Supplementary Information

Transforming Plastic Waste into Fuel: Upgrading and Utilization of Polypropylene Pyrolysis Oil in Diesel Engines

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Table S1. Technical specifications of the single-cylinder diesel engine for testing the UPPO-diesel fuel blends.

Specifications	*Model: Kirloskar TV1*
Ignition type	Compression engine
Diesel Engine Type	1 cylinder
No. of Strokes	4
Compression ratio	17.5:01
Cylinder diameter	87.5 mm
Stroke length	100 mm
Governor	Centrifugal Type
Intake system	Direct Injection
Speed	1500 rpm
Orifice diameter	20 mm
Connecting rod length	234 mm
Displacement volume	661.45 cc
Dynamometer arm length	185 mm
Software	IC ENGINESOFT 9.0
Rated power	3.5 kW
Fuel Pipe diameter	12.40 mm
Fuel ignition timing	23° before TDC
Fuel injection pressure	180 bar
Pulse per revolution	360°
Cooling	Water cooled
Lubricant	20W40

Formula used for the calculation of Brake Thermal Efficiency

$$Brake\ Power\ (BP) = \frac{2 \times 3.14 \times \mathrm{N} \times \mathrm{T}}{60000}$$

$$Brake\ Power\ (BP) = \frac{2 \times 3.14 \times \mathrm{N} \times \mathrm{W} \times \mathrm{R}}{60000}$$

$$Total\ Fuel\ Consumption\ (TFC) = \frac{10 \times \mathrm{Density} \times 3600}{1000 \times \mathrm{t}}$$

$$Brake\ Thermal\ Efficiency\ (BTE) = \frac{\mathrm{BP} \times 3600}{\mathrm{TFC} \times \mathrm{CV}}$$

where, N = speed of dynamometer in rpm

R =length of the rod = 0.185 m

W = load in kg

t = time taken (s) for fuel flow of 10 mL volume

CV = calorific value of the fuel

Uncertainty analysis

To validate the accuracy, precision, and reliability of experimental data, uncertainty analysis plays the pivotal role. In this work, uncertainties of important performance indicators, such as Brake Thermal Efficiency (BTE) and emission of various gases were analyzed using the propagation of errors from primary measurements and instrumentation specifications.[1]

Uncertainty in Brake Thermal Efficiency (BTE)

The ratio of brake power output and energy input in the form of heat from the fuel is known as BTE. It was computed using the following relation:

$$BTE = \frac{BP\ \times 3600}{TFC \times CV}$$

The BP was calculated from torque (T) and engine speed (N) using the standard equation:

$$BP = \frac{2\pi NT}{60000}$$

The uncertainty in BTE was determined by propagating the uncertainties associated with the individual measured parameters, following the root-sum-square (RSS) method:

$$\left(\frac{\partial BTE}{BTE}\right)^2 = \left(\frac{\partial BP}{BP}\right)^2 + \left(\frac{\partial TFC}{TFC}\right)^2 + \left(\frac{\partial CV}{CV}\right)^2$$

$$\left(\frac{\partial BP}{BP}\right)^2 = \left(\frac{\partial N}{N}\right)^2 + \left(\frac{\partial T}{T}\right)^2$$

The uncertainty in torque (T) and engine speed (N) were determined based on the specifications provided by the eddy current dynamometer and digital tachometer, respectively.

$$\left(\frac{\partial BP}{BP}\right)^2 = (0.005)^2 + (0.002)^2 = 0.000029$$

$$\left(\frac{\partial BTE}{BTE}\right)^2 = (0.005)^2 + (0.0054)^2 + (0.0054)^2$$

$$\left(\frac{\partial BTE}{BTE}\right) = 0.0091$$

Uncertainty in Emission Measurements

Emissions, including CO, CO_2, NOx, O_2, and unburned hydrocarbons (UHC), were measured using a calibrated INDUS 5 exhaust gas analyzer. The uncertainty values are mentioned with the analyzer's specifications, stated as an accuracy in Table S2.

