CREATING OPPORTUNITIES FOR BLACK SOLDIER FLY (BSF) WASTE PROCESSING

A toolkit for operators

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Setting the stage

1 Setting the Stage

This toolkit for operators is written for existing and potential future Black Soldier Fly (BSF) biowaste conversion operators, entrepreneurs, investors and NGOs. It offers practical guidance on planning of BSF implementation as well standardized daily operations based on the selection of system options and the technological elements needed for these applications.

This toolkit builds on existing reports and practical evidence, in particular:

- Climate and Clean Air Coalition (2025). Transforming Organic Waste with Black Soldier Flies: A Guide for Decision-Makers, Entrepreneurs, and Implementers to Unlock the Organic Waste Potential of Black Soldier Fly Systems.
- Diener, S., and Gold, M. (2022). Global study on black soldier fly sector, Subnational Climate Fund.
- Zurbrügg C., et al. (2024). Is Black Soldier Fly waste-processing a sustainable solution? A feasibility assessment approach.
- Dortmans B.M.A., et al (2021). Black Soldier Fly Biowaste Processing - A Step-by-Step Guide, 2nd Edition.

1.1 What is BSF biowaste conversion?

Black Soldier Fly (*Hermetia illucens)* biowaste conversion technology is an innovative, sustainable and efficient approach to organic waste (biowaste) management. It addresses waste management challenges while producing protein-rich feed, organic soil amendment, and other valuable byproducts. Additionally, BSF biowaste conversion presents several compelling business opportunities across various sectors.

- Answers to a growing need for sustainable protein sources for aquaculture, poultry, swine, and pet food industries.
- Offers a cost-effective, eco-friendly alternative to traditional fishmeal and soy-based feeds.
- Responds to an increasing awareness and demand for organic fertilizers (frass) for use in agriculture and gardening.
- Provides nutrient-rich, sustainable fertilizers that promote healthy crop yields.
- Creates products that can be sold or self-used to partly replace conventional products, thus reducing reliance on imported goods.
- Offers a waste management service and solution for waste generators or local authorities in charge of waste management (e.g. municipalities, large food producers, and agricultural operations) seeking sustainable alternatives to waste disposal and innovations towards a circular economy.
- Opens opportunities to provide educational and training services as well as consulting.

BSF biowaste conversion technology leverages the BSF larvae's ability to convert biowaste into valuable products. The process begins with the collection and pre-treatment of biowaste, which can include food scraps, agricultural residues, and manure. In the reproduction unit, BSF eggs hatch into neonate larvae (newly hatched larvae). After five days of rearing on a nutritious feed (e.g., chicken feed), five-days old larvae (5-DOL) are then introduced into the biowaste, where they rapidly consume and decompose it. Over about two weeks, the larvae feed on biowaste, grow, and reduce the volume of biowaste significantly, by up to 75%.

Before reaching the prepupae stage in which they turn dark brown, the larvae are harvested, and can then be used or processed into animal feed or other products. The remaining frass (larval residue) is rich in nutrients and beneficial microorganisms, and can serve as an organic fertilizer and soil amendment (Figure 2-2).

The main advantages of BSF biowaste conversion technology can be summarized as:

- BSF technology recycles organic waste (biowaste) into useful products, reducing landfill use and respective methane emissions.
- BSF larvae rapidly process waste, providing high-speed throughput and biowaste volume reduction.
- BSF technology generates biomass for animal feed, reducing reliance on imported and conventional feed sources.
- BSF technology is versatile and can be set up using low-cost equipment and low energy requirements compared to conventional waste treatment methods.
- BSF technology is suitable for various biowaste types and is scalable from small farms to large industrial facilities.
- The versatility of BSF biowaste conversion opens numerous avenues for entrepreneurs and companies to develop sustainable, profitable businesses, strategic partnerships, innovative products and scalable solutions that can position these ventures effectively in local markets.

1.2 Rationale and scope

BSF biowaste conversion is increasingly receiving attention from various stakeholders. This shows in investments in larger BSF companies worldwide, but also start-up of new enterprises at small and medium-scale. This is especially the case in low and middle-income countries, where BSF ventures increasingly rely on low-tech and decentralised approaches to empower farmers, entrepreneurs and communities to create jobs, increase resilience by tackling their waste problems and generating self-supply of feed and fertilizer.

Despite the increasing interest in BSF biowaste conversion, its widespread scaling has so far been hampered by several barriers. Some common issues include:

- Limited knowledge sharing has been identified as a key barrier. Exchange of information is very difficult as networks are dispersed and informal. Knowledge is often dispersed across research papers which are difficult to access and understand. Pilot programmes as well as existing BSF facilities lack documentation of setup and procedures or are purposely not shared to gain competitive advantage. All this making it harder to get consolidated guidance.
- In some regions, there is a lack of accessible, comprehensive resources or best practices for setting up and managing BSF farms, especially for farmers or new entrepreneurs. As BSF biowaste conversion involves specific biological, environmental and engineering knowledge, farmers or operators without specialised training may face difficulties planning or optimising their operations.
- Entrepreneurs or farmers may also lack clear information about regulations, certifications, or market opportunities, which requires knowledge sharing and collaboration.

Besides newly established knowledge sharing platforms, such as the WhatsApp Community "BSF-Africa", this toolkit hopes to fill part of this gap.

The scope of this document is to focus on simplified small to medium scale, mainly labour based, non-industrialised BSF biowaste conversion setups and the operational aspects of such systems. The choice of systems covered in this toolkit focuses only on systems 2,3 and 4 of the six systems as described by Climate and Clean Air Coalition (2025):

- SYSTEM 1: Micro-scale home system
- SYSTEM 2: Simplified BSF Approach SIMBA
- SYSTEM 3: Centralised facility in tropical region
- SYSTEM 4: Container-based/decentralised system
- SYSTEM 5: Centralised medium- to large-scale facility
- SYSTEM 6: Large-scale industry pioneers

After introducing the key elements of a BSF biowaste conversion operation (**Chapter 2**), and the key performance indicators when operating BSF biowaste conversion (**Chapter 3**), this toolkit presents two options of BSF production models and four different business models for consideration (**Chapter 4**). Thereafter this toolkit proposes consolidated guidance on BSF biowaste conversion operating procedures, also called "Standard Operating Procedures" for a Simplified BSF Approach (SIMBA) as well as a step-by step guide for operating a small to medium-sized facility (**Chapter 5**). If you are considering starting a BSF biowaste conversion system, **Chapter 6** suggests a stepwise planning and implementation approach, and then briefly describes the financial considerations of implementing and operating a BSF system. For cost-revenue modelling and well as greenhouse gas (GHG) emissions estimation, links to excel-based tools are provided. **Chapter 7** lists some aspects of troubleshooting with BSF biowaste conversion. Finally **Chapter 8** provides other key readings on BSF biowaste conversion

