We have been developing "Alternative Energy" - Solar, Wind, Geothermal etc. for 30 years since the first oil embargo. While these have niche applications, they are not fuels. They are intermittent, costly and unlikely to replace more than 10% of our current fossil fuel needs.

Alternative Energy Sources are a RED HERRING tolerated to divert our attention from our real needs. Oil is a fuel and its products can be used anywhere, anytime. The era of "cheap oil" is over and now we need to find ALTERNATIVE FUELS.

Oil prices are rising and availability falling. I expect prices to at least double every 5 years. This will make a profound difference to our Civilization. Our Earth would be far beyond its carrying capacity for Humans if it weren't for cheap oil. Cheap oil has gone. We hear a lot about substituting "alternate energy". We aren't running out of energy - we are running out of "cheap oil", and need to find an "alternate fuel". Windmills and solar panels can provide small amounts of energy, but we can't picture a significant fraction of earth covered with them. The earth is already covered with plants and trees busily converting sunlight to biomass products and fuel. All we need to do is learn how to use the fuel fraction. See **Biomass Energy** for details.

While we have deplored the "hydrogen economy" as a red herring for practical energy, WoodGas has a high concentration of hydrogen and is VERY clean burning. So, we have been using and promoting "hydrogen rich gas" made from wood and coal. We are now also involved in reforming liquid fuels to a hydrogen rich gas.

"**Woodgas**" is my nickname for the gases that can be made from wood, other biomass and waste for heat, power and synthesis of ammonia and fuel (it is also called "producer gas", "synthesis gas" etc.). I have worked in this field since 1973 when I began experimenting with methanol as a gasoline additive and oil supplement. Hydrogen is both the best of fuels (because it burns fast and clean) and the worst of fuels (because it is difficult to ship and store, because it must be made from other fuels, preferably at the point of use). However, it constitutes about half the fuel value of our "hydrogen rich gas", so making it from wood and biomass is a proven technology. Probably your grandmother cooked on a hydrogen rich gas stove and didn't even know it.

Site News

We are currently reorganizing the BEF to develop and promote "hydrogen rich gases" for clean efficient combustion. We are currently under construction and may soon have a sister site for members.

We now have online purchasing for books and other articles listed on our pages.

In 1974 I was embroiled in a controversy at MIT with the oil and motor companies over the use of methanol as an alternative fuel. They won! As a result we have paid higher prices for foreign oil and funded the terrorism that has taken a million lives, culminating in 9/11 in the U.S. Check it out at **METHANOL**.

Three billion people in the world cook slowly on smoky, inefficient **woodfires**. We have developed a novel "**WoodGas CampStove**" that we believe far exceeds the performance of any other biomass cooking device because it first turns the wood to gas, and then burns the gas with the correct amount of air. It puts out up to 3 KW of heat, comparable to the big element on an electric stove, it burns only 10 g of fuel/min (40% efficient), and it can be used indoors with minimal emissions. We hope similar designs will be used in developing countries where the need is greater, but we want to develop our product first in the U.S., so we have developed a company to manufacture, market and distribute the stove.

We believe that these stoves will have a much wider application in the developing countries of the world. See our WoodGas Stove page for other information about WoodGas stoves. We hope to see a billion of these stoves in use in the next the next few decades.

We have re-issued our 3 volume "**Survey of Biomass Gasification**" from 1980 as a one volume "Encyclopedia of Biomass Thermal Conversion". The National Renewable Energy Lab, (SERI then, NREL now) commissioned it as a prerequisite for me to build gasifiers. It contains chapters by various experts on many aspects of thermal conversion and other aspects of biomass for energy. I wish there were something more current that covers all aspects of biomass, but this is the best to date. See this and our other books on gasification and biomass in the **BEF BOOKSTORE**.

SITE OVERVIEW

Biomass Energy is the oldest, most widespread and practical form of renewable energy. The residues from agriculture and forestry could provide 20% of U.S. energy. Biomass has been a major concern of mine since 1974, the first "energy crisis". This page has lots of information on the properties and availability of biomass in its many forms, particularly **moisture content**, **fuel densities**, and the **biomass analyses** and energy content.

BIOMASS **Gasification** turns biomass into a more useful form, WoodGas. "WoodGas" is my nickname for gas produced from biomass for heat, power and synthetic fuel applications. During World War II, over a million vehicles, boats etc. ran on Woodgas. (See **History** of Woodgas). While I have written a number of articles and books on all aspects of gasification, my specialty has been **small gasifiers** for power, transportation and cooking.

Cookstoves consume most of the biomass in developing countries, often wastefully with terrible health effects. We cook now much better with propane or natural gas, but this requires infrastructure not available for half the world. A great deal of research is in progress to improve world stoves, see **Cookstoves**.

Synthetic Fuels and chemicals can also be produced from renewable biomass and as petroleum runs out we will increasingly turn to biomass as a renewable resource. I am a chemical engineer and have worked toward oil replacement fuels for 28 years (for the future fuel security of my grandchildren and the rest of us).

BOOKS on biomass energy are difficult to find. The Biomass Energy Foundation Press publishes 20+ books on biomass energy and related subjects and you can order them online, by mail, fax or phone. You can buy our books at our online **BEF store**.

The Biomass Energy Foundation, the BEF is a 501-C-3 non-profit organization. Founded by the flamboyant and fascinating Dr. Harry LaFontaine, now deceased. It is currently operated by Dr. Tom Reed and his wife Vivian. Find out about the **History** and **Current Research** of the BEF. Finally, we have links to other sites that will give you more information on biomass energy.

This Website combines two previous websites and has more content and advanced features. We would appreciate your comments either on the site itself or its contents.

Biomass Gasification is a very old art ... and there isn't enough science in it, but we're working on that here at BEF and other places. Visit our Biomass Books to learn most of what is currently known about about wood and other biomass gasification, and what you can do with the gas. Lots of practice, lots of science, some gasifier plans and other related subjects there. Visit our **History** page for a quick overview of gasification.

Tom Reed has been working in this field since the first energy crisis in 1974 and knows all the names that have been used for the gases produced by various processes. However, in his casual conversation, he calls it "WOODGAS", a term easily understood and acknowledging the first renewable source, wood since >100,000 years ago. So he has chosen this for the name of this renewable energy web site. In practice it includes gas from agricultural and forest residues and even Municipal Solid Waste as well, though these materials are harder to gasify.

Briefly biomass can be gasified pyrolytically by heating to >400 C, yielding also 25% charcoal and LOTS of condensibles - tars). Or it can be gasified with air to make "producer gas" (typically CO 22%; H_2 18%; CH_4 3%, CO_2 6% and N_2 51%). During World War II there were over a million small gasifiers running cars, trucks, boats and buses (see **HISTORY**). OR it can be gasified with oxygen to make synthesis gas (typically 40% CO, 40% H_2, 3% CH_4 and 17% CO_2, dry basis) which can be used to make methanol, ammonia and diesel fuel with known commercial catalytic processes. I expect that gasification will be even more useful in the future as we deplete our low cost fossil fuels. For more on this, visit **SYNTHETIC FUELS**.

I have been particularly interested in **small gasifiers** for distributed power, cookstoves or transportation. Visit that site if you are interested in kW rather than MW.

