TECHNICAL BRIEF

Designing Carbonisation Solutions for Sustainable Livelihoods

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CGIAR Multifunctional Landscapes Program

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1. Context

Access to clean, affordable, and reliable energy remains a persistent and multidimensional challenge across rural and fragile landscapes in Sub-Saharan Africa. According to the International Energy Agency (IEA, 2022), nearly 600 million people in the region lack access to electricity, while over 900 million still rely on traditional biomass, such as firewood and charcoal, for cooking and heating. This heavy dependence on unsustainable fuel sources is linked to widespread deforestation and degradation of natural ecosystems.

The health impacts of energy poverty are profound. Fossil fuel and incomplete biomass combustion contribute significantly to hazardous air pollution, which disproportionately affects children's cognitive, respiratory, and physical development, particularly in poor and vulnerable communities (Perera, 2017). Young children face an increased risk of respiratory illnesses, developmental delays, and long-term chronic diseases due to their biological susceptibility and higher per-body-weight exposure to pollutants. Moreover, indoor air pollution from traditional cook stoves remains one of the top risk factors for premature death in low-income regions. These cumulative burdens intersect with environmental degradation, such as soil erosion, creating a feedback loop where degraded ecosystems further limit energy options and exacerbate poverty.

In humanitarian and displacement settings, where infrastructure is often strained or nonexistent, the fuel gap is even more pronounced (GPA, 2022; FAO/UNHCR, 2016), heightening the vulnerability of displaced populations, particularly women and children, and increasing their dependence on emergency relief mechanisms. An estimated 94% of displaced people in camps lack access to electricity, and over 80% still rely on traditional biomass such as firewood and charcoal for cooking, often collected manually under hazardous conditions (GPA, 2022). This reliance contributes to forest degradation, environmental stress, and conflict with host communities, especially in protracted settings like Kakuma (Kenya), Melijo (South Sudan), and West Nile (Uganda), where both refugees and host populations compete for scarce biomass resources (FAO & Practical Action, 2020).

Addressing these issues requires the deployment of decentralized, low cost, low-emission energy options that are safe and adapted to complex operating environments. It can ensure these populations do not remain trapped in cycles of energy insecurity, environmental degradation, and chronic vulnerability.

While the energy crisis in rural landscapes remains acute, these same environments possess considerable untapped, underused agricultural and organic residues. Agricultural by-products, for example maize stalks, rice husks, coconut shells, sugarcane bagasse), cow dung, and even invasive plant species present viable raw materials for conversion into clean and efficient fuel products. Carbonization technologies, including slow pyrolysis and torrefaction, offer a promising pathway to transform these residues into briquettes or biochar, which can be used as low-emission cooking fuels. When tailored to local conditions and integrated into community-based energy strategies, these systems can help decentralize fuel production, reduce forest pressure, and support sustainable livelihoods in resource-constrained settings. Moreover, the co-benefits extend beyond energy as biochar can be used to rehabilitate degraded soils, improve agricultural productivity, and contribute to long-term carbon storage (Lehmann & Joseph, 2015). In addition, decentralized carbonization systems, when designed for local use and operated safely, can reduce deforestation, create income opportunities through briquette micro-enterprises, enhance food and energy security, and promote climate resilience through soil enrichment and carbon sequestration (Njenga et al., 2014).

However, the adoption and scaling of carbonization technologies face notable challenges that must be addressed to realize their full potential. A significant barrier is the high initial cost of acquiring efficient carbonization equipment, especially for smallholder users or women-led enterprises in low-income settings. While low-cost, rudimentary kilns are plausible, they often produce inconsistent products and pose safety or efficiency concerns. On the other hand, more advanced kilns, batch-fed retorts, or mechanized production units remain financially out of reach for many communities without external support or financing mechanisms. Beyond affordability, technical capacity constraints further hinder equipment uptake. In many rural or humanitarian contexts, there is limited local expertise in the fabrication, installation, and maintenance of carbonization systems. This leads to the premature abandonment of promising innovations. The absence of trained operators and the lack of standardized manuals or performance guidelines also contribute to inefficient use, low product quality, and operational challenges, especially in remote or conflict-affected areas.

These challenges highlight the need for clear design guidelines and locally adaptable technology models that inform the development of cost-effective, context-appropriate carbonization systems. This report summarizes the design and development of a low-cost carbonization system intended to support resilience and livelihoods in resource-constrained environments. Drawing from field experience, user feedback, and technical evaluations, the design prioritizes affordability, durability, and ease of use, making it suitable for decentralized deployment in rural development and humanitarian response settings. The report also reflects on the iterative co-design process to ensure alignment with user needs, material availability, and operational capacity.

Against this backdrop, the project, as part of the CGIAR Multifunctional Landscapesis, set out to design and develop a context-appropriate, low-cost, low-emission carbonization system that could be safely operated and scaled for broader use across rural and peri-urban communities to improve product consistency and reduce health and environmental risks. The design of the carbonization unit was guided by three (3) core principles: affordability, adaptability, and operational simplicity, shaped through direct engagement with end users, including small-scale producers, women-led cooperatives, and youth entrepreneurs. The overarching goal is to advance the innovation beyond a single pilot toward scalable, community-driven solutions. In the process, build local capacities and skills, foster income generation, and strengthen sustainable value-recovery chains from waste resources in low-income settings.

