



Assessment of energy potentials, chemical composition and characterisation of bio-oil yields production from fast pyrolysis of biomass waste

Joseph A. Oyebanji ^a, Sunday O. Oyedepo ^{a,*}, Olusanya O. Omolara ^b, Olawumi T. Oyebanji ^c

^a Department of Mechanical Engineering, Bells University of Technology, Ota, Nigeria

^b Department of Computer Engineering, Bells University of Technology, Ota, Nigeria

^c Department of Chemistry, University of Medical Sciences, Ondo, Nigeria

ARTICLE INFO

Article history:

Received February 5, 2026

Revised July 26, 2026

Accepted July 29, 2026

Available online July 29, 2026

Published July 30, 2026

Keywords:

Agro waste,
Waste-to-Energy
Technology,
Biomass,
Biofuel,
Renewable Energy.

ABSTRACT

In this investigation, two distinct wood samples Anogeissus Leiocarpa (AL) and Cordia Milleni (CM)) were converted to bio-oil using a rapid pyrolysis procedure. Chemical components of the bio-oil yields were identified by gas chromatography-mass spectrometry (GC-MS) analysis. Experimental runs are 450°C, 500°C, 550°C, 650°C and 650°C, with energy content for AL and CM at optimum Temperature 550°C was 33.20 and 33.33 MJ/kg, respectively. Results of the study further shows that the bio-oil yields from AL and CM contained low nitrogen (0.88% and 0.77%), sulphur (1.36% and 0.94%) and another organic compound. Wood samples have a modest pollutant effect, as a result of low sulphur and nitrogen content. The study highlight the possibility of using the bio-oil yields as energy for internal combustion engines, raw materials for the chemical processing sector and serve as alternative energy supply sources to encourage the use of renewable energy sources to reduce pollution.

1. INTRODUCTION

The influence of mankind on the environment has risen significantly due to population growth with severe decline in ultimate natural resources that has followed, making sustainable development a top priority for policymakers around the world. It is now our duty to teach the next generation about alternatives and more environmentally friendly ways of living in general, and one of the most crucial

* Corresponding author, E-mail address: sooyedepo@bellsuniversity.edu.ng



lessons is to reduce waste (Rana, 2026). According to recent estimates, methane emissions and other greenhouse gases are responsible for approximately 0.5 °C of global warming since the pre-industrial era and account for nearly one-fifth of total global emissions. In addition, untreated waste is strongly linked to public health risks and environmental degradation, including air and water pollution. Governments allocate significant portions of their budgets to waste management due to the growing awareness of the consequences of improper waste disposal practices (Kaza et al, 2025). However, in low-income countries, more than 90% of waste is still openly dumped or inadequately managed, exacerbating environmental and health challenges. Addressing these issues remains a critical component of achieving the United Nations Sustainable Development Goal 11 (SDG 11), which focuses on creating sustainable cities and improving quality of life (UN DESA, 2026).

The amount of waste generated worldwide is predicted to increase by 70% by 2050 to 3.40 billion tonnes and managing solid waste sustainably is advantageous for energy production in addition to being important to address disposal problems. In comparison to all other methods of managing solid waste, waste-to-energy (WtoE) technology is more suited to helping developing nations increase their energy supplies. The effective management of biomass leftovers has gained even more significance in the modern day as biomass waste streams serve as a possible feedstock for a range of environmentally friendly products and as a key alternative energy source on the path to carbon neutrality. The importance of plant biomass in the emerging bioeconomy cannot be overstated, since it is a very abundant renewable resource that forms the base for innovation production, chemicals, and second-generation biofuels. We must maximize the value of renewable plant feedstocks, such as lignins, oils, and other carbon-rich compounds, in order to move society beyond the constraints imposed by fossil-derived feedstocks. WtE technologies are essential to integrated waste management because of their capacity to recover energy from nuisance, and thoroughly disinfect (Atofarati et al., 2025). Environmental risks associated with the use of fossil fuels and the expected reserves depletion and greenhouse gas emissions have emerged as the world's greatest environmental threat in recent years. As a result, focus has shifted to renewable energy sources and technologies for both transportation and electricity generation by bridging the gap between a sustainable environment, energy supply and energy recovery systems for economically and environmentally viable to mitigate against growth of greenhouse gas emissions beyond 2050 (Dong et al., 2018; Ayodele, et al., 2018; Sidibe et al., 2020; Cohen-Sacal, et al., 2023; Rana, 2026).

