BIOMASS GASIFICATION AND THE BENEFITS OF BIOCHAR

When we think of air pollution, we normally think of outdoor air pollution in heavily populated urban areas. However some of the worst air pollution occurs indoors in rural areas. The burning of biomass such as wood, coconut husk and other crop residues as a source of fuel generates smoke, particulates, carbon monoxide, methane and hundreds of organic compounds including many carcinogens. As a result, thousands of people in Vietnam die each year.

According to World Health Organization estimates, more people in the developing world die each year from conditions related to indoor air pollution—mostly from inefficient, solid-wood-burning stoves—than tuberculosis or malaria.[1] *In the year 2004, indoor air pollution from solid fuel use was responsible for almost 2 million annual deaths and 2.7% of the global burden of disease. This makes this risk factor the second biggest environmental contributor to ill health, behind unsafe water and sanitation.*

Acute lower respiratory infections, in particular pneumonia, continue to be the biggest killer of young children and cause more than 2 million annual deaths. Dependence on polluting solid fuels to meet basic energy needs is one of the underlying causes of pneumonia among children. Every year, indoor air pollution is responsible for nearly 900 000 deaths due to pneumonia among children under five years of age.

But the use of cook stoves is not limited to rural areas. Throughout Vietnam, city streets are often filled with smoke coming from small outdoor kitchens and restaurants. Low-grade biomass is often burned in the preparation of fresh noodles, the distillation of rice wine and in other applications where a lot of heat is required. Households, even in an urban setting, burn yard waste and other trash as a means of getting rid of it. This practice continually fills the air with dioxins and other deadly pollutants. Pine forests in the highland areas of Vietnam are set on fire each year in a strategy of controlled burns in order to prevent catastrophic forest fires.

One might argue that many people cannot afford kerosene, LPG or propane, and that little can be done to stop the burning of low-grade biomass as a source of fuel. Ultimately the answer does not lie in abandoning low-cost biomass fuels, but in extracting from them a gas that burns almost as cleanly as propane or any other fossil fuel.

Here we turn to the simplicity of top-lit, updraft (TLUD), forced-air gasifiers. These gasifiers operate quite well on many types of fine biomass such as rice hulls, rice straw, coffee bean husks, bagasse, wood chips, the shells of nuts, pine needles, tobacco waste and so forth. Some types of biomass, such as straw and pine needles, must be compacted or shredded to increase their bulk density. Forestry waste should be chipped. Ideally the moisture content of the biomass should not exceed 12%. Biomass can be sundried, it can be dried thermophilically using a compost fleece,[2] and/or it can be dried using residual gasifier heat.

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[1] See: http://www.newsweek.com/id/226941/page/1
[2] See: http://www.tencate.com/smartsite.dws?ch=&id=1185 as well as http://www.angliawoodfuels.co.uk/_Attachments/Resources/12_S4.pdf

The gasifier seen here is nothing more than a vertical cylinder with a removable burner on top and a grate at the bottom. A small fan supplies air underneath the grate. On a given biomass and at a given fan speed, the diameter of the reactor determines the amount of gas produced, and the height of the reactor determines the length of time that this gas is produced.

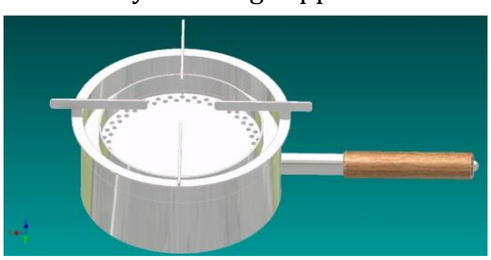
Many types of undensified biomass, such as rice hulls and bagasse, have a negative angle of repose and have a tendency to resist movement or flow through a gasifier, a hopper or any other device. In this design, biomass is never in movement within the reactor during the gasification process. Other than a small fan that supplies air underneath the grate, there are no moving parts. Very little can break down. There is virtually no maintenance. The process is easy to monitor and control, and the turnaround time between batches but a minute or two.

In starting the process, the burner is removed and the reactor is filled with biomass. The fan is turned on, and paper is placed on the top of the biomass and lit. Once the paper burns over the entire surface of the biomass, it only takes seconds for the biomass to ignite. The biomass can also be lit with a small amount of biomass that has been soaked in kerosene. Or the biomass can be lit with hot biochar from a previous gasifier batch.

A flame then rises up from the top of the reactor. The burner is placed on the reactor, and the flame comes through the holes of the burner. In many instances, it is not necessary to light gas.

