

# THE POWER OF SMALL-SCALE GASIFICATION

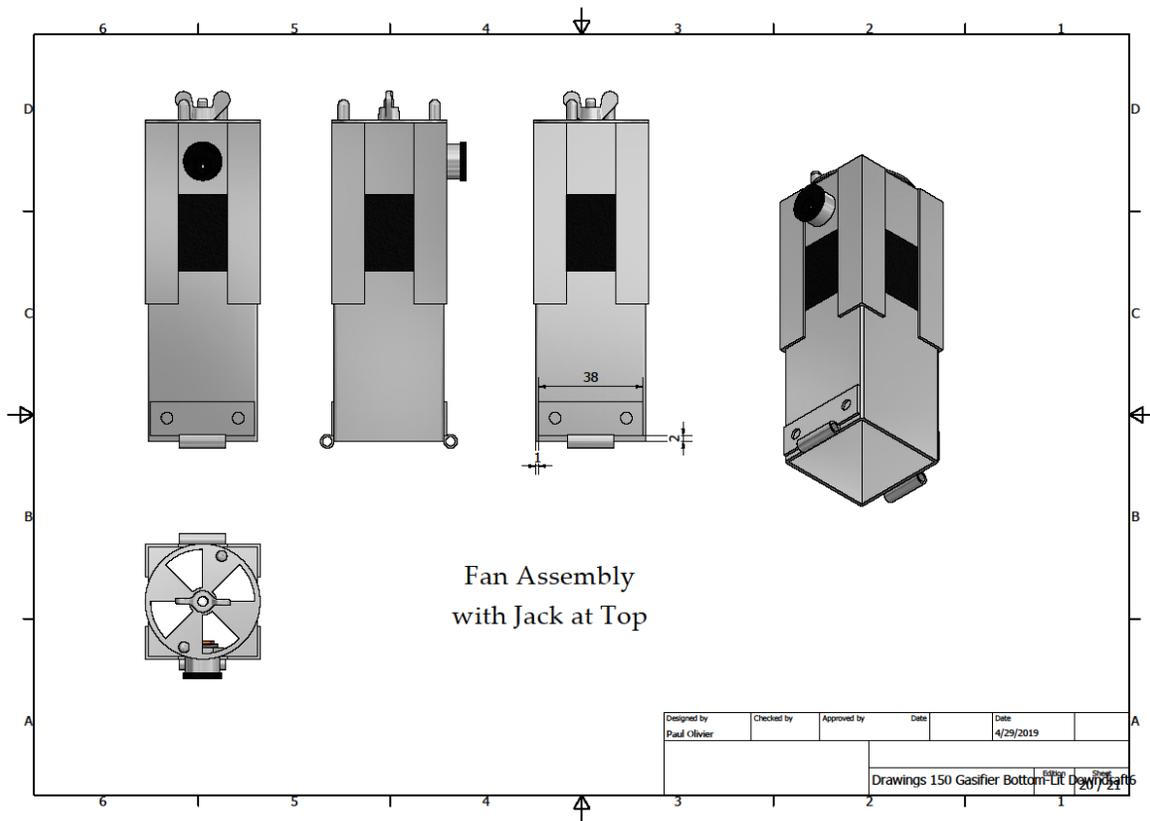
By Paul Olivier

About 8 years ago I received a set of drawings of a top-lit, updraft, rice hull gasifier from Alexis Belonio of the Philippines. After having built and tested this gasifier, I proceeded to make changes to enhance its performance and to increase its acceptability within Vietnam.

The size of the fan supplying primary air to the reactor was reduced almost 10-fold. This increased the holding capacity of the reactor. The fans chosen come in two sizes: 40x40x20 mm and 40x40x28 mm.

The smaller fan consumes up to 0.91 watts and serves gasifiers ranging in power from 3 to 7 kW. The larger fan consumes up to 7.2 watts and serves gasifiers ranging in power from 20 to 60 kW. A marginally more powerful 40x40x28 mm fan of 12 watts can serve gasifiers of an output up to 200 kW. These are computer fans, and they are guaranteed to operate continuously for 65,000 hours.

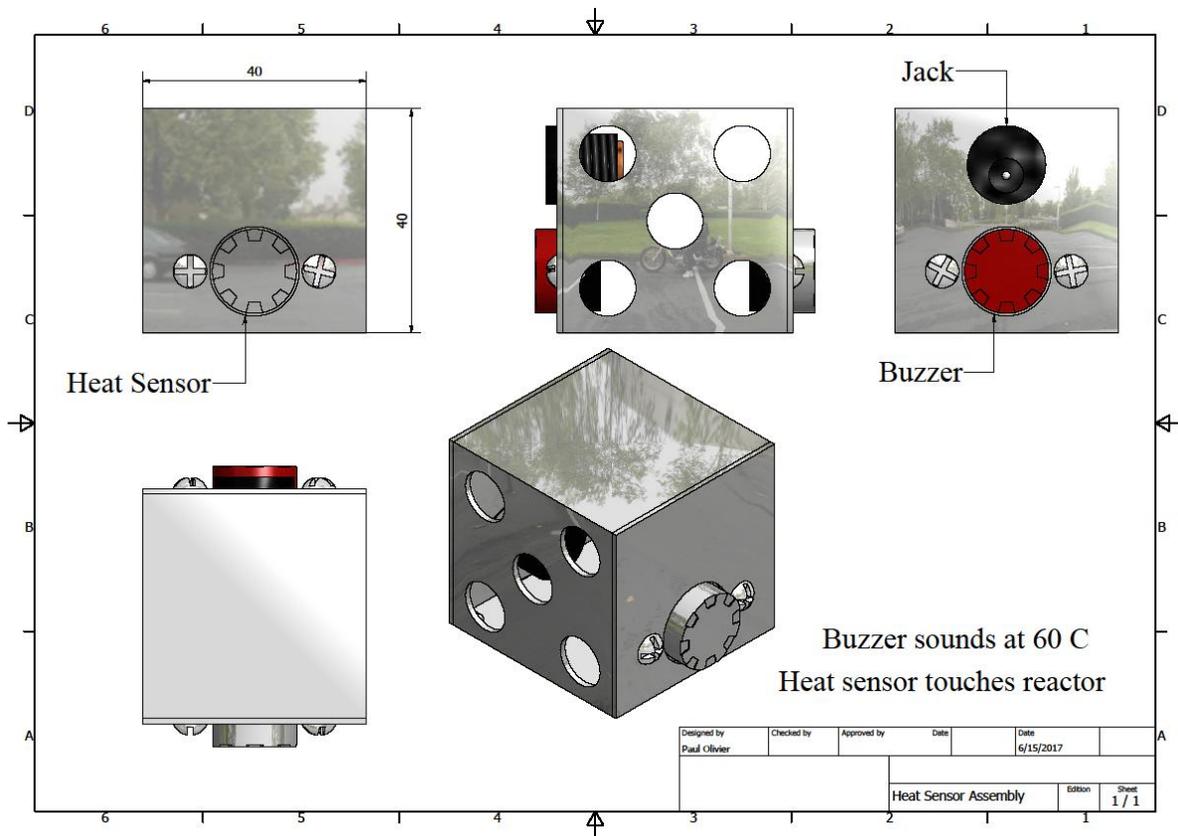
Initially airflow was controlled by adjusting the speed of the fan with an [electronic speed regular](#). But electronic speed regulators are relatively expensive, and they often breakdown. Airflow is now controlled by means of a dial situated above the fan. As airflow into the fan is restricted, both power consumption and noise go down. The fan assembly comes in two sizes: a small one for the 100 gasifier (drawing [001](#)), and a larger one for all other gasifiers (drawing [002](#)). Here is the drawing of a new fan assembly that is held in place by a hinge:



