# First-of-its-Kind Biochar Pilot from Food & Beverage Waste in Kenya

# Feasibility Report

Prepared for Sustainable Manufacturing and Environmental Pollution programme

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## C_005a Sanergy Inc

# Feasibility Report

## Executive summary

This feasibility report for Sanergy's biochar facility outlines the process design, vendor selection, risk identification, financial modelling, and carbon credit potential assessment. The project aims to demonstrate profitable biochar production at a scale that builds a business case for further investment, with a target production of >800 ton/year. Through an iterative design process and vendor evaluation, TakaChar was selected as the vendor of choice due to its scalable, modular design with low operating costs. The report identifies key risks, including equipment capability, biochar creditworthiness, and operational costs, with a need for further testing to validate assumptions.

Two vendors and equipment routes were deemed viable - TakaChar’s Takavator and Mingjie Group’s MJT-1000. Financial modelling shows that while TakaChar and Mingjie present viable options, TakaChar offers the lowest capital costs and highest margins, with significant carbon credit potential enhancing financial viability. The most likely scenarios modelled indicate an operationally sustainable project, after accounting for financing costs. However, achieving the modelled assumptions is critical to the project's success. The report shows that proceeding with TakaChar offers a risk-managed approach to demonstrating performance metrics and supporting the project's financial viability.

A key risk identified is the lack of data for operations of the equipment with the feedstocks of interest, impacting the performance of the business case. The recommendation is to proceed with a single TakaChar module to demonstrate the performance of some of the core technical aspects of the equipment. From this, further optimisation and expansion can be done to achieve the project goals.

# Process Design

## Approach

Design of Sanergy's biochar facility followed the following steps:

- Definition of design basis
- Prepare initial design documentation
- Identify and evaluate capable equipment vendors
- Select vendor and refine design documents

The approach was iterative. As more information from vendors, feedstock supply and internal modeling was produced, design documents and financial models were updated.

## Design basis

The core design basis for this project is outlined in the table below. In brief, the design goal of the facility is to demonstrate the profitable production of biochar at a scale that sufficiently builds the business case for further investment. The volume required was selected at approximately 800-1000 ton/year biochar representing a scale that would be sufficient to demonstrate both supply, scale operational costs and the market. Operational cost targets are set based on an equivalent cost to produce compost.

Biochar quality is also an important design parameter to be met. Consultation with the literature and experts in the industry and academia suggest that aiming for producing biochars with a high ratio of hydrogen to carbon atoms indicates more complete pyrolysis, more stable biochar and better physical properties. This ratio is measured as hydrogen/carbon, or H/C. Credit registries and certifications use this as a critical parameter to predict carbon permanence in biochar, with a maximum specification of $H/C < 0.7$

*Table 1. Summary of core design basis constraints.*

| **Basis Variable** | **Value** |
|---|---|
| Volume of biochar | >800 ton/year |
| Target production cost | <$120/ton biochar |
| Target wastes | Avocado pits, sugarcane bagasse, mango pits |
| Ability to produce credits | Must produce biochar with a ratio of hydrogen to carbon (H/C)<0.7 |

## Design completion

Prior to engaging vendors, design documentation was prepared including:

- Block and process flow diagrams
- Mass and energy balances
- A techno-economic model
- Specification sheets for main equipment
- An initial layout and bill of quantities cost estimate for construction

These documents were prepared before engaging vendors, but were further updated after receiving more information including updated equipment lists, layouts, energy requirements and costs. The mass and energy balances and equipment designs were reviewed and updated by an external consultant.

Data for the design work was obtained from vendors, literature, expert consultation and our own data measurements. Significantly, data for feedstock properties was robustly sampled and compiled into a feedstock database and cross referenced against literature.

Through the design process, it was identified that both shredding and drying would be required for the waste streams of interest. Additionally, pelletising was also investigated and forms part of the initial design. However, further physical validation is required preparing feedstock and testing in pyrolysers to settle on a specific design and approach to shredding, pelletising and drying. For the sake of modelling, we used vendor data from the most promising pretreatment equipment routes.

## Vendor selection

Vendors were first identified through online search and recommendations of experts in the industry. Initial screening was done based on critical design basis constraints and targets not being met. Engagement with vendors included a combination of email and interview conversations, using standard questionnaires and specification sheets to request information from vendors. A set of additional qualitative criteria were also developed above the core design constraints to evaluate the best solution. Finally, vendors were asked to provide references to follow up on.

