Biomass Gasification:
Clean Residential Stoves, Commercial Power Generation, and Global Impacts

Prepared for the LAMNET Project International Workshop on
"Bioenergy for a Sustainable Development," 8-10 Nov 2004, Viña del Mar, Chile

Paul S. Anderson (Ph.D.) and Thomas B. Reed (Ph.D.)
Biomass Energy Foundation, 1810 Smith Rd, Golden, CO 80401, USA.
Contact info: psanders@ilstu.edu tombreed@comcast.net

Abstract

Renewable dry biomass is extremely abundant, but only a highly selective small fraction is utilized for energy. Available technology for gasification could utilize a much wider variety and greater quantities of the biomass and provide significant energy while alleviating several pressing environmental concerns. "Gasifiers" are defined as devices in which the dry biomass is transformed into combustible gases in processes *distinctly separate* from the eventual combustion of the gases.

The history of gasifiers began around 1800 and includes the manufacture of over a million vehicles during World War II. For affluent societies, electricity generation of 3 KWe to 100 MWe capacities via large gasifiers is accomplished but not common.

For resource-impoverished societies, the major issues of residential energy are cooking, light, room heating, and refrigeration. For these needs, the co-authors have created (from 1985 to 2004) an appropriate variety of forced-air and natural draft TLUD ("Top-Lit Up-Draft") micro-scale gasifiers (combustion chambers) to power appropriate stove/heater structures and (in 2005) mantle lanterns fueled by "woodgas."

Controlled pyrolysis and partial oxidation of diverse low-value biomass produces woodgas that, with close-coupled combustion, yields substantial clean heat plus charcoal as an optional co-product. Basic descriptions of construction and operation are provided.

Eleven benefits are presented: 1) Reduced smoke (IAP) yields better personal health; 2) Improved personal safety; 3) Reduction of drudgery for women and children; 4) Home benefits including room heating; 5) Job creation; 6) Available energy for societal development; 7) Probable provision of lighting via woodgas; 8) Reduced deforestation; 9) Reduced dependence on fossil fuels; 10) Improved air quality; and 11) Assisting the "carbon cycle" and climatic stability. Therefore, these low-cost innovative gasifiers (with a goal of US$5 for a minimal unit) should benefit the two billion people who rely daily on burning dry biomass, mainly wood, for their residential energy.

Concerning implementation, financing, and mutually supportive activities we present nine favorable issues: A. Families use low-value biomass and cut fewer trees; B. Society also sees reduction of atmospheric global warming gases via charcoal production while, C. Generating Kyoto/CDM "carbon credit" for this charcoal which, D. Helps to finance the stoves for impoverished societies so that, E. People can have better health with less indoor air pollution. F. Permanent verifiable sequestration (via scattered burial) of the carbon that receives Kyoto/CDM credit will; G. Improve the fertility of weak soils (and improved crops) via addition of carbon powder to create "terra preta do índio". H. Capacity building and employment via stove production and fuels preparations is supportive of, I. De-centralized implementation of gasifier stoves to allow maximum localized adaptations while having international exchanges of gasifier developments for shared problems.

All readers are invited to participate in accomplishing these benefits.

[End of Abstract]

1. Energy, Biomass and Gasification

Regardless whether the source of energy is fossil, direct solar, hydro, nuclear, or biomass, no energy is useful until humans have acceptable ways to access and utilize it. In modern societies, we go to almost any extremes to generate clean (but relatively expensive) electricity and to refine the fossil materials into precise gaseous and liquid fuels that can be burned very efficiently and cleanly. Because the solid fuels of biomass and coal can't be easily mixed with air in the right proportion, they generally are not as clean burning. Hence, we process solid biomass to create liquids and gases such as alcohol, gel-fuel, and biogas. This article focuses on an additional way to obtain the benefits of gaseous fuels: "gasification of dry biomass."

Renewable dry biomass is extremely abundant, but only a highly selective small fraction is utilized for energy. The main biomass fuel is wood for many reasons. But its appeal also can lead to the problems of deforestation exactly in the most environmentally sensitive locations. Therefore, while continuing to use woody biomass where abundant, we have great interest in obtaining energy from other dry biomass sources, including agro-wastes (stems, hulls, husks, roots, cobs, by-products of production, etc.), tree-wastes (sawdust, trimmings, coconut shells/husks/fronds, twigs, seedpods, leaves, etc.), municipal wastes (discarded combustibles including paper/cardboard and dried sewage) and environmental excesses such as bamboo and (when dried) aquatic invaders.

Currently, vast amounts of these non-wood and waste-wood materials are left to decompose, become pollutants/landfill, or are burned *in situ* to clear an area. To obtain that energy in controlled conditions, improved methods of harvesting such "wastes" and then processing (densification, de-hydration, uniform shaping, etc.) and burning this dry biomass need to be utilized. Our conference discusses several methods, most of which are specific to one or a limited few of the biomass forms.

In virtually all combustion of dry biomass, solid materials are converted by *endo*thermic pyrolytic actions into gases (plus some particulates and condensates ranging from ash to soot and tars). These gases, when combined with oxygen of the air, can combust [*exo*thermic action] to release heat energy. Normal fires involve the virtually simultaneous and poorly controlled creation of the gases and their subsequent combustion. But when we speak of "gasification" processes and devices, the key and defining issue of gasification is the *ability to separate* the creation of the gases from the event of the combustion of those gases.

[Note 1: A smoldering smoky pile of biomass can be "autothermic" in which the necessary heat for pyrolysis is generated by small (oxygen starved) combustion, referred to as "flaming pyrolysis," but the conditions for the combustion of the smoke/gases are usually absent.]

