

From Urban Waste to Energy Through Performance Analysis of Pruning Residue Gasification in a Pilot-Scale plant

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According to the International Energy Agency (IEA), biomass use, and modern bioenergy must boost its share to about 15-20% of global energy needs by 2050 to meet the targets set by the Net Zero Emissions (NZE) roadmap (International Energy Agency, 2023). In 2020, biomass accounted for 12.6% of the global Total Final Energy Consumption (TFEC), with 5.7% coming from modern bioenergy production (*Market Developments*, 2021). To achieve the mentioned goals and also contribute directly to SDG 7 (IEA, IRENA, UN, 2022), which aims to ensure access to affordable, reliable, sustainable, and modern energy, biomass utilization serves as a renewable energy source that reduces dependence on fossil fuels and lowers greenhouse gas emissions. Through thermochemical and biological processes, it can be converted into biofuels, biogas, and electricity, supporting a cleaner and more resilient energy system. Colombia has made efforts to quantify the potential of biomass residues through the *Atlas of Biomass Energy Potential*. (Escalante et al., 2011) and making policies that foster sustainable resource utilization like the Action Plan for Sustainable Biomass Management (MinAmbiente & MinAgricultura, 2022). Regarding pruning waste, Bogotá accounted an average production of 599.64 tons/month in 2022 (Datos Abiertos Bogotá, 2023). Assuming a LHV of 6.83 MJ/ton (Escalante et al., 2011), the estimated energy potential is about 45.05 TJ/year. Considering that in 2024 the power consumption in the city was approximately 74 TJ/year (Rubio, 2024), pruning residues can supply nearly 60% of the energy demand. A well-known technology for the valorization of these wastes is gasification. A thermochemical process which uses biomass to produce synthesis gas that can be utilized for many purposes (Flori et al., 2024; Gallezot, 2012; Nikolaidis & Poullikkas, 2017; Pereira et al., 2012; Tijmensen et al., 2002). Globally, the main commercial technologies include 75% downdraft gasifiers, followed by 20% fluidized bed technologies, and 5% from other designs (Rey et al., 2024). The success of each of these technologies is strongly linked to the biomass utilized and its physico-chemical characteristics (Chanthakett et al., 2021). In this context, the aim of this work is to evaluate the energy performance of a downdraft gasification process of Bogotá's pruning waste at pilot scale. To address this problem a systematic methodology was proposed to allow pretreatment of pruning residues in order to guarantee the best performance of the gasification system. Subsequently, the energy performance of the gasification system was evaluated by quantifying the products and by-products generated in the process.

The biomass used comes from tree pruning activities carried out throughout the city by ENEL COLOMBIA. There are an average of 260 different species in Bogotá. (*Jardín Botánico de Bogotá José Celestino Mutis*, 2025), Therefore, the variability in the origin makes a comprehensive characterization by species impossible. A sieving showed that the particle size distribution (PSD) includes sizes that do not meet the requirements of the gasification system (10-40 mm, recommended by manufacturer). Thus, two kinds of residues can be described as follows: Trunks, branches and stems, which have ideal characteristics for the downstream gasification process (OPT), and fines residues, whose particle size and bulk density is too low and not suitable for the performance of the equipment. The ratio of optimum size residues to fines was approximately 1:3. To overcome this hurdle, fine residues were pelletized to a particle size in the range of OPT. The moisture of raw fines varied from 10 to 15 % (w.b.) and the process was conducted at ambient temperature (Stolarski et al., 2022). A characterization of pellets was performed including proximate and ultimate analysis, bulk density and Lower Heating Value determination (LHV, MJ/kg). Then, the energy performance of the system was evaluated using 4 feedstock configurations and treatments, namely: pruning residues from screened trunks and stems with optimal size (OPT100), a ratio of 50% OPT mixed with 50% pelletized fines (OPT50-PELLET50), fine pellets only (PELLET100), and finally, raw residues as received (RAW). Two different equivalence ratios (ER = 0.3 and 0.4) were tested for all treatments. Table 1 summarizes the proximate analysis of the different feedstocks used in this study.