A woman in Kisumu, Kenya spreading carbonised briquettes on drying racks (Photo Credit: STIPA)


Photo Credit: James Kinyua Gitau

2. Use Case: Woman-Led Briquette Enterprise in Kisumu, Kenya

In the informal settlement of Manyatta, Kisumu County, Kenya, fuel insecurity and limited economic opportunities have long challenged low-income households, particularly women and persons with disabilities. Many residents engaged in small-scale briquette production using charcoal dust, clay as a binder, and water. However, these efforts were constrained by manual methods, a lack of technical expertise, and limited access to equipment and markets, resulting in low-quality outputs with high breakages and minimal financial return.

With support from the CGIAR Nature-Positive Initiative and the CGIAR Gender Impact Platform, over 30 women were supported with targeted training in briquette production, carbonization techniques, and business management (Somorin et al. 2023). Building on this foundation, they formed the Tich En Tich Makwangla Women's Group, a cooperative dedicated to improving livelihoods through clean cooking energy entrepreneurship. The intervention strengthened both technical and organizational capacities. Participants were introduced to improved carbonization methods tailored to locally available biomass residues such as agro-industrial waste, cow dung, and pruning from fences and trees. In combination with semi-mechanized briquetting equipment, these enhancements led to a substantial increase in output, from approximately 360 pieces to over 1,300 pieces of briquettes per day, while significantly improving product quality, price and market competitiveness. Training sessions were complemented by the provision of two briquette-making machines (12 piston presses each), a crusher, and a mixer, allowing the group to mechanize key parts of the production process and construct a production facility.

In parallel, governance and financial skills were strengthened through the adoption of a "table banking" model, enabling members to pool savings and reinvest in business expansion. Feedback from these groups during a follow-up workshop highlighted recurring challenges with traditional carbonization systems (Box 1), such as inconsistent product quality and yield, especially when using biomass feedstock such as rice husks. They described both the open half-drum kiln and the full-drum kiln as inefficient and unsafe.

The traditional kilns lacked air-flow control mechanisms, resulting in either incomplete carbonization or excessive burning out of biomass. Additionally, poor design integration of exhaust and smoke management features led to high levels of particulate emissions, posing health risks to operators and contributing to local air pollution. Concerns were also raised regarding occupational health and safety, especially with manual kilns that require frequent moving, lifting, and direct handling of biomass during loading and unloading. Existing designs were also largely immobile and unsuitable for cooperative ownership or rotational use, restricting opportunities for shared access across production sites. In addition to technical and safety challenges, cost-related barriers hinder adoption and sustainability. Traditional kilns may seem low-cost at the outset, but their short-term lifespan and inefficient fuel conversion result in high operational costs over time. Conversely, advanced carbonizers are often prohibitively expensive for community-level users, with prices ranging from USD 1250 to 8400, depending on size and features, excluding maintenance and repair.

Tich En Tich Makwangla Women's Group in a practical biomass briquette production demonstration session (Photo Credit: Edwin Okoth)

Box 1: User Feedback on Traditional Carbonization Systems

The **open half-drum kiln (Figure 1)** requires continuous loading and tending to prevent the biomass from burning completely to ash due to the lack of oxygen control. Operators are exposed to high heat and heavy smoke, and risk burns from naked flames and the hot drum. Continuous turning of biomass during carbonization is physically demanding and time-consuming. The biomass-to-char conversion efficiency is typically below 20%.

Figure 1: The Open Half-Drum Kiln: a) Women carbonizing in a half drum kiln and b) char produced. Photo Credit: James Kinyua Gitau

While the **full-drum kiln** (**Figure 2**) does not require continuous turning, determining the optimal moment to cut off the oxygen supply is difficult. Participants reported frequent under- or over-carbonization, leading either to unconverted biomass or to ash formation, which further lowers conversion efficiency. The drum's outer surface becomes extremely hot and is not insulated, posing a risk of accidental burns. Furthermore, the system is ineffective for carbonizing certain feedstock such as rice husk, sawdust, and sugarcane bagasse. More so, the participants noted that smoke released through the full-drum kiln's chimney is not clean, representing a potential environmental and health concern for users and surrounding communities.

Figure 2: The full-drum kiln: a) loaded with biomass, b) during carbonization and c) char produced. Photo Credit: James Kinyua Gitau

3. Design Considerations

The carbonization unit was designed with a focus on seven interrelated objectives to ensure relevance, performance, and user acceptance in low-resource settings. Firstly, low-cost fabrication was prioritized through the use of locally available and affordable materials, including mild steel (alternatively re-purposed oil drums), enabling communities and local artisans to build and repair units without dependency on imported parts. Secondly, the system is designed as a mobile unit, allowing for ease of transport and on-site assembly, and is ideal for cooperative or mobile applications. Thirdly, the system was engineered for multi-feedstock compatibility, allowing users to carbonize a wide variety of regionally available biomass residues. Fourthly, the system employs a batch-fed operation, simplifying user engagement by eliminating the need for continuous supervision, fuel feeding, or advanced control systems. Fifthly, emissions reduction is built into the design through integrated airflow control, afterburner and baffle systems, which can significantly reduce visible smoke and particulate release, improving both environmental and public health outcomes. Sixthly, user safety is addressed through surface insulation, safe access points, and heat shielding, minimizing the risk of burns and improving the working conditions for vulnerable users. Finally, units are designed in modular form to enhance scalability and ease of maintenance. **Table 1** provides a summary of the key design objectives and the corresponding features integrated into the carbonization unit.