[Note 2: Pyrolysis leaves behind solid carbon (char or charcoal) which, with appropriate conditions of heat, oxygen and water, can also be converted into highly combustible gases CO and H_2. This "gasifying of the carbon" is here referred to as "carbolysis" or "carbolytic" action until a more appropriate name is accepted. "Gasification" is the generic term used by laypersons to include both pyrolysis and carbolysis processes that convert solids into gases through the addition of heat.]

Please note that "gasifiers" are defined here as devices in which the dry biomasses are transformed into combustible gases in processes *distinctly and controllably separate in time and location* from the eventual combustion of the gases. Also, because the term "biogas" has an established definition referring to gases made from anaerobic digestion of *wet* biomass, we need an acceptable and understandable term for gases made from *dry* biomass. We will use the term "woodgas" even though we know that such gases are also produced from non-woody dry biomass and waste. [Technically, "biogas" should refer to all the gases from both the wet and the dry biomass, but we are unlikely to convince others to change to terms like "rotgas" or "swamp-gas" when referring to the gases from the wet biomass. Similarly, we want to encourage the exclusive use of the terms "gasification" and "gasifier" to refer to dry biomass, and never to refer to the biogas generation from wet biomass.]

Because gasification separates gas creation from gas combustion, gasifiers can utilize an extremely wide variety of raw materials to provide significant energy while alleviating several pressing environmental and societal concerns.

2. A Very Brief History of Gasifiers

The technology for gasification of coal and wood has been known and used since 1800, and by 1850 London and Paris had “gaslight”. The greatest usage for wood was during World War II when well over a million vehicles were operating on “woodgas” because of severe shortages of gasoline, especially in Europe. Considering the pending crisis of Peak Oil (when the ability to obtain oil begins to diminish and prices rise dramatically), the experiences with early gasifiers could become increasingly important. For further information about the history of gasifiers and pictures of early vehicles with gasifiers, please refer to the BEF website at http://www.woodgas.com/ and use the link to “Books” to view numerous publications that include classic international items from these earlier years of gasification. Pictures of gasifier vehicles are in Figure 1 and at http://www.woodgas.com/History.htm

Fig. 1.A. Tom Reed with friend’s gasifier truck.

Fig. 1.B. Motorcycle with gasifier.

Fig. 1.C. Gasifier production during WWII.

1979. This wood-burning 1978 Chevrolet Malibu station wagon (from which the fuel tank has been removed) drove 4,320 km (2,700 miles) from Jacksonville, Florida, to Los Angeles, California, fueled entirely by scrap wood. The generator holds enough wood for about 160 km (100 miles) of travel. On the open highway the vehicle easily cruised at 91 kph (55 mph) and reached a top speed of 108 kph (65 mph). Fuel economy averaged about 3.5 km per kg of wood (1 mile per lb), a considerable savings in fuel cost over gasoline. Body-mounted 1981 versions of the wood-powered generator are shown below. (Ben Russell, President, ECON, P.O. Box 828, Alexander City, Alabama 35010, USA)

Fig. 1.D. Gasifier on trailer; crossed USA.

Figure 1: Vehicles with internal combustion engines powered by gasifiers.

3. Current Capabilities of Gasifiers for Societies with Reasonable Financial Resources

Currently no biomass gasifiers compete in the category with large thermoelectric, hydroelectric, or nuclear power generation facilities. Indeed, the large fossil fuel facilities utilize very well the same chemical equations and engineering principles of combustion, as do the biomass gasifiers. But they are dependent on large quantities of fossil fuels that have high energy content. Instead, the current generation of "large" biomass gasifiers that could be used for electricity generation (or heat) have capacities of 3 KWe to 100 MWe in biomass-fired IC engine/turbine cycle or steam cycle. Their advantages can include being dispersed close to the sources of the biomass and to the consumers. In general, current (late 2004) rising fossil fuel prices are beginning to make electricity generation via biomass gasifiers increasingly attractive. Prices from US$5000 for small systems to $1200 for large systems per kilowatt of capacity are possible. These gasifiers are commercial/industrial enterprises with significant investments. One supplier reports having twenty systems in commercial operation on five continents with a wide variety of applications and currently operating around the clock (some for over twenty years) with low maintenance and only two high school-educated operators. Although dozens of suppliers are listed in the references below, there are perhaps five to ten noteworthy suppliers of large gasifiers around the world. Figure 2 shows some of the large gasifiers in pictures taken from corporate websites.

Gasification (REPP): http://www.repp.org/articles/static/1/1011975339_7.html
Small Scale Gasifiers (REPP):
http://crest.org/discussiongroups/resources/gasification/200kWCHP.html
Gasifier Inventory (BTG): http://www.gasifiers.org/
Status of Gasifiers in IEA Countries (IEA) 2002:
http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=iea/countries.xml