In the original Belonio design, the fan was permanently attached to the gasifier and was not removable. But now the fan assembly can be easily detached from the gasifier. In this way, rising hot air does not damage the fan when the reactor is turned upside down.

The fan is sandwiched in between two short sections of a 40x40 mm square pipe. Fasteners are not needed. The fan assembly fits on top of a square air pipe of the same size as the two short sections. The fan assembly is held in place by three stubs positioned at the end of the air pipe, as shown in this [drawing](#). The air pipe serves four functions: an air pipe, a handle, a means of stabilizing the reactor and a means of evacuating any biomass that might fall through the reactor grate.

When the gasification front reaches the bottom of the reactor, the fan should be disconnected and removed. If the fan continues to operate, the biochar within the reactor begins to burn, and the reactor gets extremely hot. Therefore, an alarm sensor has been designed to warn the operator to disconnect and remove the fan at the end of a run:



The alarm sensor is simply placed on top of the air pipe, as shown in [jpegs 013](#) and [014](#). The heat sensor (a bi-metallic strip) touches the bottom of the reactor.

There is, however, a simpler and cheaper way to sound an alarm at the end of a burn. The steam whistle shown in these [jpegs](#) requires no electricity. Heat from the reactor causes a small amount of water to boil.

Normally the gasifier fan is powered by an AC/DC adapter. But if power from the mains is interrupted, any 12-volt battery can be used. Motorbikes can be easily wired to provide electricity to the fan when power fails. In rural areas of developing countries with no access to power lines, small solar panels costing less than \$20 US dollars can be used for charging a 12-volt battery.



No improvements could be made with respect to the Belonio burner. Belonio placed burner holes along the periphery of the burner. The number of holes, the diameter of holes, the spacing of the holes, and the staggering of the two rings of holes – all remained the same. When any of these dimensions are changed, the burner does not function properly.

But a bare Belonio burner still produces a long diffusion or candle-like flame. A burner housing is needed to force secondary air to mix properly with the gas exiting the burner holes.

The gas that exits the burner holes does so under mild pressure, and at the same time, secondary air

is introduced via an 8-mm gap at the base of the burner holes. This secondary air is also under mild pressure created by the natural draft of the burner housing. As gas entrains air, and as air and gas come together, a mixing takes place all along the periphery of the burner. The long diffusion flame is replaced by a series of small flames situated fully underneath the pot or pan, as is seen in these two videos: [video1](#) and [video2](#).

Lighting biomass within the reactor, especially pellets, has always been problematic. The procedure typically involves lighting several strips of cardboard and placing them on top of the biomass. Only when the cardboard strips begin to emit radiant energy does the biomass light. After the biomass is lit, the ash from the burnt cardboard strips should be removed, otherwise particulate matter from the burnt cardboard is released during the burn. But cardboard ash often disintegrates into fine particles and is difficult to remove.

Instead of lighting biomass with cardboard strips, one might use a thin steel wool disk. The fibers of superfine grade 0000 steel wool have a diameter of 25 microns. A single match or cigarette lighter flame is placed under the steel wool disk ([004](#)). The lit disk is then placed on top of the biomass in the reactor. As air rises up through the biomass, abundant oxygen is uniformly fed to the steel wool disk above. The reaction is quick and intense ([001](#)). The temperature of burning steel wool varies from 800 C to 1,000 C. Radiant energy is directed downward onto the biomass. After the steel wool disk is placed on top of the biomass, a uniform lighting of the biomass takes place within about 10 seconds.

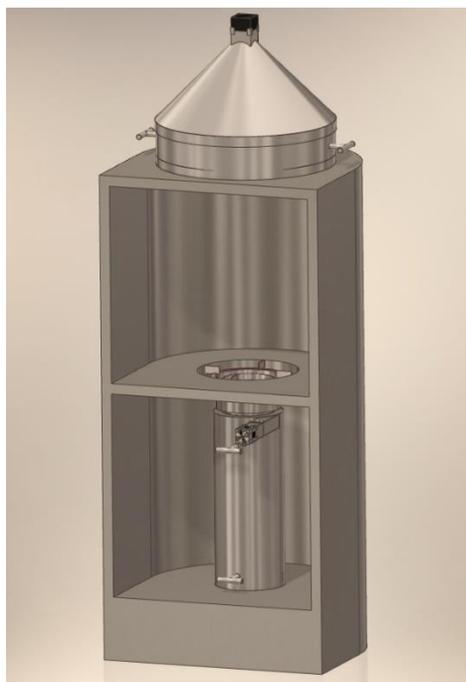
After the biomass is lit, the oxidized steel wool is not removed from the reactor. The oxidized steel wool breaks down complex gases. It serves as a filter. It enhances the Boudouard reaction (explained below). And hopefully it can be used to sorb arsenite and arsenate from drinking water.