Table 1. Proximate analysis of different biomasses used in this study on a dry basis.

Proximate analysis (%)	RAW	OPT	PELLET
FC	16.37	20.17	18.27
VM	82.3	62.89	72.55
Ash	1.33	17.03	9.18

The pilot scale plant used was the Power Pallet GEK 20 kW downdraft gasifier (PP20) with an average biomass consumption of 1.2 kg/kWh. The syngas composition as well as LHV was measured with the “Click! Gas Analyzer”. Biomass consumption was measured using an industrial scale including ABS digital display and data storage. The ER was controlled using an arrangement consisting of a Mass Air Flow meter and an acceleration body. Two type-K thermocouples were used to measure temperature in oxidation and reduction zones. The gravimetric syngas tar composition was measured adapting the European standard CEN/TS 15439:2006 “tar protocol” to the gasification setup. The average values obtained through all the tests are summarized in table 2.

Table 2. Average values of gasification process for all tests.

Feature	OPT100	OPT50-PELLET50	PELLET100	RAW
Biomass flow rate (kg/h)	15.0	16.0	17.0	9.5
Syngas flow rate (m ³ /h)	22.3	18.7	17.8	12.0
Gravimetric tar composition (mg/m ³)	35.0	41.1	56.0	47.3
LHV (MJ/m ³)	5.5	5.2	4.9	4.3
Cold Gas Efficiency (%)	0.42	0.31	0.26	0.28

In addition to the quantitative operating variables mentioned, qualitative conditions inherent to the process were tested. Fine particles can cause blockages or unwanted accumulations in continuous operation, especially into the drying bucket which feeds the reactor and also causing bridging at the feeding hopper. The RAW test showed some operational problems due to small size and low density of the material, evidencing problems in the bed formation of the reduction zone in the gasifier *i.e.* major pressure drop was verified for this test. This result was consequent with other studies in which the use of residues was tested in a downdraft gasifier (Biagini et al., 2015). Also, the biomass flowrate was higher for the RAW test, this condition is attributable to the lower LHV of the raw material due to its lower bulk density. However, these negative conditions did not prevent the gasification system from operating under relatively normal conditions. This coupled with the fact that untreated biomass makes the overall process less extensive in energy use, allows establishing the possibility of pretreatment alternatives that do not involve pelletization, as a more thorough screening that will potentially be evaluated in further studies. For all the rest of the tests, no operational hurdles were evidenced.

Systematic methodology was established for the pretreatment of pruning residues, ensuring that the biomass used in the gasification process meets the size and density requirements for optimal system performance. This pretreatment allowed improving the efficiency of the process by minimizing variations in the gasifier feed and maximizing the energy conversion of the residues. Among the treatments evaluated, OPT100 proved to be the most efficient option in a long period operation. This treatment allowed greater stability in combustion zone in the gasifier, optimizing the production of synthesis gas and improving the energy use of pruning residues. On the other hand, it was shown that an adequate balance of size and density of the material favors the efficiency of the gasifier, reducing the generation of tars and improving the quality of the gas produced. The gasification of urban pruning residues represents a viable and sustainable alternative for the energy use of biomass in Bogotá. The use of this technology can contribute significantly to the transition towards renewable energies and the efficient management of urban waste. In addition, its implementation could strengthen circular economy strategies, promoting the valorization of residual biomass in the generation of clean energy.