When the burner is placed on top of the reactor, the open flames within the reactor go out, and gasification begins. Soon the temperature within the reactor reaches as high as 1,000 C, provided of course that the biomass is sufficiently dry.

The burner is equipped with a housing that delivers hot secondary right at the base of the burner holes (picture below on left). This housing extends down beyond the point where the burner rests upon the rim of the reactor. If any gas should leak at this point, it is safely pulled into the stream of secondary air being supplied to the burner. A gasket is not needed.



As the gasification zone proceeds from top to bottom of the reactor, a thick layer of fine hot char is formed above the point where the gases are released. As gas is forced through this bed of fine char, most complex hydrocarbons are broken down into hydrogen and carbon monoxide. It is this intimate and prolonged contact of gas with hot char of a large surface area that results in the beautiful blue flame so characteristic of this type of gasifier. This does not happen in a bottom-lit updraft gasifer or in a side-draft gasifier.

The temperature of the gas exiting the reactor can be as high as 500 C. To cool down this gas before combusting it makes little sense. In this gasifier design, hot gases are burned right at the top of the reactor. This approach eliminates the inefficiency, danger and cost associated with remote burners. This is why, in many cases, the bottom-lit downdraft design is not ideal. Since the burner in this TLUD design serves as the lid of the reactor, fabrication costs are reduced. If more burners are required, more gasifier are put in operation. They might be of different diameters and heights, and their fans might all be operating at different speeds. This results in a high degree of flexibility and control.

Someone might argue that a natural draft gasifier is simpler and therefore better than a gasifier that requires a fan. But in order to draft naturally, a TLUD gasifier must be filled with fairly large pieces of biomass that allow for the easy passage of air and gas. But if the gas can freely flow around large pieces of char that lie above the gasification zone, there is no close contact between fine char and gas. Therefore very little filtration and cracking of gas take place, and this generally results in a relatively dirty flame.

A natural draft stove, filled with large chunks of biomass, takes relatively long to light, and during this lengthy start-up procedure, a lot of smoke is released. Also it often happens in a natural draft unit that hot pieces of char break loose and drop down to points below the gasification zone. This creates multiple fronts, and the uniformity of the descending burn, an absolutely critical aspect of this process, no longer exists.

Therefore, it makes sense, if possible, to chip or shred large chunks of woody biomass and to present this fine material to a TLUD gasifier equipped with a fan. Chippers capable of chipping up to one ton of biomass per hour are fabricated in small workshops throughout Vietnam, and they are relatively inexpensive, less than $200 US or 4.2 million dong.

The electricity required for this type of gasifier is virtually nothing. During most of the batch cycle, no more than a few watts are needed to power the two smaller gasifier featured in this paper, and no more than about 10 watts is needed to power the largest.

The speed regulator moves in small increments and gives the operator a high level of control throughout the gasification process, especially in start-up when a lot of primary air is required. Note that the speed regulator is situated right above the inlet of the fan. The speed regulator box shields the inlet of the fan (a fan guard is not required), while the heat fin within the speed regulator is continually cooled by the fan. A powerful fan and good speed regulator are two of the most important features of this type of gasifier.

When the operator turns the reactor upside down to empty it of char, hot air begins drafting upwardly, and if the fan is still attached to the reactor, the fan is easily damaged by this rising heat. Therefore, in this gasifier design, the fan can be easily and quickly detached from the reactor before the reactor is emptied (see picture on right). Note that the air pipe not only delivers primary air to the reactor, but it also serves as a handle and a leg.

We foresee the fabrication of three models of gasifier. The model number and the diameter of the reactor in mm are the same:

1. model 150 = 5 kW selling for $50 USD
2. model 250 = 14 kW selling for $100 USD
3. model 500 = 56 kW selling for $250 USD

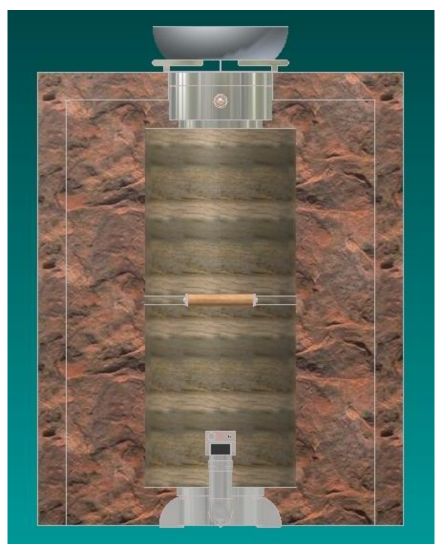
The above prices will drop considerably when these gasifiers are mass-produced. These prices include the fan, the adapter, the speed control unit and a set of motorbike cables. If there is no electricity from the mains, the speed regulator can be connected to any 12-volt battery, even the battery within a motorbike.