Database

The book, "A SURVEY OF BIOMASS GASIFICATION-2001", was written for the National Renewable Energy Laboratory, NREL by T. B. Reed and S. Gaus. It has now been published by the BEF PRESS. It contains (Chapter 2) a database of gasifiers. Please visit the **DATABASE** page to see large gasifier systems, small gasifiers and gasifier equipment manufacturers in the table. The database was created in MS Access and can be downloaded and viewed there or in MS Excel or other spreadsheets.

The database is included in our recent book "**A Survey of Biomass Gasification - 2000**" (available from the Biomass Energy Press, see order blank) which also discusses the various technologies and issues in gasification.

If you wish, you can search the database for a particular item (using Control F for find). Or, you can download it and use it in your own computer if you will have continual need to refer to it. (Select the table with Control-A and copy with Control-V, then insert in a spreadsheet or database).

If you are listed in the database, please examine your listing. If there is any factual mistake, please let Dr. Reed know at **tombreed@comcast.net** and he will fix it. If you would like to be listed, send the data to Dr. Reed by Email so he can transfer it to the database. We hope you find this information useful.

BIOMASS - THE ONLY RENEWABLE FUEL

The name "Biomass" was invented about 1975 to describe natural materials used as energy sources. The Office of Technology Assessment (**OTA**) estimated in 1980 that biomass could potentially supply more than 20% of US energy requirements - if we were serious about energy independence (we're not, since oil and oil profits are international). Biomass now supplies 3% of US energy (see **EIA** and their **table** of biomass consumption).

Truck unloading wood chips

While biomass is one of the best forms of renewable energy, it is not a great fuel. It occurs in a wide variety of forms (wood, paper, trash, ...). This can be reduced by **densification** (pelletization) to a uniform fungible fuel that can be easily shiped, stored and used.

Biomass varies widely in both mass and volume fuel density. It varies in chemical composition and the **proximate/ultimate analysis** gives records this data. It often has high **water content**, and the different methods of recording and measuring MC can be confusing.

While biomass can be used directly (mostly in wood fires), it can be converted to higher forms of fuels. Biomass is converted to various fuel forms in thermal (combustion, pyrolysis and gasification) processes and biological (fermentation and digestion) processes. **Click here** for a road map to all the various biomass conversion processes.

Probably most of you were exposed to chemistry in high school and promptly forgot it. The chemistry of biomass and other conversion processes is very simple, involving primarily carbon, C, hydrogen, H and oxygen, O. A brief explanation is given here in terms of a "**Ternary diagram**" of fuels which will help to keep the chemistry of fuels straight in your minds.

This website is devoted primarily to biomass gasification, the primary business and pleasure of Tom Reed over the last 3 decades. However, all combustion and gasification processes must pass through pyrolysis at low temperature, so there is a lot of information here about pyrolysis and combustion as well.

One inch birch dowell pyrolysing at 600C

Biomass fuels are characterized by what is called the "Proximate and Ultimate analyses". They can be burned directly for heat or to make steam for power. The "proximate" analysis gives moisture content, volatile content (when heated to 950 C), the free carbon remaining at that point, the ash (mineral) in the sample and the high heating value (HHV) based on the complete combustion of the sample to carbon dioxide and liquid water. (The low heating value, LHV, gives the heat released when the hydrogen is burned to gaseous water, corresponding to most heating applications.)

The "ultimate" analysis" gives the composition of the biomass in wt% of carbon, hydrogen and oxygen (the major components) as well as sulfur and nitrogen (if any).

The attached table of **Proximate and Ultimate analyses** is from Appendix A of our book1, and gives analyses of over 140 fuels, including biomass components, natural biomass (woods, agricultural products), processed biomass, other solid and liquid fuels.

(1) "Thermal Data for Natural and Synthetic Fuels", S. Gaur and T. Reed, Marcel Dekker, 1998.

Currently (2002) we obtain over 80% of world energy from petroleum, our "birthright" gift from Mother Nature. Predictions differ as to when world petroleum production will peak and then start to decline. Some say as early as 2008; others pooh pooh this and act as if tar oil shale, sands, bitumen and other ucky stuff will prolong the oil age (but at ever increasing prices) through their lifetimes and that seems to be all they care about. If you think we have plenty of time to develop alternate fuels, check out the time of peak oil production and other links at "**Oil**".

I have 4 children and 7 grandchildren (not to mention the rest of you) who will also need liquid fuels, so I have been motivated for 25 years to find alternate, renewable fuels. Unfortunately, the oil companies are not motivated to encourage any competition from alternative fuels. Read how they killed **methanol** in 1974.

Some liquid fuels (ethanol) are made by biological processes, slow with lots of water. They are currently not competitive with oil except with subsidies. Others (synthetic methanol, Fischer Tropsch diesel) are made by **gasification** of organic energy sources (biomass, coal and natural and landfill gas) and conversion to liquid fuel.

In 1973 (the year of the first OPEC Fuel Crisis) I began testing **methanol** as an alternative fuel with great success in 10% blends with gasoline in 10 cars. I wrote an article for the journal Science "**Methanol: A Versatile Fuel for Immediate Use**" (Vol. 182, pp 1299, 1973) showing that methanol was the easiest alternative fuel to make by gasification and one of the best for engines and fuel cells. That article changed my life from being a material scientist at MIT to a fuel scientist at NREL, the Colorado School of Mines and now the Biomass Energy Foundation. In addition to methanol there are groups that promote "ecalene", a mixture of many alcohols that have more energy than pure methanol and are more compatible with gasoline.

I have operated my own personal cars on mixtures of 10% methanol and pure methanol. Methanol is a component today in making biodiesel which we also developed at the Colorado School of Mines in 1990.

OTHER ALCOHOLS

Ethanol is currently the favored alcohol fuel in the US (from corn) and Brazil (sugar cane). But there are other alcohol choices on this page.

BIODIESEL

Biodiesel is another alternate fuel, though it is not made by gasification.

HYDROGEN

Hydrogen as a fuel has been much in the news lately. This is a red herring. Hydrogen does not occur naturally and must be made from other fuels and energy sources, always with some and usually considerable loss of energy. In my view, hydrogen is being touted either by those who don't understand the source to application chain that must be in place for any new fuel to be successful, or by those who are cynically diverting the view from our current wasteful energy policies by promising pie in the sky in the future. But, if you think hydrogen may be the answer, read an **extended review** by some responsible scientists working in the field.

One of the worst problem for 2-3 billion people in the world is cooking on wood fires. They cook slowly, the smoke causes glaucoma and lung diseases for the women and children, the children get burned in the fire, and they burn much too much fuel that must be gathered from greater and greater distances. For a colorful tour of Nepal and their stove problems, visit **Nepal Stove Research**. Our heart bleeds for our cousins and we believe gasification of biomass holds a significant part of the answer.

We became aware of this world cooking problem in 1985 on a trip to South Africa, and invented a new type of gasifier. One solution to the world cooking problem is to convert wood and other biomass to gas which can then be burned cleanly in a "**WoodGas Stove**" with the correct amount of air. After 18 years of research we have a WoodGas Stove that you can buy (sometimes) in our store. We hope to see a billion of these stoves in use in the next the next few decades.

Alas, most wood cooking is not done with gas, so will be smoky and less efficient. However, there has also been a lot of progress in more conventional wood cookstoves, so be sure to check on **wood cookstoves**. We at the BEF are peripherally involved with many groups developing these stoves and are also interested in improving them. We know a lot about simple stove fabrication and insulation techniques. In particular, visit the **Aprovecho** website, and if you are serious, consider visiting their workshops for a week in Summer, or attend their annual stove event.

