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 coir 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 and in other applications where a lot of boiling water 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.

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 fuels. Ultimately the answer does not lie in abandoning low-cost biomass fuels, but in extracting from them a gas that burns as cleanly as propane or any other fossil fuel.

The fabrication of top-lit, updraft (TLUD), forced-air gasifiers has begun. These gasifiers operate quite well on many types of fine and undensified biomass wastes such as rice hulls, coffee bean husks, coconut coir, bagasse, wood chips, sawdust, the shells of nuts and so forth.

Some types of biomass, such as straw and pine needles, must be slightly compacted or shredded to increase their bulk density. Forestry waste should be chipped. But the costly step of pellitization (as much as $125 US/ton) is generally not required. Ideally the moisture content of the biomass should not exceed 12%. Biomass can be sundried, it can be dried thermophilically using a compost fleece, and it can be dried using residual gasifier heat.

This gasifier is nothing more than a vertical cylinder with a removable burner on the top and a grate at the bottom. A small fan supplies air underneath the grate, and the speed of the fan is controlled by means of a speed regulator. 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.

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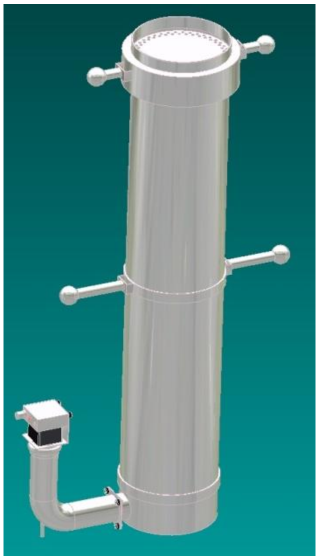
[1] See: http://www.newsweek.com/id/226941/page/1



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 or any other device. In this gasifier, biomass is never in movement within the reactor during the gasification process. Other than the 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 is measured in seconds, not minutes.

In starting the process, the burner is removed and the reactor is filled with biomass.[2] The fan is turned on, and paper is placed on the top of the biomass and lit by means of a match or cigarette lighter. Once the paper burns over the entire surface of the biomass, it only takes seconds for the biomass to ignite. 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. The fan speed is lowered according to the amount of heat required. Note that in most in most instances, there is no lighting of gas.

This is quite important from the point of view of safety, since at no time is carbon monoxide being discharged. Once the burner is placed on top of the reactor, the open flame within the reactor goes out, and true gasification begins. Soon the temperature within the reactor reaches as high as 1,000 C, provided of course that the biomass is sufficiently dry.

As the burn proceeds from top to bottom, a thick layer of hot fine char is formed above the point where the gases are released. As the 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.

Also, there is a distinct advantage in burning the gas at the top of the reactor. The gas does not cool down or have to be cooled down prior to combustion. Here there is none of the inefficiency or loss of heat associated with remote burners. This is why, in many cases, the bottom-lit downdraft design is not ideal. In the case of this TLUD design, if more burners are required, more gasifier are put in operation. They might be of different diameters, 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 hot char and gas. Therefore very little filtration and cracking of the gas take place, and this usually results in a relatively dirty flame.

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[2] The start-up procedure is clearly shown in a video clip at: http://www.esrla.com/pdf/gasifier.mpg

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 that poses health risks to the operator. Also it often happens in a natural draft unit that hot pieces of char break loose and drop down to points well below the gasification zone. This creates multiple fronts, and the uniformity of the descending gasification zone, an absolutely critical aspect of the process, no longer exists. When this happens, the process is completely compromised.

Therefore, it makes sense, whenever possible, to grind or chip large chunks of woody biomass and to present this fine material to a TLUD gasifier equipped with a fan. But when ones says “fan”, many people panic and shake their heads in dismay concerning the amount of electricity required. But the electricity requirement in this type of gasifier is virtually nothing. During most of the batch cycle, no more than about one watt is 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 air is required. A powerful fan and good speed regulator, therefore, 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 high heat. Since the temperature of this air is much higher than 80 C, a fan can be destroyed in a matter of weeks.

Therefore the fan must be easily detached from the reactor before the reactor is emptied. This is done by means of a press fitting. A press fitting allows the operator to detach and reattach the fan in seconds.

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

1. model 100 = 1.5 kW selling for $25 USD
2. model 150 = 3.5 kW selling for $50 USD
3. model 250 = 10 kW selling for $100 USD
4. model 500 = 40 kW selling for $250 USD

All components, except for the burner, are fabricated out of high-quality stainless steel. These prices will drop by as much as 50% 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. All parts that protrude out from the reactor and burner can be unscrewed and removed for easy transport.

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 inefficient, and the housing still becomes hot. Very little is gained in terms of safety, and a housing in stainless steel is relatively expensive. If the reactor should overheat due to channeling, the operator cannot see the wall of the reactor which generally turns red hot. If the operator does not slow down or shut off the fan in time, the reactor begins to melt and deform. Also, if ever the reactor should corrode and develop a leak, once again, the operator sees nothing.

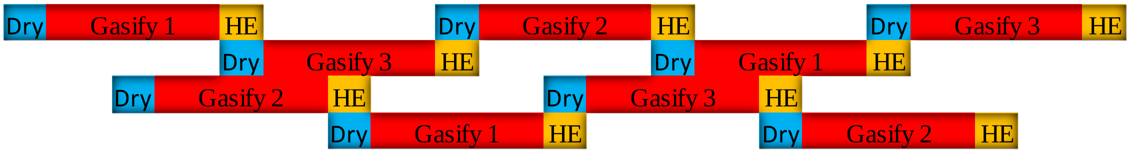
It is advisable, therefore, that the reactor not be housed but that the gasifier be enclosed. An enclosure not only limits access in touching the hot reactor, but it also makes it quite difficult for someone to accidently knock over the gasifier. With an enclosure, pots and pans are not supported by the gasifier, but by the burner grate on the top of the enclosure. An enclosure can be inexpensively constructed out of brick or stone (see picture above).

