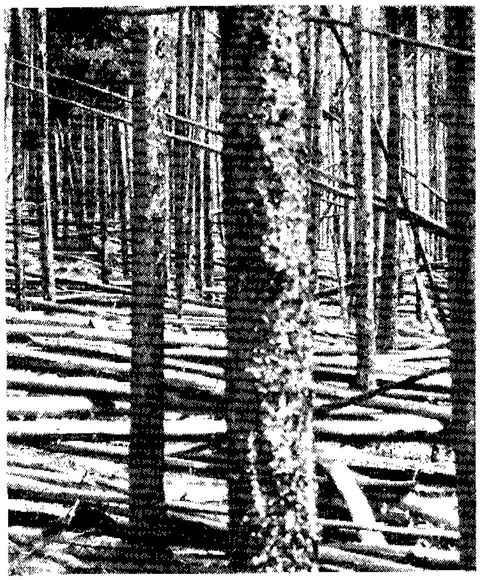
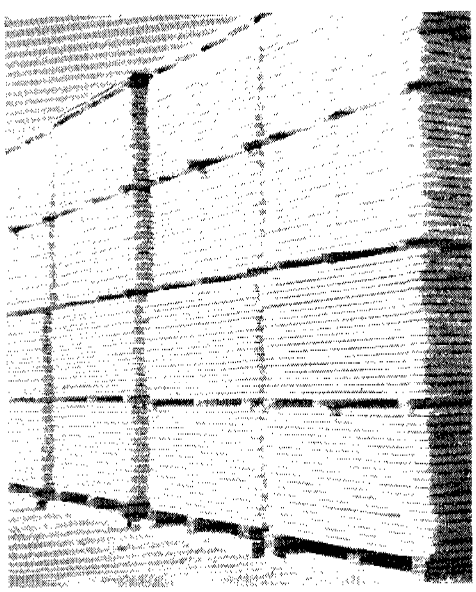
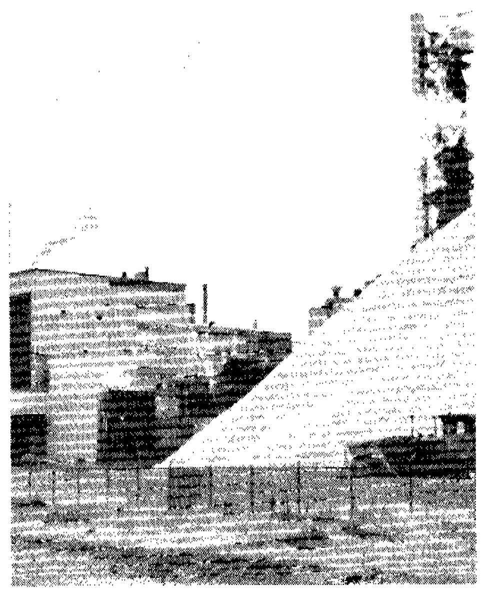
HARVESTING AND UTILIZATION OPPORTUNITIES FOR FOREST RESIDUES in the northern rocky mountains







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U.S. Department of Agriculture
Forest Service
Ogden, Utah 84401

REVIEW OF BIOMASS GASIFICATION

James D. Kerstetter

Program Manager
National Center for Appropriate Technology

ABSTRACT

This paper reviews the topic of biomass air gasifiers. The gasification process chemistry is outlined and the operating characteristics of two types of gasifiers are presented. A few typical applications are discussed and the economics for a particular system are presented in comparison with the costs of natural gas. Finally, the appendix gives a list of biomass research, demonstration projects and manufacturers.

KEYWORDS: gasification, biomass fuel

Biomass air gasifiers offer one of the many contributing solutions to our current energy problems. Interest in these devices increases when more convenient energy sources, such as oil and gas, become scarce or very expensive. Air gasifiers must still compete, however, with other energy uses for biomass, such as heat and steam from direct combustion, pyrolysis processes and even methanol production. Moreover, biomass feedstock end uses must compete in the economic market with requirements for lumber and fiber.

GASIFICATION PROCESSES

The gasification process is simply one of converting a solid fuel into a gaseous fuel. However, there is often some confusion between the terms pyrolysis, gasification and combustion. The distinguishing quantitative characteristic between these conversion processes is the amount of air (oxygen) used relative to the quantity of fuel. One study (Reed and Jantzen 1979) determined that pyrolysis predominates when the air used to convert a given quantity of fuel is less than 20 percent of the theoretical air required for total combustion. The main product from a pyrolysis process is char along with some gases and oils. The gasification process predominates when 25-50 percent of the theoretical air required is used, resulting in a low to medium Btu gas. Finally, the combustion process predominates when the air supply is equal to or greater than 100 percent of the theoretical air required for total combustion. This process results in total conversion of the fuel's chemical energy to thermal energy.

The conversion of solid biomass material to a gaseous fuel involves many separate chemical reactions. The more important of these reactions are given in table 1 along with the heat from the reaction. Besides actual chemical transformation, the physical process of drying wet biomass also is included. All of the reactions, of course, do not yield a gaseous fuel and the main example is reaction 1 (table 1).