Table S2. Technical specification of the INDUS 5 Gas Analyzer (model: PEA 205N)

Gases Measured	Carbon monoxide, carbon dioxide, Oxygen, Oxides of Nitrogen & Hydrocarbon
Principle	Non-Dispersive Infrared for CO, CO_2, & HC. Electrochemical sensor for O_2 and NOx.
Range	CO: 0 to 15%, HC: 0 to 3000 ppm as hexane, O_2: 0 to 25%, NOx: 0 to 5000 ppm
Data Resolution	CO: 0.001%, O_2, CO_2: 0.01%, HC & NOx: 1 ppm.
Accuracy	CO: ±0.06%, CO_2: ±0.5%, HC: ±12 ppm, O_2: ±0.1%
Gas flow rate	500 to 1000 mL/min
Intrinsic response time	less than 15 seconds
Data Communication	RS232 interface for computer connectivity
Operating temperature	0 to 50 °C

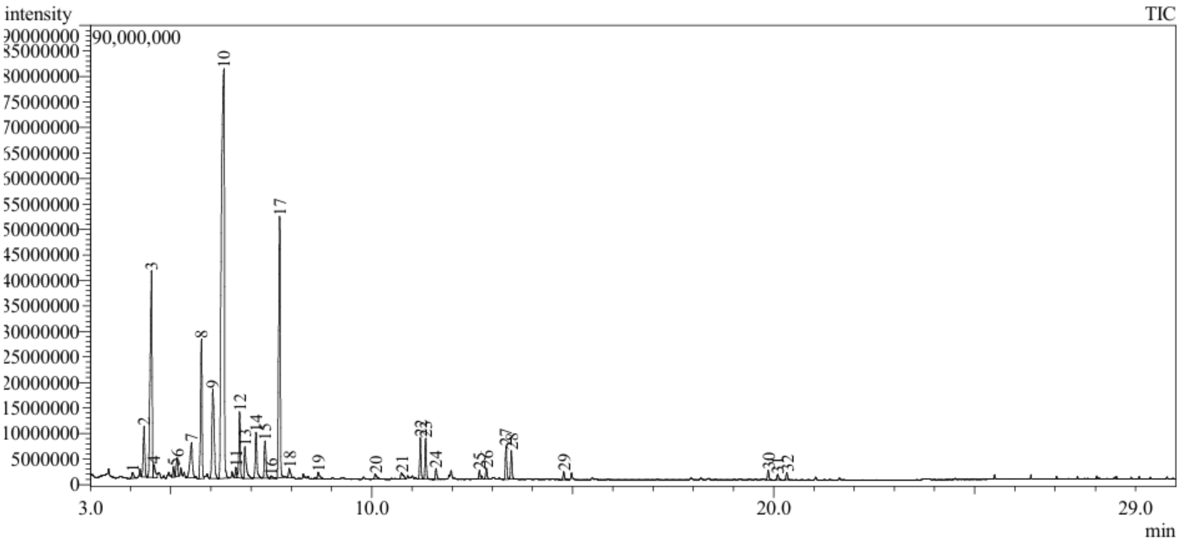

Figure S1. The GC chromatogram of DPPO-N fraction showing the major molecular components.

Table S3. Major peaks report of GC-MS data DPPO-N

Peak number	*Residence Time (min)*	*Area*	*Area (%)*	*Similarity index (%)*	*Name of Compound*
3	4.523	135401945	11.79	94	Heptane, 4-methyl-
7	5.517	28611717	2.49	92	Cyclopentane,1,1,3,4-tetramethyl-, cis-
8	5.762	73916936	6.44	96	Heptane, 2,4-dimethyl-
9	6.048	65651239	5.72	90	2,3-Dimethyl-3-heptene
10	6.323	420854026	36.64	91	1-Undecene
12	6.714	30831894	2.68	96	Cyclohexane, 1,3,5-trimethyl-
13	6.846	19678518	1.71	98	Ethylbenzene
14	7.120	27286812	2.38	86	Hexen-1-ylcyclohexane
15	7.345	21707979	1.89	91	1,3-Hexadiene, 2,3,5-trimethyl-
17	7.712	144496126	12.58	87	1-Undecene, 8-methyl-
22	11.209	19728259	1.72	95	Nonane, 2,6-dimethyl-
23	11.342	18849129	1.64	96	Nonane, 2,6-dimethyl-
27	13.341	15409367	1.34	91	1-Undecene, 7-methyl-
28	13.471	13580194	1.18	91	1-Undecene, 7-methyl-

