbon ultimately resides

Measured carbon fate informs, but does not define, renewable-carbon attribution

Physical carbon fate

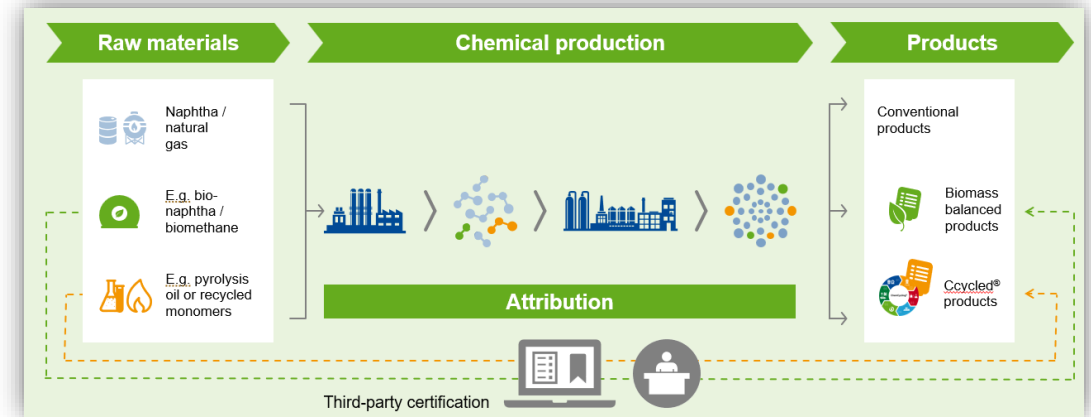
Where does renewable carbon physically go?



- Renewable carbon is distributed among products, gas, and coke
- Radiocarbon analysis measures where renewable carbon resides

Renewable Credit Allocation

How are renewable credits assigned?



- Measured carbon fate provides the scientific basis for attribution decisions
- Certification frameworks define how renewable claims are assigned
- Attribution outcomes may differ from physical carbon fate

Measurements determine where carbon goes; attribution frameworks determine how claims are assigned

Summary

- Most renewable carbon is retained in liquid products, while measurable fractions partition to gas and coke
- Feed pretreatment matters most, with feed hydrogen content strongly influencing carbon fate
- Catalyst selection is a practical lever for improving renewable-carbon utilization
- Measured carbon fate provides the physical basis for informed attribution, while policy and certification frameworks determine allowable claims.

Thank you for your attention!

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Acknowledgements

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RADIOCARBON DATING

SGS

BASF
We create chemistry



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