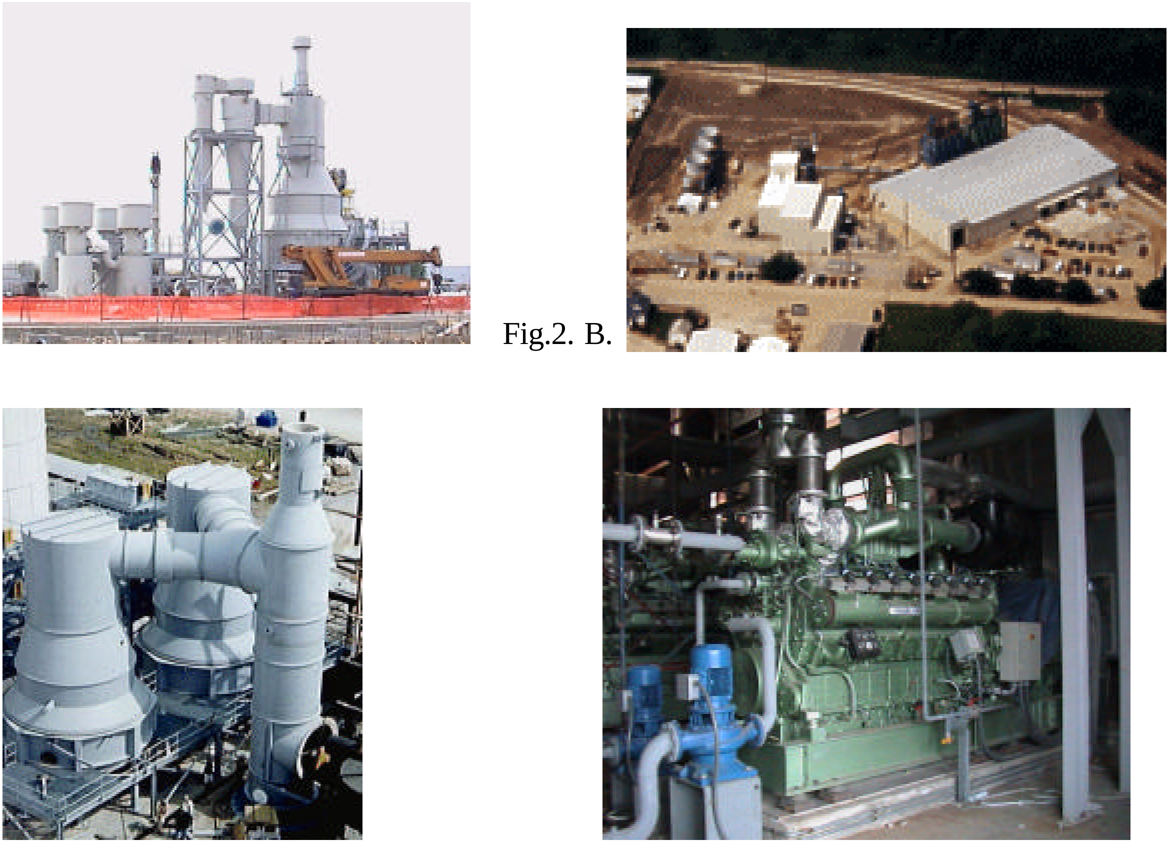

Fig. 2.A. Fig.2. B.

Fig. 2.C. Fig. 2.D.

Figure 2. Three large gasifier installations (A-C) and a large engine powered by biomass gas.

Concerning gasifier-powered vehicles, the only ones currently in existence would best be considered experiments and curiosities. A major crucial issue concerns the combustion of the gases in the internal combustion (IC) engines. Gasification of wood and other dry biomass commonly creates significant amounts of tars and particles that can accumulate in the valves of IC engines. For optimal operation, the tars and particulates must either be filtered (scrubbed) out of the gases to < 50 ppm (50 mg/m^3) or, preferably, are never created because of improved gasifier designs now available in some systems. Either solution can be costly, bulky, or both, but progress is being made.

Therefore, for the developed (affluent) societies, the gasification technologies for "modern" purposes of electricity generation and vehicle operation exist but are currently far short of being able to step in rapidly once the Peak Oil crisis arrives.

4. Current Capabilities of Gasifiers for Resource-Impoverished Societies

The majority of the world population is either impoverished or with serious limits on their available resources. Approximately two billion people currently do their daily cooking with dry biomass, mainly wood but including some agro-wastes and animal dung cakes. For these people and probably another billion or two, the major issues of residential energy are cooking, light, room heating, and refrigeration.

For these needs, the co-authors have created (from 1985 to 2004) an appropriate variety of forced-air and natural draft TLUD ("Top-Lit Up-Draft" = "Inverted Down Draft" -- IDD) micro-scale gasifiers (combustion chambers) fueled by "woodgas." Dr. Reed is a recognized world expert on gasification and other combustion issues, including fuel characteristics. Dr. Anderson (a geography professor with no prior stove/gasification experience) met Dr. Reed in 2001 and has become a co-developer of the small gasifiers, especially those with natural draft and those that relate to the needs of the resource-poor populations. Details about that early work is in "The Origins of the Juntos Gasifier Stoves: Short Version," found at http://www.ilstu.edu/~psanders; and in an appendix to this article.

Dr. Reed has developed and commercially sold a quality-manufactured "WoodGas CampStove." Due to limited production the cost in the US is $60, but we believe it could be manufactured on a large scale to sell for $20 in many countries. Dr. Anderson has designed and made his "Juntos Gasifier Stoves" mainly with simple sheet-metal technology (what "tinsmiths" do) intended for local production in developing societies. His 100+ prototypes are "Juntos A" gasifiers; the "Juntos B" design is this one being released for production by others. Anderson's and Reed's two variations are in Figure 3.


Fig 3. A. Two "Juntos B" combustion units.


Fig. 3. B. Two air bases with fan & blower.


Fig. 3. C. Assembled Juntos B.

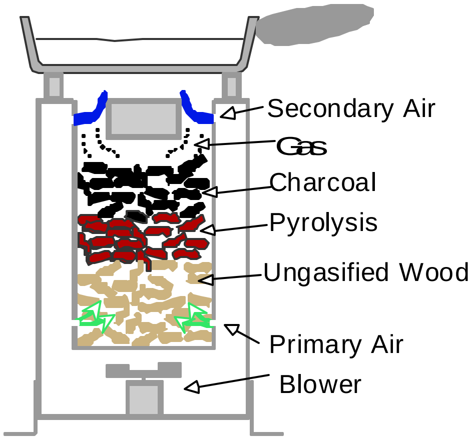

Fig. 3.D. Cross-section.