So the steel wool disk potentially fulfills five functions: 1) lighting biomass, 2) breaking down complex gases, 3) filtering particulate matter, 4) enhancing the Boudouard reaction and 5) sorbing inorganic arsenic.

The gasifier should not be operated as a stand-alone device, as in the picture above. It is easy for a pot, pan or wok to slide off the burner. The gasifier should always be operated within a tabletop, as shown, for example, in jpeg [001](#) and jpeg [002](#). The four pot holder fingers of the burner rise up 1 mm from the top of the tabletop. If a pot or pan should slide off the burner, it merely slides onto the tabletop. Once the gasifier is placed within the tabletop, the gasifier cannot fall over (jpeg [009a](#) and jpeg [003](#)).

A removable tray containing biochar (a biochar produced by the same gasifier) serves as a filter (jpeg [003](#)). The tray has a perforated bottom and contains 21.7 liters of loose biochar. A hood is placed above the perforated tray filled with biochar (jpeg [004](#)). A detachable fan (60x60x38 mm, AD0612HB) is placed above the hood (jpeg [005](#) and jpeg [006a](#)). The fan pulls air through the filter and hood. The fan discharges into a small funnel connected to a chimney pipe ([The Lotus Fire Gasifier with Enclosure](#)). Cooking oil fumes stick to the biochar. Fine particulate matter sticks to the oily biochar. Cooking oil fumes ([Cooking Fumes and Risk of Developing Lung Cancer](#)) and fine particulate matter ([Particulate Matter \(PM\) Pollution](#)) should never be allowed come into a kitchen, nor should they be vented outdoors. Both are carcinogenic.

Here below is the design of a new tabletop, windshield, filter, hood and fan made out of aerated concrete. This gasifier has a housing for heating primary air (for more detail, see [Heating Primary Air2](#)).



After the biomass is lit and the burner is placed on top of the reactor, all open flames within the reactor are extinguished. This elimination of open flames within the reactor is quite important, for it is this that distinguishes a gasifier stove from an ordinary combustion stove and all stoves in between. To the extent that syngas is burned within the reactor, the gasifier is no longer functioning as a gasifier but as a combustion stove. All combustion stoves release gases that burns at a distance above the biomass from which it was derived. But with a gasifier, this distance is controlled and optimized. The combustion of syngas should take place outside the reactor and right under the pot.

The gas exiting the burner should be comprised mainly of CO and H<sub>2</sub>, and should contain little CO<sub>2</sub>. If a gasifier produces CO<sub>2</sub> in large quantities, this not only creates a considerable inefficiency in the transfer of heat to the pot, but it also involves a problematic mixing of CO<sub>2</sub> with syngas. If syngas gets diluted with CO<sub>2</sub>, it might not burn properly, and this increases the risk of carbon monoxide escaping the burner.

The original Belonio burner has certain advantages over most gasifier burners. If at any stage in the gasification process a significant amount of CO<sub>2</sub> should exit any of the burner holes, the operator can clearly see what is going on. If air should channel unevenly through the biomass creating a lot of CO<sub>2</sub>, the operator can see irregularities in flame formation at the base of the burner holes. When channeling occurs, hot spots are formed within the reactor. Channeling can raise temperature to well over 1,000 C. Such overheating can severely damage even the finest stainless steel.

Putting a metal housing around the reactor is not a good idea. If the sides of the reactor begin to overheat and glow red hot, the operator cannot see what is going on, and the reactor can get badly damaged. Since a housing can be subjected to high heat, it, too, like the reactor, should be made out of high-quality stainless steel. Making a housing out of high-quality stainless steel would almost double the price of the gasifier.

Properly formed syngas exits the reactor at relatively high temperatures (> 500 C). Syngas should not be cooled down prior to combustion, since this would involve a huge inefficiency. Syngas should not be routed to remote burners. Gas lines and valves to remote burners might leak, as is often the case with biodigesters. Gasifiers are inexpensive. If more burners are needed, more gasifiers are used.

Some gasifiers on the market today have a burner with a single large hole in the middle. There is no detachable burner that serves as a reactor lid. Without a clear distinction between reactor and burner, it is hard to spot irregularities in flame formation indicating the presence of CO<sub>2</sub> in syngas. But even more troubling is the fact that an adequate mixing of air with the gas at the center of such a large hole is difficult to achieve. Inadequate or inefficient mixing produces a long candle-like flame.

If the biomass within the reactor consists of large chunks of woody biomass mixed with smaller pieces of biomass, small pieces of hot char can drop down below the main gasification front, creating multiple gasification fronts. When multiple gasification fronts are created, some biomass might receive too little oxygen, and some biomass might receive too much oxygen. When this happens, biomass does not gasify in a uniform manner. The process can become so complex that such a unit, even though it is top-lit and updraft, should not be called a gasifier.

If a gasifier is fueled with biomass that is not uniform, channeling will occur. An irregular biomass produces a poor quality gas composed of too much CO<sub>2</sub>, as well as a poor quality char containing ash and inadequately gasified biomass. Also even if loose biomass is uniform, channeling can still take place if air flow is too high. When this happens, the operator must lower air flow and tap the reactor to let settle biomass and collapse the channel.