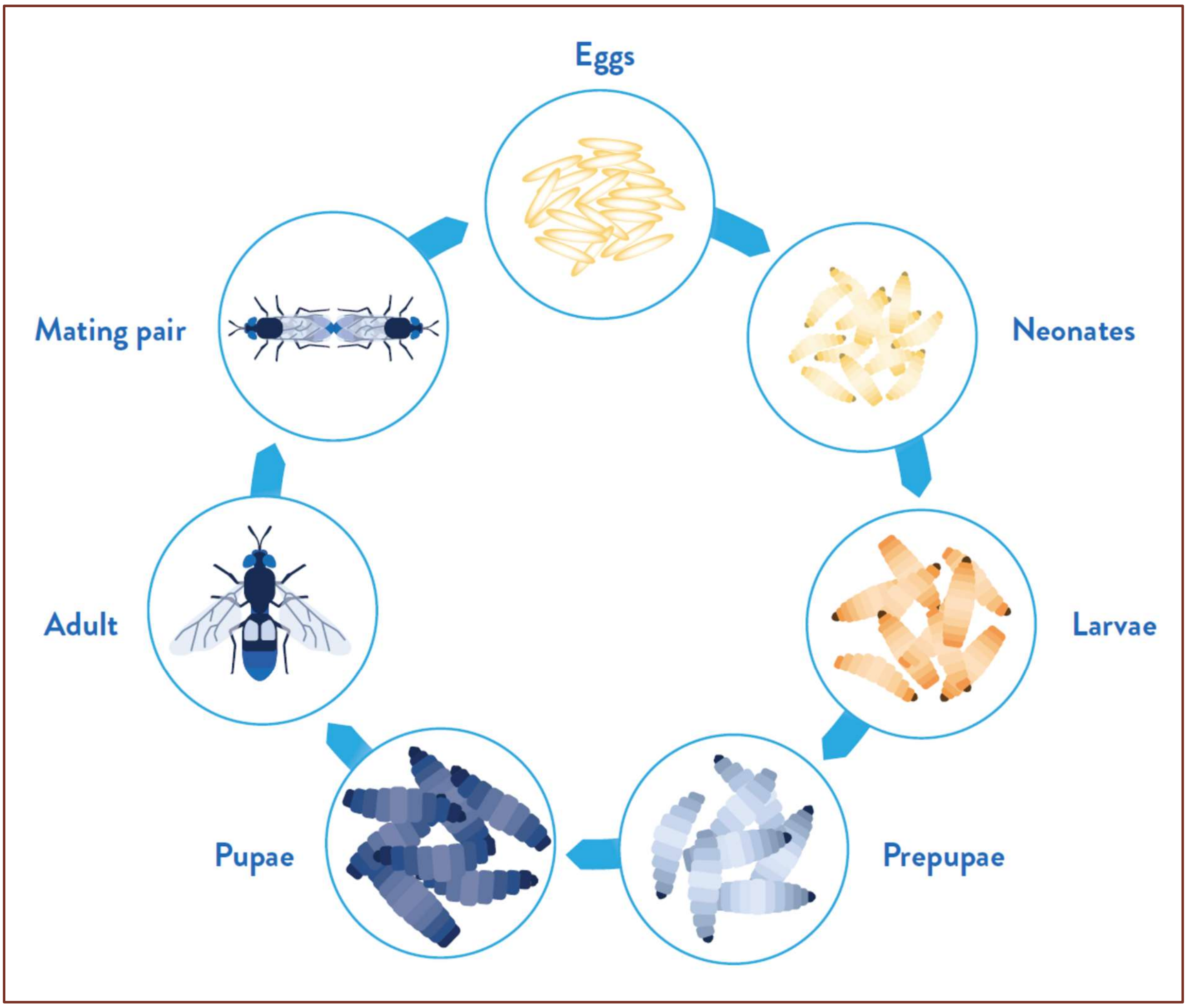
Elements of BSF biowaste conversion

2 Elements of a BSF biowaste conversion facility

The BSF is naturally habituated in the tropical and sub-tropical areas worldwide. Optimal conditions for its lifecycle are given in areas with temperature ranges between 25°C and 30°C, and with humidity levels around 60-80%. As such, these areas are also especially suitable for setting up BSF biowaste conversion facilities.

To optimise the production and efficiency of a BSF biowaste conversion facility, understanding the life cycle of BSF is fundamental. Figure 2-1 illustrates the BSF lifecycle. The importance of the stages for biowaste conversion are explained below.

Figure 2-1 The lifecycle stages of the Black Soldier Fly

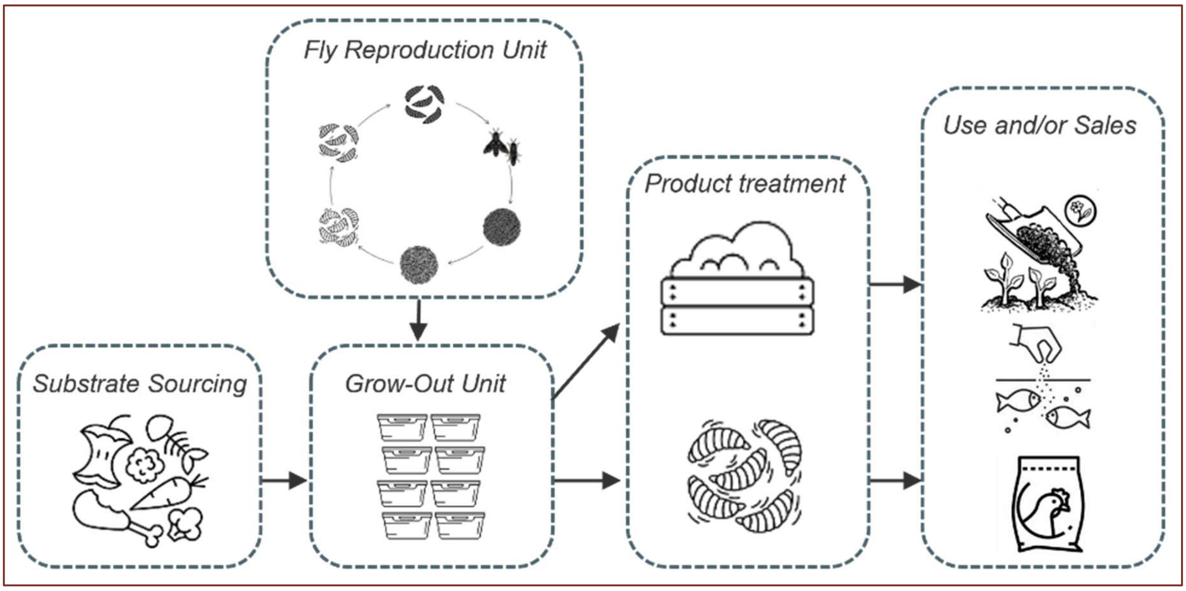


Source: Climate and Clean Air Coalition (2025)

- **Egg to Larvae Stage:** One adult female fly lays between 300 and 800 eggs in crevices near decaying organic matter. These eggs hatch within 2 to 3 days. The newly emerged larvae (also called neonates or hatchlings) begin feeding immediately. BSF larvae feed on a wide range of organic materials and thereby transform them into valuable biomass.
- **Larvae to Prepupa Stage:** Over approximately 10 to 14 days, larvae feed on biowaste and grow from less than 1 mm to about 2.5 cm (or in weight: 0.003 g to 0.2 g), depending on the substrate characteristics and its nutritional value. For optimal growth, larvae depend on moist biowaste substrates (with a moisture content of approx. 60-75%) which provides them with enough nutrients. Once fully grown, larvae enter the prepupae stage, in which feeding ceases as they seek suitable and secure locations to pupate.
- **Pupae Stage to Adult Fly:** Once the larvae found a suitable and secure location, they develop from prepupae into pupae. Pupae are dark in colour, stiff and immobile. Pupae stage lasts around 14 days, after which adult flies emerge as flies.
- **Adult Fly to Eggs:** Adult flies do not need to feed and can consume only water as their primary purpose is reproduction. Under ideal conditions – i.e. temperature, moisture and light – the flies mate and the female lays the fertile eggs in crevices. This completes the life cycle in roughly 45 days.

The BSF lifecycle, and as such the biowaste conversion, can be optimised by utilising the natural cycle in BSF biowaste conversion facilities. Engineered design and operations have the goal to manage and optimise the lifecycle stages with its requirements and respective environmental conditions to ensure a continuous and efficient bioconversion process and good harvest of larvae and frass. A BSF biowaste conversion facility can be subdivided into different elements as shown in Figure 2. Each element of the facility is further introduced below.

Figure 2-2 Elements of a BSF biowaste conversion facility



Source: Eawag

2.1 Substrate sourcing

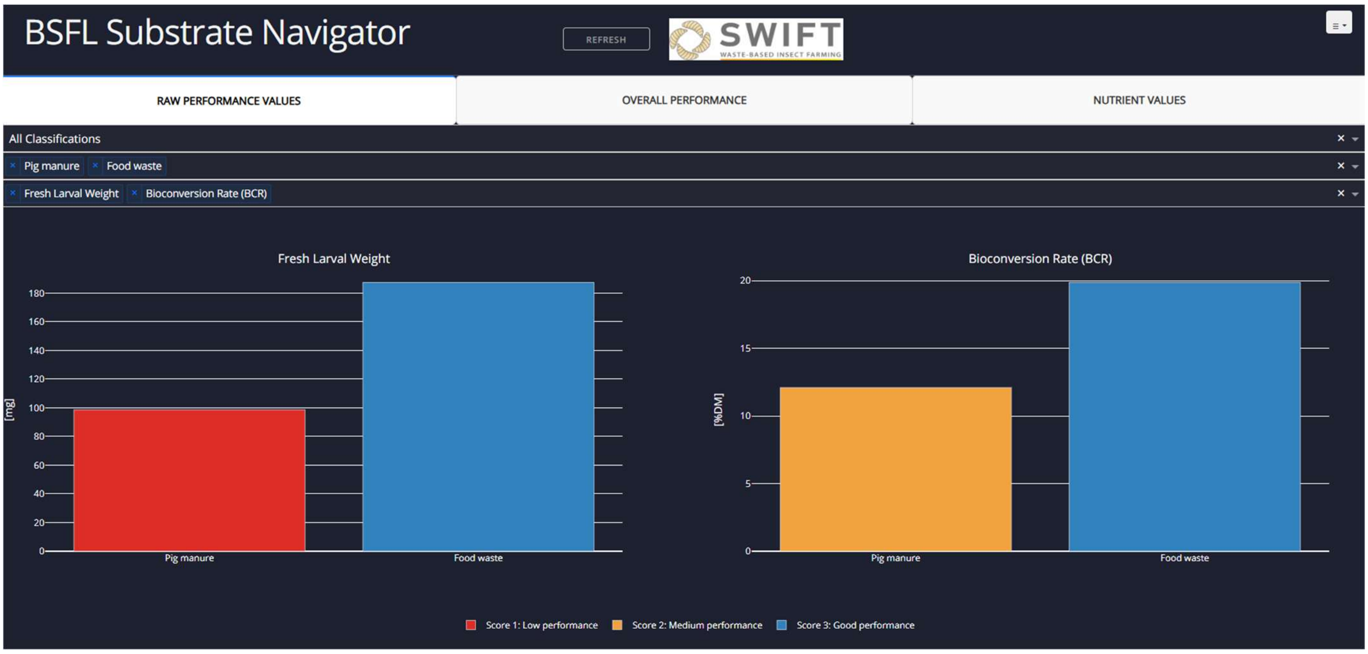
A critical factor in optimising BSF systems is the sourcing, preparation and use of suitable substrates - biowastes - on which the larvae feed and grow. Depending on what biowaste substrates are available and how they are prepared and used will directly affect larval growth, waste reduction efficiency, and the nutritional content of the larvae and frass.