Fig. 3.E. Woodgas CampStove.

Figure 3: Reed-Anderson biomass gasifier combustion units.

The Reed-Anderson gasifiers differ from previously discussed gasifiers in at least six significant ways. They:

1. Can be very small (to boil a cup of tea) or large enough to operate a small bakery,
2. Can have very low cost (with a goal of US$5 for a minimal unit).
3. Create pyrolysis gases prior to significant gasification of the solid charcoal.
4. Can produce charcoal as a co-product. (The importance of the charcoal is discussed later in this article.)
5. Have "close-coupled" combustion. (They do not save the gases for later use, but combust them a few seconds later and a few centimeters away.)
6. Are currently batch-fed, but continuous-fed models will be forthcoming.

The results are inexpensive devices with controlled pyrolysis of diverse low-value biomass to produce woodgas that, with close-coupled combustion, yields substantial clean heat plus charcoal as an optional co-product.

Below we discuss the basics of designs and operations that apply to both styles of our small gasifier stoves. [A more detailed discussion of the physical and technical characteristics of these stoves and how to make and operate them will be a separate publication.]

5. Basics of the Reed-Anderson Small Gasifier Stove Designs

A. With Forced Air

There are only three main components to the designs of the WoodGas/Juntos small gasifiers with forced air. Their principal characteristics are listed below, but many variations are possible. We present the three components of the *gasifier-combustion units*. We do not address here the wide varieties of devices for the use of the heat, the most common of which are a "stove" structure (legs, chimney, plancha, etc.), pot, oven, drier, and room heater. The gasifier can work with a full variety of applications of heat.

1. The "combustion unit" or "fuel unit" (made from two cylindrical "cans")

1.a. Fuel chamber:

This cylindrical container 10 cm (4 inches) in diameter and 6 to 8 inches tall, with closed bottom and open top, has twelve primary-air holes of 7/64th inch diameter (almost 1/8th inch) evenly spaced around the can about 1 cm (half inch) above the bottom of the can. It also has thirty-two secondary-air holes of 11/64th inch diameter (almost 3/16th inch) evenly spaced around the can about 2.5 cm (1 inch) down from the top. Although tin cans will suffice, better steel helps withstand the temperatures of pyrolysis (approx. 400 deg. C.) and of burning charcoal (over 900 deg. C). This chamber is the most critical part of the small gasifiers because a one-to-five ratio of primary to secondary air (allowing for resistance by the fuel) is extremely important.

1.b. Outer cylinder for air control:

This cylindrical container is 15 cm (6 inches) in diameter with the same or slightly less height as the fuel chamber, with an open bottom, and a sealed top, through which the fuel chamber is inserted approximately 1.5 cm (half inch) and attached using heat-tolerant rivets, screws, spot-welds, clamps, etc. (Avoid aluminum and plastic fasteners). The attachment of a heat-tolerant handle on this outer cylinder is highly recommended but is not considered to be a separate piece.

2. Air base:

The above described combustion unit is to be placed on top of the air base, a component that will direct the forced air upward to enter the primary and secondary air holes. Gravity holds the combustion unit on top of a flat-topped air base, preventing major leakage of the air. The air base must be sufficiently open on the top to allow the passage of the forced air upward into the combustion unit, sufficiently sealed on the sides and bottom to prevent the escape of the forced air, and with provision of access (side or bottom) for the entry of the forced air. Note that the device to provide the forced air (a fan or a blower) could be incorporated into the air base or could be external to the air base.

3. Fan or blower:

For each kg of fuel burned, approximately six cubic meters (6 m^3) of air needs to be delivered with sufficient force and control. Surplus airflow is not a crucial concern because one blower could service several air bases or have controls as simple as a baffle to reduce the flow. If available, electricity (via any grid, battery, or photo-voltaic device) is the simplest power for using fans and blowers. A typical hair-dryer blower would be far too much power. Small one-watt DC electric motors can be sufficient power for a fan if properly ducted via the air base. A small battery (perhaps recharged by solar photo-voltaic cells or at a recharge shop) can provide hours of forced air, depending on the configuration of the air base. Peltier effect thermoelectric devices (TED/TEM) could be used, being powered by the heat of the stove itself.

Manual power can be used but would require the person to be present continually or also require a storage mechanism. A wind-up spring mechanism is being considered. Stirling engines or steam ejectors also could be adapted. Households and societies can choose from several acceptable options to obtain the forced air.

Note that Reed's "WoodGas CampStove" has the air base and the fan built into the lower part of the outer cylinder. This has advantages and disadvantages depending on the user's intentions. It also has four "pot supports" on top, and therefore is a totally self-contained stove.

B. For Natural Draft

All stoves depend on acceptable airflow. The only two sources are forced or natural. Natural draft is basically air movement caused by the tendency of hot air to rise. Chimneys are the main instruments to strengthen natural draft.

In Anderson's Juntos designs for natural draft small gasifiers, the combustion unit and the air base appear to be similar to those described above, but the positions and sizes of the primary and secondary air holes are importantly altered. The biggest difference in the natural draft gasifiers is that instead of the fan or blower, a chimney configuration is needed. A chimney between the combustion chamber and the cooking area (thereby providing space and time for complete combustion of the gases), is an "internal chimney." When it is beyond the cooking area, it is a regular chimney or a post-point-of-heat-use chimney (or an "exit chimney"). Because of several design variables that must be considered for proper operation, we do not present detailed descriptions and discussions of the Juntos natural draft small gasifiers in this presentation/ publication. Interested parties should contact Dr. Anderson directly.