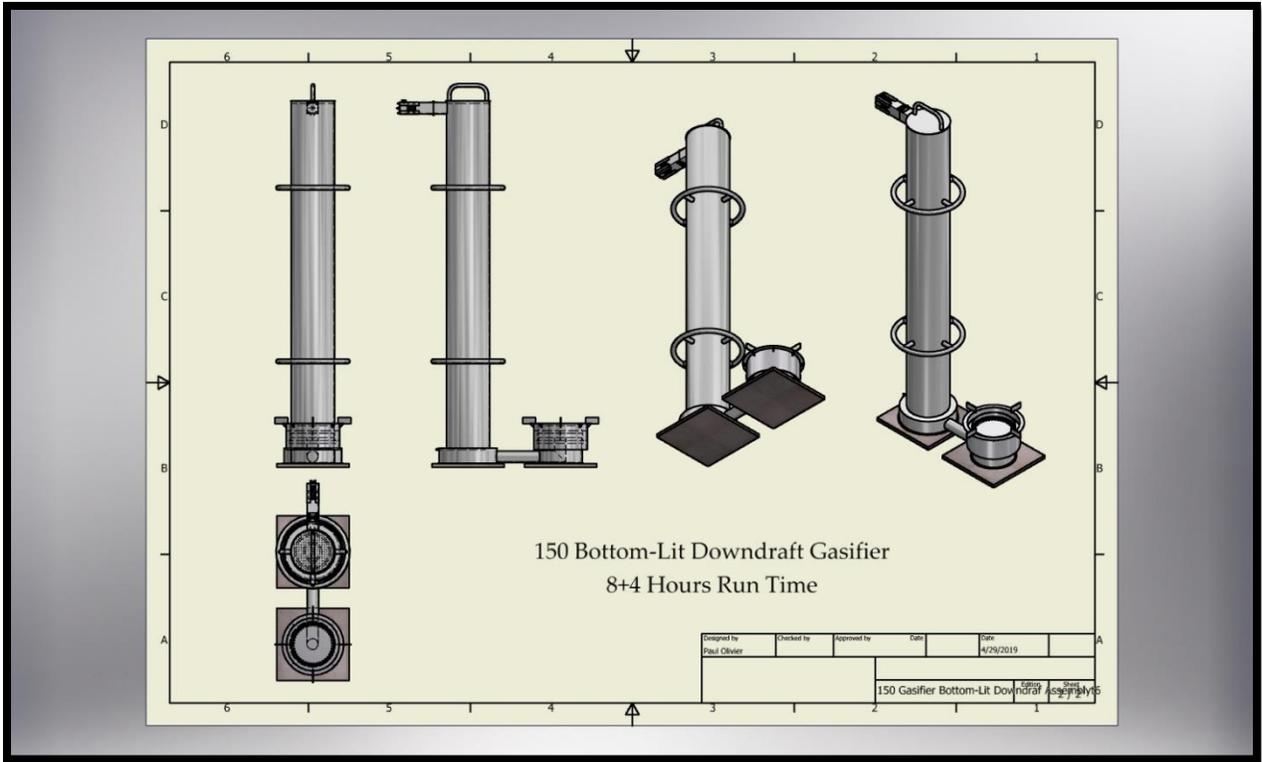
Biomass such as rice hulls, coffee husks and palm kernel shells are uniform. Biomass such as walnut shells, macadamia shells and pecan shells should be screened in order to achieve uniformity. Biomass such as sawdust, wood shavings, coconut coir and bagasse are not uniform and cannot be rendered uniform through screening. Ideally they should be ground up and formed into pellets, [briquettes](#) or some other type of uniform fuel.

The length of the pellet should be controlled in the extrusion process to assure that pellets are not too long and are of a uniform length. The bulk density of pellets increases as pellet length is reduced, and pellets that are not uniform in length give rise to channeling. The length of a pellet should not be more than about 50% greater than its diameter. Ideally pellets or briquettes should be made from torrefied biomass ([A review on biomass torrefaction process and product properties for energy applications](#)). I am engaged at the moment in designing low-cost torrefiers to process the huge quantities of pine forest debris (in the south Central highlands of Vietnam) that get burned each year to prevent catastrophic forest fires. Superheated steam will be used to torrefy.

Normally air flow that is high does not create a channel through pellets. Pellets are too dense to be displaced by the flow of air. Since airflow through pellets can be increased without channeling, the temperature of gasification of pellets can be considerably higher than that of loose biomass.

With pellets, the bulk density of the biomass can increase, in some cases, by as much as eight times. This means that the height of the reactor can be substantially reduced. With a much shorter reactor and a less powerful fan, the cost of the gasifier is reduced by almost 50%.

The batch operating time on pellets of a reactor of a net height of only 20 cm (8 inches) is about an hour and 15 minutes. The batch operating time on pellets of a reactor of a net height of 45 cm is about 3 hours. The batch operating time on pellets of a reactor of a net height of one meter is over 6 hours ([Gasifiers](#)). The use of pellets is ideal in an urban setting where the transport, handling and storage of loose biomass is not economical or practical. A new bottom-lit downdraft gasifier of a run time of 12 hours:



Instead of using pellets, one can split bamboo internodes into chopsticks, and cut the chopsticks in granules as shown here:



The moisture content of biomass should be less than 12%. If the moisture content of the biomass is too high, then the process temperature within the reactor can drop below 700 C. If temperature drops too much, the process starts to resemble low-temperature pyrolysis in which condensable gases are formed. If some of these complex gases exit in the syngas and are improperly combusted, they escape the burner as soot. If

they remain in the biochar, they degrade the quality of the biochar as a feed ingredient. They also degrade the quality of biochar as a vermicompost, compost or animal bedding ingredient. But why 700 C?

In the initial combustion reaction within a gasifier ( $C + O_2 \rightarrow CO_2$ ),  $CO_2$  is formed. In the case of true gasification, most of this  $CO_2$  is converted into CO before it leaves the reactor. This conversion takes place by means of the Boudouard reaction ( $C + CO_2 \rightarrow 2 CO$ ). This reaction is endothermic and requires process temperatures as high as 700 C. If the Boudouard reaction does not take place, then the quality of the gas exiting the reactor is poor. Such gas burns in a weak and ethereal manner – so easy to observe.

A gasifier stove must not only function properly, it must also look good. If after a few months of operation the stove begins to rust and corrode, it will be viewed as a piece of junk. Even poor people who need low-cost energy will shy away from buying it. Ideally a gasifier stove should look like any modern kitchen appliance. It is important that it be fabricated out of the high quality, heat-resistant metal, such as bright annealed 304 stainless steel.

At gasification temperatures as high as 700 C, 430 stainless steel corrodes and flakes within just a few months of operation and should never be used in the fabrication of gasifiers. Using ordinary mild steel is out of the question.

The Lotus Fire Gasifier model 100-250 pellet gasifier will retail in developing countries for about \$35 US. The Lotus Fire Gasifier model 150-250 gasifier will retail in developing countries at a price of about \$50 US dollars ([drawing](#)). Prices in developed countries could be higher, and some of the profit here could be used to lower the price of gasifiers for the poor.