We are currently working on developing a biomass cookstove for field kitchens for the army. We presume that what works there will also work for many others. Stay tuned.

Questions? Contact Dr. Tom Reed at **tbreed@comcast.net**

WOODGAS COOKSTOVES

ıy specialty and the name of this site.

It is now possible to turn wood into Wood-Gas which is then easy to burn efficiently with low emissions, as shown above. I have been working on wood-gas stoves since I became aware of the world cooking problem on a trip to South Africa in 1985. We have developed both **natural convection** (with Ron Larson) and **forced convection** stoves (Patent applied for). Check out these papers for the principles of WoodGas stoves and performance details. We expect to continue this work indefinitely and hope to deploy a billion stoves to ease the world cooking problem - an ambitious target. (You can also use larger variations of these stoves for clean, indoor cooking and other major heat applications.)

Our first target for this fundamental new development is the U.S. campstove market. There are lots of campers that don't want to lug propane or gasoline on their backs and do want to use the biomass they find along the way. There are lots of others worried about possible cutoff of gas or power. They are critical users and we will welcome their comments (at **tombreed@comcast.net**).

We believe our WoodGas Cook Stove far exceeds the performance of any other biomass cooking device. It will burn twigs, chips or the wood-pellets widely sold in hardware stores (typically $3 for a 40 lb bag). It generates 1.5 - 3 KW of heat, comparable to the big element on an electric stove; it burns only 10 g of fuel/min (40% efficient); and it can be used indoors with minimal emissions. It uses a single AA cell that lasts 3 hours on HIGH and 6 hours on LOW. We hope a lithium hydride battery and solar charger will be available as an accessory soon.

We plan to sell these stoves in the US campstove market first to establish our manufacturing and sales abilities before designing stoves for the international community. The stove sells for $60 plus shipping and comes with a supply of chip fuel and a full instructional manual. We plann to set up a new site, WoodGasLLC for the campstove and you can purchase the stove at their store.

Our second target for wood-gas stoves will be the refugee camps around the world that have 40 million mouths to cook for, and are currently using propane, gasoline or kerosene. They have the skills to manufacture the stove and labor to do it. They could also manufacture for the country as a whole. The BEF is prepared to apply our skills to the needs of developing countries and recommend a stove program that fits local conditions. If interested in working with the Biomass Energy Foundation to develop a stove program for other countries, please check with us at **tombreed@comcast.net**.

Designing a Clean-Burning, High-Efficiency, Dung-Burning Stove: Lessons in cooking with cow patties.

Mark Witt, Kristina Weyer, David Manning

February 2006,Aprovecho Research Center, ASAT Lab, contact: mark.witt@trincoll.edu

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Dung drying on tree in Mysore, Karnataka, India.[1]

Introduction

People around the world use wood and biomass as their primary fuel source. From China to Kenya, Guatemala to India, half of humanity cooks over biomass fires. There has been much effort in the past in improving stoves that burn wood or charcoal, but a great number of people do not use or have access to wood fuel. Many of them use dung as their primary fuel source. However, not much work has been done on improving stoves designed specifically for burning dung. Testimonies from the field state that the burning of dung is a smoky and inefficient process. Aprovecho Research Center has begun efforts to design better dung-burning stoves and just like with wood-burning stoves it is believed that with the implementation of advanced combustion techniques significant improvements in efficiency and emissions can be gained. In fact, dung can be as good or better than wood as cooking fuel. The contents of this report lay out our efforts thus far, but first an introduction to the history and practice of cooking with dung.

Background

For many people worldwide, dung is the only available fuel source. Deforestation and erosion have contributed to great fuel wood shortages in many areas of central Asia, south Asia and Africa.

2: Dung drying on wall, Turkey.

3: Dung drying in piles, north India.

4: Dung drying in pile, Armenia.

5: Storage of dung in home in Turkey.

Great quantities of dung are dried and burned, often very inefficiently, yet very little focus has been made in the area of improving dung-burning stoves and most stoves are built without consideration of advanced combustion principles. Chulah-type stoves that are simple u-shaped combustion boxes are used throughout north India and Nepal (Fig. 6). This model does nothing to improve air flow or raise combustion temperatures and likely burns as a smoky, inefficient mess.

Figure 6, Chulah-type dung stove.

In India, the hara stove is widely used in rural areas of Rajasthan, Bihar and Madhya Pradesh. As can be seen from the diagram below (Fig. 7), the pot sits directly on the dungcakes. Presumably, this generates many problems, including creating a great deal of smoke by reducing air flow. There is nowhere for burnt ash to escape. Both the ash and the pot act to smother the flame. It is worth noting that hara stoves are primarily used for the slow heating of milk without boiling over a few hours. Thus, an inefficient smoldering fire is useful but the same task can also be accomplished without the high emissions and inefficient fuel use.

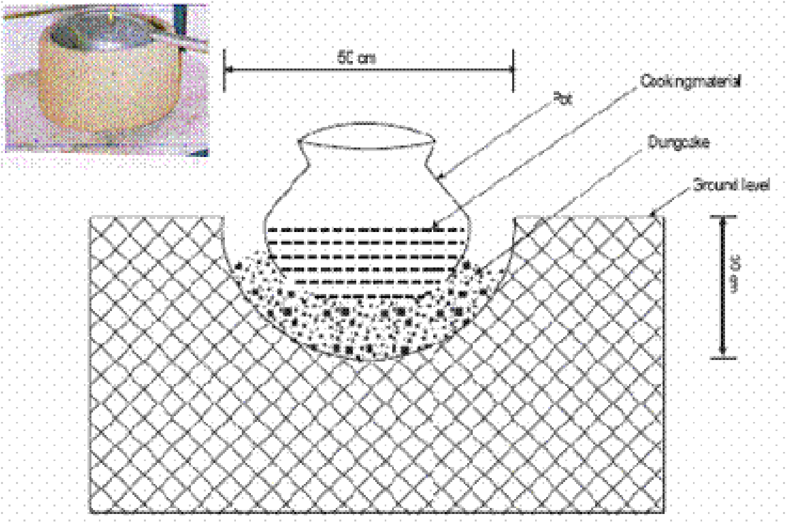

Figure 7, Photo and diagram of hara stove, India. [5]

In Tibet, where climates are colder, stoves are used for both heating and cooking. Yak dung is the primary fuel source. Notice the stoves in Figures 8 and 9 are equipped with chimneys which should significantly reduce the levels of indoor air pollution in the home. However, there is room for improvement, especially in terms of heat transfer efficiency. From these photographs, there is evidence that with minor modifications, significant reductions in fuel use could be achieved.

Figure 8, Photo of cooking/heating stove, Tibet.

Figure 9, Photo of cooking/heating stove, Tibet.

Considerable debate remains over fixing a value for available energy in cow dung fuel, whereas most other fuels agree within a reasonable degree across the published literature. This could be due to a wide variety of compositional ash content in dung, thus significantly affecting the energy content. Published values for ash content range from 20-50 percent. Accordingly, published values for the firepower of dung range from about 50-75% that of wood reflecting the discrepancies over ash content. Table 1 shows heating values for three fuels. Notice the consistencies across sources for ricehulls and wood, but the disagreement over energy in dung.

