The Bio-Conversion of Putrescent Wastes

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Putrescent Waste

We generate huge quantities of putrescent waste:

- farm waste from plants, animals and birds,
- food storage waste,
- commercial food preparation waste,
- kitchen waste (institutional, restaurant & domestic)
- plate waste or table scraps,
- human waste.

An exceedingly simple way to dispose of all of the above: larval bio-conversion.

The Black Soldier Fly

The larvae that we have chosen for this waste disposal process is the larvae of the black soldier fly (BSF, *Hermetia illucens*). It is a tropical fly indigenous to the whole of the Americas, from the southern tip of Argentina to Boston and Seattle. During WW II, BSF spread throughout the world. Today it can be found in China, Japan, Korea, the Philippines, Vietnam, Laos, Cambodia, Thailand,

The Black Soldier Fly

Indonesia, Singapore and even Australia. Unlike many other flies, BSF adults do not go into houses, they do not have functional mouth parts, they do not eat waste, they do not regurgitate on human food, and therefore, they are not associated in any way with the transmission of disease. BSF adults do not bite, bother or pester humans in any way. Even though BSF larvae have been known to survive

Enteric Myiasis

inside the human gut if swallowed whole, this only happens under utterly extreme and bizarre conditions and poses no real danger to humans. True enteric myiasis does not exist in man, through the agency of BSF larvae or any other fly larvae, whereas pseudomyiasis can occur, even through the agency of ordinary houseflies, *M. domestica*.

See: http://www.nih.go.jp/JJID/55/191.pdf

The Adult Black Soldier Fly

A Beneficial Fly

Many of you may panic when you see the word "fly," just as we often panic when we see the word "bacteria." Yes, there are noxious, filth-carrying flies that transmit deadly, disease-bearing bacteria. But not all bacteria and not all flies are harmful to humans. Without bacteria and flies, life as we know it on earth could not exist. Both play an essential and vital role in the recycling of nutrients within the

A Beneficial Fly

food chain. Just as benign bacteria compete with harmful bacteria and block their proliferation, so too, the black soldier fly aggressively competes with filth-bearing flies and very effectively blocks their proliferation. Just as we use the larvae of certain Caliphorides to clean out necrotic human tissue, we can use BSF larvae to dispose of the large quantities of putrescent waste generated through human activity.

BSF Life Cycle

BSF adults are around only for the purpose of mating and laying eggs. The adults congregate in small numbers near a secluded bush or tree in order to find and select a mate. After mating, the female searches for a suitable place to lay her eggs. She produces about 900 eggs in her short life of 5 to 8 days. Filth-bearing housefly adults, by contrast, live up to 30 days.

BSF Life Cycle

Half of the population of adult black soldier flies (the males) never go near waste, since males do not lay eggs. Actually the females prefer not to lay their eggs upon the waste, but either above or to the side of the waste. In this way, the eggs have a far better chance of surviving. The eggs are relatively slow in hatching (102 to 105 hours). The newly hatched larvae then crawl or fall onto the waste and begin to

BSF Life Cycle

eat it with amazing speed. Under ideal conditions, it takes about two weeks for the larvae to reach maturity. If the temperature is not right, or if there is not enough food, this period of 2 weeks may extend to six months. This ability of BSF larvae to extend its life cycle under conditions of stress is a very important reason why it was selected for this waste disposal process. BSF larvae pass through 5 stages or instars. Upon reaching maturity, prepupal

Tough and Robust

larvae are about 25mm long, 6mm in diameter, and they weigh about 0.2 grams. The larvae are extremely tough and robust. They can survive under conditions of extreme oxygen deprivation. It takes, for example, approximately 2 hours for BSF larvae to die when submerged in rubbing alcohol. They can be subjected to several 1000 g's of centrifugation without harming them in any way. BSF larvae are

Tough and Robust

strong, robust, flexible, adaptable and very easy to manage. But their greatest attribute, of course, lies their ability to eat and digest raw waste. They can devour, for example, a large, raw, Irish potato in just a few hours. Over a 100,000 active larvae can be found in a typical waste disposal unit, and as soon as waste is deposited in the unit, larvae rapidly migrate toward it and consume it.

95% Reduction in Weight & Volume

Powerful Enzymes

Since BSF larvae have very powerful mouth parts and digestive enzymes, they can ingest raw waste far more efficiently than any other known species of fly. However, they cannot ingest large pieces of food waste of a high cellulosic, calcium or chitin content, such as the shell of a coconut or crab, or a piece of bone. Therefore, it would be advisable to shred these tough objects to a more digestible grain size. This also assures a relatively uniform grain size with

Waxahachie Experiment

respect to the larval residue. In a small experiment conducted in Texas over a period of one year, ESR determined that the BSF larvae can digest over 15 kg's of raw waste per square meter of disposal unit surface per day, or roughly 3 lbs per square foot per day. We also noted a 95% reduction in weight and volume of the food waste. On the surface of the disposal unit, one finds a thick layer of actively

Rapid Digestion

feeding larvae in all stages of growth. The moment food waste is deposited into the unit, it is digested by the BSF larvae, long before it has had a chance to rot and smell. Thermophilic bacteria and anaerobic bacteria never have a chance to degrade complex organic compounds. Therefore, with the help of these tiny creatures, we are able to conserve and recycle most of the nutrients and energy within the waste.

Info-Chemical

While actively feeding, the larvae secrete a chemical, more precisely an info-chemical, that permits them to communicate with other species of flies. This info-chemical or synomone allows them to tell other flies to stay away, that it makes little sense to lay their eggs within an area full of actively feeding BSF larvae. This interspecies communication is, indeed, very effective. In the vicinity of the disposal unit, we note the near absence of houseflies and all other flies

Absence of Flies

that are a pest to humans. After about two weeks of feeding, the BSF larvae reach maturity. They turn from white to black, their mouth parts transform into a digger, they empty their guts of waste, they secrete an antibiotic to protect themselves from bacteria, and they set out in search of an ideal pupation site. BSF larvae will easily crawl over 100 meters in search of an ideal pupation site.

An Ideal Pupation Site

An ideal pupation site must be free of the enormous bacteriological activity which characterizes the waste disposal area, free of small predators such as predatory mites and pseudo-scorpions, and free as well of large predators such as birds, rats and mice. Furthermore, an ideal pupation site is never simply out in the open. It must be a shaded, dry area providing refuge or cover for the mature prepupal

Prepupal Migration

larvae. BSF larvae are negatively phototactic (afraid of light), and therefore most of their migratory activity takes place at night. Their migration initially appears to be a random search for a way out of the waste. If a ramp of an upward inclination lies at the edge of the waste, they will make every effort to climb up this ramp.

Evacuation Ramp

As long as the ramp has an angle less than 45 degrees, the larvae have no problem exiting the waste. Such a steep angle makes it difficult for the larvae to drag or carry along any adhering residue, and it also serves as a barrier for the larvae of most other species of fly. Housefly larvae generally are not even able to climb a dry ramp of a 30-degree angle. If housefly larvae cannot get out of the disposal area, they cannot pupate,

The BSF Fly Trap

and if they cannot pupate, they cannot become adults and reproduce. The BSF waste disposal unit mounted with steep ramps serves as a very effective sink or trap for the larvae of just about every species of flies that ignores the chemical warning to stay away from the unit. Once trapped within the unit, these uninvited larvae and pupae eventually become one more item of food for the hungry BSF larvae.

Totally Self-Harvesting

At the summit of the ramp, an exit hole is provided, and this exit hole then discharges into a collection bucket. BSF larvae are totally self-harvesting. They abandon the waste only when they have reached their final mature pre-pupal stage, and they crawl out of the waste into a container without any mechanical or human intervention. In the picture below, we see mature BSF larvae that have self-harvested into plastic pan.