They offer several other advantages, including cost savings, contemporary energy systems assessment, organic waste treatment, enhanced human health, local job opportunities, social cohesion within the community, better livelihoods, and sustainable development, renewable energy technologies are gaining more attention. Climate change is an urgent global issue in the modern world. These are global problems that call for global cooperation and international solutions. Globally, more people are becoming aware of the value of green energy, the advantages of mitigating climate change, and the significance of advancing sustainable development (Dong et al., 2018; Ayodele, et al., 2018; Rana, 2026). Significant source of sustainable energy is biomass, which encompasses a variety of natural and generated resources such waste paper, wood waste, bagasse, agricultural and industrial residues, herbaceous and woody species, and municipal solid waste (MSW). Developing countries with a huge biomass resource base, like Nigeria, have a huge potential to use that biomass to produce biofuel for generation of electricity and transportation. In Nigeria, there are numerous potentials for the exploitation of various biomasses, with an estimated 2.01 EJ (47.97 MTOE) of biomass leftovers and wastes available for exploitation each year (Sidibe et al., 2020; Cohen-Sacal, et al., 2023). Nigeria has a lot of renewable energy sources, but because of its dense population, access to clean energy is limited. Therefore, turning the massive amounts of biomass resources—mostly agricultural wastes and animal, food, and municipal wastes—that are currently burned or dumped into energy could potentially increase energy supply and improve the country's energy mix and balance. Additionally, producing clean energy from biomass and providing

electricity in rural regions can help the environment by lowering greenhouse gas emissions (Altayib & Dincer, 2022; Kaza et al., 2025).

Fossil fuel depletion, rising greenhouse gas (GHG) emissions, climate change, and higher energy demand are the major challenges that call for sustainable alternative energy sources. Several critical knowledge gaps impede the full-scale commercialisation and technological applications of waste-to-energy (WTE) technologies, such as: poor energy potentials quantification, biomass waste inadequately characterization, lack of optimisation process with relevant data, limited evidence-based policy formulation and industrial investment decisions (Somorin et al., 2017; Oyedepo et al., 2019; UN DESA, 2026). Waste-to-energy technologies produce biogas, bio-oils, bio-alcohol, and bio-hydrogen from waste biomass, which accounts for one-seventh of global energy consumption and 43% in some developing nations (Somorin et al., 2017; Oyedepo et al., 2019; UN DESA, 2026), helping to cut greenhouse gas (GHG) emissions and environmental pollution. It has the advantage of being greenhouse gas (GHG) emissions-neutral compared to fossil fuel sources, such as coal, oil, and natural gas, to help sustainably produce biopower and biomaterials (Ahmadi et al., 2020). The goal of the agro waste (AGW) management system is to address issues with incorrect waste disposal that are related to employment, economics, aesthetics, land usage, and health (Kumar, et al., 2015; UN DESA, 2026). Increases in population, urbanization, and living standards all contribute to the generation of AGW in emerging countries (Wang et al., 2019). However, determining the economic viability of WTE conversion methods is necessary. As a result, this study focuses on improving biofuel generation, decarbonization, agro-waste utility, decreased pollutant emissions, and nutrient recycling through practical application with a holistic approach (Wang et al., 2019). In view of the above, the main study objectives are to: (i) assess the energy potential and chemical composition of bio-oil yields produced by fast pyrolysis from selected bio-mass wastes and (ii) characterize the composition and functional groups of bio-oil yields from the selected sawdust feedstocks.

2. METHODOLOGY

2.1 Samples collection and experimental analysis

Sawdust samples of *Cordia Milleni* (CM) and *Anogeissus Leiocarpa* (AL) were collected from Ota, situated in the southwest region of Nigeria. The samples were air dried and ground into 0.5mm particles using a Philip milling machine. For subsequent research, the ground samples were sieved into particles with diameters between 0.25 and 0.5 mm and kept at room temperature. To find the contents of C, H, N, O, moisture, and ash, elemental analysis was done using an elemental analyzer (CE-440) (Oyebanji et al., 2023).