6. Basic Operations of Small Gasifier Stoves with Forced Air

A. Fuel: The fuel must be a "chunky" dry biomass, permitting airflow through the fuel bed. This airflow can also relate to the power of the fan/blower. For simplicity, think of the typical fuel as being irregularly shaped wood chips with dimensions of 0.5 x 1 x 2 cm, plus or minus half of each dimension. Standard pellets for pellet stoves are about as small as would be acceptable. Sawdust *does not* work because it settles too compactly. Loose big sticks *do not* work because there is too much space between them. Basically, the user should be able to gather up by handfuls or with a small scoop the fuel to load into the fuel chamber. The fuel level should be at least one cm below the level of the secondary air holes.

B. Starter material: It is very important to light the fuel on the *top only*. Because we are top-lighting, we need to have reasonable immediate combustion of the upper layer of the fuel. For this, we use a "starter" material (tinder) that will ignite easily with one match and stay lit for a minute or two. Simple paper is *not* acceptable because it burns out too quickly. The simplest way to obtain starter material is to take some of the basic fuel (described above) and coat it with a *small* amount of any of the following liquids: kerosene/paraffin, citronella oil, flammable alcohol, diesel fuel, or other "reasonable" flammable liquids. Some pine residues could be acceptable. (*Do not* use gasoline, and *do not* add a liquid starter directly onto fuel already in the combustion chamber because a drip can provide a path for the fire to reach the bottom, causing too much gas to be released in too short a time to be useful.) Place a small amount of the starter (equal to 5 to 10 pieces of the typical wood chips described above) across the top of the fuel.

C. Ignition: Ignite the starter fuel with a match to have flame in all areas of the top of the fuel chamber. Allow it to burn for a few seconds, and then turn on the forced air in a *low* amount. When the flames stabilize in about a minute, you can increase the amount of forced air. If you observe any sooty flames at the beginning, it is probably because of excess starter material. If the flame is not uniform over the top of the fuel chamber at the level of the secondary air holes, you probably need to follow more closely the instructions about the level of the fuel or the ignition of the flame over the entire top of the fuel. With a little practice you will be able to avoid these conditions.

D. Operation during the burn: The fire will continue for 10 to 45 minutes depending on the amount and type of fuel and the amount of forced air. The "pyrolysis front" is progressing downward through the fuel supply at a rate controlled by the amount of primary air entering via the bottom air holes. To increase or decrease the heat being produced, you can make adjustments to the amount of forced air during this time. But try to avoid sudden shifts. For example, an excessive gust of air (internal or external to the stove) can extinguish the flame at the secondary air holes. That will result in voluminous smoke (pyrolysis gases which are the fuel for the secondary combustion). A single match should be able to re-ignite the gases, but there can be other complications that are left for more detailed discussions elsewhere. Also, to extend the time of the burn, *small* amounts (about 1/4 handful maximum) of the dry biomass can be added on top of the fuel during the pyrolysis stage of the burning.

E. Conclusion of the burn: When all goes well (as it usually does), the pyrolysis (smoke-making) process proceeds all the way down through the fuel, resulting in only charcoal remaining in the fuel chamber. Then the primary air is blowing directly onto the hot char, making a much hotter but much smaller fire of red-glowing char at the bottom of the charcoal bed. If this amount of heat is sufficient for the cooking needs (such as simmering), simply let it burn until virtually all the char is consumed. Alternatively, the user can remove the combustion unit and dump the hot char into a "snuffer can" that is simply a metal can with a tight-fitting lid. The char will be extinguished in about 5 minutes. [To continue the cooking, a second combustion unit could have been loaded with fuel and starter material, then lit just before removing the first combustion unit, and placed onto the air base.]

One of the most sensitive times of the operation is when the pyrolysis is almost complete. Sometimes there is still some pyrolysis occurring but insufficient gases to maintain the secondary combustion. That means smoke is released. Usually the best option is to dump quickly the remainder of the fuel into the snuffer can. However, with experience, the user might learn to re-ignite the secondary combustion. These are details of operation left for a separate discussion.

7. Benefits for People, Societies, and the World.

The benefits of the gasifier combustion device come in three levels: Personal, Societal, and World. Eleven are listed. They are not presented in order of importance. Also, whereas individuals and families can singly appreciate benefits for themselves, World benefits depend on substantial numbers of users. The potential usage or "market" is several hundreds of millions of improved cookstoves to serve two billion people. How to attain that number is discussed in Sections 8 and 9.

A. Personal Benefits:

1. Personal health: Lower Respiratory Infections (LRI) form a disease-group classified by the World Health Organization (WHO) as the second worst category of disease and injury that impacts the "Disability-Adjusted Life Years - DALYs" of people in the poorest countries of the world. The *World Health Report 2002* (WHO, 2002, Annex Table 14 on page 232 at http://www.who.int/whr/2002/whr2002_annex14_16.pdf) states that in the High Mortality Developing Countries (HMDC), LRI with 8.2% of DALYs is second only to HIV/AIDS (9.0% DALYS) and worse than Diarrhoeal Diseases (6.3% DALYs) and even the combined Childhood Cluster Diseases (5.5% DALYs).

The four risk factors named by WHO concerning LRI in these poorest countries include two of lesser importance zinc deficiency (a nutritional problem), and tobacco (an "individual choice" issue). The two **major risk factors** are "indoor smoke from solid fuels," [elsewhere called Indoor Air Pollution (IAP)], and "underweight" which is partially caused by carbon monoxide poisoning of pregnant women using faulty stoves. "Indoor smoke from solid fuels" (or IAP) is the fourth worst risk factor (with 3.7% DALYs) for the HMDC, and is the eighth worst risk factor (1.9% DALYs) in the low mortality developing countries (LMDC) (Annex Table 15 in WHO, 2002). Thus, the solution to this health issue is *prevention* of the disease-causing conditions, not a cure for those who have been affected. This problem requires a technological solution to avoid smoke, as can be accomplished via small gasifier stoves.