For applications demanding a lot of heat, such as in the drying of agricultural products at the level of a social enterprise, there are larger Lotus Fire gasifiers as shown in these drawings: model [250-500](#), model [320-800](#), model [500-800](#) and model [800-1000](#). A [gantry](#), hoist and [trolley](#) are needed in filling and emptying the largest gasifier (drawing [003](#)). The largest gasifier delivers 200 kW of heat, it has a batch operating time of over six hours, it is made entirely out of 304 stainless steel, and it costs less than 1,000 US. If batch times longer than six hours are required, one might work with two reactors. A switch can be made between a spent and a replenished reactor in a matter of seconds. Lotus Fire gasifiers have no moving parts, other than the little 40x40 mm fan.

Since it is easy to switch reactors, it is not necessary to invest in continuously fed down-draft gasifiers. Such gasifiers are problematic. Since biomass is always in movement within the reactor, there will inevitably be biomass pockets that give rise to channeling in spite of the uniformity of the biomass. Continuously fed gasifiers have a lot of moving parts, they easily break down, and they are relatively expensive. Down-draft gasifiers of a 200 kW capacity can cost over \$500,000 US, five hundred times more than a Lotus Fire gasifier of the same capacity.

The biochar from the Lotus Fire Gasifiers is produced at temperatures greater than 700 C, it has a large surface area, and it is thoroughly uniform. Each time someone uses this gasifier, one makes biochar. Biochar has a greater value than the biomass from which it is derived. Therefore each time someone uses this gasifier, one has high-grade heat at a profit. Combined heat and biochar gasifiers do away with the need for messy biochar kilns.

In the United States biochar from biochar kilns can retail at times for over \$2.20 per kg, and in Singapore for over \$20.00 US per kg. Since biochar is so valuable, making biochar has become needlessly industrialized, embellished with proprietary know-how and often segregated into an unnecessary monetary stream. Small farmers should not have to buy biochar from people operating biochar kilns. Small farmers who need biochar as a feed, bedding or compost ingredient, should be able to make it themselves, and at the same time, they can meet their demand for high grade heat.

Unfortunately one might see (especially in developed countries) biochar kilns that vent or flare syngas, while not far away there might be households using bottled gas or natural gas to cook a meal. Why waste syngas to make biochar and then use fossil fuels to cook a meal?

If biochar is put into feed, biochar ends up in the feces of the bird or animal that ate the feed. If this fecal matter is fed to [larvae of the black soldier fly](#), biochar ends up in larval residue. If larval residue is fed to red worms, biochar ends up in vermicompost. Vermicompost formed in the presence of biochar (vermichar) is the finest fertilizer that exists. Also biochar can be incorporated into a thermophilic composting mix, prior to composting ([Synergisms between Compost and Biochar for Sustainable Soil Amelioration](#)).

In the vermicomposting and composting processes, humic and fulvic acids are formed, and the surface activation of biochar takes place. This enhances the capacity of biochar to “chemisorb nutrients, minerals and dissolved organic matter.” The overall reactivity of biochar surfaces increases in the vermicomposting and composting processes. Adding vermicompost or compost tea to raw biochar does not constitute adequate activation. Vermicompost and compost should be formed or created in the presence of biochar.



A good biochar provides a lot of surface area (300 to 600 m<sup>2</sup>/g) for fermentation microbes; for the gut microbes of poultry, animals and fish; for the gut microbes of larvae and red worms; for composting microbes; and finally for an endless variety of beneficial soil microbes – powerfully increasing efficiency and productivity at all levels.

In [Preston and Sophanh 2016](#), we see that biochar improves the conversion of crude protein into true protein in the lactic acid fermentation process. When biochar is added in small quantities to feed (generally less than 1% on a dry matter basis), biochar significantly promotes cattle growth ([Biochar reduces enteric methane and improves growth and feed conversion in local “Yellow” cattle](#)), poultry growth ([Biochar in Poultry Farming](#)) and fish growth ([Feeding biochar or charcoal increased the growth of striped catfish and improved water quality](#)).

In the study on cattle cited above, live weight gain increased by 25% through the addition of 0.62% rice hull biochar (dry matter basis) to their diet, and the production of enteric methane was reduced by 22%. When a source of nitrogen was added along with biochar, the reduction in enteric methane reached 41%! In the study on poultry, the addition of 0.60% biochar in feed improved growth in young chickens by 17%. The authors recommend adding biochar to the fermented feed of chickens. In the study on fish, biochar increased the growth rate of catfish by 36%.



When rice wine distillers by-product was added to the basal diet of “Yellow” cattle (4% DM intake), live weight gain improved by 37%. When biochar was added to the mix, live weight gain increased to 60% ([Effect of rice-wine distillers’ byproduct and biochar on growth performance and methane emissions in local “Yellow” cattle fed ensiled cassava root, urea, cassava foliage and rice straw](#)). Here we see that the [Growth performance of goats was improved when a basal diet of foliage of \*Bauhinia acuminata\* was supplemented with water spinach and biochar](#).

To understand why biochar increases animal, poultry and fish growth: it likely facilitates the “formation of biofilms as habitats for gut microbiota,” as Dr. Preston explains. Dr. Preston and his colleagues have done more than 20 studies on rice hull biochar, and he sums it up so well when he writes that the role of biochar “is much wider with potential application in all components of farming systems that involve microbial activities” (Preston 2015).

When biochar is added to the feed of poultry and animals, biochar helps prevent the escape of nitrogen from feces. When biochar is added to animal bedding, biochar helps prevent the escape of nitrogen from urine. When biochar is added to fish feed (not to the water of fish), Trinh Thi Lan, T.R. Preston and R.A. Leng saw that water quality improved, as values for total ammonia N (TAN), nitrite  $\text{NO}_2^-$ , phosphate ( $\text{PO}_4^{3-}$ ) and chemical oxygen demand (COD) were all lowered.

What is sorely missing in many discussions about biochar is its cascading multi-functionality.

Incorporating fresh biochar directly into the soil is not recommended, since biochar can fulfill so many important functions before it reaches the soil. But once it cascades its way down into soil, the cascading and looping continues on a far more complex and intensive manner. Biochar has a mean residence time in soil on a millennial time scale (between 1,300 to 4,000 years) and serves to sequester carbon.