Neat and Clean

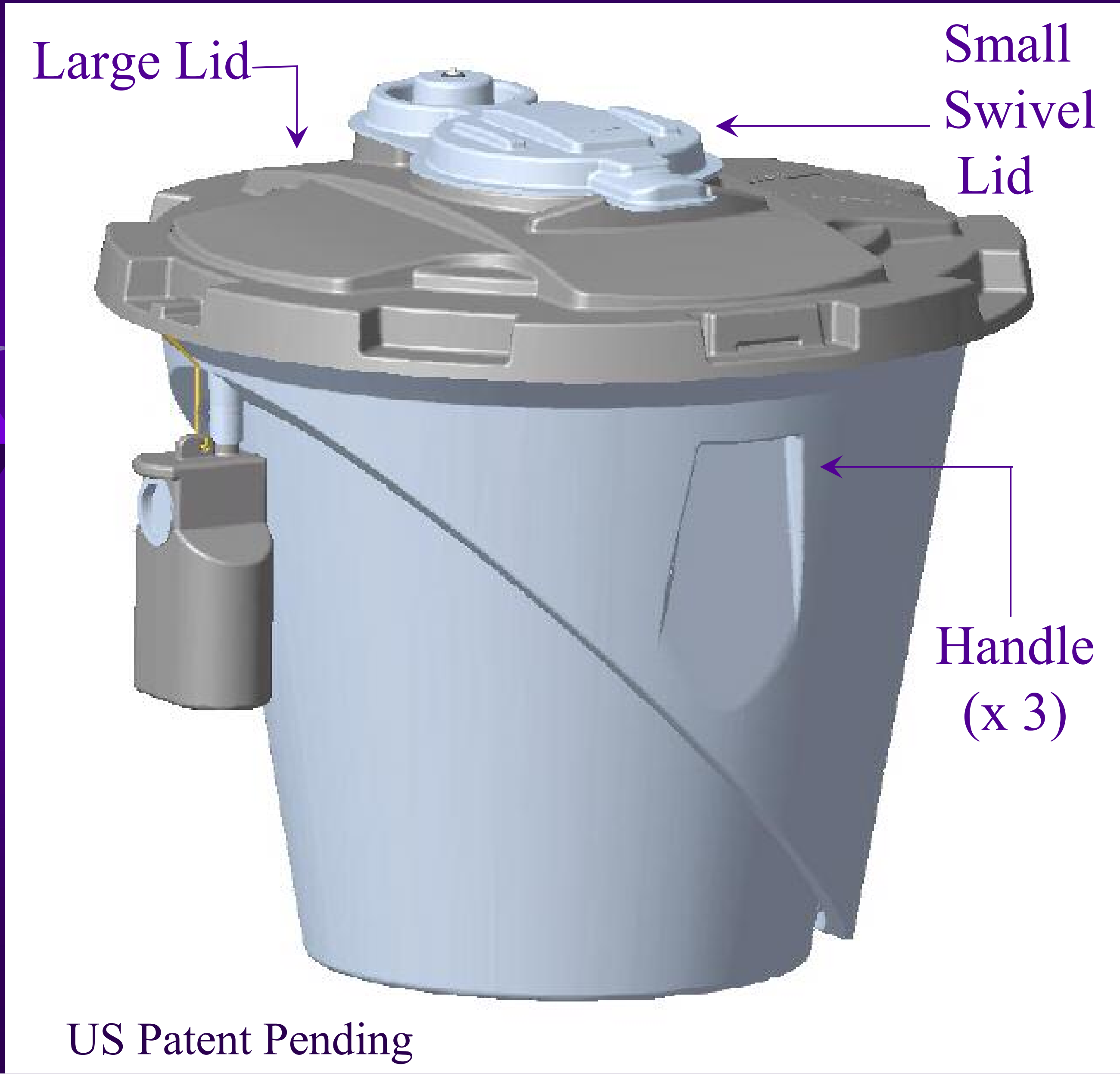
Two BSF Bioconversion Units

ESR will soon begin the manufacture of two BSF bioconversion units: one of a 2-foot base and the other of a 3-foot base. The small unit is designed to be serviced manually, while the large unit is designed to be serviced by means of a forklift. The small unit has two lids and can be situated outdoors. The large unit has but a single lid and must be situated under a roof.

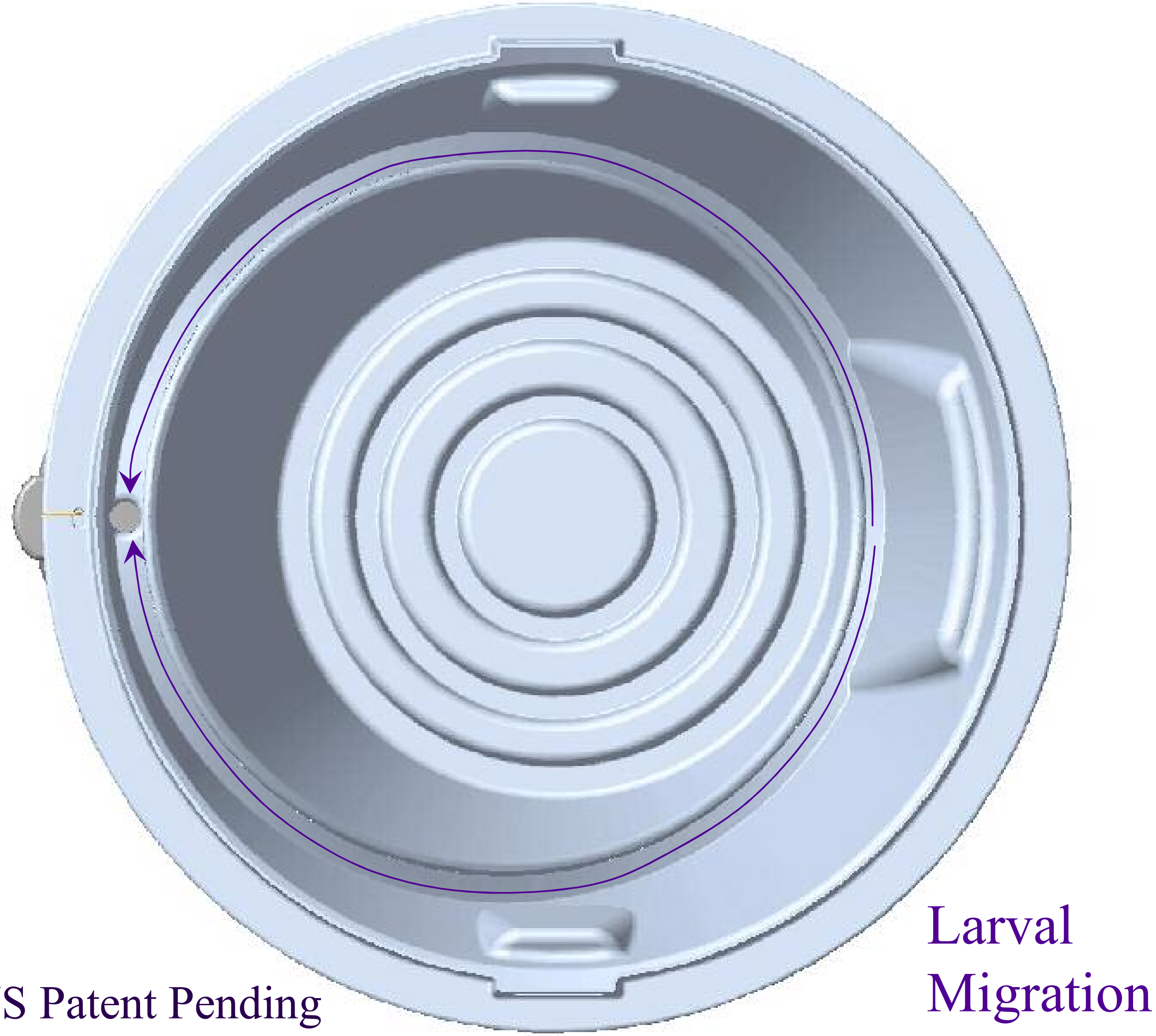
Large and Small Lids

The small unit has a large and a small lid. The small lid is a swivel lid that is easy to open and close for the daily input of waste. The large lid protects the unit from rain and blocks the entrance of birds and other large predators. Three indented handles aid in the servicing and emptying of the small unit.

Small Unit of a 2-Foot Base



Top View Without Lid



US Patent Pending

Two Spiral Ramps

The two ramps of the domestic unit need not be wider than about one inch. Consequently they occupy little space and incur very little loss in the holding capacity of the unit. The two ramps are created by means of a fold in the wall of the container. In this way, there is no underside of the ramp within the container where migrating larvae might uselessly congregate. The round shape of the unit greatly assists the mature

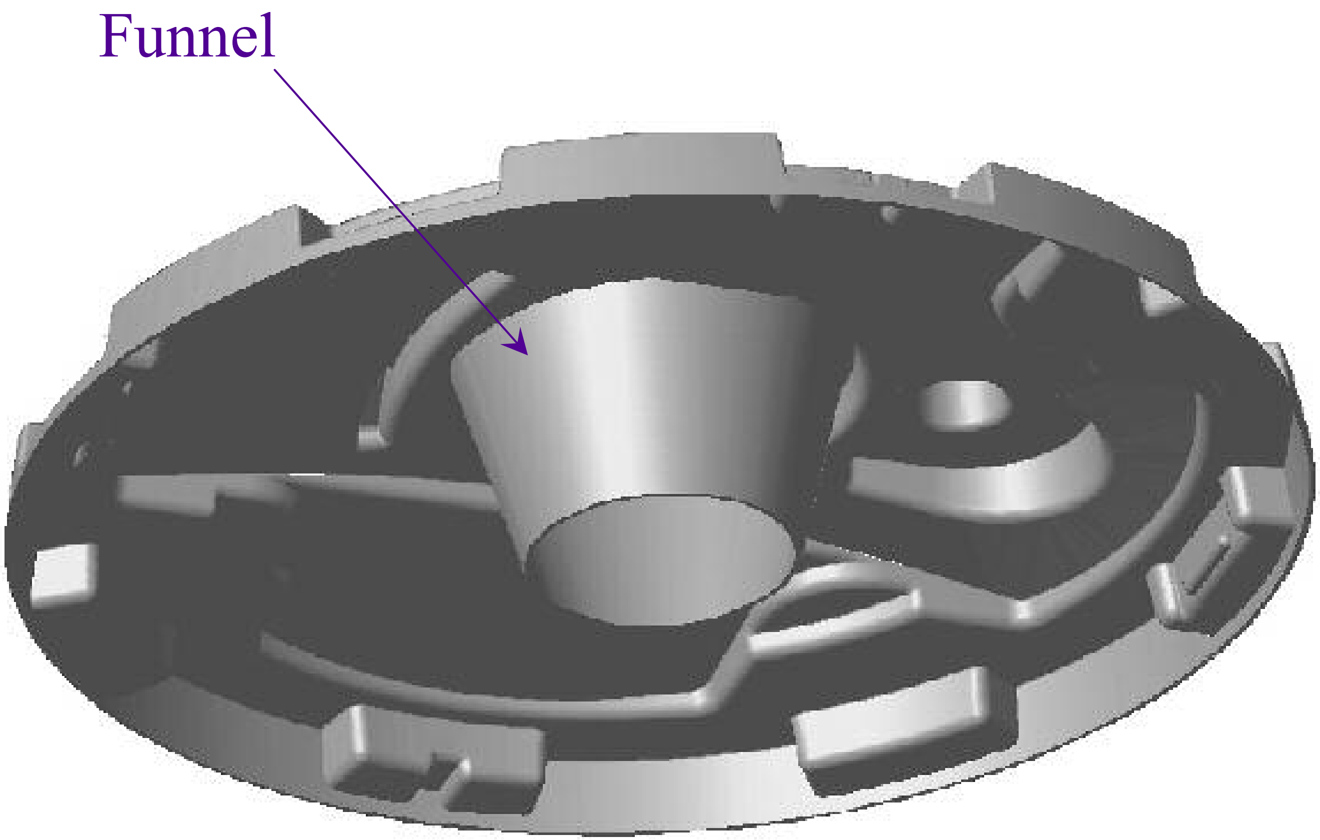
Two Spiral Ramps

prepupal larvae in exiting the unit. As they randomly orient toward the periphery of the waste, they encounter the rounded wall of the container, at which they turn either right or left. If they turn right, they eventually come to the base of the right ramp, and if they turn left, they eventually come to the base of the left ramp. Since the total distance that the larvae have to travel in exiting a unit is very small, the efficiency of larval crawl-off is fully optimized.