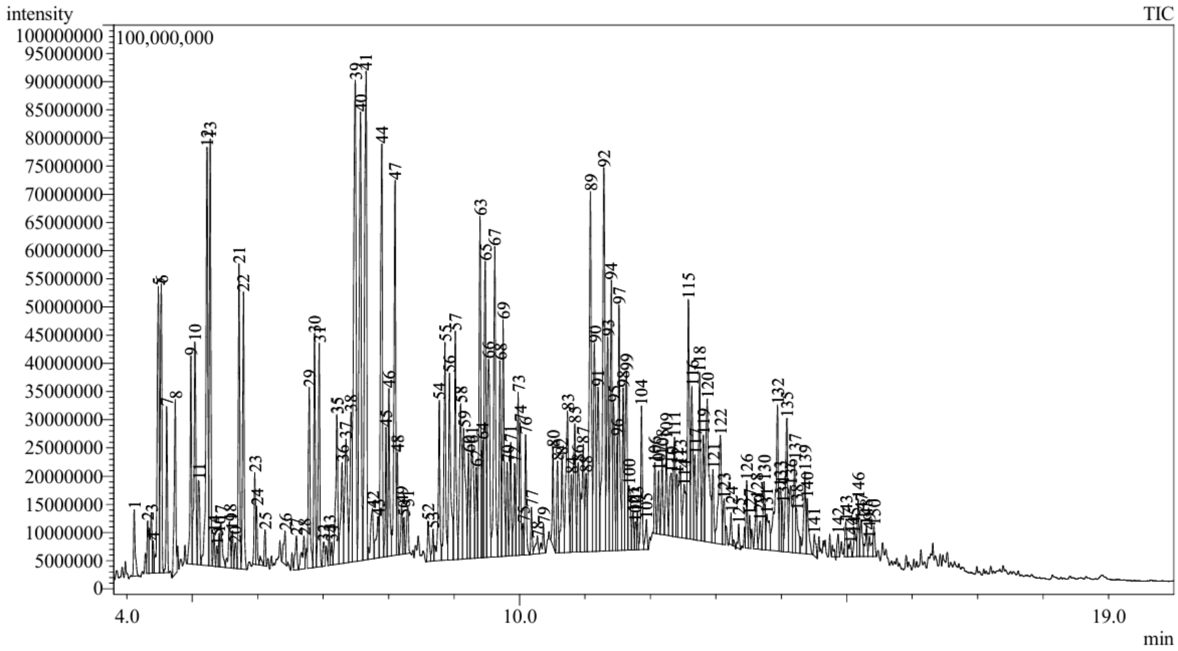

Figure S2. The GC chromatogram of UPPO.

Table S4. Major peaks report of GC-MS data UPPO

Peak number	*Residence Time (min)*	*Area*	*Area (%)*	*Similarity index (%)*	*Name of Compound*
5	4.480	94852555	1.44	92	Oxalic acid, 2-ethylhexyl isohexyl ester
6	4.525	81303556	1.23	92	Oxalic acid, 2-ethylhexyl hexyl ester
12	5.227	156829029	2.38	90	3-Octadecene, (E)-
13	5.275	123181447	1.87	90	1-Tetradecene
21	5.715	79486864	1.21	89	Pentadecafluorooctanoic acid, tridecyl ester
39	7.492	223147868	3.39	90	Trifluoroacetic acid, pentadecyl ester
40	7.570	186284723	2.83	90	2-Isopropyl-5-methyl-1-heptanol
41	7.655	203026227	3.08	90	2-Isopropyl-5-methyl-1-heptanol
44	7.894	143869037	2.18	90	1-Dodecanol, 2-hexyl-
47	8.098	125956316	1.91	90	Pentadecafluorooctanoic acid, hexadecyl ester
63	9.397	120146799	1.82	90	Octacosyl trifluoroacetate
65	9.474	96099979	1.46	89	1-Dodecanol, 2-hexyl-
66	9.526	86349905	1.31	90	Dodecyl nonyl ether
67	9.621	113039964	1.72	90	Pentadecafluorooctanoic acid, octadecyl ester