BSF larvae have particularly good growth on substrates that are high in digestible nutrients such as protein (>10% protein in total dry mass), non-fibrous carbohydrates (e.g., starch and glucose; 20-30% of dry mass), fat (10-15% of dry mass), and are low in indigestible fibres (e.g., hemicellulose, cellulose and lignin) and non-organic content. Optimal moisture of the substrate is between 60-75%. Often a combination of different types of substrates (e.g., pig manure, fruit and vegetables, or agricultural crops) may be most beneficial to provide a well-balanced diet and optimal moisture for the larvae.

To assess the suitability of the substrates available to you, the BSFL Substrate Navigator can be used. This online tool is designed for both practitioners and researchers and provides scientific literature-based information on the performance and nutrient values of certain substrates for Black Soldier Fly Larvae (BSFL).

Figure 2-2 shows an example screen shot comparing the performance values of pig manure, and food waste regarding fresh larva weight and the bioconversion rate.

Figure 2-2 : Example screen shot from the *BSFL Substrate Navigator*



Source: https://bsfl-substrate-navigator.onrender.com/

https://bsfl-substrate-navigator.onrender.com/Once you have determined the composition of the biowaste substrates, it is important to ensure its quality for further usage. Materials with very high cellulose and lignin content, such as wood, straw, and paper, are not digestible by BSFL. These materials should be avoided as a sole substrate but might serve as a bulking agent to balance moisture or add structure to the substrate. Additionally, toxic substances like heavy metals, pesticides, and high salt or acid content can threaten the larvae and must be avoided. Other contaminants like plastic, glass, or metals may not be harmful for the larvae but must be removed as this improves safety and prevents physical harm to larvae or equipment. Moreover, avoiding such contaminants prevents the frass from becoming polluted, thereby safeguarding soil quality when frass is applied.

The next step is to ensure the moisture level and reduce the particle size of the substrate. Dry substrates may need to be wetted (e.g., by adding water or liquid food waste), while overly wet materials may need to be either drained or else mixed with a drier material (e.g., sawdust, wheat bran, cocopeat). Chopping, shredding, or grinding increases the surface area of the substrate, making it easier for larvae to digest the material. Fine but not overly compacted texture supports larval movement and oxygen flow.

Finally, prepared substrates should be used promptly or else stored under hygienic, cool, and airtight noncorrosive containers to slow microbial spoilage or pest infestation. Fresh substrates can be stored for 2 to 5 days, but should not exceed one week unless treated by fermentation.

Substrate use is often subject to national regulations, especially when larvae are used in feed. Some countries restrict the use of certain waste types for insect feed (e.g., meat-containing waste) for insect feed. Compliance with local laws is essential for commercial-scale operations.

Choice of legally allowed substrates for BSF biowaste conversion is typically a trade-off between different attributes of the substrate such as: nutritional quality, safety, purity, amounts available, seasonality, complementarity with existing value chains, logistical effort of procurement, costs, and environmental benefits. As substrate supply is a key aspect of the BSF activity, a diversification of suppliers helps reduces risks of dependencies and supply disruptions. Furthermore, it is advisable to ensure long-term supply contracts to strengthen resilience of the BSF activity.

2.2 Fly reproduction unit

The fly reproduction unit consists of a dedicated area, structure and equipment where larvae, prepupae, pupae and adult flies are kept. This unit, sometimes also called 'love cages', plays a critical role in sustaining a continuous production cycle of larvae to supply the grow-out unit and to maintain a certain number of larvae to complete the life cycle.

Optimal conditions for the fly reproduction unit are: ambient temperatures between 25-32°C, air humidity between 60-80%, and light (bright, high-power lights with a spectrum matching natural sunlight, or natural sunlight) for 12-16 hours/day.

In the reproduction unit, pupae are kept in boxes in netted cages (Figure 2-4). When pupae develop into flies and emerge in the netted cages, ideally at fly densities of around 5,000/m^3, they are provided some water for drinking and are stimulated by sunlight to mate. While light is essential, direct sunlight should however be avoided as this may lead to rapid dehydration of the flies. Females are naturally attracted to decaying organic matter and laying eggs within crevices. Therefore, to harness this behaviour, they are purposely provided with materials containing slits and crevices, called '*eggies*', where they deposit their eggs. These eggies are harvested regularly (daily or every second day) and transferred to another location for hatching. Eggies are placed on top of nutritious substrate in hatchling boxes. As neonates are particularly sensitive to environmental conditions and food quality, it is advisable to keep them in a controlled and protected environment in nursery containers for 4-7 days to increase their survival rate and feed them a special nutritious substrate (e.g., chicken feed). When eggs hatch, the neonates drop into the provided substrate and start to feed and grow.

After approximately 5-7 days the young larvae are ready to be transferred into the grow-out unit for biowaste conversion (explained in the following section). About 2-5% of the larvae population is kept in the reproduction unit, and is further fed and left to grow until they reach the pupation stage. This closes the life cycle and ensures a sufficient reproduction of flies to sustain the biowaste conversion. Although more costly, providing larvae throughout the reproduction unit with a controlled nutritious substrate lowers the risk of failure. Diet affects the physiological and morphological traits of adult flies and in particular female fertility. Therefore, maintaining a consistent larval diet in the reproduction unit helps ensure a healthy and productive colony.

Another option is keeping all the larvae in the grow-out unit and then retain a fraction of the larvae to develop into pupae to close the life cycle in the reproduction unit.

Implementing a monitoring system is crucial to track key performance indicators (KPIs) in the reproduction unit (see Chapter 3). The most crucial KPIs are:

- the number of larvae kept for pupation,
- the number of pupae,
- the 5 or 7-day-old larvae obtained after hatching, and
- the egg mass (in grammes).

Good hygiene in the reproduction unit is key to maintain a healthy reproductive environment, which ensures healthy egg output, reduces disease risk, and improves the overall efficiency of the reproduction unit. This should be based on routine care, including the regular cleaning of all equipment and the surface area, as well as careful pest control.

Figure 2-3 Elements of a reproduction unit.

		
Love cages in a facility in Kenya	Eggs in tea strainers over feed – the so called "hatchling shower"	Nursery containers to produce new prepupae for the reproduction unit (Uganda)

Source: ©Eclose

2.3 Grow-out unit

The grow-out unit comprises the conversion of waste by the larvae and the harvesting of the larvae and frass. In the grow-out unit, young larvae (5-7 days old), obtained from the reproduction unit, are fed with biowaste substrate in crates, basins, containers or other enclosures over a period of around 10 days. The goal is to achieve optimal growth of the larvae during this time, while keeping the operational costs as low as possible.

The size of the containers used determines the number of larvae and amount of substrate. The parameters "larvae density" (number of larvae per cm^2 surface area of container) and "amount of substrate" (kg per cm^2 surface area) are the two critical parameters in operations of the grow-out unit, whereby larvae density is ideally reduced depending on the age (and therefore size) of the larvae. Formulas listed in

Table 2-1 provide an estimate for these values depending on container size.