References:

- Biagini, E., Barontini, F., & Tognotti, L. (2015). Gasification of agricultural residues in a demonstrative plant: Vine pruning and rice husks. *Bioresource Technology*, 194, 36–42. <https://doi.org/10.1016/j.biortech.2015.07.016>
- Chanthakett, A., Arif, M. T., Khan, M. M. K., & Oo, A. M. T. (2021). Performance assessment of gasification reactors for sustainable management of municipal solid waste. *Journal of Environmental Management*, 291, 112661. <https://doi.org/10.1016/j.jenvman.2021.112661>
- Datos Abiertos Bogotá. (n.d.). Retrieved February 21, 2023, from https://datosabiertos.bogota.gov.co/dataset?q=rbl+2022&ext_bbox=&ext_prev_extent=
- Escalante, H., Orduz, J., Zapata, H., Cardona, M., & Duarte, M. (2011). Atlas del potencial energético de la biomasa residual en Colombia. In *Colombia: Ministerio de Minas y Energía*.
- Flori, G., Frigo, S., Barontini, F., Gabbrielli, R., & Sica, P. (2024). Experimental assessment of oxy-CO₂ gasification strategy with woody biomass. *Renewable Energy*, 228, 120593. <https://doi.org/10.1016/J.RENENE.2024.120593>
- Gallezot, P. (2012). Conversion of biomass to selected chemical products. *Chemical Society Reviews*, 41(4), 1538–1558. <https://doi.org/10.1039/C1CS15147A>
- IEA, IRENA, UN, W. B. and W. (2022). *Tracking SDG 7 | The energy progress report 2022*. <https://trackingsdg7.esmap.org/downloads>
- International Energy Agency. (2023). *IEA bioenergy annual report 2023*. <https://www.ieabioenergy.com/blog/publications/iea-bioenergy-annual-report-2023/>
- Jardín Botánico de Bogotá José Celestino Mutis. (2025). <https://Sigau.Jbb.Gov.Co/SigauJBB/VisorPublico/VisorPublico>.
- Market Developments. (2021). https://www.ren21.net/GSR-2023/Topics/Market_developments/.
- MinAmbiente, & MinAgricultura. (2022). *Plan de Acción para la Gestión Sostenible de la Biomasa Residual*. 1–22. chrome-extension://efaidnbmninnbpcjpcglclefindmkaj/<https://economy.circular.minambiente.gov.co/wp-content/uploads/2022/04/Plan-de-Accion-para-la-Gestion-Sostenible-de-la-Biomasa-Residual.pdf>
- Nikolaidis, P., & Poullikkas, A. (2017). A comparative overview of hydrogen production processes. *Renewable and Sustainable Energy Reviews*, 67, 597–611. <https://doi.org/10.1016/J.RSER.2016.09.044>
- Pereira, E. G., Da Silva, J. N., De Oliveira, J. L., & Machado, C. S. (2012). Sustainable energy: A review of gasification technologies. *Renewable and Sustainable Energy Reviews*, 16(7), 4753–4762. <https://doi.org/10.1016/j.rser.2012.04.023>
- Rey, J. R. C., Longo, A., Rijo, B., Pedrero, C. M., Tarelho, L. A. C., Brito, P. S. D., & Nobre, C. (2024). A review of cleaning technologies for biomass-derived syngas. *Fuel*, 377, 132776. <https://doi.org/10.1016/J.FUEL.2024.132776>
- Rubio, L. Q. (2024). *Demanda de energía subió 2,3 % en 2024: detalles de las regiones y sectores donde hubo más consumo*. <https://www.eltiempo.com/Economia/Sectores/Demanda-de-Energia-Subio-2-3-En-2024-Detalles-de-Las-Regiones-y-Sectores-Donde-Hubo-Mas-Consumo-3420039>.
- Stolarski, M. J., Stachowicz, P., & Dudziec, P. (2022). Wood pellet quality depending on dendromass species. *Renewable Energy*, 199, 498–508. <https://doi.org/10.1016/j.renene.2022.08.015>
- Tijmensen, M. J. A., Faaij, A. P. C., Hamelinck, C. N., & Van Hardeveld, M. R. M. (2002). Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification. *Biomass and Bioenergy*, 23(2), 129–152. [https://doi.org/10.1016/S0961-9534\(02\)00037-5](https://doi.org/10.1016/S0961-9534(02)00037-5)