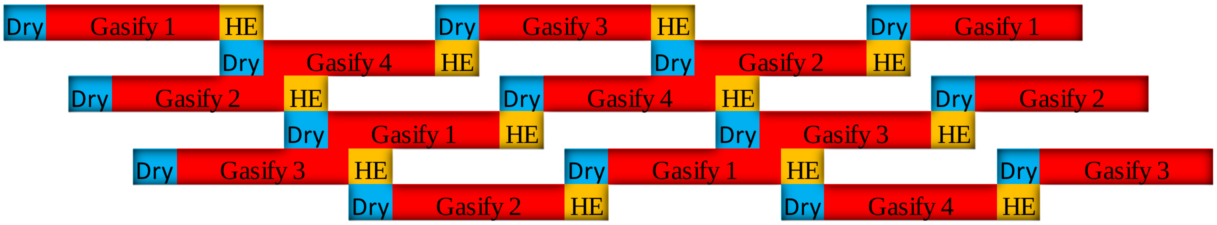
The fact that this gasifier operates in batch mode allows it to fulfill other important functions. At the end of a batch cycle, the biochar within one reactor generally contains enough heat to dry the biomass (loaded but not lit) within a second reactor. Therefore the one reactor can be designed to serve as a multi-purpose vessel: a dryer, a gasifier and a heat exchanger.

Air devoid of oxygen is blown in at the bottom of a first reactor filled hot char. This hot air slowly rises through the char and is then routed to the bottom of a second reactor filled with moist biomass. The moist air from this drying process is routed to coils within a tank filled with water. The moisture within the air condenses out, and this dry air is routed back to the first reactor filled with hot char. This cycle repeats until the biomass in the second reactor is fully dried. In this way, warm water is also produced.

Therefore biomass does not have to be transferred from dryer to gasifier, and char does not have to be transferred from gasifier to heat exchanger. When biomass is finally lit in a reactor that served as a dryer, it is fully dry and gasifies at maximum temperatures. When biochar is finally evacuated from a reactor that served as a heat exchanger, it is relatively cool and does not have to be sprayed with water.

The following diagram shows two time sequences with respect to a dryer/gasifier/heat exchanger:one with 2 reactors and the other with 3 reactors. There is always a continuous flow of gas:





Wood, branches and other waste of a high cellulosic content can be shredded by means of low-cost shredders, as designed, for example, by the SPIN organization in Hanoi. One model of shredder costs about $35 US or 735,000 VND, and can process up to 600 kg's of chips per hour. These chips can be dried thermophilically down to about 23% moisture under a compost fleece.[3] The final drying down to 12% moisture can be accomplished using residual gasifier heat, as explained above.

Municipal waste of a high cellulosic content can be shredded by means of low-cost shredders in a small-scale, decentralized manner. The shredded material can be used as mulch, it can be composted, or it can be gasified. There are significant advantages, as we shall soon see, of mixing compost and biochar.

Take note in the above pictures above and below that the burner is equipped with a housing. Secondary air rises between the burner and the burner housing, and is heated up. It then hits a flange where it is deflected horizontally onto two staggered rings of burner holes. Such a burner configuration makes it hard for wind to blow out the flame, and it allows the operator to adjust flame height over a broad range: from a height of just 8 mm to a height of over 80 mm. Such a big turn-down ratio is quite useful in cooking.

In this burner design, the flow of secondary air is determined primarily by the height of the pot or pan situated above the burner. If the pot or pan is less than about 20 mm from the burner, the flow of secondary air is relatively low. If the pot or pan is more than about 20 mm, the flow of secondary air increases proportionally. The operator can easily see when there is too much secondary air: the flamelets are no longer situated right above the burner holes but are displaced a few mm's toward the center of the burner. This

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

displacement always occurs the moment the pot or pan is removed from the stove top.

A slight excess of secondary air is quite useful in the first few minutes of a gasifier run. In the gasification of rice hulls, an excess of secondary assures that one does not have to wait 10 minutes or more before the flames turn completely blue. The flamelets are immediately blue.

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). In other words, 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 both rice husks and rice straw have a slightly higher value per ton than paddy rice. Now we know what it means to make of waste our greatest resource.

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 should 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 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.*[4]

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 on the left (see picture on right), a nutrient-rich bio-digester effluent was added to the soil. This first treatment represents what most farmers consider to be good growing conditions. 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.[5] 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

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[4] See: International Biochar Initiative (IBI)

[5] 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.[6] 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 which also includes a deposit for 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.

Many soil scientists believe that the agricultural benefits of biochar can be enhanced even more by combining biochar with vermi-compost.[7] 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. 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 symthesis 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.*[8]

[6] See also http://www.springerlink.com/content/8p413624j3n0440x/ as well as http://pubs.rsc.org/en/Content/ArticleLanding/2008/EM/b712809f
[7] See: http://www.scribd.com/doc/30909297/Biochar-Article
[8] See: http://www.r3sciences.com/biomass.html

Methanol can be utilized directly in motorbikes and automobiles as a source of fuel,[9] and it can be dehydrated into a type of diesel fuel called dimethyl ether or DME (CH_3OCH_3).[10] The small-scale production of bio-methanol for local transportation needs is truly an exciting possibility.

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, of agricultural 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.

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[9] "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

[10] "Only moderate modifications are needed to convert a diesel engine to burn DME." http://en.wikipedia.org/wiki/Dimethyl_ether