Table 2-1 Calculating number of larvae and amount of biowaste substrate depending on container surface area

Number of larvae of 5-10 day old, per container	$= Surface\ of\ container\ (in\ cm^2) \times 30$
Number of larvae of 10-17 day old, per container	$= Surface\ of\ container\ (in\ cm^2) \times 6$
Total amount of biowaste substrate (kg)	$= \frac{Surface\ of\ container\ (in\ cm^2)}{200}$

The larvae density is important since BSF larvae rely on collective movement and feeding to efficiently break down organic matter. With too low or too high larvae density, the system become less cost-effective (labour, space, inputs vs. output). Too low larval density has negative impacts, such as:

- An increased risk that the substrate will not be completely utilised and will still be moist on the day of harvest. This makes it almost impossible to separate the larvae from the frass.
- Insufficient mixing of the substrate which leads to the risk that the substrate is not aerated as effectively, with the risk of rotting, mold, pathogen growth, housefly breeding inside the substrate.
- Depending on ambient temperature, there may not be enough metabolic heat to maintain the optimal temperature for growth.
- Less microbial stimulation, leading to slower conversion as the system becomes less biologically active and efficient.
- Lower overall harvest, even if each larva grows large leading to decrease in cost-effectiveness (labor, space, inputs vs. output).

Too high larval density also has negative impacts, such as:

- Increased microbial and metabolic heat which can exceed the optimal temperature ranges, stressing larvae.
- intense competition among larvae for limited nutrients. This leads to stunted growth and lower biomass gain.
- When in competition for feed, not all larvae will get equal access to feed. The result is a large variation in size and reduced uniformity when harvesting.

Feeding of substrate can be a one-time task for the whole period but can also be split into two feedings, once when starting with the grow-out and a second feeding 4 days later.

At an age of 15 to 17 days, the larvae are then separated from the frass, which is called the "harvest". The right time to harvest is indicated by visual characteristics: When a few larvae show a beige-brown colour instead of their normal light-beige colour. The frass should have a dark, almost black colour. The finer particles of this frass should have a round particle shape. When frass has a suitable moisture content, ideally very little material should remain clinging to your hand when pressed. Separation is done by sieving with a mesh size of about 4 mm.

Figure 2-5 Elements of a grow-out unit.

		
Bioponds in a facility in Côte d'Ivoire	Stacked crates, each fed with 12 kg of waste, in Indonesia	Dosing young larvae into grow-out crates, in the Philippines

Source: ©Eawag & Eclose

2.4 Product treatment

Harvested larvae can be used directly as animal feed - as "fresh larvae", on the day of harvest or with appropriate storage for the next few days. If larvae need to be stored for more than a week, they should be killed and dried. The larvae can be killed by briefly blanching them for a few seconds in boiling water. Once killed, batches of larvae can be dried in either a microwave oven, conventional hot air oven or by sun drying.

Besides larvae, the harvesting produces frass - a mix of larval excreta, undigested substrate, shed exoskeletons, and microbes. Frass cannot be considered a stable product. To use it safely and effectively (especially as a fertilizer), treatment by composting is recommended. Composting of frass is achieved in turned piles or windrows over a period of 4-6 weeks. This not only stabilizes the organic matter but also contributes to improved nutrient availability and helps reduce potential pathogens.

2.5 Use and/or sales

BSF products can be used for animal feed and soil conditioner. BSF larvae are rich in protein (40-50% dry mass) and fat (and 30-40% dry mass), making them a suitable alternative to fishmeal in animal feed. Larvae also provide beneficial fats, such as lauric acid, which can improve the energy content in animal diets. Additionally, larvae provide essential amino acids, key minerals like calcium and phosphorus, and antimicrobial peptides. Whether used in aquaculture, poultry, or pet food, BSF larvae offer a sustainable and economically viable feed option. Harvested larvae can be fed directly to animals (e.g., chickens, ducks, pigs, fish), replacing up to 20% of the conventional feed by weight. Here it should be noted that when dried larvae are used, the replacement rate should not exceed 5-8% of the feed weight. Besides using larvae as animal feed the larvae can also be processed into higher value products. Some of those are the following:

- Defatting of the larvae can produce a pure, high-quality fat (i.e., > 99% fat) that is high in antimicrobial lauric acid and a similar composition to coconut fat. It can be used as an ingredient for feed, cosmetics, or biofuel production.

- The exoskeleton of BSF flies and larvae contains the polymer chitin (larvae: 8-12% dry mass; exuviae: 22-26% dry mass) which shows to have negative effects on the growth of livestock such as fish, poultry, and pigs. However, chitin is a valuable biopolymer with applications in the pharmaceutical, biomedical, and agricultural industries.
- All BSF life stages contain the high molecular weight pigment melanin. Melanin has potential uses in electronics, cosmetics, and medicine.

These options might open new markets, although careful consideration is needed regarding the required additional processing and treatment steps which typically come with technological and operational challenges and increased costs.

The BSF frass serves as a nutrient-dense soil conditioner which can improve soil health and promote sustainable agricultural practices. It contains essential nutrients like nitrogen, phosphorus, and potassium (NPK), making it comparable to compost. Frass can also be converted to biochar through pyrolysis. Biochar can be used substitute for wood-based charcoal or as a soil conditioner and is considered an effective way of carbon sequestration. Furthermore, fresh frass can produce relevant amounts of biogas when treated by anaerobic digestion thus provide a source of fuel. Here also, careful consideration is needed regarding the required additional processing and treatment steps which typically come with technological and operational challenges and increased costs.

Regarding sales, although still in its infancy, the market for BSF-derived products shows promising growth with applications in aquafeed, livestock feed, and organic fertilizers. This also includes niche markets, like pet food (ornamental fish, singing birds), as well as insect protein for aquaculture and poultry. Prices for BSF-derived products depend heavily on local factors, and the level of product processing conducted. In general, however, BSF-derived products have to compete with established products unless the added benefits can clearly be brought to the attention to customers. For instance, BSF larvae contain chitin and antimicrobial compounds that, although indigestible, may enhance gut microbiota and disease resistance in animals.

2.6 Safety, hygiene and maintenance

Safety and hygiene aspects are critical aspects in BSF biowaste conversion systems, due to the nature of the feedstock (biowaste) and its potential risks to workers, consumers, animals, and the environment.

One major challenge arises from the pathogens, contaminants, and toxins present in the feedstock. Substrates that include animal by-products (e.g., slaughterhouse waste) may, through insects, introduce harmful bacteria, prions, or other contaminants into the food value chain. Heavy metals or chemicals in the substrate may accumulate in the larvae, and in turn when fed to animals or humans, can lead to bioaccumulation. Ensuring that insects are fed safe, controlled substrates and processed correctly helps avoiding public health threats and supports building trust in insect-based products.

During operations, workers are exposed to pathogens, mold spores, dust, odours, and allergens, as well as physical risks by injuries. Good practices to avoid these risks include the provision of personal protective equipment (PPE), cleaning, sanitary facilities and good ventilation.

Finally, maintaining hygiene in the facility itself is essential to ensure a productive and effective life cycle and thereby contribute to sustainable operations. Regular cleaning of the facility and the equipment is a critical part of hygiene management. Best practices include daily cleaning of surfaces and tools after handling waste or larvae, scheduled cleaning of nets, containers, open surface areas and waste areas, as well as safe storage of wastes. Such measures help minimize infestation by house flies or rodents, avoid unpleasant smells and prevention of pathogen buildup or microbial contamination that could affect the health of the flies, eggs and larvae.

2.7 Ensuring BSF welfare

As with other animal husbandry, it is important to consider welfare of the animals. BSF flies, larvae and pupae are no exception. One critical aspect of the BSF biowaste conversion is the killing step of the larvae. The slower the death of the larvae the more likely it is to cause more pain. The most humane methods are boiling/blanching, rapidly freezing in liquid nitrogen, and grinding, as these approaches cause near-instantaneous death.

Other considerations of BSF welfare are providing suitable living conditions and proper handling to minimise stress and anxiety of flies and larvae. This includes proper nutrition and hydration, an appropriate living environment providing suitable conditions which includes shelter and the possibility to exhibit natural behaviours, such as movement and social interaction. Another critical aspect threatening BSF welfare is genetic modification of BSF. Examples of concern are gene modifications to enhance their feeding capacity and larvae size or to modify genes that control wing size and shape to develop flightless adults, which could then be housed in smaller cages (Climate and Clean Air Coalition (2025).