2.2 Experimental Set-up

The pyrolysis reactor was made of 4 kW heater with a gas collector, a condenser, an ice bath, a *Proportional-Integral-Derivative* (PID), and gas flow system. The experimental procedures stated in Oyebanji et al (2023) was adopted in this study. The experiments were conducted at various temperatures in pyrolyzer in an inert environment. Char was left in situ while the fluids were transferred to a condenser utilizing the fundamentals of condensation and the gas was transported to a gas collector during experimental processes. The products and samples were weighed using a digital scale that had an accuracy of ± 0.1 g. The percentage of the pyrolyzed wood samples' initial weight that was converted into product yields was reported.

2.3 Bio-oil characterization

Extracted bio-oil was examined to GC-MS analysis using Japanese Shimadzu GCMS-QP2010 analyzer at scanning range of 40 - 700 mz^{-1} in a helium atmosphere (45.0 ml/min). The oven was set up to range from 60°C to 280°C for one minute, then to 180°C for three minutes, and finally to 280°C for two minutes. The injection mode was split ratio 41.6, the injection temperature was 250°C, the purge flow was 3.0 ml/min, the pressure was 56.2 kPa, finish durations were 3.5 and 24.0 minutes (Oyeboji et al., 2023).

3. RESULTS AND DISCUSSION

3.1 Elemental composition and heating value of wood sawdust

The elemental composition, moisture content, ash content, fixed carbon, volatile matter, Oxygen (O), Nitrogen (N), Carbon (C), Hydrogen (H), Sulphur (S) and higher heating values (HHV) of the selected wood samples were determined based on the Standard procedures. Table 1 shows that *Anogeissus Leiocarpa* (AL) and *Cordia Milleni* (CM) contained low nitrogen (0.88% and 0.77%) and sulphur (1.36% and 0.94%), respectively. This reveals that the wood samples have low pollutant effects and indicate that they are ecofriendly compare to that from (Echresh Zadeh, et al., 2020; Oyeboji et al., 2023; Said et al., 2025). HHV average values are 18.07MJ/kg and 15.64 MJ/kg for AL and CM, respectively. HHVs obtained from the selected fuel woods in this study are adequate for use in an engineering thermal system and can be efficiently transformed into a valuable energy source.

Table 1. Elemental composition of raw sawdust sample

	Proximate analysis (wt%, dry basis)				Ultimate analysis (wt%, dry basis)					HHV (MJ/kg, dry basis)
	Fixed carbon	Volatile matter	Ash content	Moisture content	C	H	N	O	S	
<i>Anogeissus Leiocarpa</i>	10.26	77.82	1.88	10.01	29.20	0.40	0.88	68.15	1.36	18.072
<i>Cordia Milleni</i>	10.25	80.03	1.70	8.01	24.76	3.00	0.70	70.57	0.94	15.641

3.2 Product yield from pyrolysis of selected sawdust samples

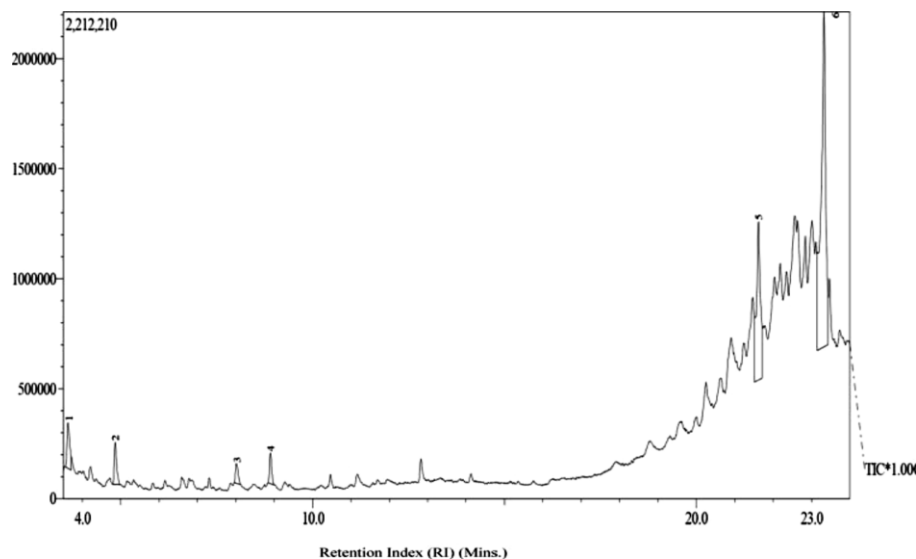
Table 2 presents product yield distributions for AL and CM at different temperature levels. As shown in the table, 450°C favours bio-char production with AL (43.15%) and CM (42.75 %), 550°C serves as the optimum bio-oil yield with AL (53.00%) and CM (52.20%), and a higher bio-gas product yield was noted in 650°C with 38.40% of AL and 41.25 % of CM, respectively. High bio-char production was noticed at a lower temperature. In comparison, an increase in bio-oil and bio-gas yields was noticed at higher temperatures, and bio-oil yield declined at higher temperatures. High temperatures enhance volatile release from biomass particles, as reported by other researchers, with the purpose of maximizing the yield of liquid products resulting from biomass pyrolysis with the aid of temperature, heating rate, and residence time. Some other researchers have reported results along this trend, to maximize the yield of bio-gas resulting from pyrolysis, a high temperature, low heating rate, long gas residence time process would be preferred (Aboelela et al., 2023; Awad et al., 2024; Ungureanu et al., 2025).