Using the World Health Organization (WHO) statistics about IAP, the widespread adoption of small gasifiers could avoid respiratory problems in many millions of people per year, avoid lost productivity in terms of millions of hours of work, and possibly save over 2 million lives per year.

2. Personal safety: Uncounted thousands of people, mainly women and children, are seriously burned every year by fires for cooking. Improved cookstoves can increase the personal safety of the family members.

3. Reduction of drudgery for women and children: In many societies, the collection of fuels for stoves is relegated to the women and children. The gasifier cookstove is able to operate on fuels found closer to home, even utilizing some waste materials.

4. Home benefits: Room-heating can be very important for even modest comfort. Other residential benefits include: cooking with increased control of the fire, less blackening of the pots, food preservation (such as drying fruits, canning, etc.), hot water for bathing, and the beginnings of cottage industries like bakeries. Other stoves and fuels can do similar things, but with different costs, performance, and acceptance.

B. Societal Benefits:

5. Job creation: The most simple of the small Reed-Anderson gasifier stoves are designed to be made (and maintained) in local or area settings, not requiring centralized production plus shipping to dependent people. Likewise, because the fuels generally consist of renewable local biomass, some people will become "fuel suppliers." Decentralized job creation is a major objective of the small gasifier stove project. The creation of jobs and organized businesses could eventually benefit many millions of workers and their dependents. The following comments are very gross approximations.

1. A team of 5 people might manufacture, transport, and market 20 combustion units (or stoves) per day, being 100 per week, or 4 per worker per day.
2. For production of 1 million units, the production rate in item 1 above translates into 250,000 days of work, being 1000 worker-years, or employment for 1000 people for one year.
3. If the average worker earned US$4 per day (which is more than the daily salary of a high school teacher in Mozambique), the labor cost per combustion unit would be $1, and the worker would earn $1000 per year, and be able to support 3 to 9 dependents.
4. $1000 times 1000 workers would equal a million dollars into the economy.
5. Also, the gatherers, processors, and marketers of fuels should be counted, along with those who make and market the heat-capture devices.

These are all estimates that are partially based on Dr. Anderson's experiences in Mozambique in 2003. We are not able to offer much additional substantiation at this time.

6. Available energy in larger quantities leads to societal development: We can "scale-up" the energy output by using several small gasifiers together to get larger fires for larger operations. We have also made larger versions of the TLUD-IDD gasifiers, but refinements should be made before recommending them to new users.

7. Future provision of lighting via woodgas: On-going development is coming close to having a practical "mantle lantern" powered by woodgas. This will be extremely useful in homes, schools, factories, and businesses that currently have no lighting or are dependent on kerosene or batteries. Light in homes assists in education and literacy efforts.

C. World Benefits:

8. Reduced deforestation: The gasifier stoves have the potential to save entire forests by diverting the tree-cutters into users of fuel-crops and agricultural waste for their fuels. This is possible because: a) small gasifiers can use a great variety of non-wood or waste-wood fuels, and b) the combustion efficiency and heat-capture efficiency of gasifiers are or can be as good as or even better than those efficiencies of open fires and stoves currently in use, resulting in the need for less fuel.

9. Reduced dependence on fossil fuels: The small gasifiers will make a minor contribution (in quantity) to the reduction of the rather limited use of fossil fuels by impoverished people, but if the dire predictions of Peak Oil are true, the affluent people who consume massive amounts of fossil fuels could find clean dry biomass gasifiers to be among their best options in future decades.

10. Improved air quality: The Asian Brown Cloud (ABC) over north-central India is mainly from the millions of small and inefficient cooking fires needed to feed economically poor people. We need stove types that do not pollute, and the small gasifier is one of those, and quite possibly the best of those.

11. Assisting the "carbon cycle" and climatic stability: Burning biomass is "carbon-neutral," placing into the atmosphere the carbon that the plants removed from the atmosphere a few decades or mere months earlier. Furthermore, small gasifier stoves are uniquely suited for the removal of carbon from the "carbon-cycle." "Carbon sequestration" is discussed separately below.

Summary of Benefits: Eleven benefits have been named. Some are (perhaps) not very important. Others are "long range" or "thinly spread" benefits that are hard to quantify. But a few (#3 - reduced drudgery - and #5 - job creation -) are highly important, and one (#1 - reduced IAP -) is literally life-and-death for millions of people. The next section discusses how to reach the large numbers of people who could benefit by the small Reed-Anderson gasifier stoves.

8. Comments about Financing and Implementation

It is one thing to have a small gasifier stove that we know functions well. It is something else to get it to the people and to have it used. The discussion that follows is the most speculative part of this paper. It makes some assumptions that might be shown to be inaccurate. But the discussion should stimulate some thinking that could ultimately be productive.

The two biggest obstacles to massive adoption of the small gasifiers are social inertia and funding of the necessary stoves projects. We will assume that when the money is available, the ways will be found to help make the stoves quite socially acceptable. Therefore, we will focus on the funding issues.

