SUSTAINABLE PRODUCTION OF ADVANCED BIOFUELS VIA CO-PROCESSING OF SELECTED NON-FOOD FEEDSTOCKS WITH ATMOSPHERIC GAS OIL

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Co-processing: Advantages vs. Disadvantages

- 🔋 **Non-edible resources/Wastes** – no food/feed competition
- 🌱 **Sustainability** – reduces environmental impact
- 🌍 **Lower GHG emissions** – less CO_2 vs fossil fuels
- 🏭 **Infrastructure-friendly** – uses existing units
- 🛢️ **Diversification** – improves supply security
- 💰 **Cost efficiency** – cheaper than edible oils

- ⚠️ **Variable quality** – impurities affect catalysts
- 🧰 **Extra pre-treatment** – increases cost & complexity
- 🚚 **Logistics challenges** – collection & storage issues
- ⚙️ **Process limits** – high co-processing ratios restricted
- 🛑 **Catalyst deactivation** – faster aging & replacement

Feedstock choice dictates pretreatment, catalyst management, and feasible co-processing levels.

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Non-edible Feedstocks/Wastes
Typical Impurity Patterns & Catalyst Deactivation Risk

Key Impurities

- 🧪 **Phosphorus** – phospholipids, gums
- 🔩 **Alkali and Alkaline Earth Metals** – Na, K, Ca, Mg
- 💧 **Water & Solids**
- 🛢️ **Polymers / Oxidized Triglycerides**
- ⚠️ **Halides** (sometimes)

Catalyst Deactivation Actions

- 🛑 **Active Site blocking / irreversible adsorption** – P, alkali
- ⚙️ **Pore plugging** – coking, oligomers
- 🔥 **Altered sulfidation / hydrogenation**
- 📉 **Refinery study** – K, P, Na major poisons

Feedstock-specific impurity patterns determine pretreatment needs and feasible co-processing severity.

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Feedstock Portfolio - Chemistry & Operational Expectation

Seed oils (technically edible, used as non-food feedstocks)

- **Camelina oil** – polyunsaturated C_{18} — high conversion, ↑H_2 demand, diesel-range C_{15}–C_{18}
- **Mustard oil** – long-chain C_{20}–C_{22} — heavier n-paraffins, potential cold-flow issues, catalyst-sensitive

Non-edible / waste / industrial oils

- **Karanja oil** – diesel-range, crude may deactivate catalyst — full deoxygenation possible, catalyst risk if crude
- **Post-fermentation corn oil (PFCO)** – elevated FFA, metals, water — requires severe pretreatment, protect catalyst
- **Spent coffee grounds oil (SCGO)** – elevated FFA, polar products — feasible for full deoxygenation, watch coking tendency
- **Used cooking oil (UCO)** – variable FFA, water, metals, phosphorus — highest catalyst risk, strict impurity control required

Not all oils behave the same — feedstock chemistry ultimately defines hydrogen demand, catalyst risk, and overall process performance.

Pretreatment - results

refining - remove unwanted phospholipids and reduce the metal cations

30 % citric acid solution for degumming ⟶ washed degummed oil ⟶ driying and silica gel refining

Oil property		PFCO		Camelina		Karanja		Mustard		SCGO	
		Raw	Ref.	Raw	Ref.	Raw	Ref.	Raw	Ref.	Raw	Ref.
FFA content	% (as oleic acid)	13	13.2	0.4	0.1	3.2	0.1	1	1.2	< 0.01	< 0.01
Iodine number	g I_2/100 g	128	127	153	152	85	86	110	108	97	97
P	mg/kg	3.5	< 3	13.2	< 3	7.8	< 3	37	< 3	69.9	5
Ca		< 1	< 1	6.2	< 1	4.4	< 1	43.8	< 1	189	< 1
Mg		< 1	< 1	2.5	< 1	1.3	< 1	10.2	< 1	20.7	< 1
Na		1.4	< 1	< 1	< 1	< 1	< 1	< 1	< 1	2	< 1
K		3.6	< 1	2.9	< 1	2.6	< 1	4.8	< 1	20.4	< 1
S		19.2	16.4	13.7	< 5	21.1	12.1	215	73.7	80.2	19.2

Effective reduces contaminants, FFA response depends on feedstock and pretreatment conditions.