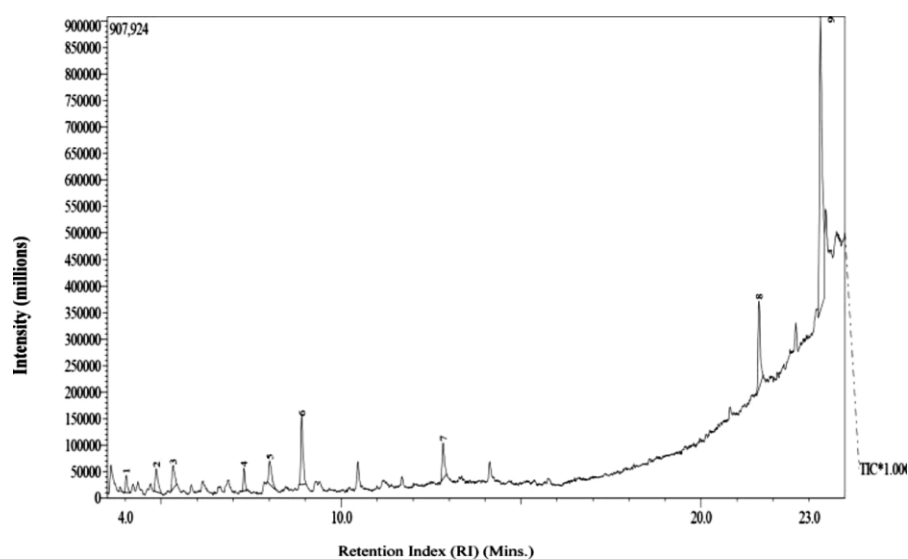
Table 2. Product Yield Distributions for AL And CM

Temperature (°C)	AL product yield			CM product yield		
	Bio-oil (wt.%)	Bio-char (wt.%)	Bio-gas (wt.%)	Bio-oil (wt.%)	Bio-char (wt.%)	Bio-gas (wt.%)
450°C	39.05	43.15	17.80	38.65	42.75	18.60
500°C	49.50	30.50	20.00	50.40	29.50	20.10
550°C	53.00	28.00	19.00	52.20	27.10	20.70
600°C	42.98	20.07	36.95	43.75	19.65	36.60
650°C	42.50	19.10	38.40	40.95	17.80	41.25