[Arbuscular mycorrhizal fungi](#), found in conjunction with 80% of vascular plant families, grow exceptionally well in the presence of biochar ([Mycorrhizal responses to biochar in soil – concepts and mechanisms](#)). A study in Japan revealed that when one kilogram of biochar was added per square meter of volcanic ash soil, “alfalfa associations with AM fungi increased by 40-80%” ([Inoculation with arbuscular mycorrhizal fungi: the status quo in Japan and the future prospects](#)). Vermicompost also promotes the growth of AM fungi ([Vermicompost stimulates mycorrhizal colonization](#)). Vermicompost formed in the presence of biochar combines both the benefits of biochar and the benefits of vermicompost in enhancing the growth of AM fungi.

All too often biochar enthusiasts look mainly at the fixed carbon within biochar as a means of carbon sequestration. But carbon sequestration must be looked at from a much broader perspective.

The cell walls of AM fungi are 60% chitin, a carbon-rich polymer that is resistant to decay. AM fungi secrete glomalin into the soil, a glycoprotein which is also resistant to decay ([Glomalin: Hiding Place for a Third of the World's Stored Soil Carbon](#)). Glomalin gives tilth to the soil and takes 7 to 42 years for it to degrade ([Glomalin](#)). Glomalin constitutes up to 60% of the carbon in undisturbed soils.

Plant exudates account for as much as 20% to 25% of carbon fixed by photosynthesis ([Misunderstanding Soil Ecosystems](#)). As these exudates get routed by means of AM fungi to many beneficial soil microbes, nutrients are protected inside fungal hyphae where pathogens cannot access them. Also when nutrients are tucked away inside hyphae, this slows down litter decomposition and the release of  $\text{CO}_2$ . The fungal slowing of decomposition is an important carbon-mitigating factor, especially when we take into account the fact that fungal mycelium can extend several meters below the surface of the soil. If we add to all of this the fact that fungal hyphae are 60% chitin, that glomalin alone can account for up to 60% of carbon in

undisturbed soils, and that biochar not only contains carbon in an extremely stable form but also promotes the growth of AM fungi, a powerful strategy begins to emerge on how to sequester carbon and fight global warming.

Healthy soil ecosystems can store “more carbon and for longer periods than above ground vegetation.” In fact, soils can “contain twice as much organic carbon as vegetation.” Some scientists estimate that in as little as 10 years, we could reduce atmospheric carbon levels down to 350 ppm simply by abandoning



conventional agricultural practices that abuse the soil ([The Carbon Underground brings down-to-earth solution to climate change](#)). Urgent action is required, for [Atmospheric carbon just reached a huge record high](#) of 407.7 ppm.

A soil in which chemical fertilizers are never used, a soil rich in worm castings and worm mucous, a soil rich in humus and biochar, a soil rich in plant exudates and extracellular polymeric substances, a soil rich in AM fungi with its decay-resistant chitin and glomalin, a soil rich in fungal hyphae that house carbon and prevent useless oxidation and evaporation, a soil rich in protozoa and

actinomycetes, a soil rich in nematode-killing fungi and iron-releasing bacteria, a soil rich in phosphate-solubilizing and nitrogen-fixing microbes, a soil rich in countless other mutualistic soil microorganisms - in other words, a soil that is alive, is precisely what a dying planet needs.

Some speculate that rice hull biochar “has been used for several thousand years since the beginning of rice cultivation in Asia” ([Introduction to the Pioneer Works of Charcoal Uses](#)). Biochar increases the ratios of methanotropic to methanogenic bacteria in paddy soils. This results in reduced methane emissions ([Mitigating methane emission from paddy soil with rice-straw biochar amendment under projected climate change](#) and [Mechanisms of biochar decreasing methane emission from Chinese paddy soils](#)). As biochar reduces methane emissions and as nutrients are retained within soil, this increases rice yield. Compost containing rice hull biochar has been shown to increase rice yield in Cambodia by as much as 300% ([Trial on Biochar Utilization in Rice Crop on Tuk Vil Luvisol](#)).

Sisomphone Southavong, T.R. Preston and Ngo Van Man did an experiment in growing water spinach ([Southavong S, Preston T R and Man N V 2012](#)). The water spinach in the control group received no charcoal or biochar. The water spinach in the second group grew in soil amended with charcoal. The water spinach in the third group grew in soil amended with rice hull biochar. Water and fertilization were the same in all three groups. The results can be seen in the picture below. Note the difference in growth between the water spinach grown in charcoal produced in a dirty charcoal kiln, and the water spinach grown in the uniform rice hull biochar produced by my gasifiers.

In another experiment Dr. Chhay Ty and Dr. Preston applied 5 kg of rice hull biochar per m<sup>2</sup> to a plot of mustard greens ([Effect of different levels of biochar on the yield and nutritive value of Celery cabbage \(Brassica chinensis var\), Chinese cabbage \(Brassica pekinensis\), Mustard green \(Brassica juncea\) and Water spinach \(Ipomoea aquatica\)](#)). To a second plot of mustard greens they applied no biochar. But this second plot received the same water, fertilizer and management as the first. The plot with biochar yielded almost four times more weight in mustard greens than the plot without biochar, an amazing 400% increase in growth.

But the improvement here was not merely quantitative. The mustard greens with biochar had 40% less fiber and 35% more protein than the mustard greens grown without biochar. Experiments with other vegetables

were also carried out in this study. With Chinese cabbage there was a 100% increase in growth. With celery cabbage there was a 300% increase in growth. In this study ([Effect of biochar and biodigester effluent on yield of Taro \(\*Colocasia esculenta\*\) foliage](#)), we see similar positive effects of biochar on the yield and protein content of the leaves and petioles of taro.

In many Asian countries there is no shortage of waste biomass to fuel gasifiers. Vietnam produces 67 million tons of rice straw annually, and yet most of this straw is uselessly burned in fields. In the Red River Delta alone, open rice straw burning on a yearly basis “can cost up to \$200 million in environmental damage” ([Open Rice Straw Burning in the Red River Delta](#)). The useless burning of rice hulls, rice straw, coffee husks, coffee parchment, forest debris and landscape waste constitutes a colossal environmental hazard within Vietnam. Soot, smoke and ash sweep through villages, cities and houses. It blackens roof tiles, human lungs and everything else it touches. Through pelletization and gasification, the useless burning of a lot of this biomass could be avoided. One can pelletize woody biomass from construction and demolition debris, from sawmills, from the manufacturing of wood-based products and so forth.