Table 1: Available Energy in Biomass Fuels, Dry

	Heating Value[1], Btu/lb	Heating Value[1], kJ/kg	Heating Value[2], kJ/kg
Wood	8750	20335	20000
Dung (Cow)	7400	17198	10000
Rice Hulls	6000	13944	13000

Prototype Design

Utilizing the design principles developed by Larry Winiarski and Aprovecho, Kristina Weyer has developed a prototype dung-burning stove with high draft, high firepower, and great flame activity with relatively little smoke. Yes, a dung-burning stove can sustain a flame!

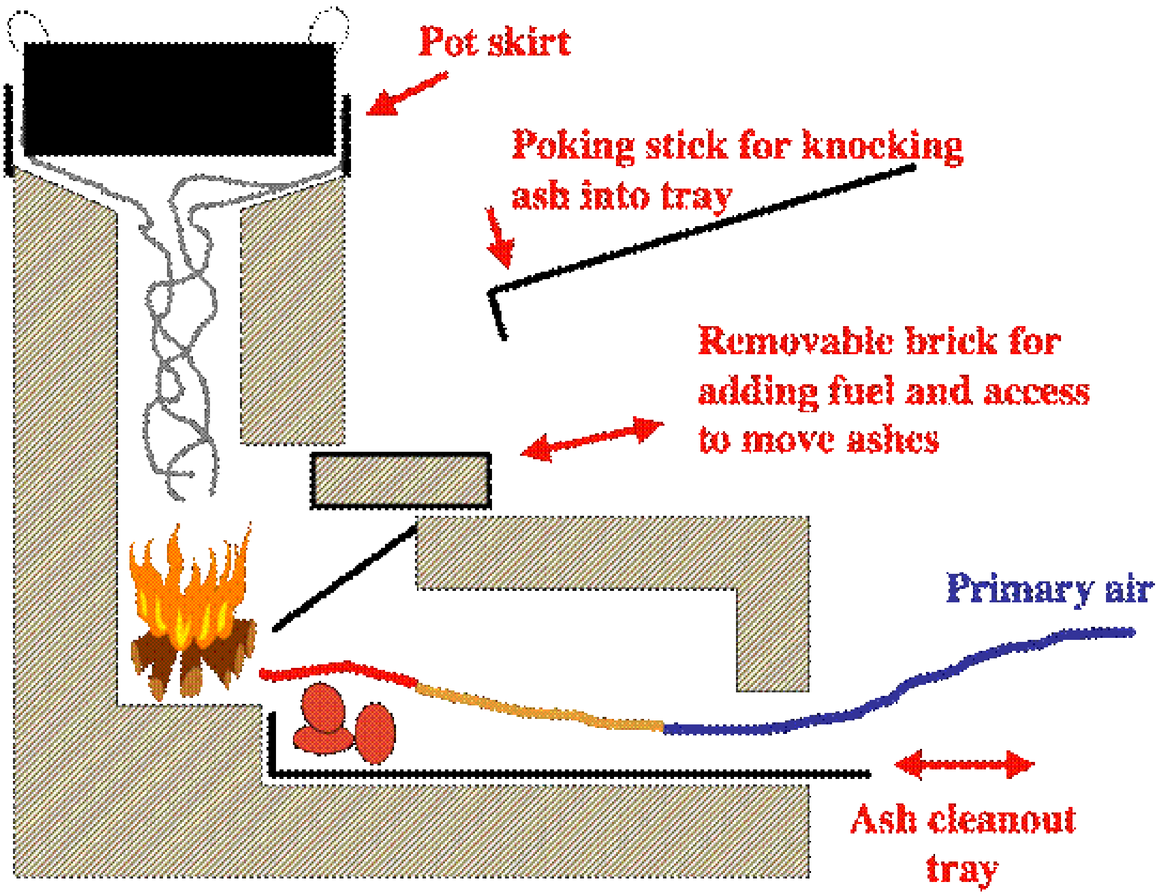

Figure 10: Concept Schematic of Weyer's Prototype Stove

The prototype employs a modified rocket stove design for encouraging draft. Notice the high draft-promoting chimney in Figure 10 of the prototype. The prototype dung stove follows the design principles used in rockets made for burning wood, but the unique characteristics of dung made two main modifications to the standard rocket necessary. First, dung is usually fed into stoves in small chunks, which means feeding it through a long opening, as is appropriate for wood, is not feasible. The prototype thus has a slot for top-feeding the fuel through a removable brick. Earlier prototypes had the feeding slot farther away from the insulated chimney, which required the flame to move some distance horizontally before getting to the insulated chimney. These designs did not work well: the draft was not strong enough to keep pulling the flame sideways, and smoke seeped out through every crack around the combustion chamber. Thus, we learned it was helpful to feed the dung directly under the insulated chimney: even a few inches made a huge difference. One potential problem with the removable brick idea in a real-world dung-burning stove is users choosing to leave the brick off, since replacing it will probably be considered an inconvenience. Replacing the brick after each fuel addition is necessary to achieve the lowest emissions. When the brick is not in place, there is a large opening for cold air to enter the fire and cool it off. Figure 12 demonstrates the use of the removable brick.

Figure 11: Weyer Dung-Burning Prototype Stove

Figure 12: Closer View of Prototype

Figure 13: Prototype Combustion Chamber

Figure 14: Prototype Ash Tray

The other main modification to the standard rocket is made necessary by the the large ash content of dung: in the range of 20-50% by weight. The dung ash tends not to break down into fine pieces and powder; it stays about the same size as the original dung piece unless agitated. In early designs, ash easily clogged the stove, blocking the pathway for primary air and resulting in a smoky, air-starved fire. Even when the dung was placed on a grate with very large openings, the ash did not fall down through the grate on its own. For these reasons, designing a mechanism for handling the ash while the stove is operating is essential. In this prototype, the design provides a convenient way to clean out ash while the stove is operating. In the dropped floor of the combustion chamber, just below where the dung is burning, a tray catches dung ash to be easily pulled out. Figure 14 shows this tray. This space also serves as the pathway for primary air, and serves a second purpose of pre-heating the air as it flows over the hot ashes on its way to the fire. Moving the dung ash from the combustion chamber down to the tray in this prototype requires agitation from the stove user in the form of a metal rod. Another possibility for dealing with the ash could be providing a large enough ash holding area such that the stove needed to be cleaned out less frequently, perhaps only a few times per day.

Prototype Testing

The dung stove prototype was tested under a hood using the Water Boiling Test at Aprovecho's ASAT Lab. Aprovecho has proposed benchmark parameters for measuring and comparing the effectiveness of efforts to improve fuel efficiency and emissions among different cooking stoves. These benchmarks are not compulsory but only offer some guideline goals for measuring the relative health and economic gains of implementing one stove over another. These benchmarks hold for different fuel types for emissions between stoves but because fuel types vary in available energy the benchmarks must be modified to reflect that for amount of fuel used. The benchmark for fuel used for dung derives from a ratio of the heating value of dung at 17000 kJ/kg to that of wood. The figures below compare the dung stove prototype to the open wood fire and a variety of improved wood-burning stoves.