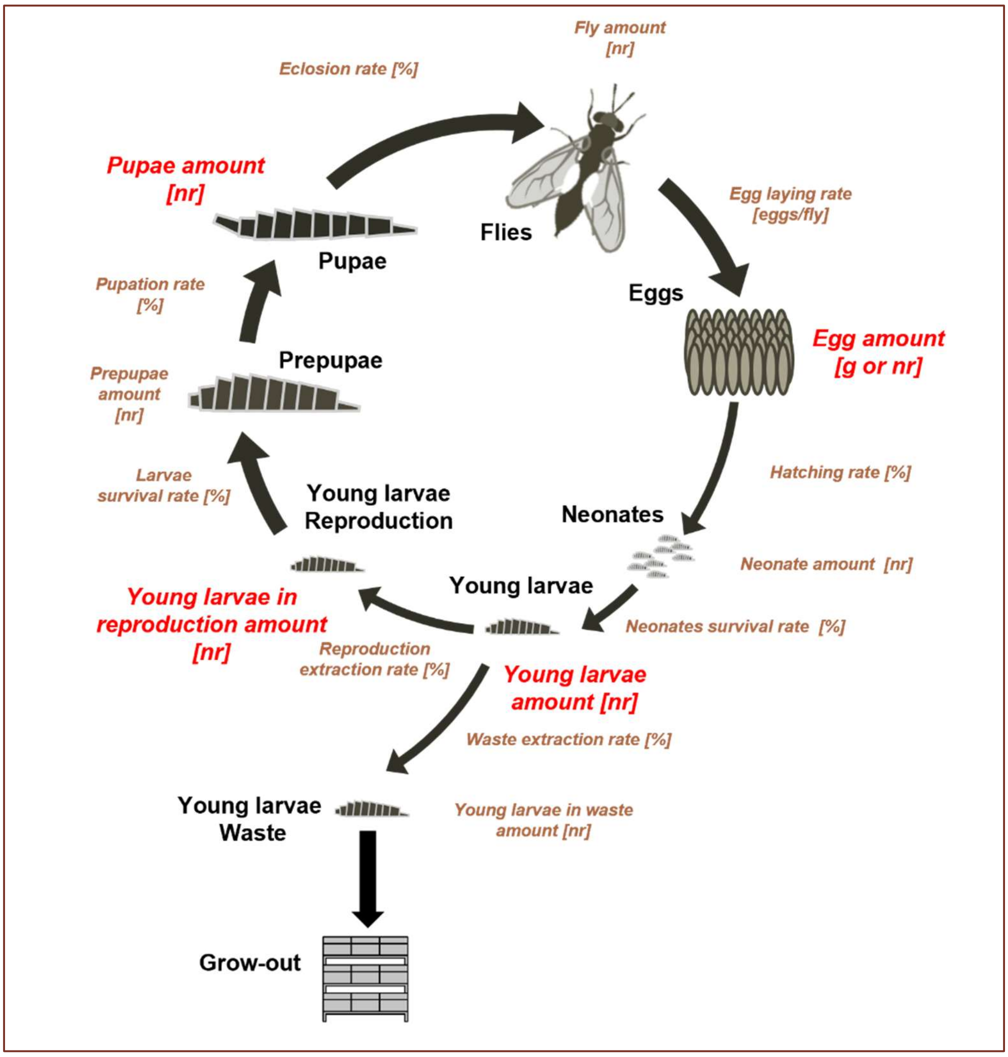
Key performance indicators in BSF farming

3 Key performance indicators in BSF farming

Running a BSF biowaste conversion facility at small (<1 t/day), medium (1-30 t/day) or large (>30 t/day) scale requires continuous and careful monitoring and evaluation of performance. The collected data can be used to alert to performance problems that need consideration. The most common key performance indicators (KPI) can be categorised by element of the BSF facility.

At the reproduction unit, as illustrated in Figure 3-1, monitoring KPIs has the purpose to maintain optimal conditions for BSF pupation, mating, laying of eggs, egg hatching, the first days of larvae feeding and the reproduction larvae feeding to then obtain pupae again.

Figure 3-1 Key performance indicators in a reproduction unit. Key indicators are highlighted in red.



Source: Eawag

One KPI is the Reproduction Performance Indicator (RPI). Depending on available data obtained it can be calculated based on egg weight, RPI-E (for eggs), or based on number of larvae, RPI-L (for larvae). Although RPI-E might be easier to assess, it does not take into account the amount of infertile eggs, dried out eggs, or neonates who never find the feed. Therefore RPI-L is a more accurate measure of performance. RPI-L also helps determine the reproduction extraction rate required to maintain a constant output of larvae in the reproduction unit.

Table 3-1 Formulas for Reproduction Performance Indicator (RPI) of eggs and larvae

RPI-E	$= \frac{Egg\ amount\ [g]}{Pupae\ amount\ [number]}$
RPI-L	$= \frac{Young\ larvae\ amount\ [number]}{Pupae\ amount\ [number]}$

At the grow-out unit, KPIs highlight how well BSF grow and how well the substrate is digested. Important measurements include:

- Biowaste amounts fed (kg weight/container)
- Moisture content of biowaste substrate and frass (%)
- Young larvae added (number/container or weight/container)
- Harvested larvae (number/container or weight/container)
- Harvested frass (weight/container)

This data allows the calculation of KPIs such as:

Table 3-3 KPIs for the grow-out unit

Key performance indicator	Formula	Description
Bioconversion Rate (%)	$= \frac{\text{Larval biomass gain (kg)}}{\text{Biowaste amounts fed (kg)}} x100$	Measures how efficiently larvae convert biowaste into larval biomass.
Waste Reduction Rate (%)	$= \frac{\text{(Initial substrate − Residual substrate)}}{\text{Initial substrate}} x\ 100$	Measures how much waste was reduced.
Survival Rate (%)	$= \frac{\text{Number of harvested larvae}}{\text{Number of young larvae added}} x\ 100$	This indicates the percentage of larvae that survive to the harvest stage.

Finally, also economic parameters should regularly be monitored to assess the financial viability of the operations. These include operational costs per tonne of biowaste converted (salaries, consumables), depreciation costs on capital investments, as well as revenues, which allow to calculate net profit, return on investment, and the net present value.

Operational models in BSF biowaste conversion

4 Operational models in BSF biowaste conversion

4.1 Production models

In biowaste conversion, feed production or any other agricultural activities, different production models can be distinguished, based on how and where the production takes place or where the "services" are rendered. Production models vary based on scale, type of resource inputs and organisational or entrepreneurial setup.

4.1.1 Scale of operations and choice of technology

Decisions on the scale of operations and the application of technology and equipment versus the use of human resources is one key decision in the planning and setup of a BSF facility.

In high-income countries, most facilities rely more on technology and automation and less on human labour, among others because of high labour costs. Given that this sector is relatively new with high complexity, the availability of suitable technology still remains limited and expensive. Additionally, increasing technological investment and their application goes hand in hand with the choice for larger scale of production in order to maximise economies of scale.

In low and middle income countries with lower labour costs, low-tech approaches that rely on human resources have a competitive advantage. This also provides more opportunity to run at smaller scale of operations and rely on simple equipment, appropriate for the local context. The trade-off of operating at small scale is the respective low product output and high relative cost of substrate procurement as well as marketing and sales expenditures per unit of product generated. Small scale BSF activities therefore often target "self-use" rather than being operated as an entrepreneurial activity with profit making ambitions.

This toolkit focuses on low and middle income countries, therefore setting a focus on simplified small to medium scale, mainly labour-based, non-industrialised scale BSF biowaste conversion. The choice of systems covered in this toolkit focuses only on systems 2,3 and 4 of the six systems as described by Climate and Clean Air Coalition (2025):

- SYSTEM 1: Micro-scale home system
- SYSTEM 2: Simplified BSF Approach SIMBA
- SYSTEM 3: Centralised facility in tropical region
- SYSTEM 4: Container-based/decentralised system
- SYSTEM 5: Centralised medium- to large-scale facility
- SYSTEM 6: Large-scale industry pioneers

SYSTEM 2: The Simplified BSF Approach (SIMBA) is a setup typically operated as a part-time activity by farmers. The scale is in the range of 50 kg up to 250 kg of substrate processed per week. Work is carried out manually relying on very simple and partly "Do-it-Yourself" equipment. The infrastructure comprises a reproduction and a grow-out shed, shaded but well-ventilated, and protected from rain and wind. Operations include chopping of biowaste obtained from local sources and the use of several smaller and larger plastic containers for conversion. The reproduction is kept as simple as possible, where pre-pupae develop into flies that lay eggs within a single enclosure. The produce is typically used on-site (self-use) or targets sales of products to small-scale farmers in the neighbourhood or the local pet food market.

SYSTEM 3: This system is of medium and operated as dedicated business and entrepreneurial venture, converting between 1 ton and 15 tons of substrate per day. Waste is sourced from selected sources such as market waste, leftovers from a fruit juice factory, or/and leftover food from a restaurant chain. Quality and quantity of the substrate must be reliable. Due to the larger scale, operations are throughout the year on 5-7 days per week. The infrastructure needs include a reproduction and a grow-out shed with a concrete floor, shaded but well-ventilated, and protected from rain and wind. Some simple climate control might be required (heating/cooling technology) but the setup relies on suitable warm ambient temperatures in its geographic location. As in system 2, the bulk of work is carried out by manual labour, but working full time at the facility. Mechanized equipment is used for shredding and mixing of the waste and for the sieving of products after the conversion step. The larvae and frass products are typically sold to local customers, either fresh or else processed by drying (larvae) or composting (frass).