Three invasive plants stand out in the United States: [Chinese tallow](#), [salt cedar](#) and [mesquite](#). In the southern United States, Chinese tallow covers over 185,000 hectares of land. In the western United States, salt cedar covers about 365,000 hectares of land. But the land infested by mesquite is huge. Mesquite has become “the dominant woody plant on 38 million hectares of semiarid grasslands” in the United States. About 25% of Texas grasslands, representing over 20 million hectares, are now covered with mesquite, thanks to the spread of seed by grazing cattle. Mesquite was also introduced to Puerto Rico, Hawaii, New South Wales and Queensland ([Prosopis pallida](#)), and is abundant in all of these places.

“The invasion of alien species is now regarded as one of the major threats to biodiversity of the world (IUCN, 2000)” ([Alien Invasive Plants of the Mekong: An Overview](#)). “Worldwide 653 woody plants species have been recorded as being invasive” ([An Overview of invasive woody plants in the tropics](#)). In South East Asia “Invasive species are threatening forest habitats ([Invasive Species The livelihoods threat](#)). In South Vietnam, [Mimosa pigra](#) is a big problem.

Getting rid of invasive woody plants is very much needed in the restoration of biodiversity in many areas throughout the world. Getting rid of invasive woody plants can also provide abundant fuel for gasifiers.

In the highland areas of Vietnam where a lot of coffee is grown, heat generated through the gasification of coffee husks and parchment could be used to dry coffee cherries and parchment beans. In the lowland areas where rice is grown, heat generated through the gasification of rice hulls and rice straw could be used to dry paddy rice. Many Vietnamese exporters of coffee and rice use coal at a cost of \$200 US per ton to dry parchment beans and paddy rice. It’s hard to imagine a more senseless and unnecessary use of fossil fuels. Small farmers or groups of small farmers equipped with low-cost gasifiers could own and operate their own drying facilities. They would have no fuel cost, and they could make their own biochar.

Globally about half of all food is wasted, some 1.3 billion tons annually. Gasifier heat can be used to boil, dry or [fry-cook](#) food waste to serve as animal, poultry or fish feed. Some of the biochar created in the heat treatment of food waste can be added to this feed to increase animal, poultry and fish growth. And as biochar in feed cascades down, it would contribute to the transformation of their waste at a very high level.

In Vietnam cow and pig bones are boiled anywhere from three to six hours to make stock for noodle soups such as [Pho](#), [Bun Bo](#), [Hu Tieu](#) and [Banh Canh](#). Such intensive boiling demands a great deal of energy - energy usually derived from bottled gas, coal, charcoal or wood. However if gasifiers are used to boil bone, this energy cost can be avoided. After bone is boiled, it’s usually thrown away and ends up in landfills. The

discarding of spent bone is incredibly wasteful, since about 80% of the phosphorous within an animal is found in bone.

So instead of dumping spent bone in landfills, one might crush bone into a fine powder, dry it, pellet it along with plant biomass, and gasify it. As fresh bone is being boiled in a pot above the gasifier, spent bone can be charred at the same time within the reactor of the same gasifier. This results in the simultaneous production of broth, bone char and biochar in a single integrated process. Heat is not wasted as in typical bone char kilns.

[Bone char](#) is a porous, granular material that consists of about 80% [tricalcium phosphate](#). Bone char is used in water filtration to remove radioactive isotopes, fluoride, bromine, chlorine and metal ions. It is highly effective (more so than activated carbon) in adsorbing metals such as copper, zinc, cadmium, arsenic and lead. It is also used in sugar refining as a decolorizing and de-ashing agent. Phosphoric acid is also used in the chemical activation of activated carbon ([Agricultural Waste Conversion to Activated Carbon by Chemical Activation with Phosphoric Acid](#)).

In contrast to rock phosphates which might contain uranium, cadmium, lead, copper, arsenic and other heavy metals, bone char is free of such contaminants. Therefore bone char can be crushed and safely



incorporated into the soil. It is referred to as a “soft” phosphate in that it is not as soluble and leachable as commercial phosphate. P-solubilizing bacteria (such as strains from the genera *Pseudomonas*, *Bacillus* and *Rhizobium*), actinomycetes, fungi (such as *Aspergillus* and *Penicillium*) and AM fungi can convert tricalcium phosphate into plant-available forms of P ([Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities](#) and [Improvement in bioavailability of tricalcium phosphate to \*Cymbopogon martinii\* var. \*motia\* by rhizobacteria, AMF and \*Azospirillum\* inoculation](#) and [Enumeration and](#)

[detection of phosphate solubilizing bacteria from the gut of earthworm varieties](#)). In this last study, we see that the gut of the earthworm and worm castings usually contain high concentrations of P-solubilizing microbes.

In 2009 Warren *et al.* we see that animal bone char is a P fertilizer of solubility intermediate between phosphate rock and triple superphosphate ([Dissolution of phosphorus from animal bone char in 12 soils](#) and [BIOTECHNOLOGICAL APPROACHES TO IMPROVE PLANT P NUTRITION BASED ON WASTE NATURAL PRODUCTS](#)). In soils rich in P-solubilizing microbes and AM fungi, the effectiveness of bone char is reported to be as good as superphosphate fertilizer.

Lactic acid can be added to bone char to produce [phosphoric acid](#). Phosphoric acid should not be applied to the soil. But it can be applied to certain plants as a foliar fertilizer. As noted previously, biochar can be used as an ingredient in the lactic acid fermentation process. If the biochar used in fermentation contains bone char, lactic acid solubilizes tricalcium phosphate. If the fermentation medium is deficient in phosphorous, the co-fermentation of bone char enhances lactic acid production. This in turn enhances the nutrient value of the fermented biomass being fed to poultry and animals. The phosphorus not taken up by poultry and animals ends up in their waste where it is captured in larvae, red worms, vermicompost or bedding.

Gasifier heat can be used in warming, blanching, pasteurizing, boiling, sterilizing, grilling, baking, toasting, parching, distilling, adsorption refrigeration and so forth. Gasifier heat can also be used in the rather delicate and precise process of roasting coffee.