89	11.084	151738348	2.30	90	Pentacosyl trifluoroacetate
90	11.144	81721418	1.24	90	1-Decanol, 2-hexyl-
92	11.291	161553566	2.45	90	Pentacosyl trifluoroacetate
94	11.402	87879317	1.33	90	Tetratriacontyl heptafluorobutyrate
115	12.582	84559732	1.28	90	Tetratriacontyl heptafluorobutyrate
120	12.869	91810886	1.39	90	Tetratriacontyl heptafluorobutyrate

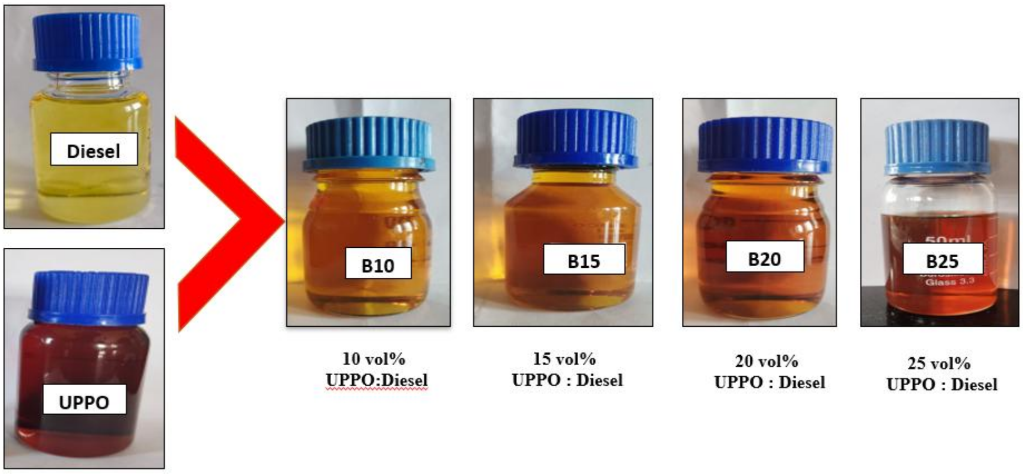

Figure S3. Photographic images of various UPPO-diesel blends showing their relative color intensity and clarity.

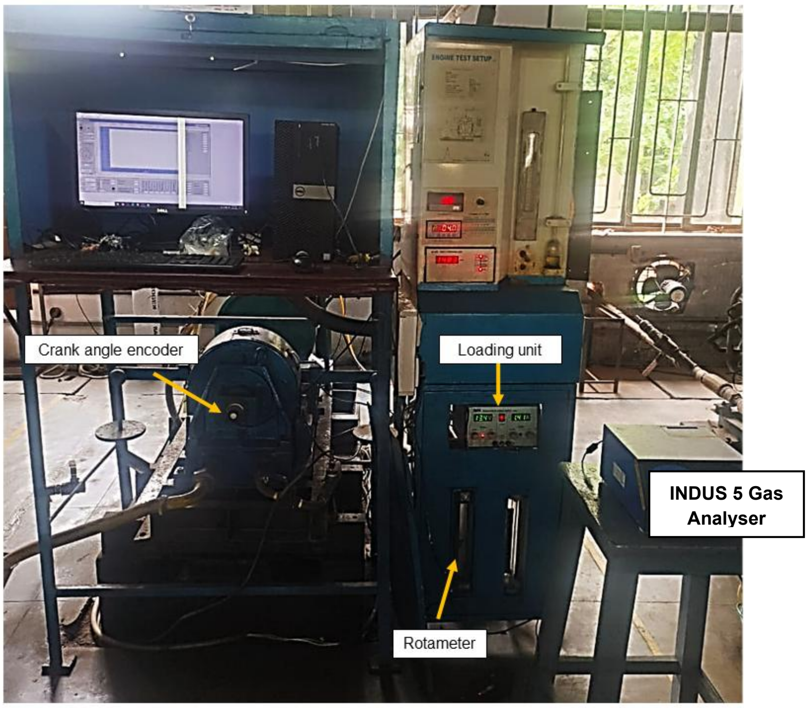

Figure S4. Computerized internal combustion engine experimental test facility (front view).