*Table 2. Longlist of vendors and summary reasons for selection and elimination.*

| | Shortlisted/eliminated | Primary reason for shortlisting/elimination |
|---|---|---|
| Beston Group | Shortlisted | Scalable design with strong engagement, sound engineering. One deployment in Cameroon with small credit issuance. |
| Pyreg | Eliminated | Very high capital costs and 2 year lead time |
| Feeco | Eliminated | 2 year lead time, no further engagement to assess capital costs |
| Mingjie group | Shortlisted | Scalable design with strong engagement, sound engineering, engaged vendor team support. |
| TakaChar | Shortlisted | Scalable, modular design with low operating costs; highly flexible |
| Kerone | Eliminated | Capital costs too high relative to performance; significant redesign of their core equipment required |
| ID Gasifiers | Shortlisted | Strong design, within capital costs. Good engineering backing. |
| ACM Alcom | Eliminated | Despite a strong design case and relatively reasonable costs, only willing to proceed with a rice husk based project |

Vendors were primarily eliminated in the longlist owing to their inability to meet operational sustainability, largely driven by high capital costs. Other reasons why vendors were eliminated include their ability to meet the order timelines, support and engagement on engineering and design queries, demonstration of track record and operating costs.

From the shortlisted vendors, ID Gasifiers were eliminated based on their lack of capacity to be able to support a build. Beston Group were eliminated based on their lack of willingness to adapt their design and to work with the engineering team in detail sufficient to vet the equipment. Mingjie and TakaChar were taken forward as the primary designs to evaluate and assess.

Primary risks identified across most vendors focus on the capability of pyrolysis equipment to achieve the desired volume, yield, cost and quality targets when utilising our specific feedstocks. Notably, the equipment offered at financially viable costs is predominantly designed for charcoal production. While this underscores the equipment's robustness and reliability due to minimal novel design elements, there are distinct concerns to address.

Firstly, while there is relatively low risk associated with processing traditional feedstocks such as dry woody wastes and rice husks, for which the equipment is explicitly designed, we face a heightened risk when introducing bulkier and novel inputs like avocado pits, bagasse, and mango pits. These new types of feedstock, which have not previously been processed, present an uncertainty regarding their impact on the equipment's ability to maintain expected volume outputs.

Secondly, there is an inherent design-related risk where the pyrolysis process might cause gases to condense onto the biochar. This condensation can result in a tarry biochar with a higher hydrogen to carbon (H/C) ratio, degrading its quality. Low-quality biochar risks not meeting the established credit standards, impacting its marketability and the financial viability of the project.

Finally, operating costs for consumption of electricity, fuel and labour also remain a risk. Vendors provide a range for each of these. The range is sufficiently broad that the “worst case” scenario (assuming maximum consumption) leads to a non-viable business case. Consulting with peers in the industry indicated that it was possible to achieve the best case scenario, but that it was heavily dependent on the vendor and feedstock.

In order to reduce these risks, testing of the target feedstocks is required. However, vendors were not able to provide this testing data and were not able to conduct the tests with one exception (some testing was possible with TakaChar, for one single feed (bagasse), and is still on-going).

## Process and financial modelling

The designs and vendor information were combined in a techno-economic model to be used to evaluate the financial strength of each opportunity. From the assessment, TakaChar produces biochar at the lowest cost and produces at the highest margins. However, it is expected that at significantly bigger scales, Mingjie's equipment will show much stronger economies of scale.

A summary of the performance of each vendor for a select feedstock (bagasse) is shown below. In the low case, yield is reduced by 5%, volume by approximately 30% and a poor H/C ratio is used (the worst allowable before the biochar is no longer credit worthy). In the high case, only H/C values and yields are improved from the likely case. After accounting for loan repayments (including principal and interest), the likely and best cases across both equipment suppliers shows an operationally sustainable business case.

*Table 3. Process and financial modelling outputs. All monetary values in USD.*

| | TakaChar | | | Mingjie | | |
|---|---|---|---|---|---|---|
| Scenario | Low | Medium | Best | Low | Medium | Best |
| Biochar produced (ton/year) | 670 | 930 | 960 | 1,400 | 1,780 | 1,930 |
| Credits produced ($tCO_2e$/year) | 890 | 1,660 | 2,000 | 1,750 | 3,000 | 3,880 |
| Revenue (USD/year) | 137,000 | 214,000 | 240,000 | 285,000 | 423,000 | 471,000 |
| Cost of goods sold (USD/ton) | 130 | 107 | 103 | 160 | 140 | 133 |
| Cash flow after loan payments (USD/year) | -58,000 | 8,000 | 33,000 | -88,000 | 9,000 | 71,000 |