3.3 Bio-oil yield characterization from selected sawdust samples

Tables 3 and 4 display the results of the GC-MS analysis of the bio-oil yield of the AL and CM samples, respectively. Stearic acid (5.0%), myristic acid (5.0%), trans-2-octadecadecen-1-ol (12.0%), 9-octadecenal (12.0%), cis-10-pentadecen-1-ol (12.0%), cis-1, 9-hexadecadiene (12.0%), oleic acid (12.3%), and palmitic acid (15.0%) are among the 22 compounds found in Table 3, which characterizes the bio-oil yield from AL. These compounds add up to a total volatile extract of 98.9%. Table 4 shows that the oil production from CM contained 34 components with a 99.2% total volatile extract. Terpenoids (6.0%), palmitic acid (6.2%), trans-2-octadecadecen-1-ol (11.0%), cis-10-pentadecen-1-ol (11.0%), 9-octadecenal (11.0%), and oleic acid (22.0%) constituted the majority of the extract. The two volatile extracts, which are composed of terpenoids, were found to have identical compositions. Both bio-oil outputs contained the conventional amounts of toluene, indene, naphthalene, methylindene toluene, methylnaphthalene, and benzene, which are aromatic hydrocarbons. The chromatograms of the bio-oil yields for CM and AL, that is, at an injection temperature of 250 °C, are presented in Figures 1 and 2. The types of fractions that form are clearly influenced by temperature. It is evident that temperature influences the kinds of fractions that develop (Oyebanji et al., 2023). The simultaneous fragmentation and depolymerization of lignocellulose at higher temperatures may be the cause of the decrease in the number of peaks (number of compounds) with increasing temperature. The retention index (RI) values and peak counts of the two chromatograms differ, suggesting that each one includes distinct substances that were identified by mass spectrometry (MS). According to the MS, the pyrolysis solutions contain alcohol, carboxylic acid, esters, ethers, ketones, and aromatic hydrocarbons. The findings of this study corroborate those of Bridgwater and Czernik (Echresh Zadeh, et al., 2020).

Fig 1. Bio-oil GC-MS chromatogram of *Anogeissus Leiocarpa* (AL)

Fig 2. Bio-oil GC-MS chromatogram of *Cordia Milleni* (CM)Table 3. Chemical composition of *Anogeissus Leiocarpa*(AL)

Compounds	Retention Index	Percentage Composition	MF	MW
1,4-dimethyl-1H-pyrazole	804	0.8	C ₅ H ₈ N ₂	96
2,5-dimethylfuran	732	2.4	C ₆ H ₈ O	96
Luprosil	676	3.0	C ₃ H ₆ O ₂	74
2-methylbutyric acid	811	1.0	C ₅ H ₁₀ O ₂	102
<i>trans</i> -3-Octene	824	0.4	C ₈ H ₁₆	112
<i>cis</i> -3-octene	824	0.4	C ₈ H ₁₆	112
5-methyl-3-methylene-5-hexen-2-one	887	0.5	C ₈ H ₁₂ O	124
4,5-dimethyl-1H-imidazol	927	0.8	C ₅ H ₈ N ₂	96
Cyclooctane	959	0.4	C ₈ H ₁₆	112
Corylone	972	0.4	C ₆ H ₈ O ₂	112
3-methylcyclopentane-1,2-dione	1003	0.4	C ₆ H ₈ O ₂	112
methyl-1-cyclohexenyl ketone	1027	1.6	C ₈ H ₁₂ O	124
<i>o</i> -guaiacol	1090	0.5	C ₇ H ₈ O ₂	124
2-nitroethylpropionate	1067	1.0	C ₅ H ₉ NO ₄	147
<i>cis</i> -1,9-hexadecadiene	1610	12.0	C ₁₆ H ₃₀	222
<i>cis</i> -10-pentadecen-1-ol	1763	12.0	C ₁₅ H ₃₀ O	226
myristic acid	1769	5.0	C ₁₄ H ₂₈ O ₂	228
palmitic acid	1968	15.0	C ₁₆ H ₃₂ O ₂	256
9-octadecenal	2007	12.0	C ₁₈ H ₃₄ O	266
<i>trans</i> -2-octadecadecen-1-ol	2061	12.0	C ₁₈ H ₃₆ O	268
stearic acid	2167	5.0	C ₁₈ H ₃₆ O ₂	284
oleic acid	2175	12.3	C ₁₈ H ₃₆ O ₂	282
Percentage Total		98.9		

Table 4. Chemical composition of *Cordia Milleni* (CM)