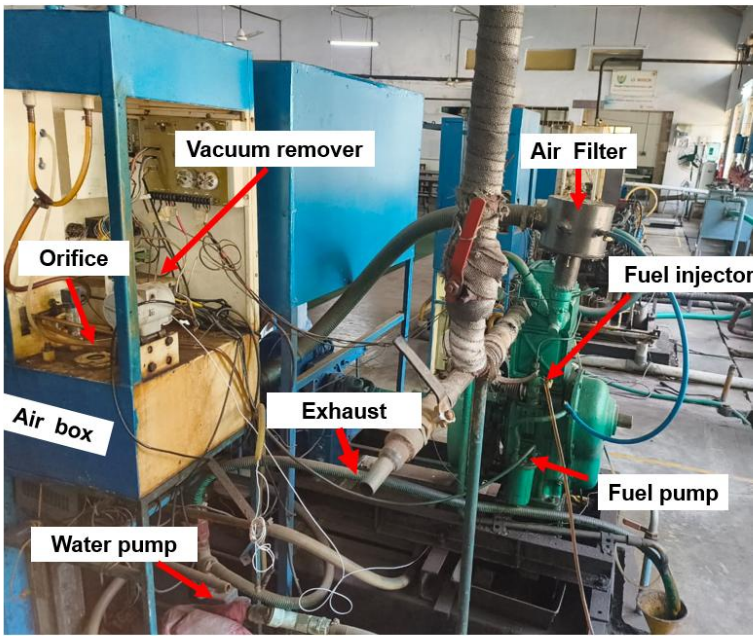

Figure S5. Computerized internal combustion engine experimental test facility (side view).

Figure S6. The IC engine (backside view), displaying the fuel injector and air filter.

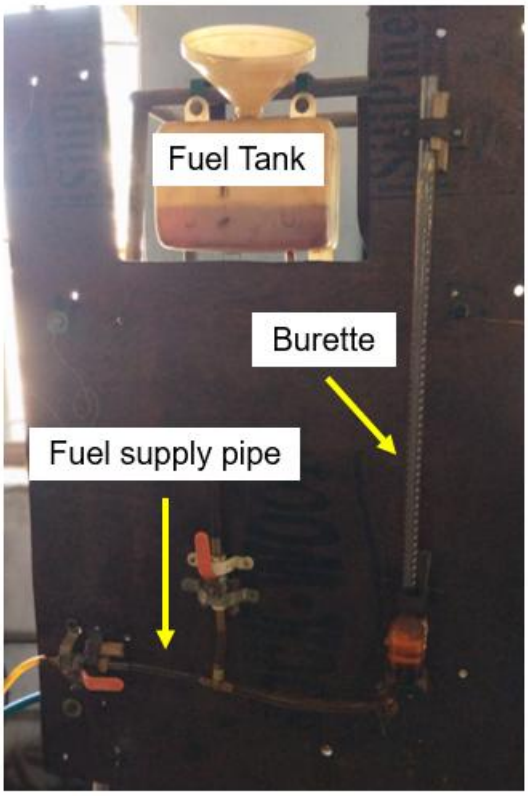

Figure S7. Photographic image of the IC engine fuel tank and burette for the measurement of fuel flow rate.