Disposal Unit Design

The edge of the ramp is fitted with a barrier that serves as a guide and prevents the larvae from falling off the ramp. The large lid of the small unit includes a non-detachable funnel molded into the structure of the lid. The funnel facilitates the input of waste and, for obvious aesthetic reasons, restricts one's view into the unit.

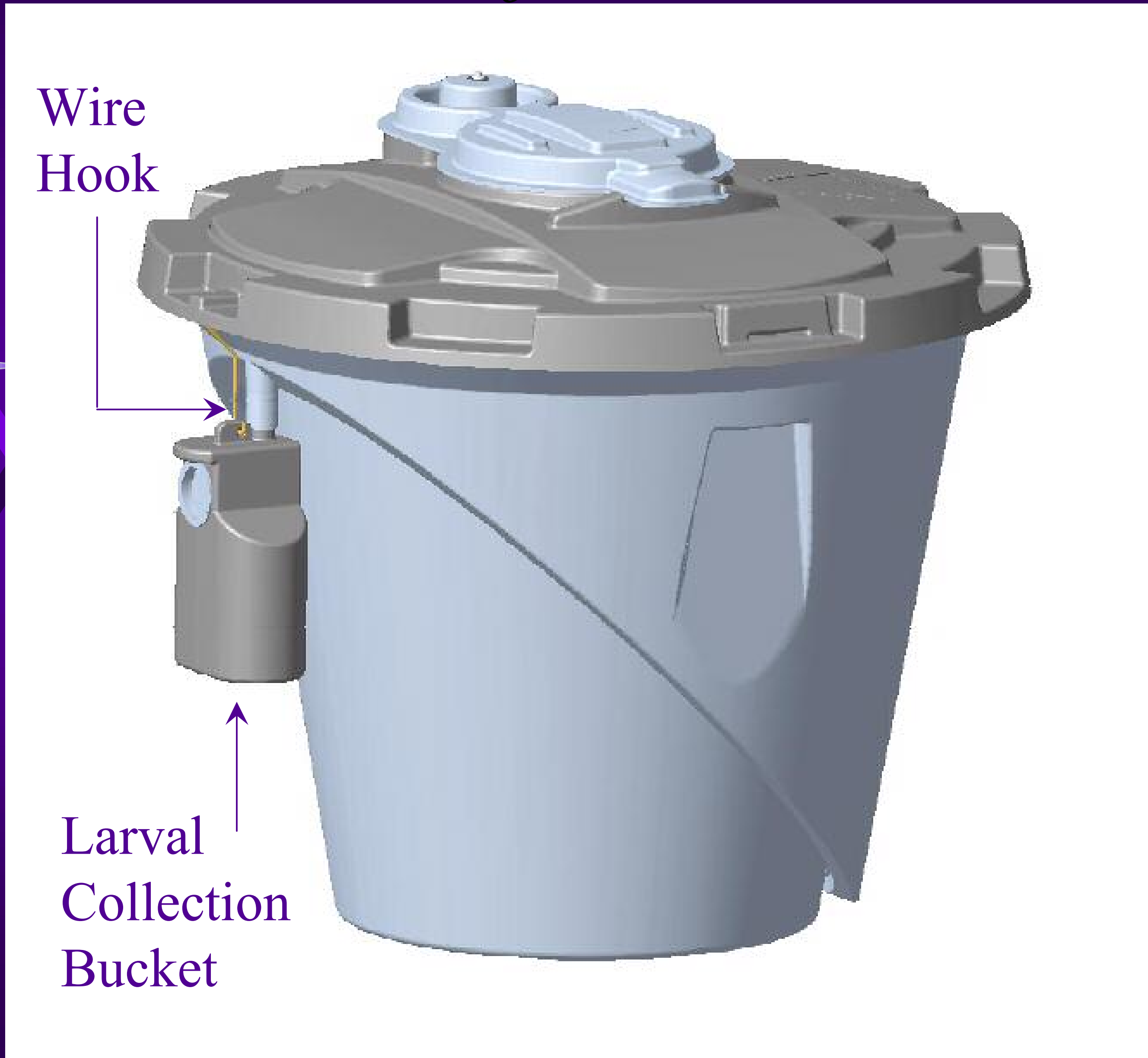
Underside of the Large Lid



The Larval Collection Bucket

The larval collection bucket is suspended from the unit by means of a wire hook. This makes it hard for ants and other creatures to prey upon the harvested larvae. The conical shape and smooth surface of the unit also make it hard for rodents to gain access to the unit.

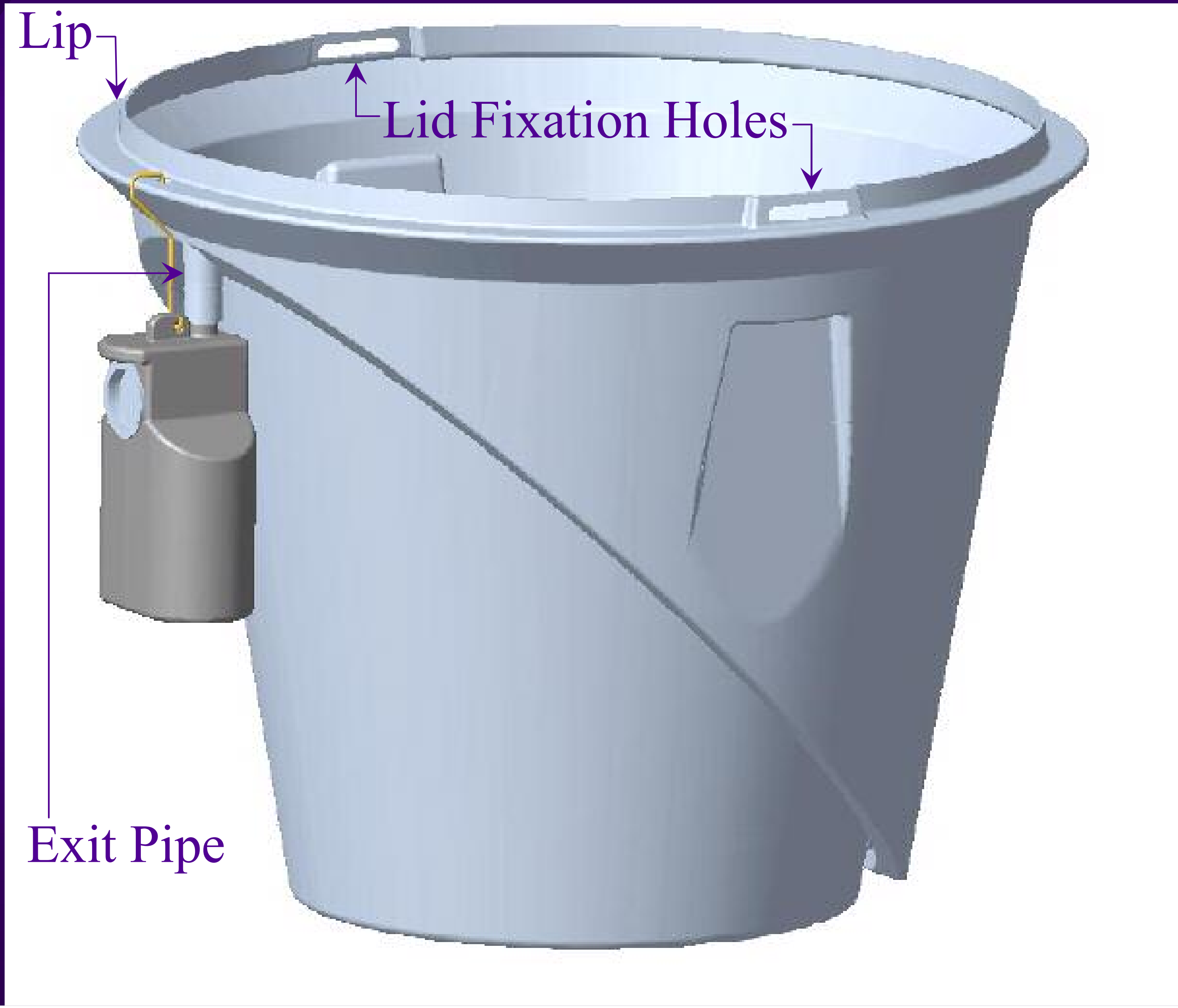
Small Unit of a 2-Foot Base



Lip or Outward Protrusion

If the sides of a disposal unit become moist with condensation, the larvae may have sufficient traction to climb straight up the sides of the unit. Therefore, at the top of both units there is a lip or outward protrusion that the larvae are not able to negotiate even under moist conditions. This assures that the larvae are able to exit the unit only by means of the exit hole and pipe provided.