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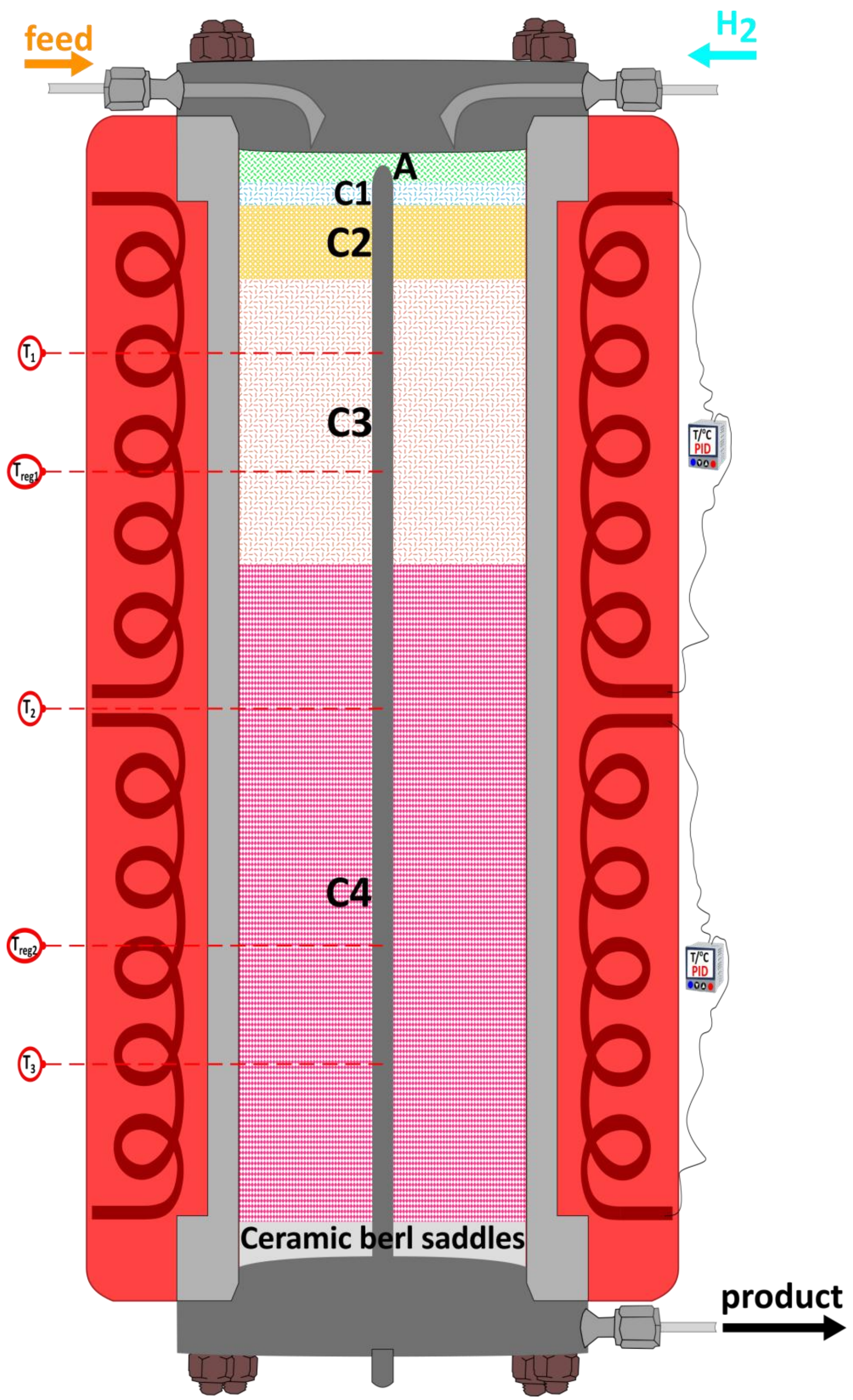
Catalyst system in Stacked Bed Reactor