SYSTEM 4: This system is based on a model where a central facility, operates a reproduction unit at larger scale, and then a decentralized series of autonomous grow-out units are located close to the source of waste generation. As the conversion process is simple, only the climate needs to be controlled at the grow-out units. Young larvae are provided by the reproduction unit to the grow-out units, and grown larvae and frass are collected from the grow-out units and further processed and sold through the central operations. Usually, these types of grow-out units could treat up to five tons of biowaste per day. This system works well when a larger amount of biowaste is produced at one location (e.g. market, industry) but lacking a nearby solution to manage this waste. It also shows advantages when existing road infrastructure is deficient, and transport of large waste amounts would be challenging.

4.1.2 Location of operations

The location of BSF biowaste conversion can be chosen based on three different approaches: a centralized approach, a decentralized approach, and a hybrid hub & spokes model.

In the **centralized production model**, all BSF biowaste conversion processes are located in one facility. Biowaste is collected from various sources and transported to a central plant, where a reproduction unit is operated and where the biowaste is then converted to larvae and frass. This setup emphasises central control, tries to maximize efficiency, consistency, and benefits of scale. In a centralized operation it is easier to monitor and standardize feedstock, larvae care, and output products (e.g., protein meal, frass). However, as this involves transport of large amounts of wastes from different sources to the BSF location, vehicles and transport costs may be required. Ideally, such a model works best if "waste delivery" and its costs is managed by another entity (e.g., the municipal waste management department). Use of the products can be on-site - in the case of a farm - or else can be sold by centralized marketing by the way of retailers or through bulk customers.

In a **decentralized production model**, the BSF biowaste conversion is spread across many small, local facilities. Each facility handles waste that is generated nearby. Typically, the scale of operations is small to medium, and products are either used on-site (self-use) or sold to customers in close proximity (farmers and community). These multiple small operations may work fully independently (including reproduction, grow-out and processing) or work in a network thus benefitting from some common supply chains, some common product refinement processes, or for common sales and marketing pathways. However from a business perspective each unit works independently.

The hybrid **hub-and-spoke** production model is an approach that combines the strengths of both centralized and decentralized production as a combined entrepreneurial approach in order to optimize logistics and consistency, and benefit from economies of scale. Here a central processing facility - the hub - is in charge of critical operations such as the reproduction unit and possibly the final product processing (e.g., drying larvae, selling larvae, packaging and selling frass), whereas the spokes are a network of smaller, local grow-out facilities (e.g., farms, waste generators, or community processing points) that handle initial steps like biowaste substrate sourcing and preparation, the substrate processing (grow-out) and potentially also the product processing and sales. The grow-out units can be operated as described in SYSTEM 2 or as in SYSTEM 4. The advantages of this hybrid model is the centralized control over quality and technical steps and increased overall scale, but nevertheless maintaining the flexibility to add new spokes, and a flexibility of each spoke to adapt to the local waste and technical capabilities. This model offers a balanced approach–combining centralized efficiency with decentralized reach–making it particularly well-suited for circular economy initiatives in regions with diverse and scattered waste streams.

4.2 Main value proposition and business model

Different key value propositions and respective business models can be pursued for BSF biowaste conversion based on products and production setup. Here we distinguish four different business models with regards to their main value proposition, adapted based on Climate and Clean Air Coalition (2025). Thereby, these different value propositions can also be combined in the same business model. The business models are:

1. Feed and/or frass production,
2. Waste management and carbon credits,
3. Producing eggs or young larval offspring, and
4. High value niche products.

4.2.1 Feed and/or frass production

Main value proposition of this business model is:

- Self-use or sales of larvae as animal feed as sustainable alternatives to fishmeal and soymeal and
- Self-use or sales of frass as alternative to compost, soil improver, and/or chemical fertilizer.

To ensure stable and reliable larvae and frass product quality and consistency, such a business typically uses selected homogenous and highly nutritious by-products as substrate to grow larvae. This may include waste from food processing industries, breweries, pulp from the fruit juice industry, or other organic by-products from the food or agricultural sector. Sales of products mostly rely on obtained product certification, strong marketing with demonstration and providing recommendations of product usage. Stable product quality relies on stable substrate quality and composition as well as strict adherence to standard operating procedures. In marketing, price competition with conventional feed is typically a challenge. Therefore, a focus should be set on highlighting the added value/benefits of the products in order to gain competitive advantage. Self-use of the products may be included within an integrated agricultural operation with the added benefit of strengthened independence from feed supply chains and even reduced expenditures for feed acquisitions. In such self-use cases, additional profits can also be generated through the sale of higher-quality chicken eggs, faster-growing broiler chickens, and improved fish and pig production.

Figure 4-1 Business model canvas for feed and/or frass production

➢ Key partners	➢ Key activities	➢ Value propositions	➢ Customer relations	➢ Customer segments
Stable and reliable supply chain for substrates (selected waste producers) Transportation partner (optional)	Efficient and reliable operation of reproduction and grow-out unit to produce high quality larvae and frass **➢ Key resources** Competent staff Cost effective technology Standardized operations Brand	Competitive price for local feed and fertilizer products Customers reduced reliance on external (import) products and respective price fluctuations	Recommended product usage Demonstration of benefits **➢ Channels** Product delivery Agricultural extension services	Feed producers Retail Livestock farmers (chicken, fish, pigs, ducks, etc.) Fertilizer producers Crop farmers Plant nurseries Landscapers
➢ Costs Salaries Expenditures for equipment operations Marketing and sales Cost of waste substrate (?)		**➢ Revenue stream** Sales of larvae and frass Cost savings in feed and fertilizer acquisition (with self-use of products)		

Source: Eawag

4.2.2 Waste management and carbon credits

Main value proposition of this business model is to provide a more sustainable alternative of a waste management service. Hereby, the focus is on treating biowaste in an environmentally safe manner and diverting waste from otherwise uncontrolled disposal with its respective high greenhouse gas (GHG) emissions. This business approach relies on getting paid for waste treatment (called "gate fees") and the reduction of GHG emissions via the selling of carbon credits.

In many countries, commercial and industrial businesses are required to independently manage their waste properly. In such cases, opportunities arise for a BSF business to receive and treat this waste in compensation for a "gate" fee. Handling of specific environmentally threatening wastes, such as invasive water hyacinths or slaughterhouse waste may also be an option. As trade-off, the business may face challenges in operations and product quality. As many different biowastes should be managed, these may not all be very suitable for BSF larvae growth. This might lead to lower amounts of larvae product and lesser consistency of product quality.

Carbon credits in BSF biowaste conversion may increasingly play a valuable role as a revenue stream. However, this has yet to be fully developed and is still in its infancy. Carbon credits are tradable certificates that represent the reduction, removal, or avoidance of one metric tonne of carbon dioxide equivalent (CO_2eq) emissions. BSF-based biowaste conversion helps to avoid emissions from traditional waste management practices (uncontrolled disposal) and industrial feed and fertilizer production. For every tonne of biowaste diverted from a disposal site, methane (CH_4) emissions are avoided, which amounts to 1.15 tonnes of CO_2 equivalent avoided. Net emission reduction by BSF conversion instead of disposal, amounts to 1.1 tons of CO2 equivalent per ton of biowaste converted. This corresponds to an avoided consumption of around 470 liters of petrol per ton of biowaste converted. Using larvae and frass instead of fishmeal soymeal or fertilizer also avoids emissions related to the production of these conventional products although this is not yet quantified systematically. Furthermore, the use of frass also improves soil carbon retention (carbon sequestration) another GHG mitigation measure. Benefitting from the carbon credit market however requires an approved net carbon emission reduction monitoring and verification methodology. This is still under development.

This toolkit provides an excel-based BSF-GHG emission "calculator" that can be downloaded for free and regards operations as described in SYSTEM 2:

- GHG emission calculator

Based on the scale of operations (i.e. intended waste amounts to be processed) this tool estimates emissions as CO_2 equivalents using values from scientific studies, as well as established methodologies shown as:

- **Direct Emissions:** which comprise the GHG emissions from the BSF reproduction and grow-out, and from the frass composting process.
- **Indirect Emissions:** which comprises all emissions linked to the use of fuel and electricity consumption to operate the whole BSF process (e.g. transport of substrate, operation of mechanized equipment). The tool does not consider fuel or electricity related to climate control under the assumption that the ambient climatic conditions are suitable for BSF biowaste conversion.
- **Avoided Emissions:** which comprises all emissions which would be produced if this waste were to instead be dumped in disposal sites or composted. The avoided emissions from use of larvae and frass hereby avoiding fishmeal production and transport as well as fertilizer are currently not considered in this tool.
- **Net avoided emissions:** which is the difference between the avoided emissions and of the sum of direct and indirect emission. This is the amount of emissions that can then be credited as emission savings (e.g. carbon certificates).