To date, no testing has been performed on unimproved dung stove designs. Thus, a fully adequate statistical marker for level of improvement cannot be obtained. Nevertheless, in most respects, a comparison to wood-burning stoves will suffice. The wood stoves chosen here represent a similar design to many unimproved dung stoves in use including the hara and chulah stoves in India in that they do not contain an insulated combustion chamber. The only one that does contain such a chamber is the WFP rocket stove which is included to show a comparison to that type of stove which is similar to the rocket elbow contained in the dung prototype.

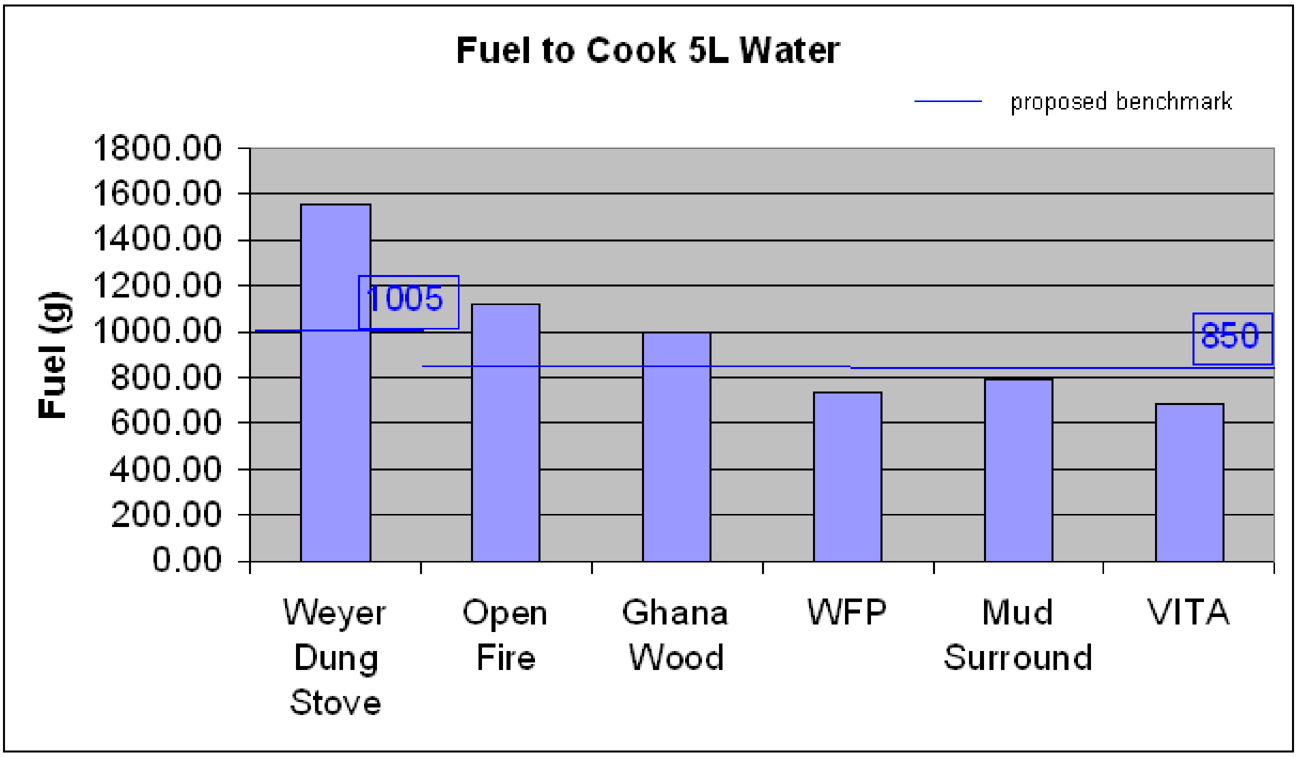

Figure 15: Comparison of dung stove to wood-fueled stoves for fuel used.

Figure 15 shows the amount of fuel used to cook 5L of water. Notice that the benchmark for equivalent wood-fuel used was not met. However, improvements could be made to reduce fuel used including a shorter chimney above the combustion chamber or modifications in operator technique. Furthermore, the amount of fuel used in an unimproved dung stove is likely much greater.

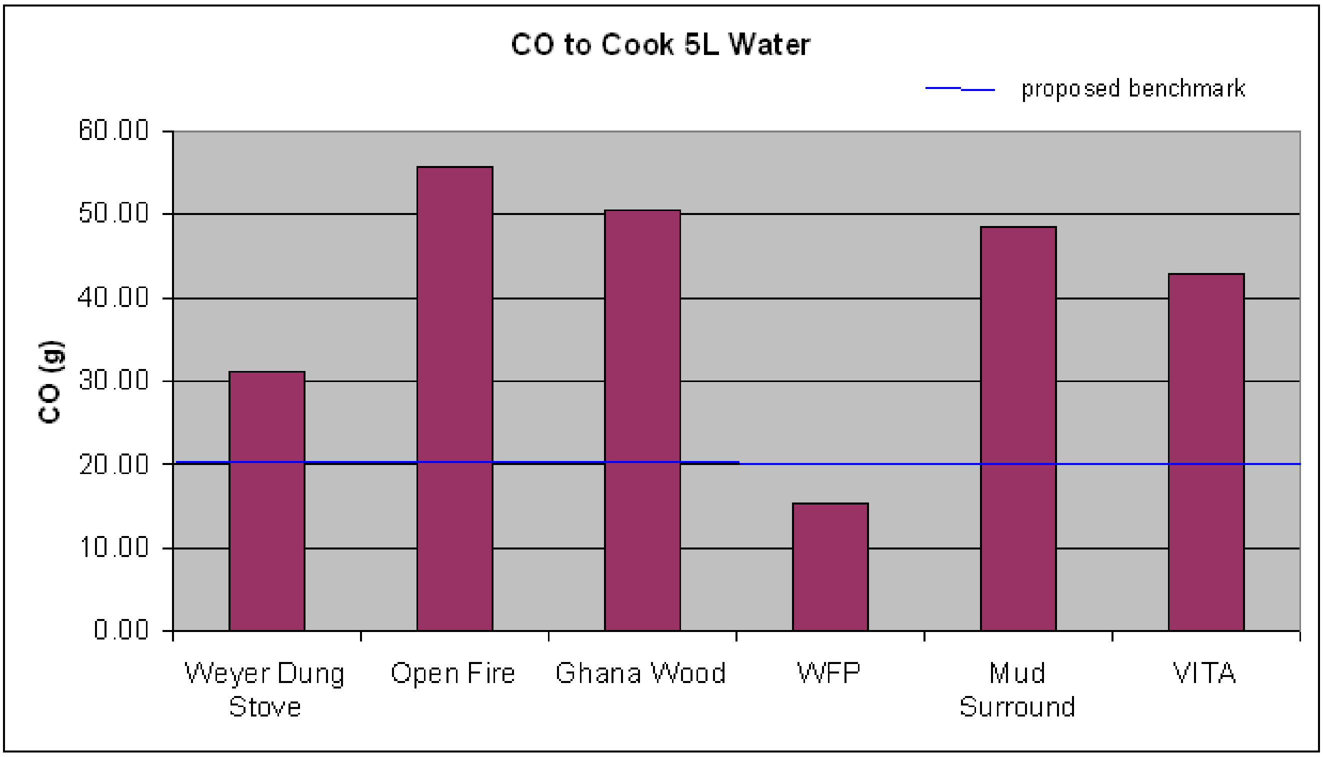

Figure 16: Comparison of dung stove to wood-fueled stoves for CO.