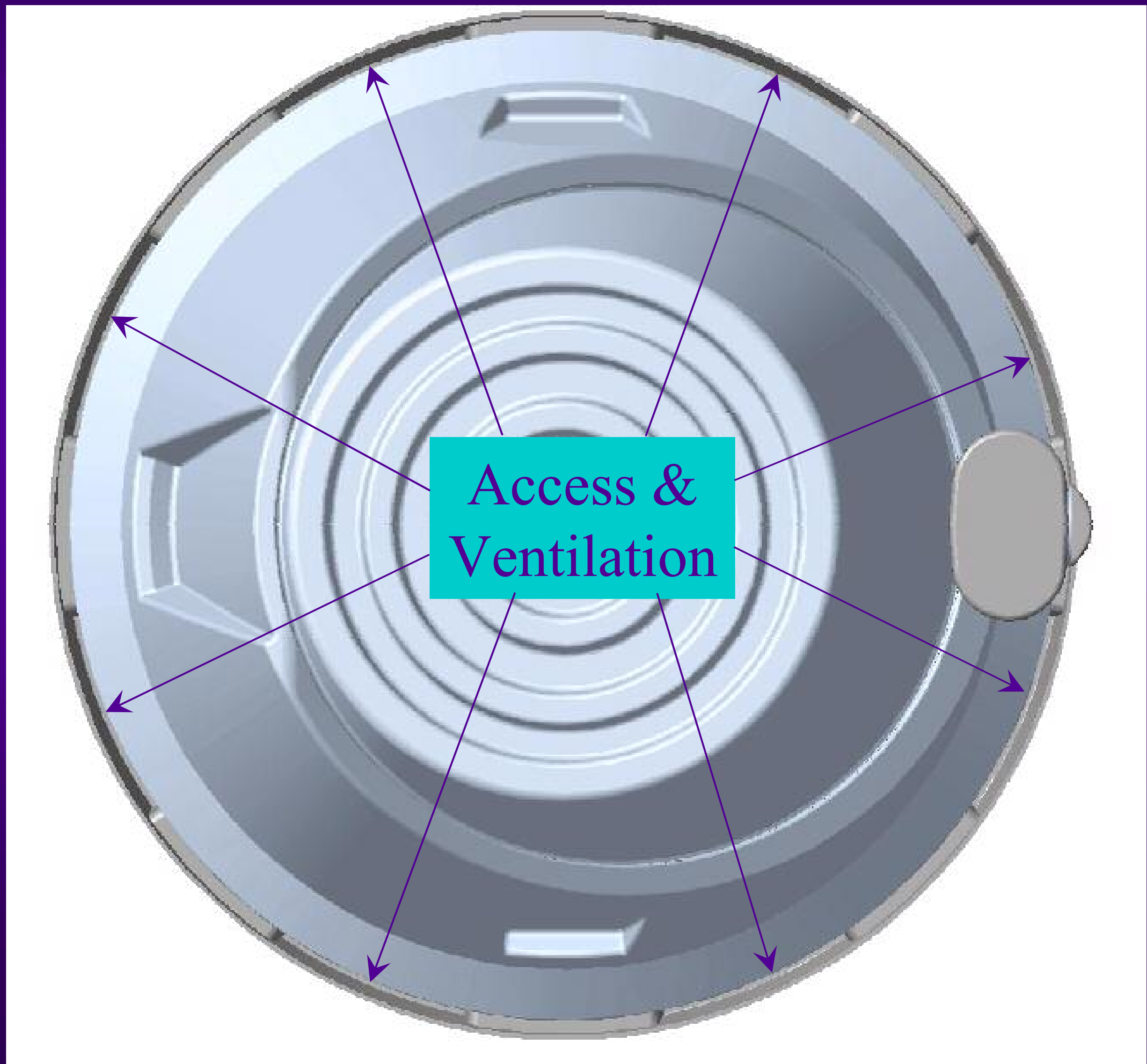
Small Unit of a 2-Foot Base



Female Access & Ventilation

Female black soldier flies must be able to enter the disposal unit to lay eggs. Female access points are situated along the periphery of the lids. These access points also serve to ventilate and aerate the unit and prevent the build-up of heat and moisture. Yet at the same time, the unit is designed so that rain cannot enter through these access points. The slightly conical shape of the disposal units permits nested stacking for easy transport.

Underside of the Small Unit

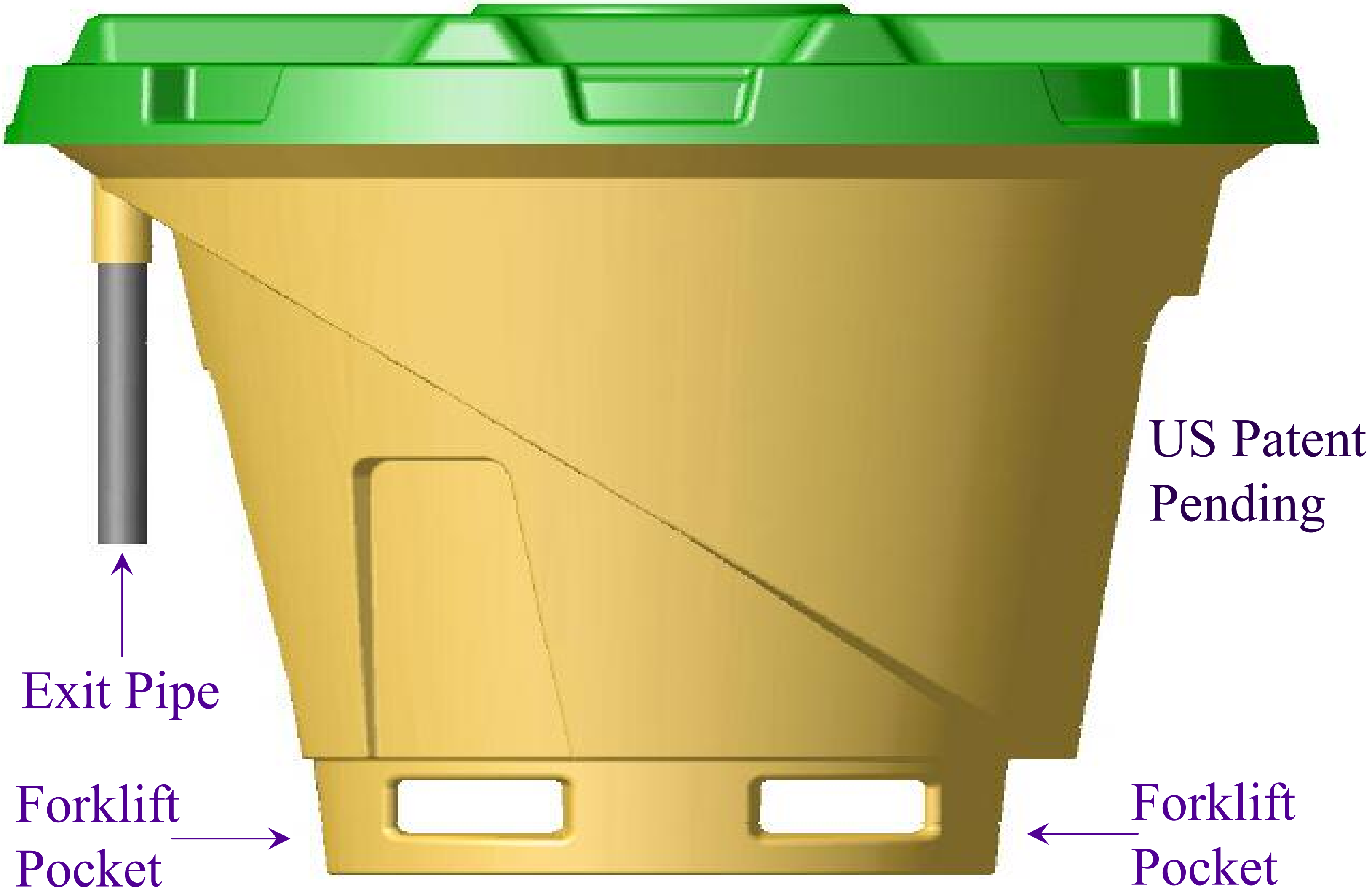


Underside of the Large Unit

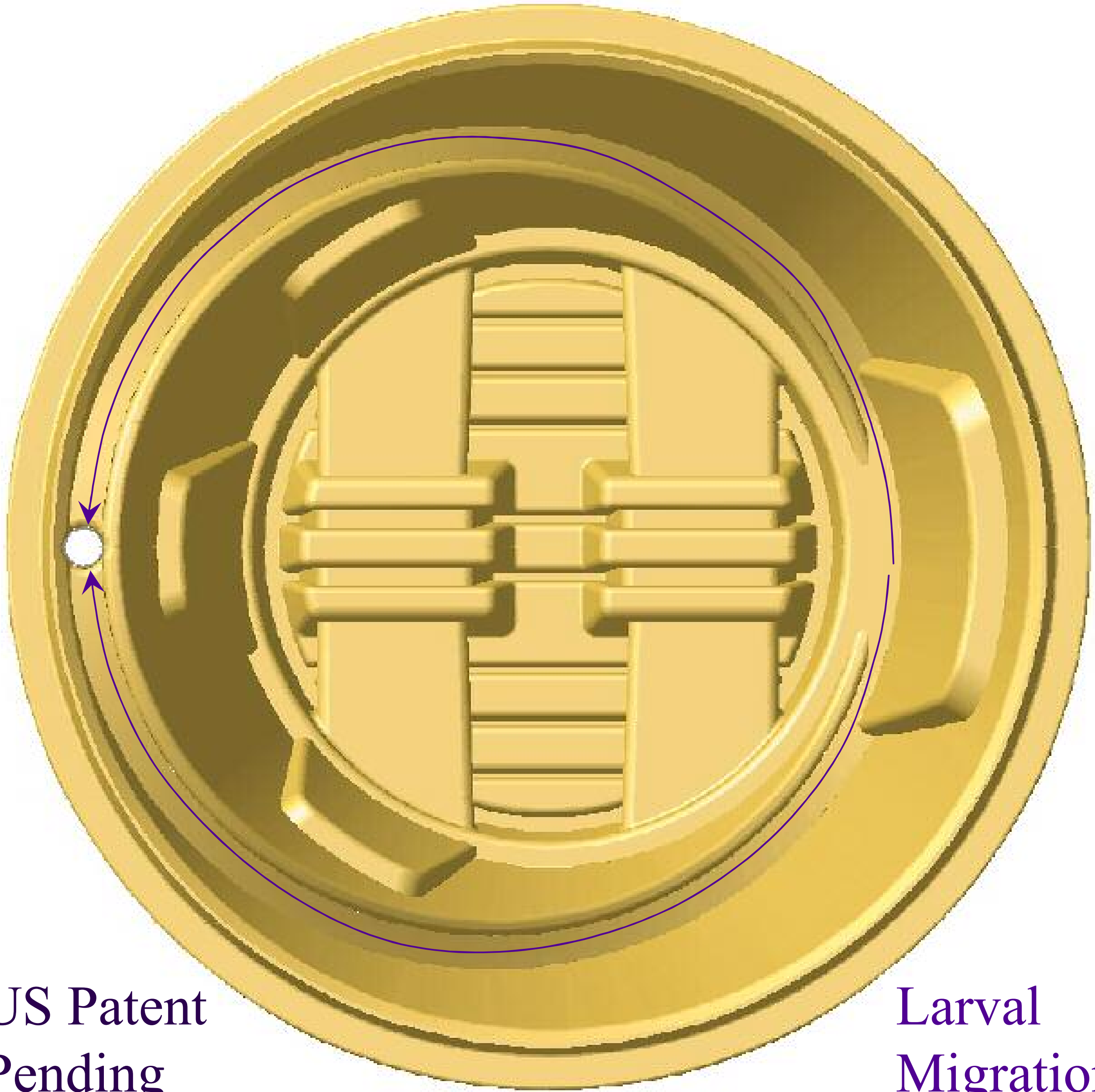
Forklift Pockets

The large disposal unit has forklift pockets designed into its base. Therefore a pallet is not needed to position it on a pallet rack. The forklift pockets are reinforced to withstand the forces exerted on the base at the time of servicing and emptying the unit. Any number of these large units can be coupled by means of a horizontal pipe so as to handle unlimited quantities of waste.