At the beginning of a gasification cycle, the gases exiting the reactor are normally quite hot: over 500 C. But as the burn progresses, a lot of heat is lost through the wall of reactor. Therefore, it is advisable that the reactor be insulated (see picture on right). At high temperatures, gases burn far more efficiently, and far more energy is transferred to the pot. With the hot reactor wrapped in insulation, one cannot accidently touch it.

Many attempts have been made to surround the reactor with a metal housing and to blow air between the two so as to prevent the housing from getting hot. But the transfer of heat to air in this case is not efficient, and the housing still remains quite hot. Very little is gained in terms of safety, and a housing in a quality metal is relatively expensive.

It is advisable, therefore, that the reactor not be housed, but that the gasifier be enclosed. An enclosure makes it virtually impossible for someone to accidently knock over the gasifier. Of course it is highly recommended that the front of the enclosure be fitted with a door, not shown in the picture on the left.

An enclosure can be constructed cheaply out of brick or more expensively out of stone, marble or granite. The only thing that should distinguish a gasifier for a rich man from a gasifier for a poor man is the quality of the accompanying enclosure. For safety reasons alone, there should be no such thing as a poor man's gasifier loosely cobbled together from tin cans or other cheap items. The lifetime of such cheaply fabricated cook stoves is usually measured in months. Every element of a gasifier should be of the highest quality, and it should be fabricated to last for many years.



Why should we expect the poor, who look up to the rich, to use an apparatus that the rich would never use? Or why should we design gasifiers that we ourselves would never use, except, perhaps, on a camping trip? No one, rich or poor, either in developing or developed countries, should rely exclusively on fossil fuels to cook food or heat water.

In a cooking situation the enclosure serves as a stovetop, and of course, stovetops are generally found in kitchens where food is prepared. The fact that this gasifier is lightweight and mobile allows it to be easily inserted within a stovetop and just as easily removed. With a lightweight and mobile gasifier, one is free to load and light biomass, as well as remove biochar, wherever it is most convenient to do so. In this way the dust and smoke generated in loading and lighting biomass, as well as the dust and fumes generated in removing biochar, can be kept at a reasonable distance from the kitchen.

A mobile, lightweight gasifier has another advantage. If ever channeling should occur within the reactor, the operator can easily solve this problem by lightly tapping or shaking the reactor. This would not be possible in the case of a ceramic reactor permanently fixed in an upright position within an enclosure.

With this type of gasifier operating on rice hulls, coffee husks and other forms of agricultural waste, we have access to energy that is abundant and free. Nothing in terms of solar or wind power comes even close, and this energy is available any time it is needed. Let us explain a bit further.

The gasification of roughly 90 kg's of rice hulls can deliver a gas of the same calorific value as 12 kg's of propane. A 12 kg tank of propane costs 400,000 VND ($19.04 USD). If so, then one kg of rice hulls will produce about 4,440 VND ($0.21 USD) in gas. Also one kg of rice hulls will produce about a half kg of biochar. In Vietnam rice hull biochar sells for about 3,150 VND per kg (about $0.15 USD). Therefore one kg of rice hulls has a combined value in gas and biochar of 5,940 VND ($0.283 USD). One ton of rice hulls has a combined value in gas and biochar of 5,940,000 VND or $283 USD.

Vietnam produces each year about 8.2 million metric tons of rice hulls each year, which, if gasified, would have a combined value in gas and biochar of $2.32 billion USD. Vietnam produces about 54 million tons of rice straw per year, which, if gasified, would have a combined value in gas and biochar of $15.28 billion USD. We should take note of the surprising fact that at times both rice husks and rice straw have a slightly higher value per ton than paddy rice. The line between product and by-product becomes blurred.