Table 1. Design Objectives and Key Features of the Carbonisation Unit

Design Objective	Integrated Feature
Low-cost equipment	Use of locally sourced steel and materials, minimal use of materials, ease of maintenance and repair.
Modular structure	Modular components that can be disassembled for easy transport, on-site assembly, repair and part replacements .
Multi-feedstock compatibility	The system can process various types of crop residues, including coconut shells,maize cobs, and rice husks.
Batch-fed, easy-to-use operation	Simple loading and unloading process with no need for continuous fuel input, reducing labour demand and user complexity; No continuous tending required: operator only loads, ignites, and collects char at the end of the batch.
Low emissions	Airflow control, flue gas afterburn and heat loss prevention to improve energy efficiency and minimise smoke.
User safety	Insulated surfaces, sealed chambers, and a heat shield to reduce burn risk
Scaling potential	Standardised modular units that can be replicated across communities and adapted to varying production scales; open-source technical designs.

4. Design Specification

The carbonization unit is approximately 1.37 meters in height, 1.10 meters in length, and 0.85 meters in width. It is designed to operate as a batch-fed, retort-style system engineered for the controlled pyrolysis of biomass under low-oxygen conditions. Its modular design allows for ease of assembly, mobility, and maintenance. It also allows for installation in limited spaces, manual repositioning, and ease of integration into existing briquetting or agro-processing operations.

The system (as shown in Figure 3) primarily comprises three sub-assemblies:

i) Carbonisation Chamber: This is a sealed steel drum that holds the biomass feedstock (e.g., maize cobs). The drum is enclosed within a double-layer heat-exchange chamber, allowing indirect heating through hot combustion gases. This structure ensures a consistent pyrolysis temperature (typically between 400–600°C) while minimising oxygen ingress and direct flame exposure conditions that are essential for producing high-quality char.

ii) Combustion Furnace: Located beneath the carbonisation chamber, this insulated, brick-lined furnace generates the thermal energy needed for pyrolysis. It is fired using biomass residues. It includes a damper-regulated iron door that allows users to control airflow and combustion rate, thereby sustaining optimal conditions without over-burning the feedstock.

iii) Emissions Reduction Unit: As biomass undergoes thermal decomposition, volatile gases are released. These are partially captured through a gas pipe assembly and redirected to the furnace for secondary combustion, enhancing thermal efficiency and reducing external fuel requirements. Valves are installed for releasing excess gases and collecting condensable by-products, such as wood vinegar or tar, which may have further agricultural applications.

Additional features include a flue gas outlet, afterburner attachment to improve combustion efficiency and reduce visible smoke, and protective insulation and heat shielding for operator safety. The kiln is mounted on wheels with stabilizing legs, allowing easy relocation and safe use on uneven terrain. Construction materials, primarily mild steel and basic insulation, are selected for affordability, durability, and local availability, with all major joints designed for bolt-based assembly and replacement.

The system is tailored to operate on a wide variety of biomass inputs, making it adaptable to diverse local feedstock such as maize cobs, rice husks, coconut shells, twigs, pruning and charcoal fines. All these integrated approaches and improved features support energy efficiency and emissions control, and improve safety and ease of use, especially compared to traditional earth or pit kilns. It addresses common technical and environmental drawbacks such as inconsistent yield, uncontrolled combustion, and operator exposure to smoke and extreme heat, thereby offering a reliable and scalable alternative for decentralized briquette or biochar production.