Figure 16 shows the amount of carbon monoxide emitted to cook 5L of water. Notice that, once again, the dung stove prototype did not meet the proposed benchmarks. Nevertheless, the CO emissions were significantly lower than in any of the other wood stoves save for the WFP rocket with a 44% reduction in CO as compared to open wood fire!

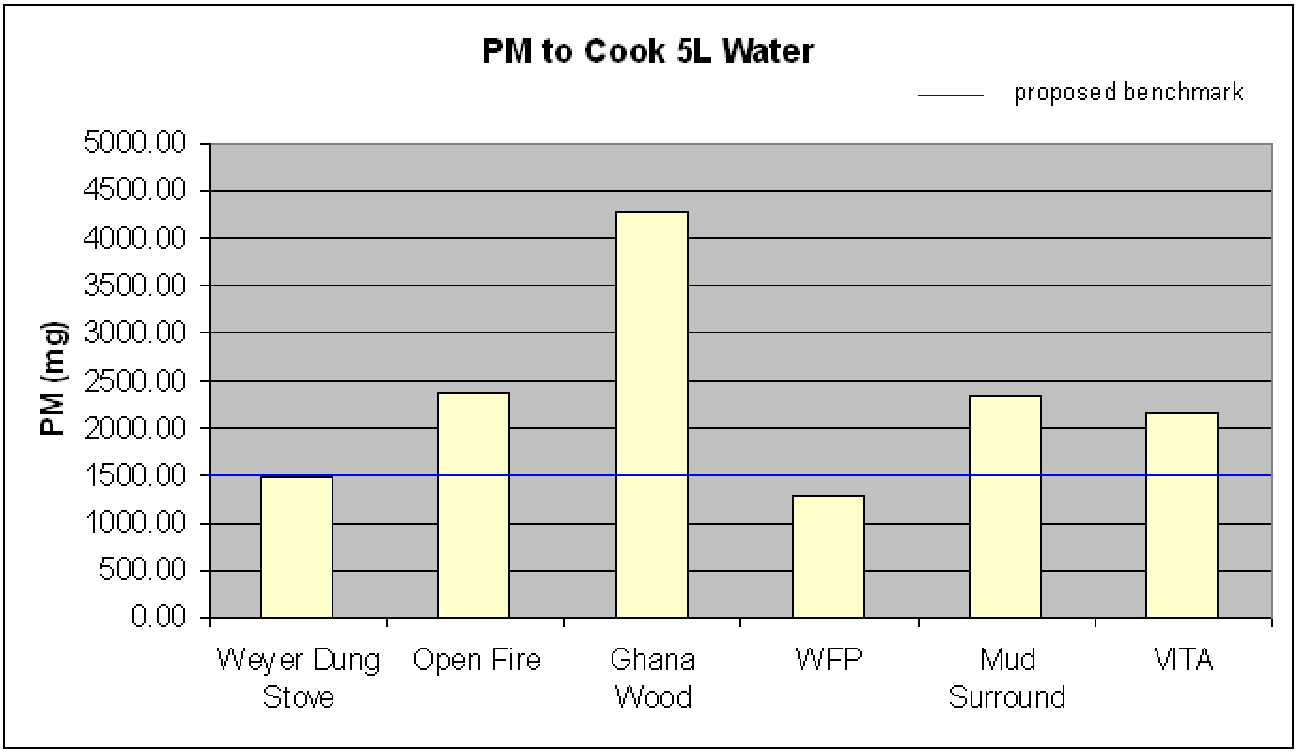

Figure17: Comparison of dung stove to wood-fueled stoves for PM.

Figure 17 shows the amount of particulate matter emitted to cook 5L of water. Notice, that the dung prototype does meet the benchmark for PM. Just barely! Once again, no other improved stove included herein met the benchmark save the WFP rocket. The improvement in PM emitted over the open wood fire was a whopping 37%!

Conclusions/Recommendations

While not meeting two of the three proposed benchmarks, the dung stove prototype demonstrates a marked improvement over most other simple, chimney-less, improved wood stoves. The benchmarks were developed as a means for comparison and as incentive to continue the great work on improving stove designs around the world. This stove has demonstrated that dung can, in fact, be burned cleanly and efficiently. Much of the carbon monoxide was emitted during the low-power simmering phase of the cooking test due to the instances of reductions in flame intensity which is crucial for completely combusting CO into CO_2.

Thus, there is room for improvement and with continued prototype development or modified operator technique those other two benchmarks could be met. This project demonstrates the need for expanded efforts in improving dung-burning. Furthermore, great potential exists for reducing exposure to harmful pollutants and reducing the economic or physical strain of high fuel use.

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1 : Avallone, Baumester, *Marks' Standard Handbook for Mechanical Engineers*, 10th Ed., pgs. 7.9-10

2 : EPA, "Greenhouse Gases from Small-scale combustion devices in developing countries," June 2000

We have been developing "Alternative Energy" - Solar, Wind, Geothermal etc. for 30 years since the first oil embargo. While these have niche applications, they are not fuels. They are intermittent, costly and unlikely to replace more than 10% of our current fossil fuel needs.

Alternative Energy Sources are a RED HERRING tolerated to divert our attention from our real needs. Oil is a fuel and its products can be used anywhere, anytime. The era of "cheap oil" is over and now we need to find ALTERNATIVE FUELS.

Oil prices are rising and availability falling. I expect prices to at least double every 5 years. This will make a profound difference to our Civilization. Our Earth would be far beyond its carrying capacity for Humans if it weren't for cheap oil. Cheap oil has gone. We hear a lot about substituting "alternate energy". We aren't running out of energy - we are running out of "cheap oil", and need to find an "alternate fuel". Windmills and solar panels can provide small amounts of energy, but we can't picture a significant fraction of earth covered with them. The earth is already covered with plants and trees busily converting sunlight to biomass products and fuel. All we need to do is learn how to use the fuel fraction. See **Biomass Energy** for details.

While we have deplored the "hydrogen economy" as a red herring for practical energy, WoodGas has a high concentration of hydrogen and is VERY clean burning. So, we have been using and promoting "hydrogen rich gas" made from wood and coal. We are now also involved in reforming liquid fuels to a hydrogen rich gas.

"**Woodgas**" is my nickname for the gases that can be made from wood, other biomass and waste for heat, power and synthesis of ammonia and fuel (it is also called "producer gas", "synthesis gas" etc.). I have worked in this field since 1973 when I began experimenting with methanol as a gasoline additive and oil supplement. Hydrogen is both the best of fuels (because it burns fast and clean) and the worst of fuels (because it is difficult to ship and store, because it must be made from other fuels, preferably at the point of use). However, it constitutes about half the fuel value of our "hydrogen rich gas", so making it from wood and biomass is a proven technology. Probably your grandmother cooked on a hydrogen rich gas stove and didn't even know it.

Site News

We are currently reorganizing the BEF to develop and promote "hydrogen rich gases" for clean efficient combustion. We are currently under construction and may soon have a sister site for members.

We now have online purchasing for books and other articles listed on our pages.

In 1974 I was embroiled in a controversy at MIT with the oil and motor companies over the use of methanol as an alternative fuel. They won! As a result we have paid higher prices for foreign oil and funded the terrorism that has taken a million lives, culminating in 9/11 in the U.S. Check it out at **METHANOL**.