Large Unit of a 3-Foot Base



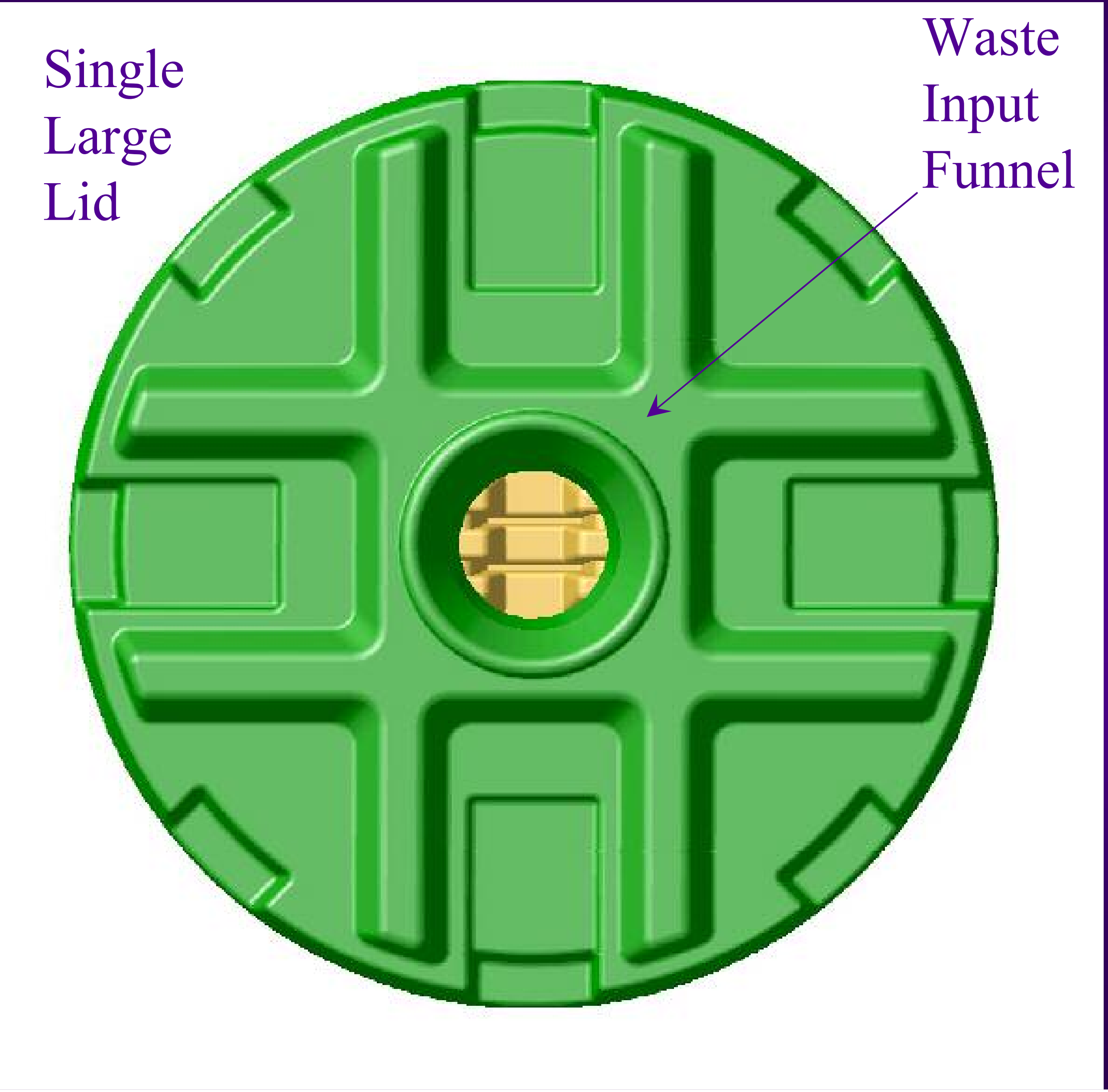
Top View Without Lid



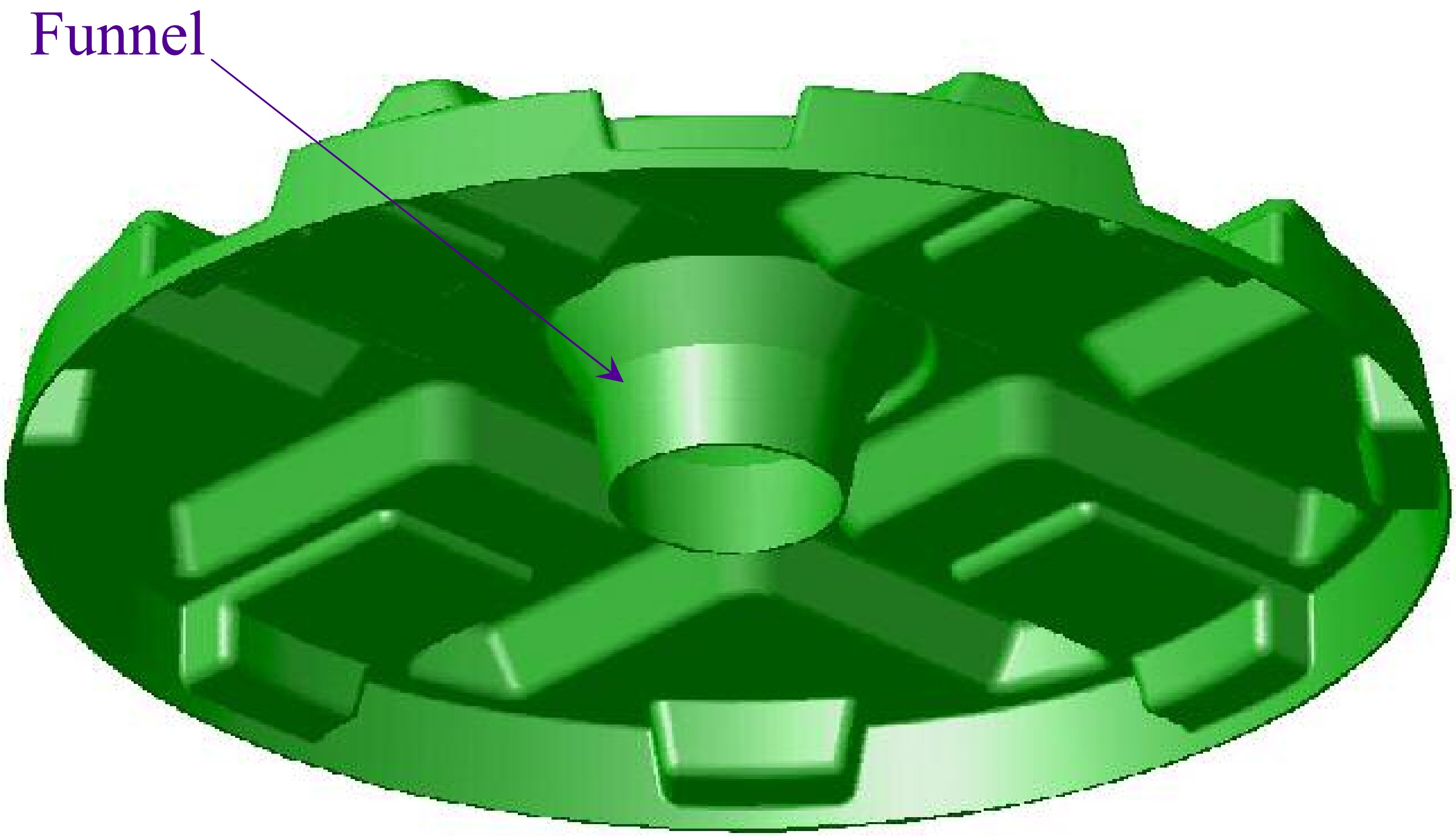
US Patent
Pending

Larval
Migration

Top View of the Large Unit



Underside of Lid



Capacity of Small & Large Units

The small unit has an average feeding surface area of 4.3 ft2, while the large unit has an average feeding surface area of 11.4 ft2. At a feed rate of 3 lbs/ft^2/day, the small unit can handle 12.9 lbs of food waste per day, and the large unit can handle 34.2 lbs of food waste per day. At a half pound of food waste/person/day, the small unit can serve more than 25 people per day, and the large unit can serve almost 70 people per day.