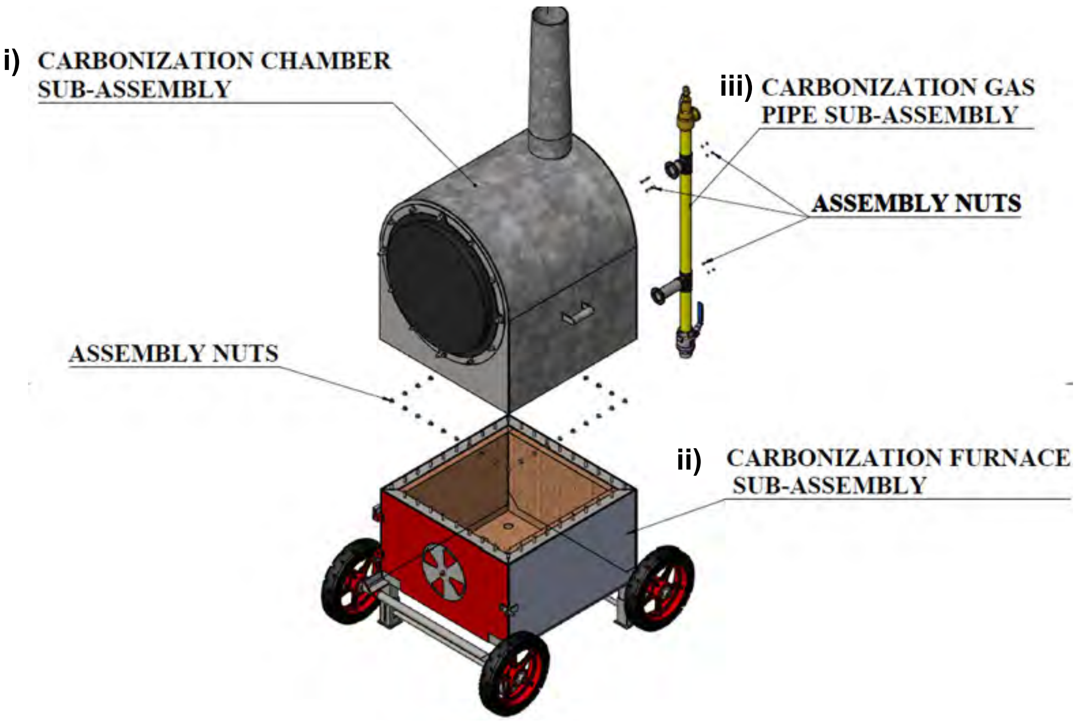

Figure 3: Modular design of the carbonisation unit showing three detachable subassemblies: (1) carbonisation chamber, (2) combustion furnace, and (3) gas recovery pipe assembly. The components are connected using standard assembly nuts, allowing for easy transport, on-site installation, maintenance, and scalability.

5. Performance Evaluation

Initial field assessments were conducted to evaluate the functionality, efficiency, and usability of the carbonization unit under real-world conditions.

The following dimensions were examined:

i. temperature profiles during carbonization,

ii. char yield rates as a percentage of initial feedstock weight (conversion efficiency),

iii. fuel-to-char conversion ratios,

iv. carbon content and calorific value of the final product and

v. indicative estimates of capital investment and operational costs.

This section summarizes the results of these assessments, drawing on pilot and preliminary tests, user feedback, and field-based observations to highlight the strengths, limitations, and areas for further improvement.

5.1 Feedstock Composition and Characteristics

The carbonization unit was tested with three representative lignocellulosic feedstock wood logs, palm kernel shells (PKS), and sawdust, whose chemical and thermal properties influence char yield, energy value, and emissions. All feedstock were collected locally from Covenant University (Ota, Nigeria) and its surrounding areas, including nearby sawmills. **Table 2** presents key proximate, ultimate, and lignocellulosic data, drawing on the detailed assessments provided.

The comparison of feedstock draws on typical literature values rather than site-specific measurements, so the data should be interpreted as indicative benchmarks. Even within a single feedstock type, properties can vary with wastes and process conditions. Thermochemically, all three biomass feedstock, wood logs, PKS and sawdust, generally exhibit higher volatile matter and lower sulfur and ash contents than coal (Tomczyk et al., 2020). These traits make them cleaner, more easily ignitable fuels, though they typically have lower fixed carbon and energy density than coal. Each feedstock offers distinct advantages: well-dried prune/wood log provides stable quality and consistent performance (Oyebanji et al., 2023). PKS, with its dense, lignin-rich structure, delivers high calorific value and robust energy output (Omotosho et al., 2025), and sawdust, with its fine, porous texture, carbonises rapidly, though overly powdery material can impede airflow during pyrolysis (Khater et al., 2024). Wood logs usually show the widest moisture range, so inadequate pre-drying can reduce char yield and overall efficiency (Oyebanji et al., 2023).

5.2 Operating Conditions

The designed carbonization machine was tested under ambient conditions at the Machine Workshop of the Department of Mechanical Engineering Covenant University, Ota, Nigeria, over a five-day period using locally collected feedstock. Wood logs were used on the first three days; during the first two days, leakages from the front of the drum were observed and subsequently rectified on the third day. To monitor the pyrolysis environment, six sets of K-type thermocouples were installed and linked to a multi-channel digital thermometer:

- K-type thermocouple (-50–1300°C) LED 6802 II digital thermometer
- K-type thermocouple (0–1250 °C) with 1/8” NPT exhaust gas temperature probe connector
- TASI TA612C 4-channel thermocouple K/J type thermocouple

These sensors measured temperature at the front and back of the drum, inside the carbonization chamber, within the furnace, and at the exhaust of the prototype **(Figure 4)**.

Figure 4: Experimental setup of the prototype

Table 2: Typical proximate, ultimate and lignocellulosic characteristics of the three biomass feedstocks used for pilot testing, wood logs, palm kernel shells and sawdust, compared with bituminous coal (benchmark). Values are expressed on a wet basis (wb) for moisture and on a dry basis (db) for other parameters.

Feedstock	Particle Size/ Dimension	Moisture wt.% (wb)	Volatile Matter	Fixed Carbon wt. % dry basis (db)	Ash	Carbon	Hydrogen wt. % dry basis (db)	Oxygen	Cellulose	Hemicellulose Lignin wt. % dry basis (db)	Lignin	HHV MJ kg^{-1}
Wood log	Logs: 10–15 cm length; 4–8 cm thickness	5–15	70–85	12–20	0.2–2	45–50	5–6	40–45	40–50	20–30	20–30	18–20
Palm Kernel Shells	20–30 mm	5–12	65–75	15–20	2–5	45–50	5–7	40–45	25–35	20–25	45–55	17–20
Sawdust	~3.5 mm	5–12	70–80	15–20	0.2–3	45–52	5–7	40–45	40–45	25–35	20–30	16–19
Bituminous Coal*	-	2–10	20–35	50–60	5–15	70–80	4–5	10–15	–	–	–	25–30