Three billion people in the world cook slowly on smoky, inefficient **woodfires**. We have developed a novel "**WoodGas CampStove**" that we believe far exceeds the performance of any other biomass cooking device because it first turns the wood to gas, and then burns the gas with the correct amount of air. It puts out up to 3 KW of heat, comparable to the big element on an electric stove, it burns only 10 g of fuel/min (40% efficient), and it can be used indoors with minimal emissions. We hope similar designs will be used in developing countries where the need is greater, but we want to develop our product first in the U.S., so we have developed a company to manufacture, market and distribute the stove.

We believe that these stoves will have a much wider application in the developing countries of the world. See our WoodGas Stove page for other information about WoodGas stoves. We hope to see a billion of these stoves in use in the next the next few decades.

We have re-issued our 3 volume "**Survey of Biomass Gasification**" from 1980 as a one volume "Encyclopedia of Biomass Thermal Conversion". The National Renewable Energy Lab, (SERI then, NREL now) commissioned it as a prerequisite for me to build gasifiers. It contains chapters by various experts on many aspects of thermal conversion and other aspects of biomass for energy. I wish there were something more current that covers all aspects of biomass, but this is the best to date. See this and our other books on gasification and biomass in the **BEF BOOKSTORE**.

SITE OVERVIEW

Biomass Energy is the oldest, most widespread and practical form of renewable energy. The residues from agriculture and forestry could provide 20% of U.S. energy. Biomass has been a major concern of mine since 1974, the first "energy crisis". This page has lots of information on the properties and availability of biomass in its many forms, particularly **moisture content**, **fuel densities**, and the **biomass analyses** and energy content.

BIOMASS **Gasification** turns biomass into a more useful form, WoodGas. "WoodGas" is my nickname for gas produced from biomass for heat, power and synthetic fuel applications. During World War II, over a million vehicles, boats etc. ran on Woodgas. (See **History** of Woodgas). While I have written a number of articles and books on all aspects of gasification, my specialty has been **small gasifiers** for power, transportation and cooking.

Cookstoves consume most of the biomass in developing countries, often wastefully with terrible health effects. We cook now much better with propane or natural gas, but this requires infrastructure not available for half the world. A great deal of research is in progress to improve world stoves, see **Cookstoves**.

Synthetic Fuels and chemicals can also be produced from renewable biomass and as petroleum runs out we will increasingly turn to biomass as a renewable resource. I am a chemical engineer and have worked toward oil replacement fuels for 28 years (for the future fuel security of my grandchildren and the rest of us).

BOOKS on biomass energy are difficult to find. The Biomass Energy Foundation Press publishes 20+ books on biomass energy and related subjects and you can order them online, by mail, fax or phone. You can buy our books at our online **BEF store**.

The Biomass Energy Foundation, the BEF is a 501-C-3 non-profit organization. Founded by the flamboyant and fascinating Dr. Harry LaFontaine, now deceased. It is currently operated by Dr. Tom Reed and his wife Vivian. Find out about the **History** and **Current Research** of the BEF. Finally, we have links to other sites that will give you more information on biomass energy.

This Website combines two previous websites and has more content and advanced features. We would appreciate your comments either on the site itself or its contents.

Biomass Gasification is a very old art ... and there isn't enough science in it, but we're working on that here at BEF and other places. Visit our Biomass Books to learn most of what is currently known about about wood and other biomass gasification, and what you can do with the gas. Lots of practice, lots of science, some gasifier plans and other related subjects there. Visit our **History** page for a quick overview of gasification.

Tom Reed has been working in this field since the first energy crisis in 1974 and knows all the names that have been used for the gases produced by various processes. However, in his casual conversation, he calls it "WOODGAS", a term easily understood and acknowledging the first renewable source, wood since >100,000 years ago. So he has chosen this for the name of this renewable energy web site. In practice it includes gas from agricultural and forest residues and even Municipal Solid Waste as well, though these materials are harder to gasify.

Briefly biomass can be gasified pyrolytically by heating to >400 C, yielding also 25% charcoal and LOTS of condensibles - tars). Or it can be gasified with air to make "producer gas" (typically CO 22%; H2 18%; CH4 3%, CO2 6% and N2 51%). During World War II there were over a million small gasifiers running cars, trucks, boats and buses (see **HISTORY**). OR it can be gasified with oxygen to make synthesis gas (typically 40% CO, 40% H2, 3% CH4 and 17% CO2, dry basis) which can be used to make methanol, ammonia and diesel fuel with known commercial catalytic processes. I expect that gasification will be even more useful in the future as we deplete our low cost fossil fuels. For more on this, visit **SYNTHETIC FUELS**.

I have been particularly interested in **small gasifiers** for distributed power, cookstoves or transportation. Visit that site if you are interested in kW rather than MW.

Database
The book, "A SURVEY OF BIOMASS GASIFICATION-2001", was written for the National Renewable Energy Laboratory, NREL by T. B. Reed and S. Gaus. It has now been published by the BEF PRESS. It contains (Chapter 2) a database of gasifiers. Please visit the **DATABASE** page to see large gasifier systems, small gasifiers and gasifier equipment manufacturers in the table. The database was created in MS Access and can be downloaded and viewed there or in MS Excel or other spreadsheets.

The database is included in our recent book "**A Survey of Biomass Gasification - 2000**" (available from the Biomass Energy Press, see order blank) which also discusses the various technologies and issues in gasification.

If you wish, you can search the database for a particular item (using Control F for find). Or, you can download it and use it in your own computer if you will have continual need to refer to it. (Select the table with Control-A and copy with Control-V, then insert in a spreadsheet or database).

If you are listed in the database, please examine your listing. If there is any factual mistake, please let Dr. Reed know at **tombreed@comcast.net** and he will fix it. If you would like to be listed, send the data to Dr. Reed by Email so he can transfer it to the database. We hope you find this information useful.

BIOMASS - THE ONLY RENEWABLE FUEL

The name "Biomass" was invented about 1975 to describe natural materials used as energy sources. The Office of Technology Assessment (**OTA**) estimated in 1980 that biomass could potentially supply more than 20% of US energy requirements - if we were serious about energy independence (we're not, since oil and oil profits are international). Biomass now supplies 3% of US energy (see **EIA** and their **table** of biomass consumption).


Truck unloading wood chips

While biomass is one of the best forms of renewable energy, it is not a great fuel. It occurs in a wide variety of forms (wood, paper, trash, ...). This can be reduced by **densification** (pelletization) to a uniform fungible fuel that can be easily shiped, stored and used.

Biomass varies widely in both mass and volume fuel density. It varies in chemical composition and the **proximate/ultimate analysis** gives records this data. It often has high **water content**, and the different methods of recording and measuring MC can be confusing.

While biomass can be used directly (mostly in wood fires), it can be converted to higher forms of fuels. Biomass is converted to various fuel forms in thermal (combustion, pyrolysis and gasification) processes and biological (fermentation and digestion) processes. **Click here** for a road map to all the various biomass conversion processes.

Probably most of you were exposed to chemistry in high school and promptly forgot it. The chemistry of biomass and other conversion processes is very simple, involving primarily carbon, C, hydrogen, H and oxygen, O. A brief explanation is given here in terms of a "**Ternary diagram**" of fuels which will help to keep the chemistry of fuels straight in your minds.