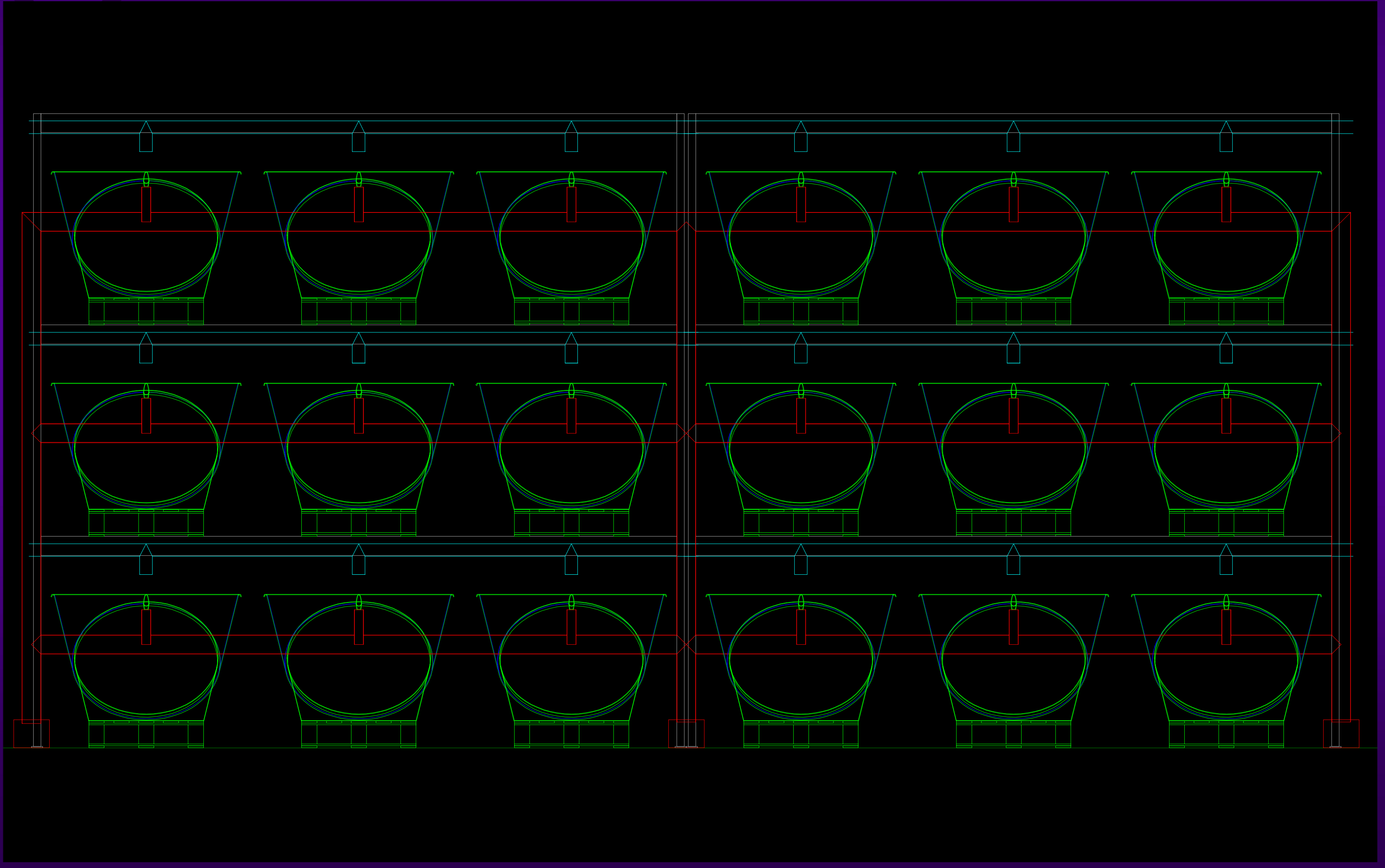
Residue Holding Capacity

The small unit can hold over 64 gallons (0.24 m3) of residue, while the large unit can hold over 205 gallons (0.78 m3) of residue. If the reduction in weight and volume situates at 95%, then the small unit must be emptied after receiving 1,280 gallons of food waste (4.87 m3), while the large unit must be emptied after receiving 4,100 gallons of food waste (15.57m3).

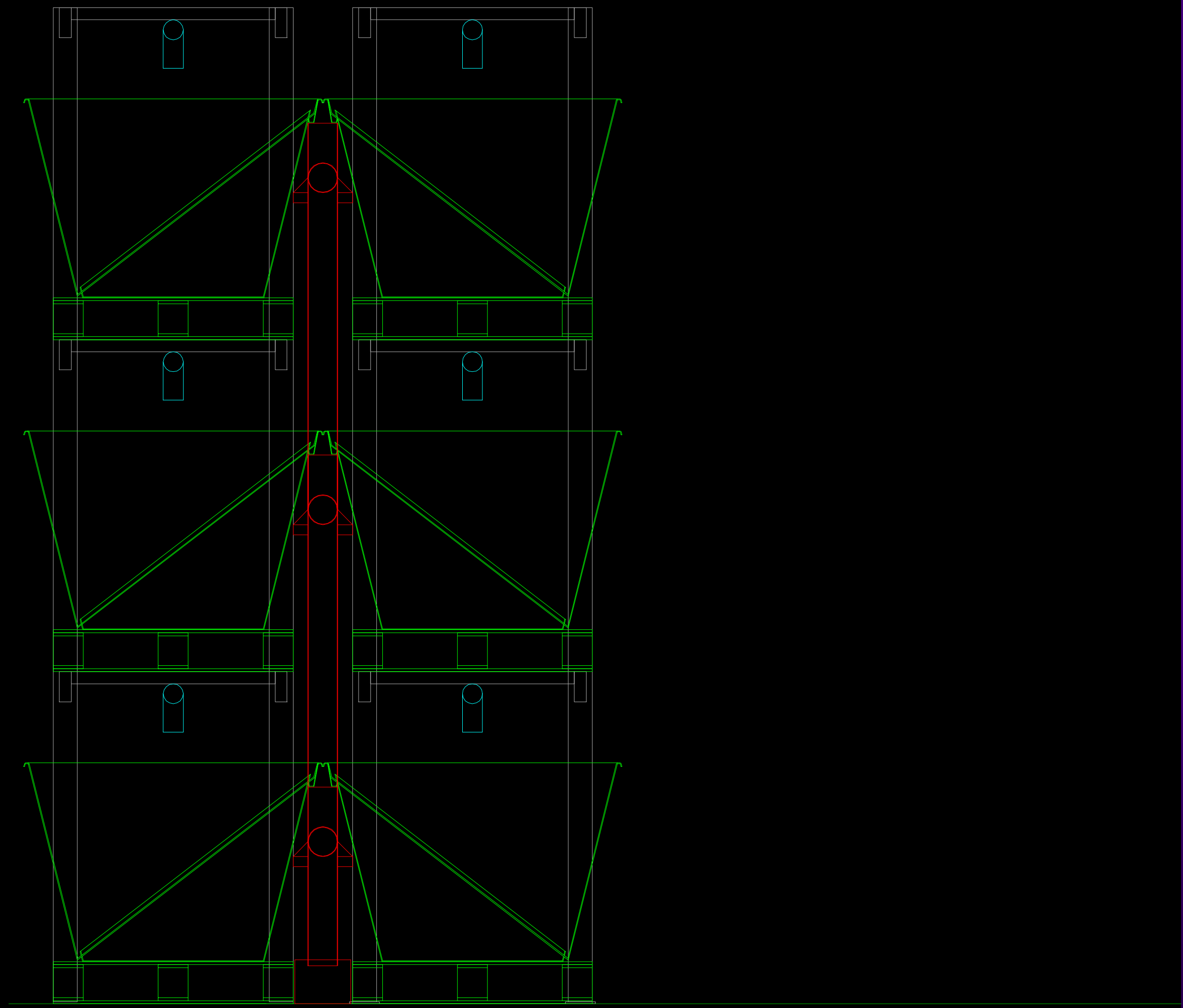
Pallet Rack

The following two drawings illustrate how domestic units could be situated on pallet racks. Putrescent waste could be pumped to larval disposal units, and a conventional fork lift would be used to service and empty the units. This pallet rack concept would be ideal to handle pig feces isolated by a belt-based manure separation system.

Pallet Rack



3-Tier Pallet Rack



Further Decomposition

The digestive enzymes secreted by the BSF larvae cannot directly degrade cellulose, and therefore, the larval residue that accumulates in a disposal unit consists primarily of organic matter of a relatively high cellulosic content. However, the long residence time of the larval residue with the unit gives ample time for fungi and actinomycetes to degrade these more recalcitrant materials. This degradation

Further Decomposition

releases nutrients into the unit that the BSF larvae readily digest. Fungi and actinomycetes over a period of several months easily effect a 50% reduction in the weight and volume of the larval residue, and provided the BSF residue is not allowed to turn anaerobic through the accumulation of liquids within the unit, the BSF larvae continually rework their own residue right down to the very bottom of the unit.

Percentage Bioconversion

What percentage of fresh food waste (bio)converts into fresh prepupae? Over a period of one year, ESR noted that roughly 20% by weight of the fresh food waste converted into fresh prepupal larvae. This food waste had an average dry matter content of 37%, and the prepupae had an average dry matter content of 44%. On a dry matter basis by weight, the bioconversion of food waste situates at almost 24%.

Analysis of Dried Soldier Fly Prepupae

42.1% crude protein

34.8% ether extract (lipids)

7.0% crude fiber

7.9% moisture

1.4% nitrogen free extract (NFE)

14.6% ash

5.0% calcium

1.5% phosphorus

Source: Newton, Booram, Barker & Hale, 1977

The Catfish Industry

Studies were conducted at the Coastal Plain Experiment Station in Tifton, Georgia, to examine the suitability of BSF larvae as a feed source for channel catfish and tilapia. The test concluded that "soldier fly larvae should be considered a promising source of animal protein in fish production." Taste tests were also conducted: "Results of the taste tests indicated

See Bondari and Sheppard (1980), pp. 103 and 108.

Menhaden Fish Meal

that fish fed soldier fly larvae are acceptable to the consumer." About half of BSF fresh weight translates into a dry matter of a 6% moisture content, and nutritionists are in agreement that BSF dry meal has roughly the same value as Menhaden fish meal at approximately $500 US dollars per ton.

See Bondari and Sheppard (1980), pp. 103 and 108.

Living Food

Live BSF prepupae have been successfully fed to bull frogs, tropical fish, reptiles, snakes and many other creatures that have a strong preference for living food. Here the value of fresh BSF larvae ranges from $4 to $20 /lbs, or $8,000 to $40,000 per ton.