Compounds	Retention Index	Percentage Composition	MF	MW
Tetramethylmethane	434	0.4	C ₅ H ₁₂	72
Dimethylvinylmethanol	600	0.5	C ₅ H ₁₀ O	86
2-methylfuran	642	1.0	C ₅ H ₆ O	82
3-methylfuran	643	1.0	C ₅ H ₆ O	82
Trimethylnitromethane	716	0.5	C ₄ H ₉ NO ₂	103
2-pentynal	724	1.6	C ₅ H ₆ O	82
4-ethyl-1,3-dioxolane	738	0.5	C ₅ H ₁₀ O ₂	102
vinyl butyrate	775	0.5	C ₆ H ₁₀ O ₂	114
1-hydroxy-2-butanone	798	1.0	C ₄ H ₈ O ₂	88
cis-3-octene	823	1.0	C ₈ H ₁₆	112
trans-3-octene	824	2.0	C ₈ H ₁₆	112
2-methoxymethyltetrahydrofuran	825	0.5	C ₆ H ₁₂ O	116
2,4-pentadienoic acid	873	1.0	C ₅ H ₆ O ₂	98
trans-2-furanmethanol	885	3.5	C ₅ H ₆ O ₂	98
5-methyl-3-methylene-5-hexen-2-one	887	2.0	C ₈ H ₁₂ O	124
tetrahydro-2-furanmethanol	892	0.5	C ₅ H ₁₀ O ₂	
Corylone	972	1.0	C ₆ H ₈ O ₂	112
Butylglyoxylate	973	0.5	C ₆ H ₁₀ O ₃	130
3-hydroxy-6-methylpyridazine	975	1.0	C ₅ H ₆ N ₂ O	110
3-methyl-1,2-cyclopentanedione	1003	1.0	C ₆ H ₈ O	112
methyl-1-cyclohexenyl ketone	1027	6.0	C ₈ H ₁₂ O	124
methyl 2-butyl-2-cyclopropene-1-carboxylate	1057	1.0	C ₉ H ₁₄ O ₂	154
o-guaiacol	1090	2.0	C ₇ H ₈ O ₂	124
pelargic acid	1272	2.0	C ₉ H ₁₈ O ₂	158
Syringol	1279	1.0	C ₅ H ₈ N ₂	96
2,4-dimethoxyphenol	1279	1.0	C ₈ H ₁₀ O ₃	154
3-nonynoic acid	1290	1.0	C ₉ H ₁₄ O ₂	154
1-methyl-3-nitro-2(1H)-pyridinone	1376	1.0	C ₆ H ₆ N ₂ O ₃	154
cis-10-pentadecen-1-ol	1763	11.0	C ₁₅ H ₃₀ O	226
n-pentadecanoic acid	1869	2.0	C ₁₅ H ₃₀ O ₂	242
palmitic acid	1968	6.2	C ₁₆ H ₃₂ O ₂	256
9-octadecenal	2007	11.0	C ₁₈ H ₃₄ O	266
Trans-2-octadecadecen-1-ol	2061	11.0	C ₁₈ H ₃₆ O	268
oleic acid	2175	22.0	C ₁₈ H ₃₄ O ₂	282
Percentage Total		99.2		

3.4 Physicochemical composition and higher heating value (HHV) of bio-oil yields

Hydrogen, oxygen, sulphur, and oxygen contents and physicochemical composition of two distinct pyrolyzed bio-oils was carried out. In addition, the heating value—a common way of measuring a fuel's energy content—was determined. Tables 5 and 6 present the physicochemical properties and heating values of the bio-oil yields from the selected wood samples at temperatures 500°C and 550°C, respectively. From Tables 5 and 6, the carbon and hydrogen contents vary from 75.50 to 80.76 wt% and 10.45 to 14.75wt%, respectively. Comparing both lignin to the values reported by other researchers, the amounts of carbon and hydrogen are acceptable (Echresh Zadeh, et al., 2020; Said et al., 2025). Bio-oil yields have an oxygen content that ranges from 5.84 to 9.06 wt%. The need to upgrade biofuel to a higher-quality biofuel is confirmed by biofuel oxygen content. Biofuel has poor properties such

corrosiveness, low energy density, and thermal stability since its oxygen concentration is believed to be the main difference between it and fossil fuels. The results of the oxygen-bomb calorimeter method, which is used to determine heating values, show that both wood waste bio-oils have a high heating value (HHV). From temperature of 500°C to 550°C, the average HHV of *AL* and *CM* ranges between 31.55 and 33.20 MJ/kg and 32.94 and 33.33 MJ/kg, respectively. Because bio-oil contains more water and oxygen than fossil fuels, its heating values are lower than that of fossil fuels that ranges between 41 and 43 MJ/kg (Wang et al., 2024). This explains the need for upgrading in order to decrease the oxygen and water levels and enhance the qualities of the bio-oil produced.