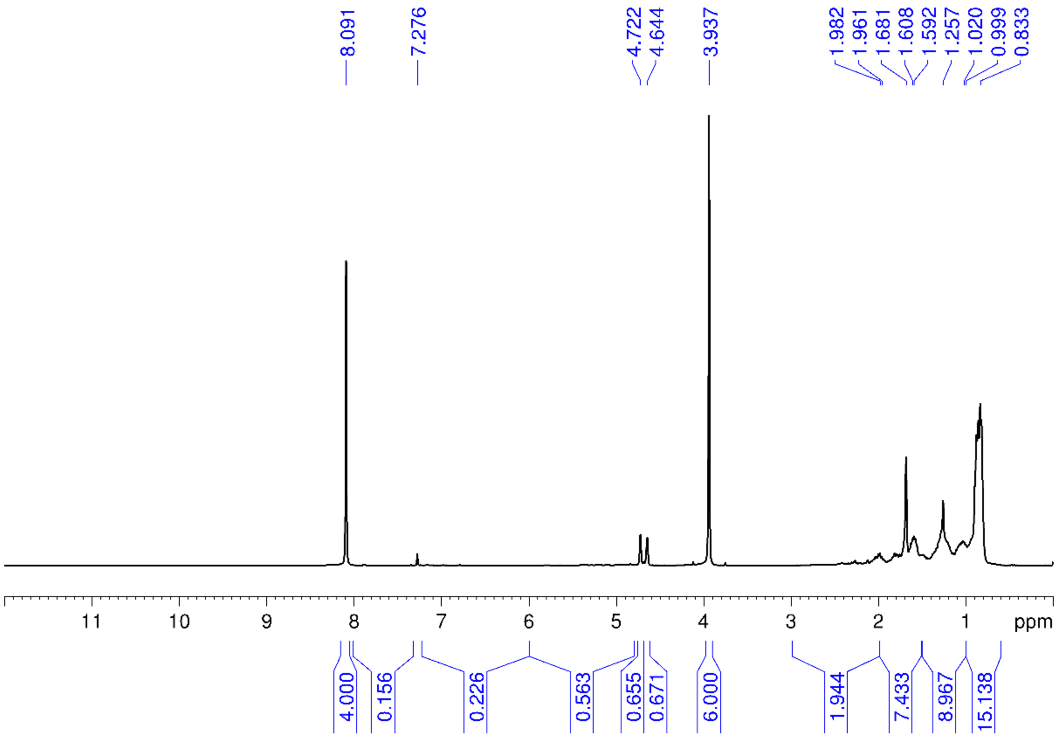

Figure S8. The [1]H-NMR spectrum of CPPO using 1,4-dimethyl phthalate as the internal standard for quantification of components.