This website is devoted primarily to biomass gasification, the primary business and pleasure of Tom Reed over the last 3 decades. However, all combustion and gasification processes must pass through pyrolysis at low temperature, so there is a lot of information here about pyrolysis and combustion as well.

One inch birch dowell pyrolysing at 600C

Biomass fuels are characterized by what is called the "Proximate and Ultimate analyses". They can be burned directly for heat or to make steam for power. The "proximate" analysis gives moisture content, volatile content (when heated to 950 C), the free carbon remaining at that point, the ash (mineral) in the sample and the high heating value (HHV) based on the complete combustion of the sample to carbon dioxide and liquid water. (The low heating value, LHV, gives the heat released when the hydrogen is burned to gaseous water, corresponding to most heating applications.)

The "ultimate" analysis" gives the composition of the biomass in wt% of carbon, hydrogen and oxygen (the major components) as well as sulfur and nitrogen (if any).

The attached table of **Proximate and Ultimate analyses** is from Appendix A of our book1, and gives analyses of over 140 fuels, including biomass components, natural biomass (woods, agricultural products), processed biomass, other solid and liquid fuels.

(1) "Thermal Data for Natural and Synthetic Fuels", S. Gaur and T. Reed, Marcel Dekker, 1998.

Currently (2002) we obtain over 80% of world energy from petroleum, our "birthright" gift from Mother Nature. Predictions differ as to when world petroleum production will peak and then start to decline. Some say as early as 2008; others pooh pooh this and act as if tar oil shale, sands, bitumen and other ucky stuff will prolong the oil age (but at ever increasing prices) through their lifetimes and that seems to be all they care about. If you think we have plenty of time to develop alternate fuels, check out the time of peak oil production and other links at "**Oil**".

I have 4 children and 7 grandchildren (not to mention the rest of you) who will also need liquid fuels, so I have been motivated for 25 years to find alternate, renewable fuels. Unfortunately, the oil companies are not motivated to encourage any competition from alternative fuels. Read how they killed **methanol** in 1974.

Some liquid fuels (ethanol) are made by biological processes, slow with lots of water. They are currently not competitive with oil except with subsidies. Others (synthetic methanol, Fischer Tropsch diesel) are made by **gasification** of organic energy sources (biomass, coal and natural and landfill gas) and conversion to liquid fuel.

In 1973 (the year of the first OPEC Fuel Crisis) I began testing **methanol** as an alternative fuel with great success in 10% blends with gasoline in 10 cars. I wrote an article for the journal Science "**Methanol: A Versatile Fuel for Immediate Use**" (Vol. 182, pp 1299, 1973) showing that methanol was the easiest alternative fuel to make by gasification and one of the best for engines and fuel cells. That article changed my life from being a material scientist at MIT to a fuel scientist at NREL, the Colorado School of Mines and now the Biomass Energy Foundation. In addition to methanol there are groups that promote "ecalene", a mixture of many alcohols that have more energy than pure methanol and are more compatible with gasoline.

I have operated my own personal cars on mixtures of 10% methanol and pure methanol. Methanol is a component today in making biodiesel which we also developed at the Colorado School of Mines in 1990.

OTHER ALCOHOLS

Ethanol is currently the favored alcohol fuel in the US (from corn) and Brazil (sugar cane). But there are other alcohol choices on this page.

BIODIESEL

Biodiesel is another alternate fuel, though it is not made by gasification.

HYDROGEN

Hydrogen as a fuel has been much in the news lately. This is a red herring. Hydrogen does not occur naturally and must be made from other fuels and energy sources, always with some and usually considerable loss of energy. In my view, hydrogen is being touted either by those who don't understand the source to application chain that must be in place for any new fuel to be successful, or by those who are cynically diverting the view from our current wasteful energy policies by promising pie in the sky in the future. But, if you think hydrogen may be the answer, read an **extended review** by some responsible scientists working in the field.

One of the worst problem for 2-3 billion people in the world is cooking on wood fires. They cook slowly, the smoke causes glaucoma and lung diseases for the women and children, the children get burned in the fire, and they burn much too much fuel that must be gathered from greater and greater distances. For a colorful tour of Nepal and their stove problems, visit **Nepal Stove Research**. Our heart bleeds for our cousins and we believe gasification of biomass holds a significant part of the answer.

We became aware of this world cooking problem in 1985 on a trip to South Africa, and invented a new type of gasifier. One solution to the world cooking problem is to convert wood and other biomass to gas which can then be burned cleanly in a "**WoodGas Stove**" with the correct amount of air. After 18 years of research we have a WoodGas Stove that you can buy (sometimes) in our store. We hope to see a billion of these stoves in use in the next the next few decades.

Alas, most wood cooking is not done with gas, so will be smoky and less efficient. However, there has also been a lot of progress in more conventional wood cookstoves, so be sure to check on **wood cookstoves**. We at the BEF are peripherally involved with many groups developing these stoves and are also interested in improving them. We know a lot about simple stove fabrication and insulation techniques. In particular, visit the **Aprovecho** website, and if you are serious, consider visiting their workshops for a week in Summer, or attend their annual stove event.

We are currently working on developing a biomass cookstove for field kitchens for the army. We presume that what works there will also work for many others. Stay tuned.

Questions? Contact Dr. Tom Reed at **tbreed@comcast.net**

WOODGAS COOKSTOVES

ıy specialty and the name of this site.

It is now possible to turn wood into Wood-Gas which is then easy to burn efficiently with low emissions, as shown above. I have been working on wood-gas stoves since I became aware of the world cooking problem on a trip to South Africa in 1985. We have developed both **natural convection** (with Ron Larson) and **forced convection** stoves (Patent applied for). Check out these papers for the principles of WoodGas stoves and performance details. We expect to continue this work indefinitely and hope to deploy a billion stoves to ease the world cooking problem - an ambitious target. (You can also use larger variations of these stoves for clean, indoor cooking and other major heat applications.)

Our first target for this fundamental new development is the U.S. campstove market. There are lots of campers that don't want to lug propane or gasoline on their backs and do want to use the biomass they find along the way. There are lots of others worried about possible cutoff of gas or power. They are critical users and we will welcome their comments (at **tombreed@comcast.net**).

We believe our WoodGas Cook Stove far exceeds the performance of any other biomass cooking device. It will burn twigs, chips or the wood-pellets widely sold in hardware stores (typically $3 for a 40 lb bag). It generates 1.5 - 3 KW of heat, comparable to the big element on an electric stove; it burns only 10 g of fuel/min (40% efficient); and it can be used indoors with minimal emissions. It uses a single AA cell that lasts 3 hours on HIGH and 6 hours on LOW. We hope a lithium hydride battery and solar charger will be available as an accessory soon.

We plan to sell these stoves in the US campstove market first to establish our manufacturing and sales abilities before designing stoves for the international community. The stove sells for $60 plus shipping and comes with a supply of chip fuel and a full instructional manual. We plann to set up a new site, WoodGasLLC for the campstove and you can purchase the stove at their store.

Our second target for wood-gas stoves will be the refugee camps around the world that have 40 million mouths to cook for, and are currently using propane, gasoline or kerosene. They have the skills to manufacture the stove and labor to do it. They could also manufacture for the country as a whole. The BEF is prepared to apply our skills to the needs of developing countries and recommend a stove program that fits local conditions. If interested in working with the Biomass Energy Foundation to develop a stove program for other countries, please check with us at **tombreed@comcast.net**.