Findings from the modelling showed the following sensitivities across all models:

- Volume and yield. The model is sensitive to volumes and very sensitive to yields. Since most costs are relatively fixed and tied to equipment operation time (notably labour, fuel and electricity), the longer the equipment runs, the more the costs are "spread out" over larger volumes. Yield plays a strong role here too, as it both improves biochar output and reduces input costs per ton.
- Feedstock cost. Although the feedstocks are nominally free, costs to freight and pretreat the feedstocks should be minimised by co-location in order to keep the overall cost of goods low.
- Energy consumption. Electricity and fuel consumption are the next largest costs after feedstocks. While our business case uses values for electricity and fuel consumption demonstrated by other peers, without using the target feedstocks, it is difficult to validate this for our business case. Assuming the worst case makes it very challenging to achieve a sustainable business case.
- Credit durability. Achieving lower H/C ratios leads to more credit production, and greater profitability.

Therefore, it is critical that these numbers are demonstrated in order to build a viable business case. Most of these numbers have not been proven at any scale above laboratory scale for the feedstocks of interest. Without achieving the modelled assumptions, the business case is not financeable.

# Carbon credit potential assessment

## Approach

In order to determine the carbon credits potential of the project, the following three steps were required:

- Understand the methodologies used by registries and certification bodies to award credits
- Using data for our feedstocks and our designs, model the number of credits expected
- Survey potential buyers, peers and marketplaces to establish a price range

Data sources included guidance documents from registries, engagement with industry experts, interviews with peers in the field, literature and talking to potential buyers. Besides price, registries were also evaluated for other factors that would impact a decision to register credits with them.

## Registry evaluation

Two registries were assessed: Verra and Puro.earth. Analysis of the registries was done based on the following dimensions:

- Evaluating whether the technology routes met methodology requirements
- Understanding restrictions that would eliminate the project
- Quantifying the volume of credits
- Quantifying costs
- Market acceptance and price
- Timeline to issuance
- Support and capacity of the registry

**General methodology overview.** The three methodologies have varying levels of rigour depending on the segment of the project lifecycle and they are not wholly consistent with each other. All approaches start from an assumption of baseline that assumes feedstock not turned into biochar would be combusted or decay. Despite the potential for methane generation, a conservative approach is taken and assumes no additional emissions (that is , there is no avoidance credited to a biochar project). Carbon credits are issued by evaluating the carbon content of the biochar and estimating the permanence of the biochar, deducting emissions generated through the project activities. This general approach is consistent across all methodologies.

**Feedstocks.** Waste biomass feedstocks are valid for all methodologies. For Verra, the biomass must not have had some other use (for example, heat or energy). The target wastes for the project are valid feedstocks for carbon credit generation.

**Equipment.** Methodologies differ more significantly when laying out requirements for equipment and facilities.

Verra has broader, more lenient requirements, allowing for “low tech facilities”. All methodologies require the production equipment/facility to have some form of the following functionality

- Mechanism to recover or combust GHG’s emitted during pyrolysis process (not allowed to let escape into environment
- Heat recovery from pyrolysis process
- Adhering to pollution controls from the local operating environment
- Measurement and reporting of production temperatures
- Minimal/no use of fossil fuels in production process

Verra has the most lenient requirements; if the above standards are not met, the project can still proceed and be labelled a “low tech facility”, with a penalty on the number of credits issued to be conservative. This will also potentially impact pricing. Puro.earth requires a full lifecycle assessment (LCA) to be completed, increasing the rigour but also project costs and timelines. It does however enable for a more future-proofed assessment, as expectations of more rigorous carbon credit assessments will be higher as the market formalises.

**Products.** All registries allow for biochar use in soil application. Puro.earth allows for credit issuance from the moment biochar is blended with compost, while Verra requires GPS tagging of where the biochar is applied into the soil, increasing the project costs and complexity.

**Timeline to Credits**. From interviews with registries and peers in the field, all registries had extensive timelines of several months from start to first credit issuance. Verra timelines were ostensibly the longest; Puro.earth the shortest with timelines estimated between 6-12 months. This is mostly attributable to a high demand for registry support and insufficient capacity.

**Costs.** Upfront costs are a significant consideration, especially for pilot projects where minimising initial outlays is crucial. Puro.earth's lower registration costs make it appealing for early-stage ventures, with the major upfront cost being the LCA. However, there is a steep percentage of credits taken - between 7-12% - as well as ongoing registration fees. Verra, on the other hand, requires a significant upfront cost, but takes a much smaller proportion of the credit costs (<1%), making it more suitable for larger projects.