adsorbent A – highly inert alumina to trap particulates and other contaminants from feed

catalyst C1 – $CoMo/Al_2O_3$ hydrotreating catalyst, helping to remove impurities (oxygenated compounds and heteroatom-containing species), improving the quality of intermediate streams in renewable fuel production

catalyst C2 – $NiMo/Al_2O_3$ hydrotreating catalyst with high hydrogenation activity, stability, helping to remove oxygen, sulphur and other impurities while improving the quality of the resulting renewable fuels

catalyst C3 – $NiMo/Al_2O_3$

catalyst C4 – $NiMoP/Al_2O_3$

The stacked catalyst configuration enables stepwise impurity removal and controlled hydrogenation during HVO co-processing.

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Product Properties

Parameter	Unit	AGO feed	AGO product	PFCO 2 % vol.	PFCO 5 % vol.	Camelina 2 % vol.	Camelina 5 % vol.
Sulphur content	mg/kg	1.07 % wt.	9.2	9.47	8.1	14.7	17.4
Nitrogen content	mg/kg	413	0.53	0.59	0.48	0.85	1.12
Aromatics total	% wt.	35.7	23.9	23.7	24	25.3	25.2
Polyaromatics total	% wt.	11.5	1.5	1.4	1.6	1.7	1.8
CFPP	°C	-3	-5	-3	-4	0	-1
Cetane index	-	48.8	53.9	54.8	55.4	54.9	55.6
C_{5+} yield	% wt.	-	99.78	99.57	99.49	99.63	99.26
C_1-C_4 yield	% wt.	-	0.22	0.36	0.36	0.24	0.37
CO	% wt.	-	-	0	0.04	0.04	0.03

AGO = mixture of atmospheric gas oil, light-cycle oil, and gas oil from resid hydrocracking unit (RHC)
PFCO = post-fermentation corn oil; detailed data for additional feedstocks are available upon request

Despite feedstock variability, the final product quality remains consistent, with only minor differences across all tested cases.