The roaster drum shown here has a mid-section diameter of 20 cm and a mid-section length of 20 cm. It is powered by the Lotus Fire Gasifier model 150-250 (if pellets are used) or the 150-500 (if loose biomass is used).

This gasifier puts out just the right amount of heat needed to roast coffee to the highest international standard. The operator can control with precision the timing of the first and second pops. The total electrical consumption of drum and fan is less than one watt-hour per kg of beans roasted. The tanks of bottled gas normally associated with the roasting of coffee are nowhere around. As one roasts coffee, one makes biochar.

Michael Wood and Cana Little of the non-profit, [filanthrope](#), brought a gasifier roaster to Laos and presented it to a coffee co-operative there of 58 minority villages. It is hard to overstate the positive financial impact that this device has had on these minority people. Instead of selling green beans (Typica and Catimor) to middlemen at a price of \$3.00 US per kg, they now sell most of their coffee as roasted beans at a value of \$34.00 per kg. They sell the remainder in their own coffee shops as brewed coffee at a value in beans of \$102 US per kg.

As they gasify and roast, they have biochar to put in feed and compost. They do not need to buy commercial feeds or chemical fertilizers. They are empowered. They no longer work on behalf of coyotes, loan sharks, middlemen and the global elite. Their coffee has been decommodified and wrestled out of the greedy hands of those who enslaved them.

This gasifier roaster can roast up to 1.85 kg of green beans per batch, and it retails for \$300 US (roaster plus gasifier). This price stands in sharp contrast to the price of conventional roasters of one kg capacity that typically sell for over \$6,000 US. The gasifier roaster in Laos paid for itself within the first day of operation. In this [video](#) Michael Wood is teaching a young man in Laos how to roast coffee with a gasifier roaster. After a short while he fully mastered the art of roasting coffee. When his coffee was cupped by professional cuppers, it ranked among some of the finest specialty coffee in the world.

In the case of commercial grade coffee beans, one kg of roasted beans sells for about 6 times more than one kg of green beans. In the case of specialty grade coffee beans, one kg of roasted beans sells for about 10 times more than one kg of green beans. Coffee shops throughout the world could use gasifier roasters. Of course larger gasifier roasters could be designed.

When 1.85 kg of green beans are roasted, this produces about 1.5 kg of roasted beans. When 1.5 kg of roasted coffee are ground and brewed, this leaves behind about 1.2 kg of spent coffee grounds ([Brewing Fundamentals](#)). Spent coffee grounds have undergone torrefaction and brewing. When dried in the sun, they make an excellent gasifier fuel. Spent coffee grounds are uniform and do not have to be pelleted.

The gasification of 1.2 kg of spent coffee grounds puts out about twice the amount of heat needed to roast 1.85 kg of green beans, and it produces about 0.3 kg of valuable biochar. There's a logical progression from green bean, to roasted bean, to brewed coffee, to spent coffee grounds, to syngas, to biochar.

If only half of spent coffee grounds are needed as fuel for roasting green beans, what might coffee shops do with the other half? There's a simple solution here. Spent coffee grounds, as well as many kinds of Type 4 waste, can be used as a substrate for growing mushrooms. Nothing quite matches the efficiency of certain

fungi in creating nutritious human food from low-grade biomass ([Fresh Mushrooms, Nature's Hidden Treasure](#)). Mushroom cultivation represents waste transformation at a very high level. Here transformation involves nothing other than sterilization with high-grade heat, and this heat can be supplied by gasifiers. Spent coffee grounds, however, have already been sterilized in the brewing process and require no further heat treatment ([Growing Oyster Mushrooms in Coffee Grounds](#)).

In this study ([Grey Oyster Mushroom for Food Security](#)), we see that when 20% biochar by weight was added to a Grey Oyster mushroom growing medium, mushroom growth increased by over 300%. In producing spent coffee grounds and coffee ground biochar, coffee shops would have two sterilized substrates in hand and could easily grow mushrooms to sell in their shops. What then might a coffee shop do with its spent mushroom substrate containing biochar?

Ideally they could ferment it and thereby increase its protein and vitamin content. They could make the fermented substrate available to small farmers raising cows. Fermented spent mushroom substrate can be fed to cattle ([Effects of Supplementing Microbially-fermented Spent Mushroom Substrates on Growth Performance and Carcass Characteristics of Hanwoo Steers](#)). The effect of supplementing the diet of steers with fermented spent mushroom substrate is quite amazing. "The mean net income per Hanwoo steer in the treatment groups was 84 to 65% higher than that of the control group." If spent mushroom substrate contains biochar, one might expect to see a significant increase in bovine growth and mean net income. Fermented substrate can be fed to poultry as well as animals such as rabbits and pigs ([The alternative uses of spent mushroom substrate](#)).

The logic now flows from green beans, to roasted beans, to brewed coffee, to spent coffee grounds, to syngas, to biochar, to a mixture of grounds and biochar, to mushrooms, to spent mushroom substrate, to fermented animal and poultry feed, to fresh feces or droppings, to black soldier fly larvae, to larval residue, to red worms, to vermichar, to cattle urine, to spent bedding compost. After all of this, many more cascades are set in motion as larvae and worms are used as feed, and as vermicompost and bedding compost are used as fertilizer.

This is but one small example of the many never-ending cascades and loops that are possible whenever biodegradable waste is correctly transformed.

This gasifier roaster can be used to roast cocoa beans and many other agricultural products. Many coffee and cacao farmers in Vietnam have never tasted the coffee and cacao they grow. They are totally alienated from the fruit of their labor. All of this is set to change as they learn to roast and market within the context social enterprises.

Small-scale gasification has great potential, far beyond what is outlined in this essay. This technology should be continually engineered and re-engineered for widespread use even in the developed world. To view this technology as a technology only for poor people in developing countries is dreadfully short-sighted. Many households, farms and businesses throughout the world should tap into the power of fire that is free.

To see how small-scale gasification fits into the broader framework of the four levels of waste transformation, see [Waste Transformation Closed Loop Farming](#). In this paper there are hundreds of references to gasifiers and biochar. If we do not understand how biochar created at Level 4 profoundly impacts the dynamics of what happens at Levels 1, 2 and 3, we will not understand the full potential of biochar.