wt. % is weight percentage; db is dry basis

5.3 Performance Evaluation Outcomes

The five-day pilot trials confirmed that the modular carbonization unit can effectively convert different locally available biomass resources into valuable biochar/energy products under field conditions. The first three days focused on wood logs. During the initial two days, small leakages at the front cover of the drum allowed excess air into the chamber, slowing the process and extending the retention times to roughly 260 minutes and 210 minutes, respectively. After the leaks were sealed with fire-resistant material, the third day showed a much shorter conversion time of about 143 minutes, illustrating how kiln integrity directly influences thermal efficiency and carbonization speed. PKS and sawdust, tested on Days 4 and 5 when the unit was fully sealed, required 148 minutes min and 165 minutes, respectively, with ambient temperatures close to 40 °C. These retention periods demonstrate that the system can handle different feedstock types once proper sealing and airflow control are maintained.

5.3.1 Temperature Profile

The pilot runs showed a consistent thermal behavior across all feedstock once the kiln was sealed correctly (Figure 5a-d). During the firewood trials, after leaks at the drum front were corrected, burn times shortened from about three and a half hours to a little over two hours and peak temperatures rose markedly. On the second day, the front of the drum reached roughly 481 K (208 °C), climbing to about 615 K (342 °C) on the third day, while the back of the drum increased from 429 K (156 °C) to about 559 K (286 °C). Within the carbonization chamber, temperatures rose from about 710 K (437 °C) to about 773 K (500 °C), the furnace climbed from about 975 K (702 °C) to 1040 K (767 °C), and the exhaust held steady near 718 K (445 °C).

When palm kernel shells were processed, the front and back of the drum reached around 585 K (312 °C) and 562 K (289 °C), respectively, the chamber about 676 K (403 °C), the furnace roughly 954 K (681 °C) and the exhaust close to 672 K (399 °C), with a burn time of about 150 minutes. Sawdust carbonization produced similar patterns: approximately 574 K (301 °C) at the front of the drum, 449 K (176 °C) at the back, 712 K (439 °C) in the chamber, 946 K (673 °C) in the furnace and 644 K (371 °C) at the exhaust, with a burn time of over three hours.

Overall, the furnace consistently maintained temperatures in the range of about 943–1043 K (670–770 °C) sufficient to sustain pyrolysis and generate biochar and bio-oil, while the other monitoring points demonstrated stable gradients. These results confirm that, once leakage problems were addressed, the unit achieved the high-temperature, low-oxygen environment required for efficient carbonization across all tested feedstock. The appearance of condensible fractions, bio-oil and unmeasured biogas, was observed to coincide with furnace temperatures of approximately 673–723 K (400–450 °C) during the wood-log runs and about 623–673 K (350–400 °C) during the palm kernel shell tests. These thresholds match typical pyrolysis ranges reported in the literature and indicate the point at which significant secondary vapor condensation begins.