Table 5. Physicochemical Composition and Higher Heating Value (HHV) of Bio-oil Yields at 500°C

	Proximate analysis (wt%, dry basis)				Ultimate analysis (wt%, dry basis)					HHV (MJ/kg, dry basis)
	Fixed carbon	Volatile matter	Ash content	Moisture content	C	H	N	O	S	
<i>Anogeissue</i>	78.98	15.70	2.50	2.82	80.76	10.45	0.65	8.04	0.1	31.55
<i>Leiocarpa</i>										
<i>Cordia</i>	74.96	21.05	1.14	2.85	75.50	14.75	0.60	9.06	0.09	32.94
<i>Milleni</i>										

Table 6. Physicochemical Composition and Higher Heating Value (HHV) of Bio-oil Yields at 550°C

	Proximate analysis (wt%, dry basis)				Ultimate analysis (wt%, dry basis)					HHV (MJ/kg, dry basis)
	Fixed carbon	Volatile matter	Ash content	Moisture content	C	H	N	O	S	
<i>Anogeissue</i>	75.85	18.05	1.25	4.85	78.35	13.95	0.86	6.78	0.06	33.20
<i>Leiocarpa</i>										
<i>Cordia</i>	75.84	18.73	2.54	2.89	79.96	13.45	0.65	5.84	0.1	33.33
<i>Milleni</i>										

4. CONCLUSION

This paper provides a case study on the rapid pyrolysis of sawdust samples to create bio-oils in addition to a thorough review of waste-to-energy conversion techniques. The aim of study demonstrating the feasibility of generating sustainable bioenergy from biomass wastes. According to the results of the case study investigation, the maximum amount of bio-oil was generated at temperatures between 500°C and 550°C for rapid pyrolysis, and the energy content of the bio-oil generated falls between 31.55 and 33.33 MJ/kg. Bio-oil produces low levels of nitrogen and sulfur, making it a suitable fuel source for engineering applications, particularly internal combustion engines.

REFERENCES

- Aboelela, D., Saleh, H., Attia, A. M., Elhenawy, Y., Majozi, T., & Bassyouni, M. (2023). Recent advances in biomass pyrolysis processes for bioenergy production: optimization of operating conditions. *Sustainability*, 15(14), 11238. <https://doi.org/10.3390/su151411238>.
- Ahmadi, A, Esmaeilion, F, Esmaeilion, A, Ehyaei, M.A, Silveira, J.L. (2020). Benefits and limitations of waste-to-energy conversion in Iran. *Renewable Energy Research and Application*, 1(1), 27- 45. <https://doi.org/10.22044/rera.2019.8666.1007>.