Our world is threatened by global warming, so much so that the Clean Development Mechanism (CDM) procedures are already in place to implement parts of the Kyoto Agreement. Basically, to avoid the addition of more carbon dioxide (CO_2) into the atmosphere, money will be paid for what are called "carbon credits." The late 2004 price is approximately US$6 per ton of CO_2 as a gas, which calculates to be US$24 per ton of reasonably pure carbon (C) as charcoal. We refer the readers to the DFID document entitled "Encouraging CDM Energy Projects to Aid Poverty Alleviation," available at http://www.iesd.dmu.ac.uk/contract_research/publications/kb1.pdf . Using Tanzania data from that document, we can say the following about Improved Cookstoves (ICS) (of which the small gasifiers are a new type that could exceed the reported results):

a. "Overall it [ICS benefits] is equivalent to 144 MW with 120,000 stoves." (p. 24) (or 1.2 MW per 1000 ICS, or 1.2 KW per stove).

b. ICS provides "Reduction over 20 years of 6450 $ktCO_2$" (p. 52) (or 322 $ktCO_2$ per year, or 2.7 tons of CO_2 per stove, or 0.67 ton of char per stove *even without saving the char for sequestration*).

c. Rated as "well balanced" and having "high sustainability" for host approval (p. 41).

Although all ICS produce heat, the Reed-Anderson batch-fed small gasifiers are the only ones that can conveniently and controllably yield a co-product of charcoal, that is, quite pure carbon. One typical household in the impoverished world could consume five to forty kilos of wood per day (depending on uses for heating as well as cooking). Even at only seven kilos of wood per day, this volume could rather easily yield a half-ton (500 kg.) of charcoal in a year while accomplishing the family cooking and without causing deforestation because of the diverse types of acceptable low-value fuels. That charcoal would be worth around US$10 as Kyoto/CDM "carbon credits."

If the gasifier combustion unit with air base and fan/blower could be produced and distributed for US$10 and function for one year, it literally could be provided "free" as long as the user produced the charcoal co-product. With a two-year life span, it would equal a US$20 gasifier stove or actually provide income or other benefits to the stove user. These or lower costs per stove per year are certainly attainable with a sizeable project.

The CDM procedures call for environmental monitoring to assure compliance and to prevent the release of the CO_2 (or C) back into the atmosphere. The monitoring of the gasifier-produced charcoal could be accomplished by supervised and documented sequestering of the charcoal in an advantageous way that would prevent it from ever being combusted back to CO_2. The sequestering of charcoal could be accomplished in local areas of production by crushing it to powder and spreading it into the soil for fertility benefits.

In recent years there have been significant research findings about the improvement of fertility of weak soils via addition of carbon powder. The research focuses on the "terra preta do indio" or, in English, the "dark soils of the Amazon." This is totally compatible with the concepts of organic farming and the improvement of soil fertility by natural biological means. Therefore, the gasifier users who create the charcoal could either want the charcoal for their own fields or sell it to others nearby. Ref: Glaser, B. and W.I. Woods (eds.) (2004) *Amazonian Dark Earths*. Springer, Germany (ISBN: 3-540-00754-7).

There are nine clear "wins" and not evident "loses" in this scenario:

A. Families use low-value biomass and cut fewer trees, reducing deforestation	WIN
B. Society observes less CO_2 entering the atmosphere (via charcoal co-product)	WIN
C. Kyoto/CDM "carbon credit" is generated by this charcoal and reforestation	WIN
D. Impoverished families receive improved cookstoves to motivate A & B	WIN
E. Reduced Indoor Air Pollution yields better health for biomass users	WIN
F. Verifiable permanent sequestration of carbon via scattered burial	WIN
G. Soil fertility is improved, crops are better, (with improved food and health)	WIN
H. Appropriate sustainable technology creates employment & capacity building	WIN
I. De-centralized implementation allows maximum localized adaptations	WIN

9. Actions Underway:

The first steps for production of the Reed-Anderson small gasifiers outside of the USA have already begun. Prototypes suitable for local production are being prepared at pilot locations in Nepal and Brazil before the end of 2004. More locations are welcomed. Maximum localized adaptations should stimulate international exchanges of gasifier developments as they relate to shared problems (such as high-altitude cooking and heating, or harvesting and briquetting of agro-waste fuels).

You could rightly ask if the gasifier-stove innovation can spread on its own merits. In other words, "would ordinary people in this field understand this device and bring it into their work?" The first of two categories of OPITF (Ordinary People In This Field) is the "Stovers," the collective name for the educated and active stove developers and stove disseminators around the world. The second category includes the "Stove Makers and Stove Users" who live and work among the target populations.

We know many of the Stovers. We interact with them via the Stoves List Serve, the annual ETHOS conferences, and various regional associations/projects such as HEDON, SparkNet, ProBEC and ARECOP, and the *Boiling Point* publication. Additional dedicated Stovers throughout the World will also be found within the coming first year of outreach activity. Stovers are far from being "ordinary" people, but they are truly "in the field." Many of them are capable social entrepreneurs, but until now have been without the gasifier innovations to carry to their associates. Stovers question everything and will make many improvements. We are confident that they will understand the gasifier innovation to be new, practical, feasible and attractive. We must anticipate their questions, act for implementation, and modify according to the feedback.

We estimate that at least forty of the Stovers will join in the efforts within the first six months. Through them we will access the leadership strength of Non-Governmental Organizations, the approvals and funding of governmental entities, and the grassroots leaders and artisans who can make the stoves in remote places. The Stovers and associates are invited to incorporate the small gasifiers into their on-going and future activities.

The second category of OPITF consists of the Stove Makers and Stove Users who are very much "in the field." Many are formally uneducated, but are very wise. When the new stove technologies are properly explained and demonstrated in their villages with their own foods and their own pots, they will make their decisions. For stove users (AKA "cooks"), an important key is to *not* change their cooking (pots and recipes), but to change their *source* of heat and fuel with clearly associated advantages of ease of use, less or no smoke, better control over the cooking, and savings of labor or funds for fuels.

Balance is needed. Every ICS project involves four essential components: fuels (source of energy); combustion chamber (where heat energy is released); usage devices (where heat has applications); and human factors (culture, habits, desires, etc. concerning the heat). All four must be addressed simultaneously. We are required to have an integrated approach.