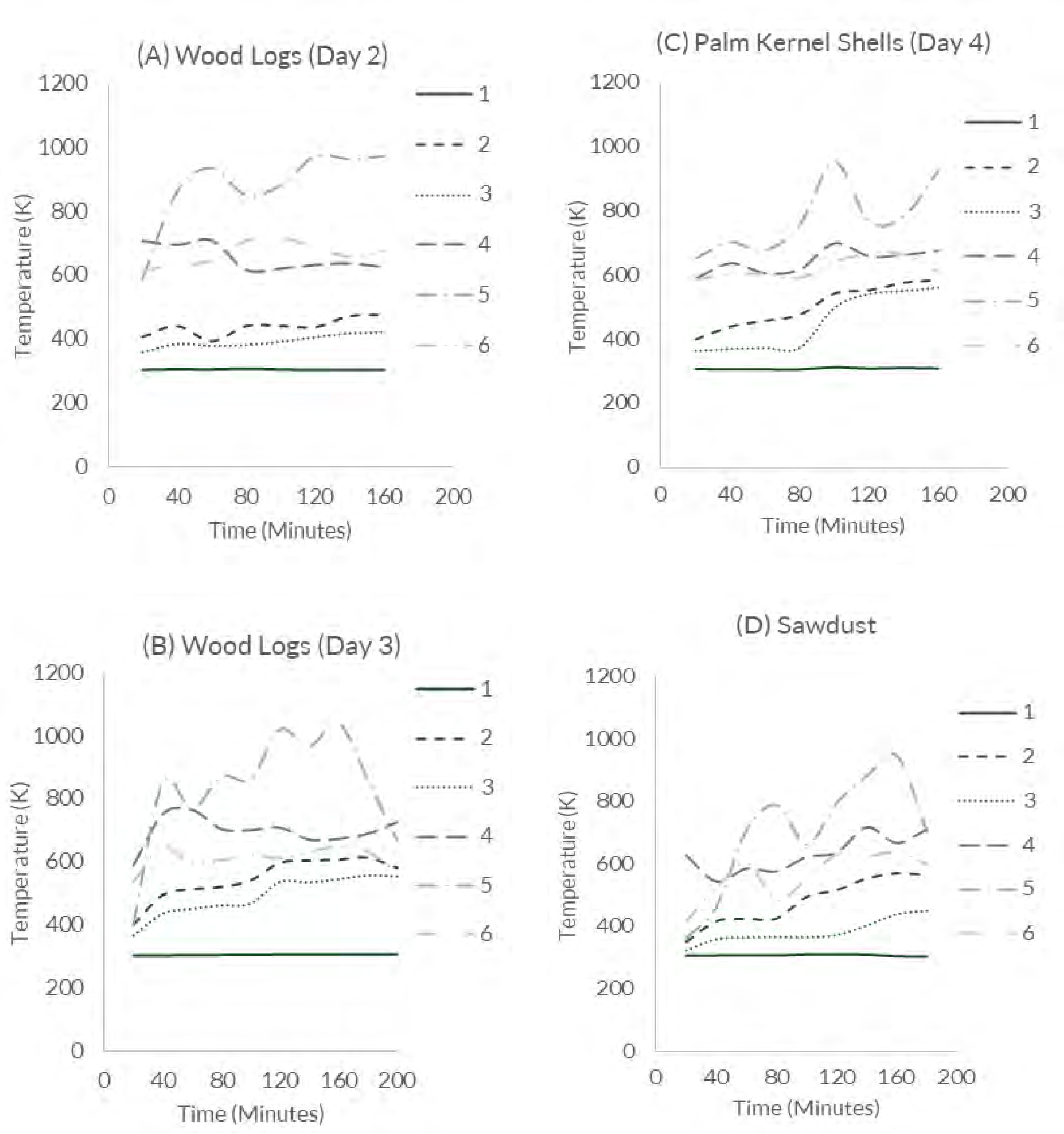

Figure 5a-d: Temperature profiles at six monitoring points: front and back of the drum, carbonization chamber, furnace (kiln), exhaust and ambient air, during pilot tests with (A) wood logs (Day 2); (B) wood logs (Day 3); (C) palm kernel shells (Day 4); and (D) sawdust (Day 5). 1 – TAMB: Ambient temperature; 2 – TFD: Temperature at the front of the drum; 3 – TBD: Temperature at the back of the drum; 4 – TCC: Temperature of the carbonization chamber; 5 – TFCE: Temperature of the furnace (kiln); 6 –TEXH: Temperature of the exhaust.

5.3.2 Bio-products and yields

Figures 6–8 collectively capture key visual highlights of the pilot tests: Figure 5 shows the carbonized form of the wood logs as well as biochar from palm kernel shells and sawdust; Figure 6 presents the corresponding bio-oil samples; and Figure 7 contrasts the kiln before and after the front-drum leakage was sealed, demonstrating the improvement in operational integrity.

Across all feedstock, the unit consistently produced biochar and measurable volumes of bio-oil, while syngas generation was observed but not quantified. Prune/wood log delivered the highest total mass of biochar (about 44–52 kg depending on the day) and the broadest range of bio-oil volumes (120–330 ml) as kiln operation stabilized. PKS produced about 19.8 kg of biochar and 260 ml of bio-oil, while sawdust yielded 16.4 kg of biochar and 245 ml of bio-oil. Moisture reductions corresponded closely with feedstock mass and ranged from roughly 12 kg for sawdust to over 20 kg for wood logs.

Considering the initial feedstock masses, the approximate biochar yields were highest for wood logs, reaching about 72–75%, followed by 57% for sawdust and about 55% for PKS (Table 3). Corresponding bio-oil outputs were about 120–330 ml for wood logs, roughly 260 ml for PKS, and 245 ml for sawdust. These figures highlight that, while all three feedstock achieved good conversion efficiencies, wood logs provided the most significant proportion of char relative to input mass and the broadest range of condensible oil production.

The pilot results reveal several practical lessons:

(i) The machine's ability to maintain low-oxygen, high-temperature conditions, monitored by the multi-channel K-type thermocouples, enabled steady pyrolysis once leaks were eliminated.

(ii) Feedstock properties, especially particle size and bulk density, influenced both heating rates and uniformity of conversion: larger prune/wood logs required careful size selection to avoid incomplete carbonization, while fine sawdust encouraged rapid heat penetration but needed controlled packing to maintain airflow.

(iii) Heat distribution inside the drum was not perfectly even; material close to the drum wall carbonized faster than the central core, suggesting that a simple rotating or mixing mechanism would help to achieve more uniform char quality and avoid "over-cooked" and "under-cooked" zones.

These field observations demonstrate that the carbonization unit can achieve reliable biochar and bio-oil yields across a range of common biomass residues when operated with basic maintenance and feedstock preparation. With minor engineering refinements, particularly improved internal mixing and consistent feed sizing, the unit offers a practical, low-emission pathway for decentralized bioenergy production in rural and peri-urban areas.

Table 3: Product yields during five-day pilot testing of the carbonisation unit using locally sourced biomass feedstocks.

Day of Experiment	Feedstock	Ambient Temperature (°C)	Retention Time	Amount of initial feedstock (kg)	Biochar Produced (kg)	Biochar Yield	Bio-oil Produced (ml)
Day 1	Prune/wood log	32.0	4 h 20 min	72.4	52.0	72%	200
Day 2	Prune/wood log	36.7	3 h 30 min	60.0	45.0	75%	330
Day 3	Prune/wood log	35.9	2 h 23 min	58.8	43.9	75%	120
Day 4	Palm kernel shells	40.1	2 h 28 min	36.0	19.8	55%	260
Day 5	Sawdust	40.3	2 h 45 min	28.6	16.4	57%	245

Figure 6: Biochar yield from various feedstocks: a) Charred wood logs, b) bio-char produced from palm kernel shells and c) bio-char from sawdust.