**Price and market acceptance.** Both registries are at this point well known, despite Puro.earth being a new player in the market. While Verra commands more name-brand recognition, Puro.earth offers a more robust assessment of credits dictating an LCA and following European Biochar Certification standards. It is likely that Verra (and the broader market) will converge to the stricter requirements in the medium term. Pricing was not possible to ascertain from Verra for biochar credits; for Puro.earth pricing ranged from \$50-350/t$CO_2$e, although these are listed prices and not sold credits.

## Credits potential

Using the design documentation and mass and energy balances, a carbon credit calculator was constructed using Verra and Puro.earth methodology. Carbon credits were then calculated and project losses and leakage estimated. From the modelling, both registries issued credits varies widely between 1.1-2.7 t$CO_2$e/ton-biochar between all variables. Despite more rigorous auditing and LCA requirements, Puro.earth offers more potential for higher credits in recognition of more durable biochar produced. The table below indicates credits estimates for different feedstocks, registries and with the top two equipment vendors shortlisted. It indicates that bagasse and avocado pits would make good feedstocks, and that we should proceed with Puro.earth over Verra as a registry.

*Table 4. Comparison of credit yields for different feedstocks, registries and equipment.*

| Feedstock | Yield | Carbon content | H/C ratio | TakaChar | | Mingjie | |
|---|---|---|---|---|---|---|---|
| | | | | Verra | Puro.earth | Verra | Puro.earth |
| Bagasse | 25% | 60% | 0.05 | 1.7 | 2.1 | 1.6 | 2.1 |
| Avocado pits | 30% | 75% | 0.05 | 2.1 | 2.7 | 2.1 | 2.7 |
| Mango stones | 30% | 42% | 0.13 | 1.1 | 1.4 | 1.1 | 1.3 |

Focusing on bagasse, the potential of credits and the impact on the business case modelled above is shown. Credits were assumed to sell at a price of \$90/t$CO_2$e, a conservative discount on the market rates. A further conservative discount of 25% was included to account for potential losses owing to regulatory changes. Finally, although lab-based H/C ratios were shown to be very low (<0.15), a conservative value of 0.4 was chosen based on vendor data for other feedstocks.

The financial potential of the credits is significant, leading to a sustainable business case should the above assumptions be proven, and assuming target yields and throughputs are achieved.

*Table 5. Credits potential for the project.*

| **Financial Metric** | **TakaChar** | | **Mingjie** | |
|---|---|---|---|---|
| | **With credits** | **Without credits** | **With credits** | **Without credits** |
| Revenue (USD/year) | 215,000 | 120,000 | 400,000 | 230,000 |
| Cash flow after loan repayments (USD/year) | 7,800 | -86,000 | 9,100 | -162,000 |

The key uncertainties and risks lie in the lack of verification and pre-certification from the registries of the target equipment. Registries stress that they evaluate credit-worthiness based on projects and not equipment and do not perform pre-verification prior to investment and deployment of the equipment. Both equipment vendors have cited and shown lab evidence of instances where they have demonstrated it is possible to achieve durable biochar with their equipment but not with the feedstocks of interest, and not at the throughputs required for a sustainable business case. This is because the primary indicator of durability - H/C ratio - tends to decrease (become more durable) with more pyrolysis, which is achievable by lowering the volume of material through the pyrolyser.

Consultants engaged highlighted that especially in the case of Mingjie equipment it would be critical to test the exact equipment we are purchasing with the feedstocks we want to process, as these equipment have been adapted from the charcoal industry where high H/C ratios are not only acceptable but desired.

In summary, it was not possible to demonstrate that we will be able to achieve biochar production at target volumes with our feedstocks and achieve H/C ratios. This value has a critical impact on the number of credits and the financial viability of the project.

# Conclusion

Sanergy completed design documentation for two technology routes. Both routes showed financial returns but relied on carbon credit sales to achieve this.

Critical parameters in the design, modelling and financial potential were not possible to be proven by vendors. This is owing to vendors inability to run trials using the target feedstocks in representative equipment. Without this validation, there is a risk that some assumptions are not met, and the project will not show a sufficient return. This directly impacts the ability to raise debt financing for the project.

The project was shown to be capable of producing significant volumes of carbon credits and a strong revenue stream to support financial viability. However, again vendors and registries are unable to guarantee performance with the target feedstocks.

The recommended steps are to proceed with TakaChar as a vendor of choice owing to the incremental and risk-managed nature of the investment. With a single module, Sanergy can demonstrate all performance metrics required.