Figure 4-2 Business model canvas for waste management and carbon credits

Key partners	Key activities	Value propositions	Customer relations	Customer segments
Waste management services or waste producers Transportation partner (optional) National authortities Carbon trading partners	Waste conversion Emission monitoring **Key resources** Competent staff Cost effective technology	Competitive price for low-emission waste management solution Transparent monitoring and auditing of emissions and emission savings	Carbon trading certificate customers Demonstration of benefits **Channels** Certification of emission reduction	Primary: Waste management authorities Large waste producers National authorities in charge of national emission targets Secondary: Potential customer for BSF derived products

Costs	Revenue streams
Salaries Expenditures for equipment operations Certification development Monitoring/Auditing of emission certificates	Sales of CO2 equivalents Gate fees for waste management

Source: Eawag

4.2.3 Eggs or young larval offspring production

The main value proposition of this model is the sales of eggs or young larvae to other BSF facilities. This may be a one-time sales for BSF start-ups or intermittent or regular sale for BSF facilities that face reproduction challenges or do not operate a reproduction unit. This approach is comparable to other animal husbandry where specialized breeders provide young animals (e.g. chicks, piglets) to farmers who then rear them to maturity.

Advantages of this model is its independence from biowaste substrate sourcing. The business needs to ensure the specialized knowledge of reliably operating the reproduction unit, a more delicate and sensitive operation.

Figure 4-3 Business model canvas for eggs or young larval offspring production

Key partners	Key activities	Value propositions	Customer relations	Customer segments
BSF farmers and operators	BSF reproduction Network management Shipping and delivery of products **Key resources** Competent staff Cost effective technology Efficient and stable reproduction	Competitive price for eggs and young larvae Safe, reliable and regular shipping of products to customers	Customer retention Demonstration of operations for start-ups **Channels** Customer retention through network and/r cooperative structures	BSF operators/farmers (grow-out units) BSF start-ups Research and academic facilities

Costs	Revenue streams
Salaries Expenditures for equipment operations Marketing, sales and shipping	Sales of eggs and young larvae

Source: Eawag

4.2.4 Production of high value niche products

In recent years some businesses have tried to focus their value proposition not on feed and fertilizer but rather on high value niche products that can be obtained by BSF biowaste conversion. Those include chitin/chitosan, melanin and bio char, among others.

Chitin/Chitosan: The exoskeleton of insects contains the polymer chitin, which when deacetylated becomes chitosan which have possible markets.

- Agriculture: Chitin/Chitosan enhances soil microbiota, stimulates plant growth and triggers plant immune responses. It also improves germination and disease resistance.
- Medical & Pharmaceutical: Chitosan promotes tissue regeneration and has antimicrobial properties
- Water Treatment: Chitosan binds suspended particles in water, aiding in purification or helps removes toxins from industrial wastewater
- Food Industry: Biodegradable chitosan films are used for food packaging
- Cosmetics: Chitosan is used in lotions, anti-aging creams, and shampoos due to its film-forming and antimicrobial properties

Melanin: All BSF life stages contain the high molecular weight pigment melanin. It serves as an antioxidant and gene-protecting agent, possesses antimutagenic properties, and can absorb heavy metals and neutralize lipid peroxidation products. Melanin can also be seen as a natural semiconductor and therefore may find its application in biodegradable electronic devices in medicine or non-recoverable monitoring gadgets in sensitive environments.

Biochar: Biochar can be produced from pyrolysis of BSF frass. Biochar can be used as a soil conditioner, to capture and sequester carbon is soils. Char can also be briquetted to substitute wood-based charcoal, one of the most common cooking fuels worldwide.

Figure 4-4 Business model canvas for production of niche products

Key partners	Key activities	Value propositions	Customer relations	Customer segments
Stable and reliable supply chain for substrates Transportation partner (optional)	Efficient and reliable operation of reproduction and grow-out unit	Conversion of waste to larvae and frass Conversion and treatment of harvested larvae and frass to niche products	Recommended product usage Demonstration of benefits	Specialized customer segments for niche products
	Key resources		**Channels**	
	Competent staff Cost effective technology Quality control Brand		Custom-made product refinement Consulting services for product as alternative to conventional material	
Costs			**Revenue streams**	
Salaries Expenditures for equipment operations Specialized operations for product refinement Marketing and sales			Sales of substances refined from BSF derived products	

Source: Eawag

Standard operating procedures

5 Standard operating procedures

Standard operating procedures (SOPs) are a detailed set of step-by-step well-defined procedures designed to guide operators in performing a specific routine task or process consistently. In BSF biowaste conversion, SOPs play a critical role in ensuring the success, safety, and scalability which contributes to effective reproduction in the BSF life cycle, as well as consistent output and quality of larvae, frass, and by-products. In the reproduction unit as well as the grow-out unit they help standardize tasks - and their timing at different stages of the process. Depending on the scale of operations, activities may involve daily tasks or when operating at small scale also task that are needed just a few hours per week on selected days. This helps maintain reliable larvae growth rates and product composition regardless of operator or location. The main advantages of strictly following SOPs can be summarized as follows:

- *Hygiene and biosecurity:* Adhering to SOPs are critical to prevent pathogen build-up and disease outbreaks. They include tasks such as regular cleaning and waste handling, protecting both worker health and your flies and larvae.
- *Performance monitoring:* Using SOPs consistently also ensures monitoring of KPIs and problem detection at an early stage.
- *Skills and workforce efficiency:* SOP are helpful as they simplify training of new staff and support supervision by clearly describing procedures. This might also reduce human error and improve overall operational efficiency.
- *Scalability and replication:* Validated SOPs help with the replication of BSF conversion at other sites or by other operators.
- *Regulatory compliance:* Following SOPs can demonstrate to the regulators how the facility adheres to local and international standards and legislation regarding hygiene, feed/food safety, and environmental protection. This may then help with certification of BSF derived products.

This toolkit provides SOPs for two different scales of operation:

- **Small scale - SIMBA:** This describes a simplified BSF approach which is operated part-time at smaller scale, requiring just a few workhours per week on selected days. SIMBA is suitable for a first step entry into BSF biowaste conversion or for a small unit that conducts BSF biowaste conversion as a part time side activity (e.g., on a farm). Two SIMBA SOPs are available for free use:
- Simplified Black Soldier Fly Approach (SIMBA) – Reproduction Unit: Standard Operations Procedure. Published in 2025
- Simplified Black Soldier Fly Approach (SIMBA) – Grow-out Unit: Standard Operations Procedure. Published in 2025
- **Medium scale - Step by step guide to BSF biowaste conversion:** This document explains the required materials and equipment, as well as each working step, required to develop and operate a medium-sized BSFL waste processing facility, able to treat 5 tonnes of waste per day.
    - Black Soldier Fly Biowaste Processing - A Step-by-Step Guide, 2nd Edition, Published in 2021

Planning and scaling BSF biowaste conversion

6 Planning and scaling BSF biowaste conversion

6.1 Assessing feasibility

Considering the possibility of becoming a BSF entrepreneur and operator requires a first step to assess if the local conditions favour BSF biowaste conversion. This is comprised in a feasibility assessment, targeted to the select area of your potential future BSF facility.

A detailed guide on how to conduct a feasibility assessment specific to BSF biowaste conversion is described in "Is Black Soldier Fly waste-processing a sustainable solution? A feasibility assessment approach" published in 2024 and available for free online.

Once the geographic area of the potential BSF facility is defined, the feasibility assessment guide mentioned above indicates what aspects to evaluate and suggests how to best do it. While the results of the assessment will not give an absolute YES or NO, the gathered information will help identify opportunities but also indicate possible threats that a BSF biowaste conversion set-up might face.

Regulatory review: National and local laws and regulations may affect substrate sourcing, BSF operations and markets for BSF products. It is therefore important to carefully evaluate existing policies, legislation, by-laws, rules, regulations that affect BSF facilities and operations, either positively or negatively. For example:

- As biowaste is the source, BSF activities might be influenced by legislation specific to waste (i.e., biowaste) management.
- As farming larvae is similar to any other animal husbandry, this activity may fall into the same category of regulations that apply to other farmed animals that are bred for animal or human consumption.
- If you want to sell or use products derived from BSF biowaste conversion you will need to check on regulations pertinent to animal feed or fertilizer use. These may be regulated by agricultural legislation.