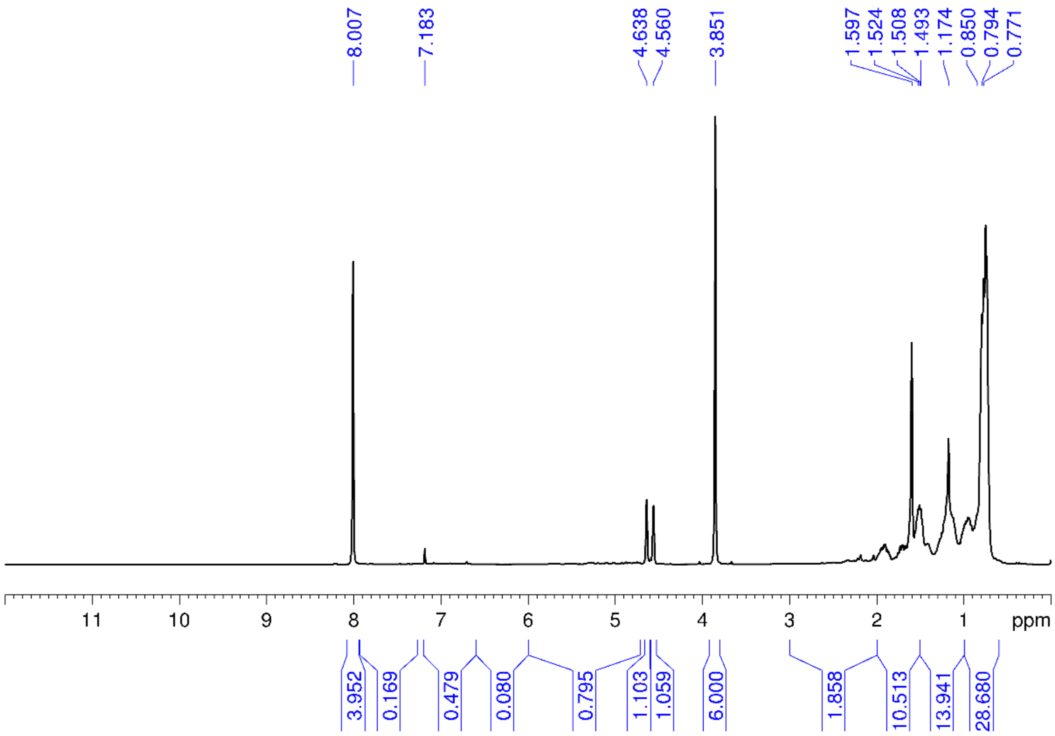

Figure S9. The [1]H-NMR spectrum of UPPO using 1,4-dimethyl phthalate as the internal standard for quantification of components.

Table S5. Chemical composition of UPPO and CPPO obtained by quantitative analysis using dimethyl terephthalate as an internal indicator.

Proton Type	Integral area of CPPO	Integral area of UPPO
Aromatics, vol%	4.5	3.3
Paraffins, vol%	63	63
Olefins, vol%	31	30.6
H/C	1.36	1.8
Isoparaffin Index	1.13	1.3

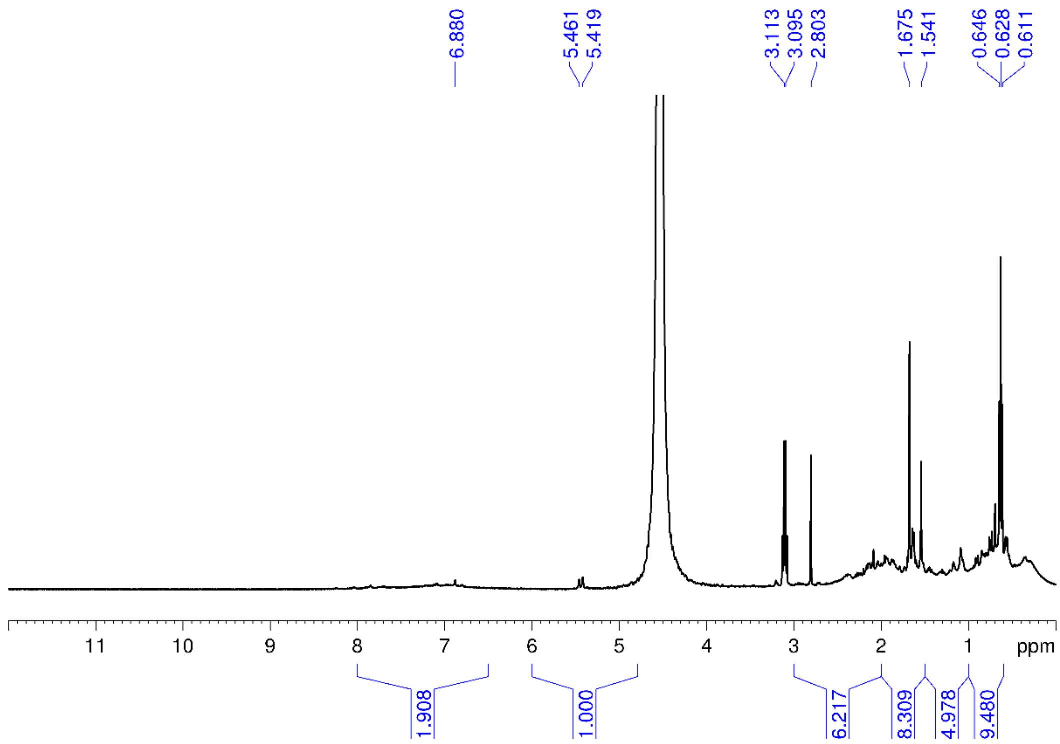

Figure S10. The ^{1}H-NMR spectrum of the degummed fraction in D_2O.

References:

[1] Yadav AK, Yadav SK, Kumar GN, Madav V, Dutta S. Biomass-derived 5-(tolylmethyl)furfural as a promising diesel additive: preparation, process scale-up, and engine studies. RSC Adv 2025;15:27933–40. https://doi.org/10.1039/D5RA04020E.