10. Conclusion and an Invitation for Cooperative Efforts

Nothing discussed in this paper should be considered as "simple" or "easy." We have worked hard to get to the point of announcing and turning loose the information about the forced air Reed-Anderson small gasifiers. We have more work to do, but now many other people are invited to participate. Hundreds of questions and issues are yet to be resolved, but we are confident that they will be answered within the next few years. We are happy that the action has started.

Except for our own time and funds, we have been working with an almost zero budget. The Biomass Energy Foundation (BEF) is very small, but is positioned to present the Reed-Anderson biomass gasifiers wherever there is interest. We hope that many will collaborate with us, each bringing their special abilities forward to benefit others.

- 0 -0 - 0 - 0 - 0 - 0 - 0 -

Appendix

On the following page is the slightly revised document "The Origins of the Juntos Gasifier Stoves: Short Version Revised 2004-10" which is also available at www.ilstu.edu/~psanders *.*

A PowerPoint presentation for the LAMNET Workshop in November 2005 in Chile will also be made available. Additional information, up-dates, and links will be announced via the Stoves list serve and at the BEF website at http://www.woodgas.com *, or contact the authors directly.*

The Origins of the Juntos™ Gasifier Stoves: Short Version (Finalized 2004-11)

Paul S. Anderson (Ph.D.), Emeritus Geography Professor, Illinois State University., Normal, IL 61790-4400
E-mail: psanders@ilstu.edu   Telephone USA: +1- 309-452-7072

The heating of biomass can cause chemical decomposition ("pyrolysis") that releases gases that can subsequently be burned as "secondary combustion." This process occurs nearly simultaneously in regular fires, making the two stages difficult to see or to control. But when the gases are generated but not burned immediately, the pyrolysis process is more easily understood, seen, and controlled. This process is informally known as "gasification." Commercially viable gasification (such as Top-Lit Down-Draft = TLDD) has long been understood and used in industry and even in transportation (over one million vehicles during WWII), but not for small applications such as a household stove.

In 1985 on a trip to South Africa, gasification expert Dr. Thomas B. Reed awoke one night thinking of a very small gasifier for the domestic stove needs of impoverished people. For ten years he worked to develop the TLUD (Top-Lit Up-Draft) natural convection gasifier stove. In 1995 Dr. Ronal Larson joined the effort with a focus on the gasifier's capacity for producing charcoal as a valuable by-product in a household stove. After testing and publications (see fig. below-left) but no real success for applications, they stopped that work in 1996. However, in 1998 Dr. Reed began work on a smaller, forced convection model with a fan with the intention to make a stove for the affluent North American camper market. He has successfully produced the "WoodGas CampStove" for marketing in 2003 and can produce an impressive heat for sustained periods (Figs. below). Some modifications are necessary for applications in developing countries.

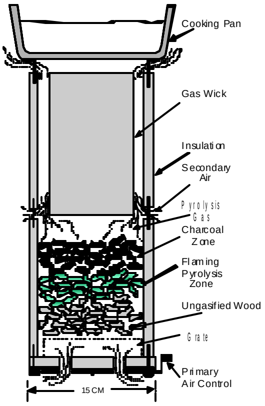

Fig. A

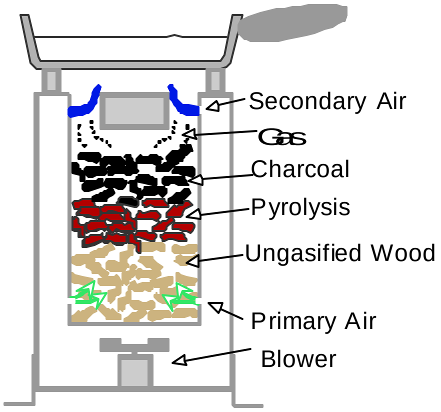

Fig.B

Fig. C.

Reed-Larson 1996   Figs. B & C showing the forced-air WoodGas CampStove by Dr. Thomas B. Reed, 2003

In 2001, Dr. Reed lit his early prototype forced-air gasifier stove on a kitchen table for Dr. Paul S. Anderson and two others to see. Sufficiently impressed, Dr. Anderson started experimenting, received on loan the original TLUD gasifier, learned much from the "Stoves List Serve," and subsequently devised numerous modifications that resulted in the Juntos stove concepts. Those modifications (some are visible in the figures below) include different stackable units (including a modified "rocket stove") in a heat column over a gasifier unit with an air pipe, with smaller holes for entrance of secondary air, with pre-heated secondary air, with a tapered chimney, and with independent structural components for the stove body. The Juntos gasifier chamber is removable and, therefore, can be emptied to save the resultant charcoal, re-loaded with biomass, re-lighted, and re-inserted into the heat column. Design improvements resulted in the "Junto B" model introduced in November 2004 at LAMNET in Chile.

Fig.D   Anderson 2002-1   Fig. E   2002-2 (Gasifier slides out)   Fig.F   2003 Natural Draft   Fig.G   "Juntos B" gasifier

In late 2003, Dr. Anderson met another gasification expert, Mr. Agua Das who stimulated ideas and development of additional variations and improvements, most specifically to obtain a lower point of exit of the heat (needed for societies that cook close to ground level) and the ability to continuously feed the fuel (vs. the batch burning of the prototype "Juntos A" designs and the released-for-production "Juntos B" designs). The efforts of Reed, Anderson, and Das are brought together for both "not-for-profit" and "for profit" efforts wherever appropriate and usually in conjunction with additional participants. *[Up-dates will occasionally be posted via links to http//:www.ilstu.edu/~psanders] [The trademarks of these gasifier stoves include the words Juntos, Together, Sath-Sath, and any other foreign words that mean "together".]*