Feedstock (Substrate) assessment: An important aspect of the feasibility assessment involves the source and quality of the biowaste available as the main feed for the larvae. Availability, consistency and nutritional quality of feedstock are important for the performance and profitability of BSF biowaste conversion enterprises. Therefore, it is key to understand what and how much feedstock can be accessed, and from where. Ideally the goal is to ensure a low cost, nutrient-rich, and stable supply chain of substrate for the BSF operations. Examples of questions that must be answered are:

- Do certain biowaste substrates have a cost?
- How and who will manage the transport?
- Can offtake agreements be easily secured?

When conducting the feasibility assessment, consideration should not necessarily be about only one type of biowaste that leads to the highest growth. Rather, mixture of biowaste types can also be considered, which allow an optimal efficiency considering accessibility and costs, handling time, biowaste safety and bioconversion rate.

Market research: Understanding the market for the specific value proposition is a key aspect when assessing financial sustainability. This is often challenging, as markets around BSF are still in their infancy, be that for BSF as waste service, for sales of BSF eggs or young larvae, for larvae as animal feed, for frass, or for niche products. This makes it difficult to determine market volume and prices. Nevertheless, possible price ranges based on current services rendered or products currently being used provide a first estimation. Understanding customer needs and perceptions further allows insights on how the BSF product needs to be refined before sales and indicates customer perception regarding the product and their willingness to switch from conventional products to BSF products.

Operational environment: Climate suitability of the potential location, as well as the availability of land and human resources are further aspects to carefully evaluate in a feasibility assessment. Although BSF biowaste conversion is also possible if climatic conditions are unfavourable, this will come with a higher capital cost of the building infrastructure as well as higher operational cost, for example for climate control inside the facility. Unfavourable conditions might thus threaten financial viability.

6.2 Business strategy and planning

The outcome of the feasibility assessment is fundamental for the next step - to develop a business strategy and development plan. This involves deciding on a production model (scale and level of technology), as well as the selected value proposition (see Chapter 5).

6.2.1 Financial assessment

The planning of a BSF facility also requires a preliminary financial cost-revenue plan which estimates capital expenses (CAPEX) (e.g., construction, equipment) and operating expense (OPEX) (e.g., labour, feedstock logistics) based on the selected scale of operations. This toolkit provides two different tools to roughly estimate the costs of a future BSF facility:

- For small scale operations, based on the SIMBA operations, an **excel-based cost-revenue model** can be downloaded for free. Based on the intended scale of operations (defined by the biowaste amount to be processed weekly), input of some equipment unit costs the tool allows to see what investments would be necessary and what revenues would be required to break even. Although at this small scale "workforce" is not assumed to be a cash expenditure, the model nevertheless also allows to enter "salaries" as a cost item.
- Similarly for medium scale operations, as described in the step-by-step BSF guide, an **excel-based cost-revenue model** can be downloaded for free with similar functions. This model assumes full time staff (given the larger scale).

6.2.2 Pilot design and proof of concept

Instead of rushing into full-scale operations, it is highly recommended that BSF operations start small and then proceed with incremental scaling. This allows to learn at small scale, improve and streamline procedures and optimize equipment if needed. Piloting at small scale first also helps limiting the risk of failing operations caused by a lack of practical knowledge about processes and markets. Hence, this also avoids disproportionate capital investments up-front. Piloting the BSF biowaste conversion activities can be beneficial for various aspects:

- **Prediction of future costs:** Based on financial data from the operation of a pilot facility, it is easier to estimate costs of a future scale-up as data is specific and locally relevant. For example, procuring the biowaste for the pilot facility will allow to make realistic assumptions about feedstock cost (e.g., price and transport costs) and will assist with negotiations on securing offtake agreements.

- **Establishing of relevant KPIs:** Testing the grow-out unit with the locally accessible biowastes will give insights on larvae growth (Bioconversion Rate (BCR)) and waste reduction (Waste Reduction Efficiency (WRE)) (see chapter 3).
- **Testing functionalities**: Equipment and operational procedures (e.g. larval density, and feeding regimes) can be tested for their applicability under real conditions. Consider equipment that is available locally and adapt technologies from other sectors. This will help to finetune procedures and equipment design to ensure efficient and stable output of eggs and young larvae, and a well working grow out unit.
- **Test the sales market:** First production of larvae and frass will allow to conduct composition and quality control of the products and provide the opportunity to make a first entry into the markets. This includes building customer relationships, for instance by giving BSF products to target customers for testing and collect feedback on quality and usability.
- **Capacity development:** Operating a pilot facility will allow to stepwise build skills of the staff and gain hands-on experience.
- **Establish stakeholder engagement:** The demonstration of successful operations at pilot scale can serve to attract potential investors for scaling or potential off takers for products. It can further serve as a demonstration site for marketing purposes and to achieve or secure a licence to operate.

6.2.3 Overcoming challenges in developing your business

Although BSF biowaste conversion is basically no different from animal husbandry, it lacks long term sector experience with corresponding technological development and optimization. As with all innovation, doing something new usually means stepping into uncertainty – both in technical and commercial terms. Difficulties can arise regarding scaling, staffing and team, as well as markets.

Scaling: Many BSF facilities face difficulties when scaling their operations from pilot scale to commercial endeavours. Incremental scaling and modularity is one way to mitigate this risk. With well established procedures and gradually acquired skills from the pilot facility operations, a stepwise increase of scales and operations using a modular approach in terms of infrastructure and equipment reduces the risk of high CAPEX, and design errors.

Staffing and team: The skills and experience of the team working at the BSF facility are crucial elements of BSF biowaste conversion. Problems and challenges are unavoidable, but how operators react, adapt, and prevent recurrences is what makes them outstanding.. Experience shows that people that have previously been active in the agriculture sector (e.g., plant and animal farming) have a suitable background to engage in and rapidly learn the specificities of BSF biowaste conversion.

Positive experiences have been made by providing training opportunities (e.g., online and offline resources) for staff and enabling them to connect to other like-minded people. Online BSF communities of practice are becoming more widespread and facilitate exchange, supporting network development and knowledge exchange; as for example the BSF-Africa WhatsApp community.

Markets: If the business model relies on sales of products, then it is important to allocate enough time for product development in close relationship with the customers and a wide range of stakeholders. This helps to understand what customers expect from the product. Experience shows that customers want to have evidence on the benefits of the product and want assistance on how the products (i.e., larvae or frass) should be used.

Being able to answer questions such as *How can feed be formulated when including BSF larvae?* or *How much frass should be applied on soil for different crop type?* may require preliminary trails with the products on-site or providing a demonstration plot where customers can visit and experience it themselves. Furthermore, obtaining product certification can add value to the products and build confidence in the products, although obtaining this may be a tedious process.

Trouble shooting in BSF biowaste conversion

7 Troubleshooting in BSF biowaste conversion

Problems and challenges in operations of BSF biowaste conversion will inevitably occur. It is therefore highly relevant to identify the problem - “the trouble” - at an early stage and understand its causes to then resolve the issue. Thereby, such an incident can be used as a learning event to adapt control and procedures to avoid this problem from reoccurring. Furthermore, measures should be put in place so that when the same problem reoccurs it can be dealt with in the most effective way possible. Hence, troubleshooting comprises:

- **Observation** – Look for deviations from the normally expected.
- **Measurement** – Process and analyse data that shows evidence of the deviation.
- **Isolation of corrective measure** – Changing only one aspect at a time to best identify the specific cause of the problem.
- **Correction** – Implement the correction, and fix and monitor their effect closely.
- **Documentation** – Record the problem and the implemented solution for future reference.
- **Learning** – Building on the process of troubleshooting will allow to implement preventive measures to ensure that this problem does not reoccur.

Based on shared experiences at BSF biowaste conversion facilities, preventive measures should be implemented to reduce the likelihood of problems. These measures include:

- Implement SOPs for feeding, cleaning, and harvesting.
- Conduct regular waste quality checks before feeding.
- Maintain good hygiene to reduce risk of pathogens and parasites.
- Monitor and analyse environmental and operational parameters meticulously to detect deviations at an early stage.
- Train staff in biosecurity and early problem detection through careful observation.

8 Key readings

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ABOUT THE CCAC

The UNEP-convened Climate and Clean Air Coalition (CCAC) is a voluntary partnership of more than 190 stakeholders including more than 91 country partners seeking to reduce methane and other super pollutants to limit global warming to 1.5°C. Through its Trust Fund, the CCAC supports countries to reduce super pollutants emissions across sectors by 2030, while advocating for elevated ambition and advancing the latest in policy-relevant science. Different funding windows exist, including for institutional strengthening, national planning, policies and regulation as well as sectoral transformation.

Following a decade of success in raising global methane ambition, the CCAC Secretariat is also providing secretariat functions to the Global Methane Pledge (GMP), a voluntary commitment of more than 150 countries to reduce global methane emissions by at least 30% by 2030 compared to 2020 levels.

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

a UNEP convened initiative

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