- Altayib, K., Dincer, I. (2022). Design and evaluation of a new solar-biomass based energy system for a small sustainable residential community. *Journal of Cleaner Production*, 369, 133275. <https://doi.org/10.1016/j.jclepro.2022.133275>.
- Atofarati, E. O., Adogbeji, V. O., Enweremadu, C. C. (2025). Sustainable smart waste management solutions for rapidly urbanizing African cities. *Utilities Policy*, 95, 101961. Doi: 10.1016/j.jup.2025.101961.
- Awad, M.I., Makkawi, Y. & Hassan, N.M. (2024). Yield and energy modeling for biochar and bio-oil using pyrolysis temperature and biomass constituents. *ACS Omega*, 9(16), 1-14. <https://doi.org/10.1021/acsomega.4c01646>.
- Ayodele, T.R, Ogunjuyigbe, A. S. O., & Alao, M. A (2018) Economic and environmental assessment of electricity generation using biogas from organic fraction of municipal solid waste for the city of Ibadan, Nigeria, *Journal of Cleaner Production*, 203, 718 – 735. Doi: 10.1016/j.jclepro.2018.08.282.
- Cohen-Sacal, D, Khan, M.S, Broumand, M, Thomson, M.J, Ellis, N., Kirchen, P., (2023). Combustion and emission characterization of upgraded biomass fast pyrolysis oil in a swirl burner. *Applications in Energy and Combustion Science*, 13, 100118. <https://doi.org/10.1016/j.jaecs.2023.100118>.
- Dong, J, Tang, Y, Nzihou, A, Chi, Y, Weiss-Hortala, E, Ni, M., Zhou, Z. (2018). Comparison of waste-to-energy technologies of gasification and incineration using life cycle assessment: Case studies in Finland, France and China, *Journal of Cleaner Production*, 203, 287–300. <https://doi.org/10.1016/J.JCLEPRO.2018.08.139>.
- Echresh Zadeh, Z., Abdulkhani, A., & Saha, B. (2020). Characterization of fast pyrolysis bio-oil from hardwood and softwood lignin. *Energies*, 13(4), 887. <https://doi.org/10.3390/en13040887>.
- Kaza, S., Yao, L., Bhada-Tata, P., Van Woerden, F. (2025). *What a waste 2.0: Global snapshot of solid waste management to 2050*. World Bank. <https://www.worldbank.org>.
- Kumar, A., Singh, J., Baskar, C., Ramakrishna, S. (2015). Bioenergy: Biofuels Process Technology. In: Ravindra, P. (eds) *Advances in Bioprocess Technology*. Springer, Cham. https://doi.org/10.1007/978-3-319-17915-5_10.
- Oyebanji, J.A., Oyedepo, S.O., Oyebanji, O.T., Araoyinbo, A.O., Kilanko, O., Dirisu, J.O., Saleh, B. (2023). Experimental investigation of heating values and chemical compositions of selected fuel woods as bio-fuel sources in developing countries, *Fuel*, 340, 127600, 1–16. <https://doi.org/10.1016/j.fuel.2023.127600>.
- Oyedepo, S.O., Dunmade, I.S., Adekeye, T, Attabo, A.A., Olawole, O.C., Babalola, P.O., Oyebanji, J.A., Udo, M.O., Kilanko, O., Leramo, R.O. (2019). Bioenergy technology development in Nigeria – Pathway to sustainable energy development, *Int. J. Environment and Sustainable Development*, 18(2), 175 – 205. <https://doi.org/10.1504/IJESD.2019.099513>.
- Rana, R.(2026). Sustainable solid waste management for environmental safety and community well-being. *Journal of Environmental Engineering and Science*, 1-15. <https://doi.org/10.1680/jenes.25.00065>.
- Said, N., Alrowais, R., Abdel-Daiem, M. M., & Mostafa, N. A. (2025). Bio-waste to bioenergy: Critical assessment of sustainable energy supply chain in Egypt. *Resources*, 14(8), 131. <https://doi.org/10.3390/resources14080131>.
- Sidibe, S., Blin, J., Daho, T., Vaitilingom, G., Koulidiati, J. (2020). Comparative study of three ways of using *Jatropha curcas* vegetable oil in a direct injection diesel engine, *Scientific African*, 7, e00290. <https://doi.org/10.1016/j.sciaf.2020.e00290>.

Somarin, T.O., Adesola, S., Kolawole, A., (2017). State-level assessment of the waste-to-energy potential (via incineration) of municipal solid wastes in Nigeria, *Journal of Cleaner Production*, 164, 804 – 815. <https://doi.org/10.1016/j.jclepro.2017.06.228>.

UN DESA. (2026). United Nations Department of Economic and Social Affairs. *The Sustainable Development Goals report 2026*. New York. <https://unstats.un.org/sdgs/report/2026/The-Sustainable-Development-Goals-Report-2026.pdf>.

Ungureanu, N., Vlăduț, N.-V., Biriș, S.-Ș., Gheorghită, N.-E., & Ionescu, M. (2025). Biomass pyrolysis pathways for renewable energy and sustainable resource recovery: A critical review of processes, parameters, and product valorization. *Sustainability*, 17(17), 7806. <https://doi.org/10.3390/su17177806>.

Wang, J., Zhao, J., Deng, S., Sun, T., Du, Y., Li, K., Xu, Y. (2019). Integrated assessment for solar-assisted carbon capture and storage power plant by adopting resilience thinking on energy system. *J. Clean. Prod.*, 208, 1009-1021. <https://doi.org/10.1016/j.jclepro.2018.10.090>.

Wang, Y., Zhao, Y., & Hu, C. (2024). Slow pyrolysis of de-oiled rapeseed cake: Influence of pyrolysis parameters on the yield and characteristics of the liquid obtained. *Energies*, 17(3), 612. <https://doi.org/10.3390/en17030612>.