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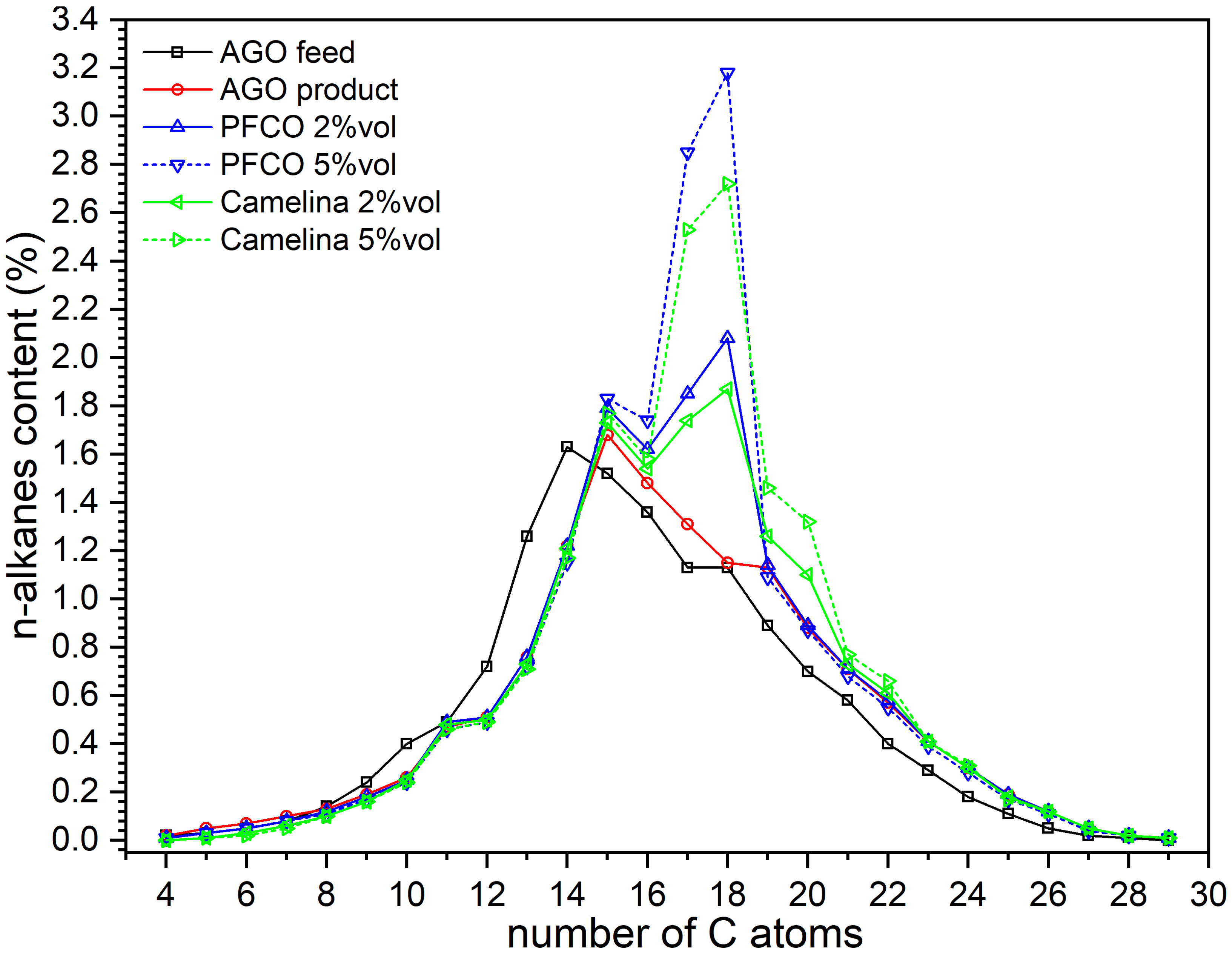
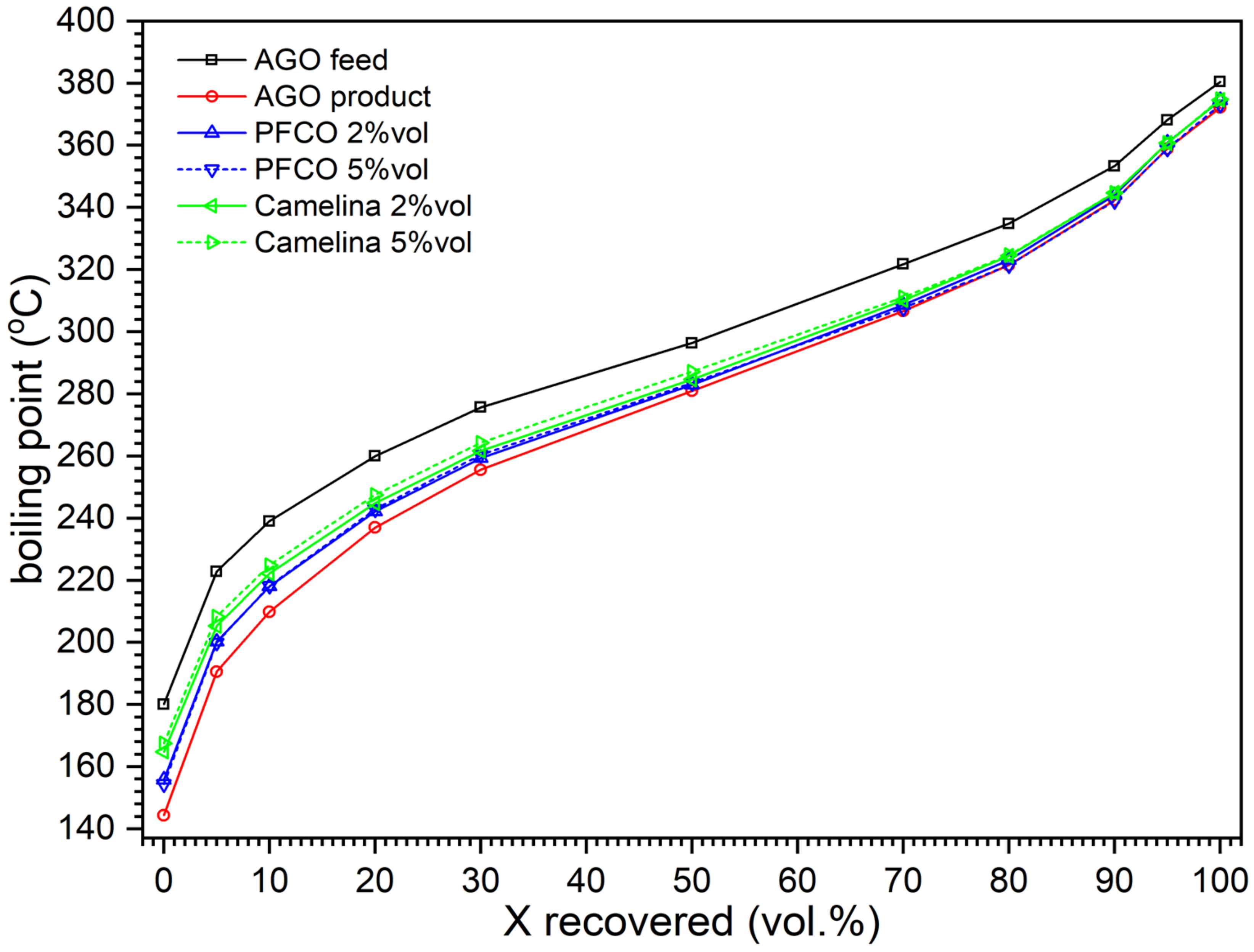
Product Properties