As Temperatures Drop

The larvae of the black soldier fly have an amazing ability to dispose of putrescent waste. But as the temperature drops below 21˚C, their ability to digest waste progressively grinds to a halt, and if they should freeze, they die. This tropical fly larva needs to be sustained at temperatures above 30˚C if it is to continue to digest putrescent waste at the standard rate of roughly 15 kgs per m^2 of unit surface per day.

A Winter Strategy

To bring bioconversion units indoors during winter would be costly, and to equip them with heating coils is not necessary. The strategy set forth here involves nothing more than placing a styrofoam sheet on top of the larval residue to retain the heat generated by mesophilic bacteria and by the movement of the larvae themselves. If this heat is not allowed to escape, the

Styrofoam Panel

temperature on the surface of the residue easily exceeds 35˚C. The first picture in the following slide shows the styrofoam panel in place, while the second picture shows the active mass of larvae underneath.

Styrofoam Sheet

Minus 1° C

When these two pictures were taken, the outdoor temperature in early January had dropped to minus 1° C. When the styrofoam sheet is lifted in the early morning, a cloud of water vapor rises up from the warm mass of larvae in full activity. Imagine such a vigorous and healthy colony of tropical larvae right in the middle of winter.

Larvae in Full Activity

Eggs Laid in October

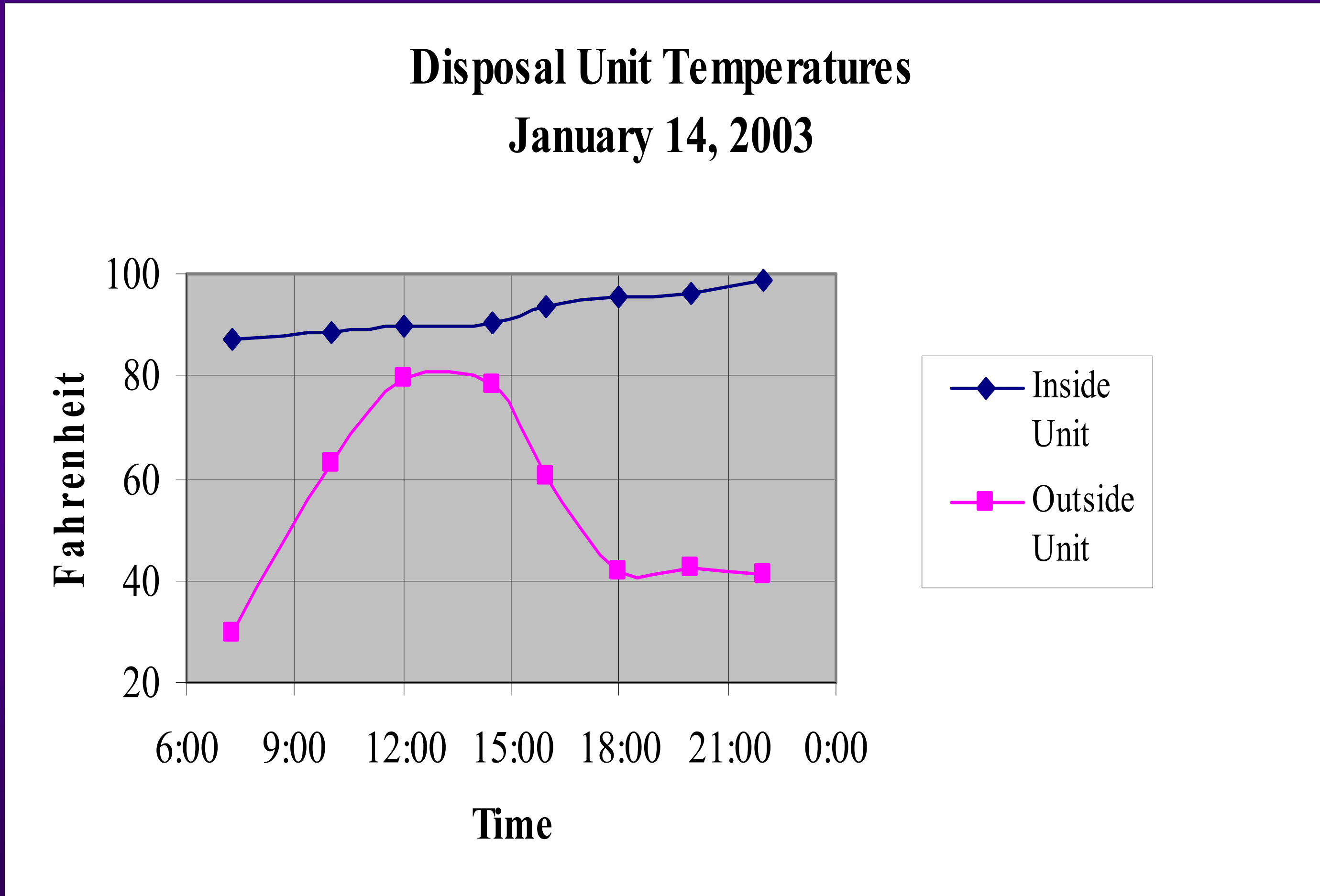
The larvae we see in this unit all came from eggs laid in October when adults females were still active. The density of larvae in January and February appears to be far higher than at any other time of the year. Likewise, the ability of these larvae to dispose of putrescent waste appears to be far greater than at any other time of the year: 10 lbs of food waste easily devoured in two to three hours.

BSF Larvae in Winter

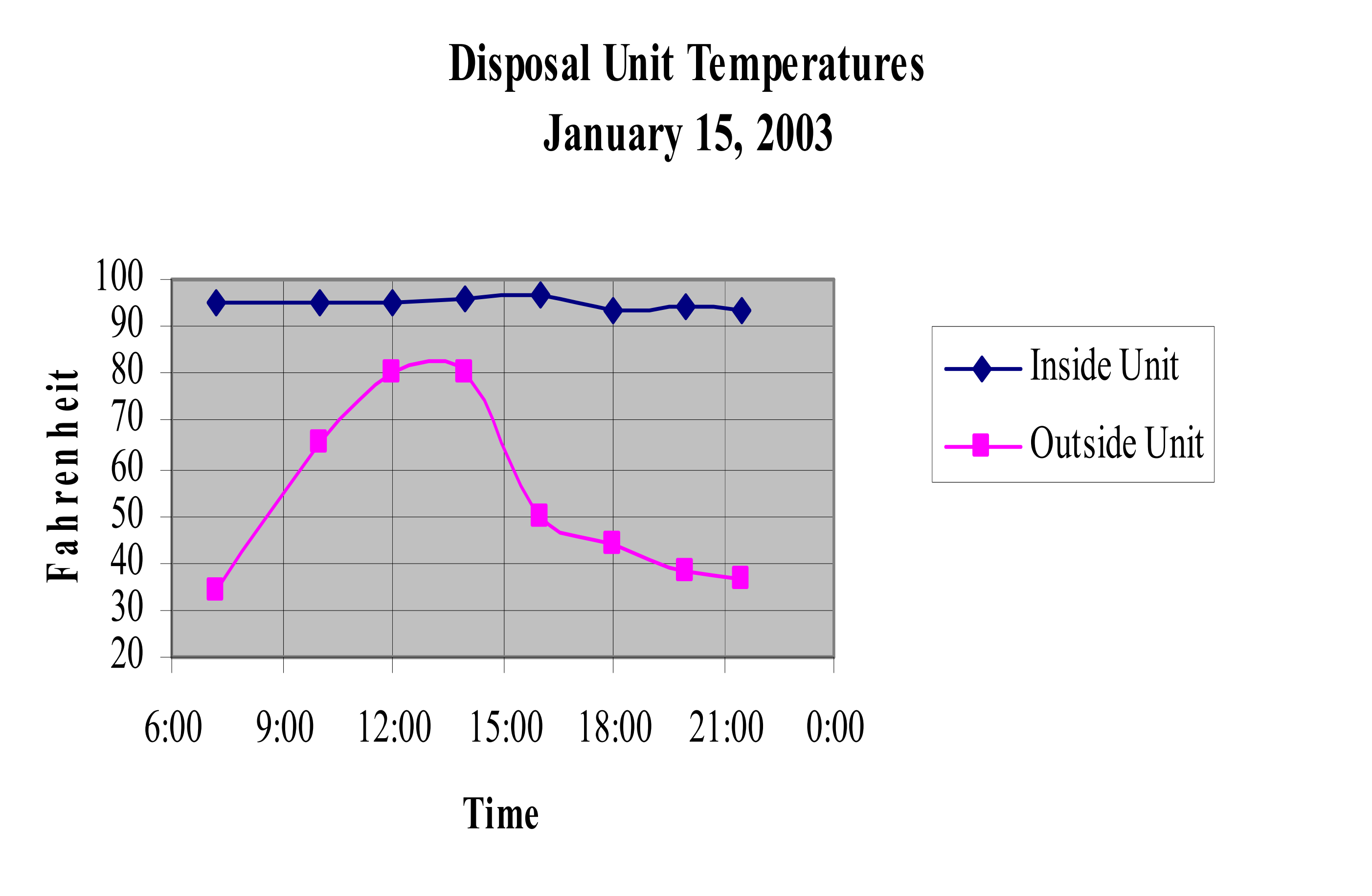
Temperature Graphs

The following graphs plot daily temperature readings recorded both outside the unit and underneath the sheet of styrofoam. Note that outside temperatures may fluctuate dramatically, but the temperature underneath the styrofoam sheet remains relatively stable. The difference in temperature between inside and outside the unit can exceed at times 82˚F or 45˚ C.