Figure 7: Bio-oil from various feedstocks: a) pruned wood (day 1), b) pruned wood (day 2), c) pruned wood (day 3), d) palm kernel shells, and e) sawdust.

Figure 8: Troubleshooting the carbonisation equipment: a) leakages at the front cover and b) no leakages after a fire-resistant material is installed.

6. User Feedback on New Carbonisation System

The women cooperative group in Kenya was introduced to the new carbonizer design through a presentation of its simplified technical drawings and invited to comment on its features and suggest potential modifications. They welcomed the concept, noting that the proposed system, designed as a fully contained unit would eliminate the need for continuous tending and thereby reduce their workload. Its insulated furnace was seen as a way to minimize exposure to excessive heat and the risk of burns, while the pipe that recirculates smoke back into the combustion zone can limit smoke exposure and related health risks. The inclusion of a wood-vinegar recovery option was also viewed positively. However, the participants acknowledged having limited knowledge of the potential uses and market value of this by-product and expressed interest in further guidance. They appreciated the kiln's ability to carbonize a broader range of waste materials and highlighted the advantage of its mobility. For example, because the kiln is mounted on wheels and fitted with stabilizing legs, it can be moved directly to biomass sources, avoiding the considerable time and cost of hauling bulky feedstock and requiring transport only of the lighter, finished char back to the production site. Finally, the women emphasized that hands-on testing is essential before they can offer more detailed and practical feedback.

7. Future Work & Recommendations

The new carboniser design represents more than a technical upgrade, it is a catalyst for community-led circular economy solutions. By coupling locally appropriate engineering with knowledge transfer and capacity development, this innovation can help rural and peri-urban enterprises turn organic waste into valuable energy products, create green jobs, and reduce environmental and health risks. With sustained support for field testing, training, and market development, the system has the potential to move well beyond a single pilot and become a scalable model for sustainable value recovery from waste across Kenya and similar low-income settings. Realising this potential will depend on more than engineering refinement. It requires deliberate knowledge and technology transfer, strong partnerships with local artisans and institutions, and sustained training and capacity development so that women's cooperatives and youth entrepreneurs can fabricate, operate and maintain the technology themselves. Equally important are field demonstrations across multiple feedstocks and ambient conditions, clear monitoring protocols to track yields and emissions, and market linkages to ensure briquettes and wood vinegar find reliable demand. By embedding these actions in local institutions and value chains, the innovation can become a scalable, community-owned model for sustainable value recovery from waste.

Priority actions to consolidate the gains and guide the next phase of work include:

Knowledge and Technology Transfer

1. Provide the carboniser's design drawings and materials list as an open-source document, making them freely accessible to local cooperatives, training centres and extension services.
2. Collaborate with local universities and polytechnics, building on existing and new partnerships, to facilitate the transfer of design know-how to other counties and regions and integrate the carboniser design into engineering and vocational training ecosystems.
3. Train and accredit local welders, metal fabricators and technical colleges to build and maintain the kiln, ensuring long-term availability of parts and reducing dependence on external suppliers.

Capacity Development and Enterprise Support

4. Deliver hands-on training for women's groups, artisans and youth on the science of pyrolysis, safe operation, maintenance and by-product recovery (e.g., wood vinegar).
5. Support training in enterprise development, market analysis and financial management to strengthen the economic sustainability of briquette enterprises.

Testing, Monitoring and Market Linkages

6. Conduct extended field testing across diverse biomass types and under ambient conditions to confirm performance, emissions and by-product quality.
7. Use feedback from these trials to refine internal mixing, feedstock preparation and airflow control for even higher conversion efficiency.
8. Establish simple protocols to track char yield, energy efficiency and emission levels.
9. Facilitate market access for briquettes and wood vinegar through linkages with local clean-energy initiatives, cooperatives and micro-finance schemes.
10. Share results with county governments and national energy agencies to integrate decentralised carbonisation into broader circular-economy and clean-energy strategies.

The overarching goal is to ensure that the innovation progresses beyond a single pilot to become a scalable, locally owned solution, building technical skills, creating green jobs, and strengthening sustainable value recovery from waste across rural and peri-urban settings.

Women group in Kisumu, Kenya learning how to operate a manual briquette press (Photo Credit: James Kinyua Gitau).