Renewable co-processing modifies hydrocarbon composition but maintains fuel properties close to standard AGO.

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LCA Assessment of Non-Edible / Waste Oils for HVO Co-Processing

Feedstock	Core LCA* (g CO_2e/MJ)	ILUC** (g CO_2e/MJ)	Notes / Range
Used cooking oil	**13.9**	**0**	Collection & processing dominate
Corn oil (Distillers)	**17.2**	***not available***	Allocation critical
Spent coffee ground oil	**25 – 40**	**0**	Indicative range, data-limited
Camelina oil	**42.0**	**-11.5**	Yield & fertilizer drive LCA
Carinata oil	**34.4**	**-10.8**	Higher yield / agronomy sensitive
Karanja oil	**47.0**	***not available***	Peer-reviewed anchor, high uncertainty

* standard life cycle emissions (g CO_2e/MJ) from feedstock supply to fuel at refinery gate

** Indirect Land-Use Change - negative values indicate a net reduction in emissions due to land-use efficiency or cover crop benefits

Waste/by-product oils offer the lowest LCA impact, crop oils are sensitive to yield and fertilizers, and pretreatment supports stable refinery operations.

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Conclusions

- At 360°C, 50 bar H_2 pressure, an LHSV of 0.7 h^{-1}, and a hydrogen-to-feedstock ratio of 250 NL/L, a sulphur content limit of 10 mg/kg was achieved only in the case of at 2 and 5 % vol. PFCO addition.
- Under the same conditions, adding 2, 5, and 10 % vol. of other tested bio-oils did not achieve the 10 mg/kg sulphur content limit, and the hydrogen-to-feed ratio had to be increased.
- During co-processing, triacylglycerides were completely converted to hydrocarbons.
- The increased content of unsaturated bonds in bio-oils also had a negative impact on meeting the sulphur content limit in co-processing products.
- Conversely, adding 2-10% by volume of bio-oil had no significant adverse effect on the low-temperature properties of the products.
- Pretreatment of bio-oils is a prerequisite for their use in co-processing.

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Thank you
very much for your
kind attention

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