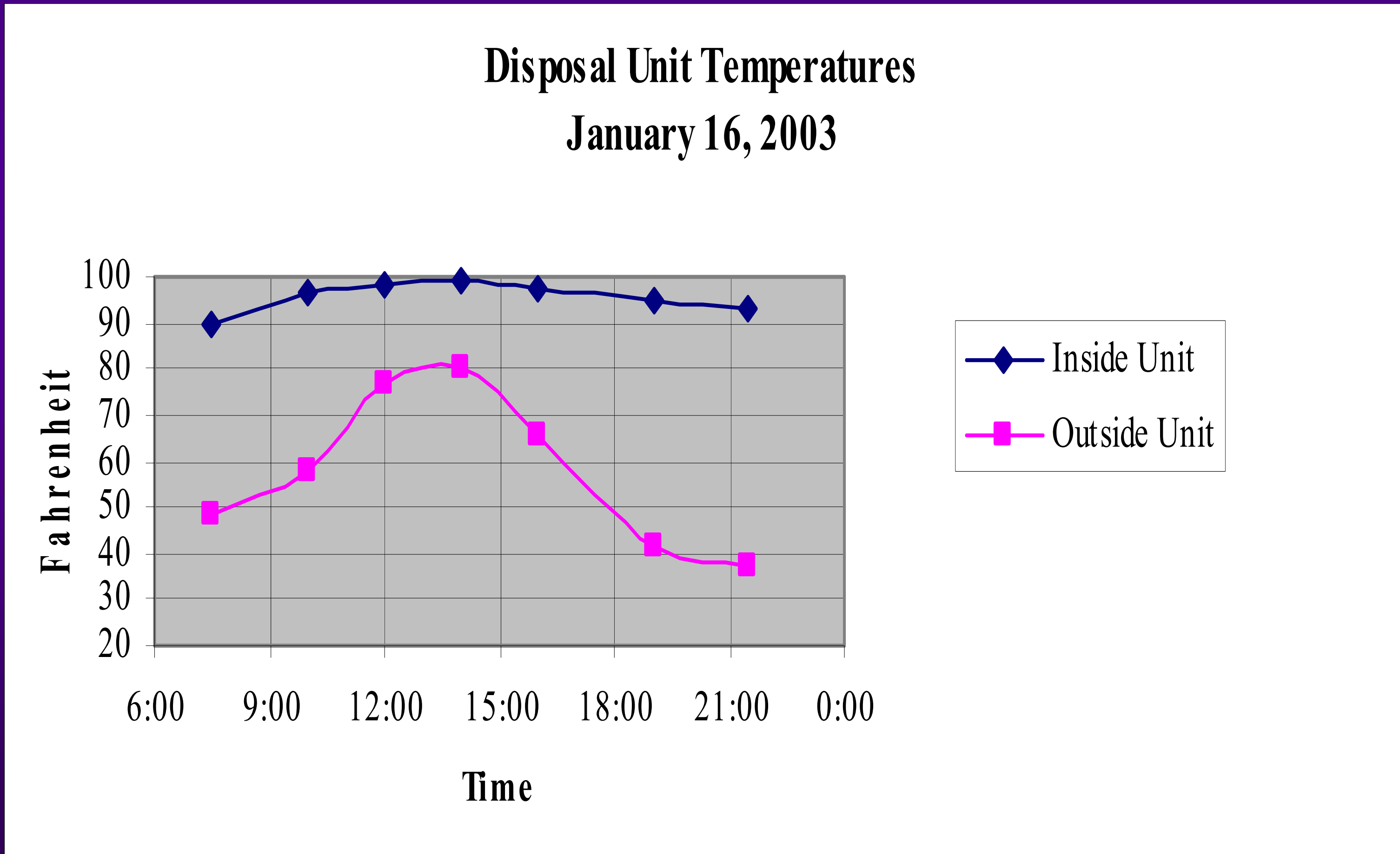
January 14, 2003
Washington, Louisiana



January 15, 2003
Washington, Louisiana



January 16, 2003
Washington, Louisiana



Insulated Bioconversion Units

As we move north from Louisiana and into the more temperate areas of the United States where winters are far colder, it may be necessary to wrap the outside of the larval unit in insulation. The new round bioconversion unit designed by ESR should be far easier to insulate than the rectangular unit depicted in this experiment. With insulation on the sides, with insulation on top of the residue, and with

BSF in Eugene, Oregon

mesophilic bacteria and larvae generating an ample amount of heat from within, the larvae should be able to thrive out-of-doors even during the harshest winters. Anne Donahue, a compost specialist in Eugene, Oregon, reports the presence of active BSF larvae during the coldest winter months in many of the vermi-composting bins in her area.

Conversion Rate Drops in Winter

During the warm summer months, the conversion rate of fresh food waste into fresh larvae runs as high as 20%. But during the cold winter months, this conversion drops to less than 5%, in spite of the fact that the larvae digest roughly the same daily quantity of food waste per ft^2 of unit surface area. Under ideal summer conditions, it takes about two weeks for newly hatched larvae to reach their mature prepupal form, but during the cold of winter,

Factors Constraining Maturation

this two-week period may extend to six months. What are the factors that inhibit larval maturation in wintertime? In this experiment, the larvae received during the winter months roughly the same amount of nutrients as during the summer months, and yet their growth and development were severely constrained. If adult black soldier flies must inherit a large fat body from the larval stages in order

What Triggers Maturation?

to complete their life cycle as adults (adults do not eat), and if larvae during winter must continually draw upon their stores of fat in order to keep warm and survive, perhaps the large majority of larvae during the winter never acquire sufficient fat to reach maturity. Or perhaps, the failure to reach maturity is part of a winter survival mechanism that is not directly related to fat

A Single Generation of Larvae

content but to a simple drop in temperature at the onset of winter. As long as they are battling cold, perhaps they do not mature in spite of an adequate fat body content. In any case, we see conclusively that a single generation of larvae can easily sustain a BSF disposal unit throughout the entire winter. We call upon entomologists to research the question of larval maturation:

Larval Maturation

is it related more to temperature than body fat content? is it part of a winter survival mechanism? just how far can larval stages be extended and under what combination of conditions? and ultimately can a single generation of larvae sustain a bioconversion unit for an indefinite period of time? As long as the surface of the unit remains uncovered in winter, the larvae are forced to remain far below the surface to avoid the cold.

Full Access to Food Waste

Since any food waste deposited on the surface of the unit can only be approached from underneath, the larvae have limited access to the food waste. But with a residue or larval cover, the larvae have full access to the waste, and therefore, the speed at which the waste is consumed appears to be higher than at any other time of the year. The styrofoam sheet creates a warm, dark, sheltered environment that apparently represents ideal feeding conditions

Ideal Feeding Conditions

for the larvae. Of course, styrofoam is not the only material that could be used, and it is easy to imagine larval covers made out of many other types of insulating materials. However we fabricate them, larval covers may become an essential element of disposal units situated in cold climates.

Easier Than Previously Imagined

If BSF larvae are able to generate their own heat throughout the winter, and if at the same time they are able to extend their life cycle until more favorable conditions return in spring, then the management of BSF larvae becomes far easier than anyone had previously imagined: no need to shut down BSF disposal units during winter, no need to supply them with eggs, no need to cut back in winter on the amount of food processed, no need to supply heat

BSF Technology in Cold Climates

to keep larvae warm. If disposal units and larval covers are well insulated, then BSF technology could be introduced to some of the coldest regions of our planet. If so, the supply of eggs to such extreme areas will become an important technical issue, and all aspects of larval maturation must be researched in a definitive and conclusive manner.

Overcrowding in Summer

How do we explain the fact that BSF larvae within a disposal unit appear to have a greater ability to dispose of waste in winter than in summer? During the warmer summer months, overcrowding easily occurs, and this overcrowding gives rise to high temperatures within the disposal unit. In order to cool down, actively feeding larvae must exit the unit in large numbers. But once they exit a unit, they have no way of getting back into the unit, as they

Increased Feeding Capacity

would in a natural setting. This migration continues until the density of larvae and temperature within the unit drops to an acceptable level. But during the winter months, actively feeding larvae can thrive in large numbers without overheating, and as the mass of actively feeding larvae increases in winter, so too, the amount of food waste consumed per square foot of unit surface.

Paradox

A disposal unit represents a unnatural, confined space for these tropical larvae. In summertime, it can easily overheat, whereas in wintertime, it provides shelter to the larvae and allows them to thrive in unusually high numbers. Paradoxically it would appear that BSF disposal units function far better in winter than in summer.

A First Step in Composting

Normally when we think of composting, we focus mainly on the activity of thermophilic bacteria. But composting should include the promotion of consumers at many different levels. The black soldier fly is just one of many creatures we could enlist to consume the staggering quantities of waste generated by human activity. This larval bio-conversion process should be seen as but a first step in the composting of putrescent waste.

Imagine

Imagine a bioconversion process that reduces the weight and volume of food waste by over 95% within a matter of just a few hours. The process requires no energy, no electricity, no chemicals, not even water. The process is totally self-contained. It produces no effluent, and aside from a small amount of CO^2, it produces no methane or other greenhouse gases. The process is housed within a

Eliminates Landfill

container that resembles a plastic garbage bin. The unit has no moving parts and requires no maintenance. Since it must be emptied but once a year, it eliminates altogether the collection, transport and land-filling of food waste. It can be situated out-of-doors in a shaded area, and any number of units can be coupled together to handle unlimited quantities of waste. The process

Requires Little Expertise

generates very little odor, and at the same time, it very effectively repels houseflies and other filth-bearing flies. The unit requires very little expertise or experience to operate, it sells for less than $60 US dollars, and it can handle the daily food waste of more than 25 people. The process not only generates its own heat, but it also regulates and stabilizes heat to assure maximal bioconversion

No Threat to Humans

throughout the winter months. The process is driven by a tiny creature native to the whole of the Americas, a creature that poses no threat to humans and has never been associated in any way with the transmission of disease. Yet at the same time, this benign creature possesses one of the most robust digestive systems within nature. It thrives in the presence of salts, alcohols, ammonia and a variety

A Bundle of Nutrients

of food toxins. Upon reaching maturity, it migrates out of the unit and into a collection bucket without any human or mechanical intervention. This self-harvesting grub represents a bundle of nutrients that rivals in commercial value the finest fish meal. This bioconversion process can also be used to process poultry waste as well as human and swine feces.

Conclusion

There is no creature on earth capable of disposing of putrescent waste more quickly and more efficiently than fly larvae, and there is no species of fly safer to work with than the black soldier fly. Nature freely gives us a voracious little grub that is by far the pre-eminent recycler of putrescent waste: the larva of the black soldier fly.