Thousands of years ago Amazon Indians incorporated charcoal into the soil to enhance its fertility, and surprisingly a lot of this charcoal still remains fixed in the soil to this day. If we want to combat global warming and remove carbon dioxide from the atmosphere, we can also incorporate biochar into the soil:

- AL GORE - *"One of the most exciting new strategies for restoring carbon to depleted soils, and sequestering significant amounts of CO_2 for 1,000 years and more, is the use of biochar."*
- BILL MCKIBBEN - *"If you could continually turn a lot of organic material into biochar, you could, over time, reverse the history of the last two hundred years…"*
- DR. TIM FLANNERY - *"Biochar may represent the single most important initiative for humanity's environmental future...."*
- DR. JAMES LOVELOCK - *"There is one way we could save ourselves and that is through the massive burial of charcoal."*

Adding biochar to the soil also increases the water and air holding capacity of the soil, and it promotes the proliferation of mycorrhizal fungi and other beneficial soil microbes. Biochar improves the cation exchange capacity of the soil and prevents nutrients from being washed away. When biochar is incorporated into the soil, we see a 50% to 80% reduction in nitrous oxide emissions, as well as a reduced runoff of phosphorus into surface waters and a reduced leaching of nitrogen into groundwater.

Biochar reduces the amount of methane released from the soil. It adsorbs dissolved organic matter and prevents their rapid consumption by soil microbes. This adds even more carbon to the soil. This eventually becomes stable humic matter, the most beneficial form of carbon needed for plant growth. *As a soil amendment, biochar significantly increases the efficiency of, and reduces the need for, traditional chemical fertilizers, while greatly enhancing crop yields.*[3]

Dr. Boun Suy Tan of Cambodia recently did a study on the benefits of rice hull biochar and compost added to the soil in growing rice. He set up four plots:

- plot 1 = no biochar and no compost
- plot 2 = 5 tons compost/ha
- plot 3 = 5 tons compost/ha + 20 tons biochar/ha
- plot 4 = 5 tons compost/ha + 40 tons biochar/ha

The yield in kg's per hectare:

- plot 1 = 1,252
- plot 2 = 1,504 (a 20% increase in yield)
- plot 3 = 1,817 (a 45% increase in yield)
- plot 4 = 3,756 (a 300% increase in yield)

As we compare plot 1 with plot 4, we should keep in mind that adding rice hull biochar not only yielded 3 times the rice, but also 3 times the rice hulls, hulls that can produce 3 times the biochar. Here we see a very positive amplification of effects.

Water spinach grown in soil amended with rice hull biochar does exceedingly well, as indicated in a recent study in Laos (April, 2011). In the first treatment (see picture on right), a nutrient-rich bio-digester effluent was added to the soil. In the second treatment in the middle, there was the same bio-digester effluent added, plus rice hull biochar from a 250 gasifier (Biochar). In the third treatment on the right, there was the same bio-digester effluent added, plus wood charcoal (Charcoal). It is easy to spot the winner in this experiment.

Biochar, and especially rice hull biochar, is easily activated or functionalized. Activated carbon currently sells from $500 to $ 2,000 per ton. But it is not always necessary to activate it.

Biochar derived from cow manure, for example, can be used to sorb from wastewater both metals and organics. It can sorb awful pollutants such as lead and atrazine (an herbicide). This cow manure biochar is six times more effective in sorbing lead from wastewater than activated carbon.[4] It can eliminate, for example, 99.5% of lead in wastewater.

Biochar produced from pine needles is quite effective in removing naphthalene, nitrobenzene and *m*-dinitrobenzine from water. Another study indicates that pine needle biochar is quite effective in

[3] See: International Biochar Initiative (IBI)

[4] See: *lqma.ifas.ufl.edu/Publication/Cao-09a.pdf*

removing some of the same polycyclic aromatic hydrocarbons from the soil. PAHs are ubiquitous pollutants in agricultural soils in China and Vietnam.[5] Soil amended with biochar derived from rice or wheat straw neutralizes herbicides such as duiron and atrazine.

The biochar produced in the gasification of biomass has a much greater value in general than the biomass utilized to produce it (including its delivery to the site). In other words, a high-quality gas can be produced at a negative cost or profit. Each household or small business operating a gasifier can sell bio-char and, in most cases here in Asia, it can completely offset the cost of gathering or purchasing the biomass it needs.

Scavengers could buy biochar from households and businesses. They might sell it to companies who would activate or functionalize it, or they might sell it to companies who would utilize it for soil remediation, or for water and gas filtration. An entire industry centered in the buying and selling of biochar could be created. If revenue from carbon credits is added to this strategy, then it is hard to imagine a cheaper form of energy that could be made available to the people of Vietnam.

A gasifier cook stove, manufactured in stainless steel, can be situated on the market for less money than a propane/butane stove top with a deposit for a gas tank. Many industries that could never exist due to the high cost of energy could arise.