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Annexes

A. Technical Drawings[1]

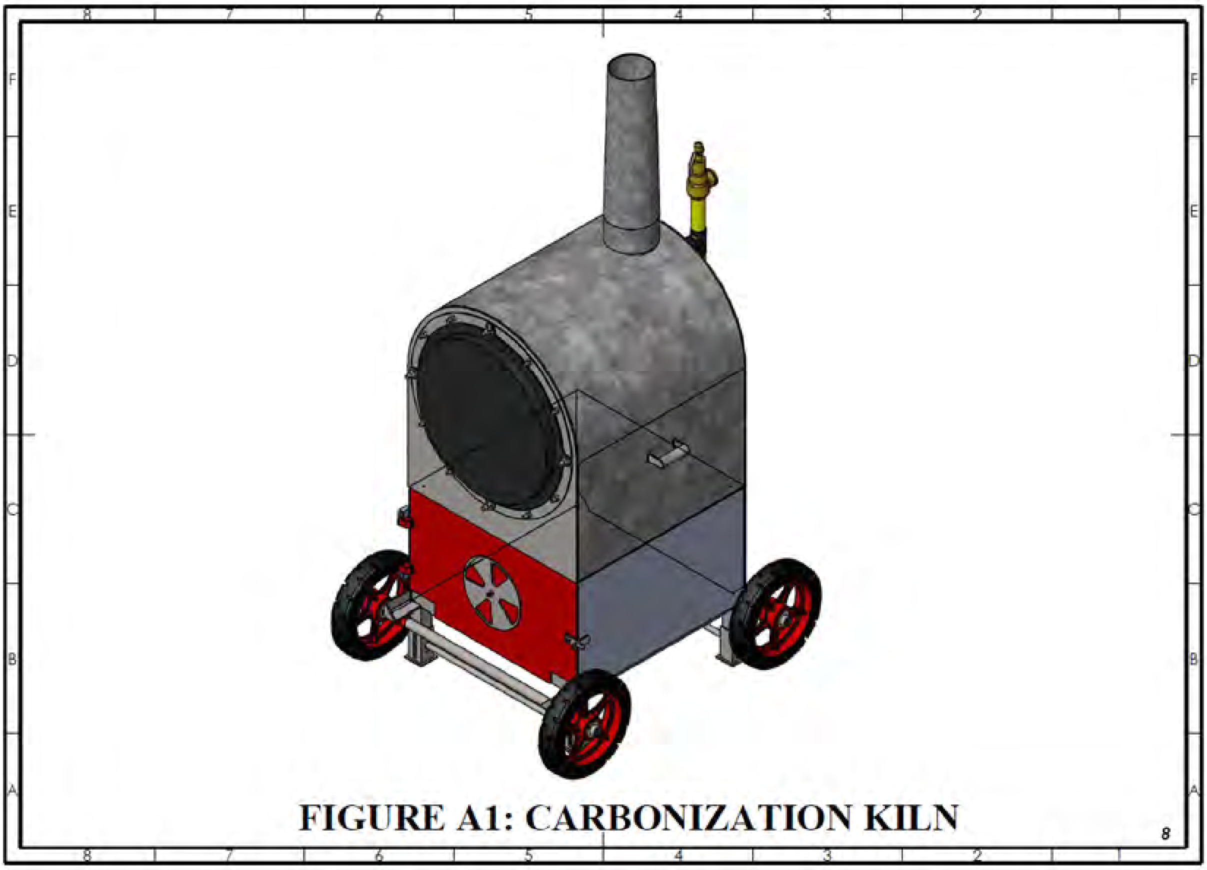

FIGURE A1: CARBONIZATION KILN

[1]Full technical drawings are available upon request by emailing t.somorin@cgiar.org

B. Bill of Materials and Cost of Fabrication[2]

SN	ITEMS	QUANTITY	TOTAL PRICE (NAIRA)
1	5mm Plate 24 X 1.2 m	2	290000
2	3mm Sheet 24 X 1.2 m	3	170000
3	Angle Iron 50 X 50 X 5mm (3 Full Lengths)	3	69000
4	Drum Cover Attachement Plates	4	8000
5	Cutting & Rolling of Plates	2	20026
6	Flame Cutting (Plates & Angle Iron)	-	32036
7	Flange Purchase & Cutting	1	40026
8	Cutting Disk	2 pcs	5300
9	Grinding Disk	4 pcs	8800
10	Electrode	2 pcks	24000
11	Arc-Saw Blades	2	3200
12	Fire Bricks	74	148000
13	Fire Brick Cutter	2 pcs	4000
14	Fire Bricks Bags	9	1800
15	Pipe 4" X 700mm	1	12000
16	Pipe Sch 40, 1" X 2m	1	12000
17	Socket 1"	4	6000
18	Nipple 1" (Barrel)	5	7500
19	Union Connector 1"	1	3000
20	NRT Valve 1"	1	12000
21	Hexagonal Nipple	1	1500
22	Cap Plug 1"	1	1500
23	Threaded Tee 1"	2	3000
24	Brass Ball Valve	1	5000
25	Pressure Gauge	-	15000
26	M12 x 40 Bolt & Nut	24	7200
27	M10 x 40 Bolt and Nut	32	8000
28	M16 x 70 Bolt and Nut	6	4800
29	M8 Bolt and Nut	8 pcs	1600
30	Bolt and Nut tools	6	7000
31	Ø25 x 1100mm Rod	2	30000
32	Hinges (for Furnace Door)	2	1500
33	Tyres	4	35000
34	Gasket Packing	-	26600
35	Black Paint & Mixtures	2 gal	26000
36	Thermocouple Probes, Display meters & Batteries	-	160513
			N1210901 (811 USD)

[2]Fabrication cost does not cover miscellaneous expenses incurred during testing, such as feedstock costs used for the one-off performance trials, transportation costs, workmanship, workshop or labour-related fees.

[3]USD Exchange Rate of 1USD = N1492 as at 18 Sept 2025)

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