Food waste can be cook and pasteurized with gasifier heat and fed to pigs. The feces of the pig is then fed to BSF larvae, and the residue of the larvae is fed to red worms. Some report that biochar added to the substrate fed to red worms results in acceleration of the vermi-composting process and a higher yield of worms. Gasifier heat initiates the process, and gasifier char comes in at the end.

Some soil scientists believe that the agricultural benefits of biochar can be enhanced even more by combining biochar with vermicompost.[6] Both BSF residue and biochar enhance red worm growth, and when both are mixed together and fed to worms, the end result is a worm casting of superior qualities. Here we see several technologies coming together and mutually supporting one another.

This same gasification technology can be used to generate electricity. Normally the gas from a gasifier has to be cooled and filtered before it can be fed to an internal combustion engine within a gen-set. Perhaps a better option is to route gasifier heat to an organic Rankine cycle unit. In this case, the gas does have to be cooled and filtered.

David Trahan of Louisiana, together with his team at 3R Sciences, has developed a small methanol synthesis plant capable of producing from synthesis gas about 100 liters of methanol per day. *The R3 GTL Methanol process converts the biomass-generated synthesis gas into methanol. The modular system is designed to allow placement at remote locations to meet supply availability of biomass feedstock.*[7]

[5] See also http://www.springerlink.com/content/8p413624j3n0440x/ as well as http://pubs.rsc.org/en/Content/ArticleLanding/2008/EM/b712809f

[6] See: http://www.scribd.com/doc/30909297/Biochar-Article

[7] See: http://www.r3sciences.com/biomass.html

Methanol can be utilized directly in motorbikes and automobiles as a source of fuel,[8] and it can be dehydrated into a type of diesel fuel called dimethyl ether or DME (CH_3OCH_3).[9] The small-scale production of bio-methanol for local transportation needs is truly an exciting possibility.

The CO and H_2 from this gasification process can also be fed to microorganisms that consume these two products and secrete ethanol as a waste. Companies such as Coskata, INEOS Bio and LanzeTech have adopted this approach to ethanol production. In syngas fermentation even the lignin contained within the biomass is transformed in ethanol:

The gasification/fermentation pathway is very interesting alternative way of producing bio-ethanol. Via traditional fermentation processes, lignin, an important component of biomass cannot be fermented. Gasification and subsequent fermentation of the produced gas enables fermentation of all carbon and hydrogen containing material, also non degradable materials like plastics.[10]

Prof. Dr. Le Chi Hiep, chairman of the Energy Council and head of the Dept. of Heat & Refrigeration at University of Technology in Ho Chi Minh City, is now designing small adsorption refrigeration units to make ice based on gasifier heat. This is one of the most efficient ways of making ice. Here electricity is not needed – only heat.

The cost of propane and butane will continue to rise. So will the cost of electricity, petrol, diesel and ice. At the same time Vietnam has hundreds of millions of tons each year of residential bio-waste, agricultural waste and forestry bio-waste that for the most part are being dumped or uselessly burned. This simple gasification technology allows someone to utilize bio-waste in the place of fossil fuels and to actually earn money in doing so. We have definitively entered a new era in fuel production and consumption.

Before concluding this essay, I would like to report the results of three boiling tests.

The first test was carried out on a normal propane gas stove. [11] Here it took 6 minutes and 6 seconds to bring one liter of water to a boil. The burner here is a very efficient premix gas burner.

The second test was carried out using the 150 gasifier.[12] Here it took 3 minutes and 39 seconds to bring one liter of water to a boil.

The third test was carried out using an insulated electric water kettle (see picture on the right). In this way we are able to compare the two previous results with what could be considered to be the fastest way to boil water in a kitchen setting. Here it took 3 minutes and 25 seconds to bring one liter of water to a boil.

[8] "The methanol gasoline can reduce emissions of carbon monoxide, hydrocarbon and nitrogen oxides, with comparable or better performance, especially at high loads." See page 14 of http://www.afdc.energy.gov/afdc/progs/view_citation.php?10828/METH/print
[9] "Only moderate modifications are needed to convert a diesel engine to burn DME." http://en.wikipedia.org/wiki/Dimethyl_ether
[10] See *Bio-ethanol from Bio-syngas*: www.ingenia.nl/flex/Site/Download.aspx?ID=1600
[11] See: http://youtu.be/w8OdW_GEhWo
[12] See: http://www.youtube.com/watch?v=vnM5Itk7wlQ