TABLE 1.--Thermo-chemistry of gasification.

No.	Reaction	ΔH, BTU/lb-mole	ΔH, kJ/gm-mole	
1	$C + O_2 \quad CO_2$	-169,288	-392.7	Exothermic
2	$C + \frac{1}{2}O_2 \quad CO$	-47,556	-110.6	Exothermic
3	$C + CO_2 \quad 2CO$	+74,160	+172.3	Endothermic
4	$C + H_2O \quad H_2 + CO$	+56,437	+131.2	Endothermic
5	$CO + H_2O \quad H_2 + CO_2$	-17,723	-41.2	Exothermic
6	$C + 2H_2 \quad CH_4$	-32,198	-74.8	Exothermic

When air is used to provide the oxygen source, a large quantity of nitrogen remains after combustion and the nitrogen acts as a dilutant to the resulting gaseous fuel. As can be seen in table 1, some of the reactions are endothermic, and thus, require a heat input from some other reaction before they can occur. This heat input generally is supplied from the highly exothermic reaction #1.

Another important thermodynamic variable that effects the product distribution in the gasification process is the chemical equilibrium constants. While actual equilibrium is seldom attained in an operating gasifier, the equilibrium values and their temperature characteristics are very important. Figure 1 illustrates the equilibrium effects for the reduction of carbon dioxide with charcoal at various temperatures and various gas velocities. The factors to note are the rather large changes in CO concentration as the temperature increases at a fixed flow rate and also the effect of the gas flow rates themselves.

The composition of the product fuel gas will depend on such factors as the type of gasifier, the moisture content of the biomass feedstock, the gas flow rate, the operating temperatures, and the oxygen concentration of the air. The total enthalpy of the gas will depend on the above factors as well as the gas temperature, when it is used, and its moisture content.

Most air-blown gasifiers yield a gas composition within the ranges shown in table 2. The updraft gasifiers also contain tars that increase the chemical energy content of the gas if they remain in the gas phase before being burned.

The effect of biomass moisture content on the heating value of the gas is shown in figure 2. This reduction in heating value limits the material with use of biomass in downdraft gasifiers to about 30 percent wet basis. Updraft gasifiers can accept material with a moisture content up to 50 percent before the thermal performance is severely affected.

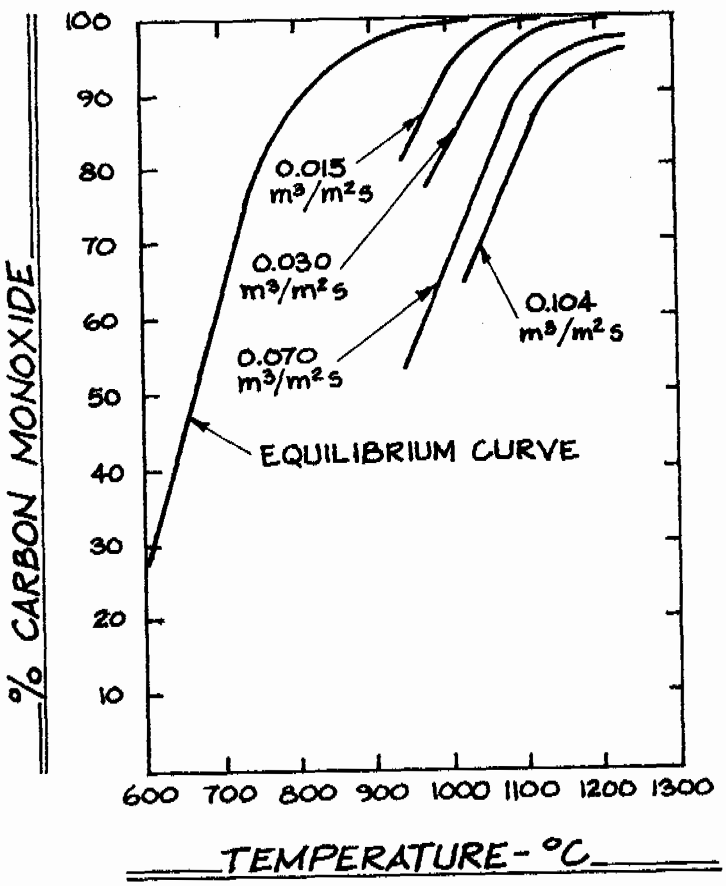

Figure 1.--Carbon monoxide concentration as a function of temperature and flow rates over heated charcoal (Widell 1950).

Table 2.--Typical gas analysis from downdraft gas producer using wood (Allcut and Patten 1943)

Gas		Range % by Volume
CO_2		9.5 - 9.7
O_2	Non-Combustible	0.6 - 1.4
N_2		50.0 - 53.8
Hydrocarbons		0 - 0.3
CO		20.5 - 22.2
H_2		12.3 - 15.0
CH_4		2.4 - 3.4
Heat Content, HHv		138 - 149 BTU/SCF

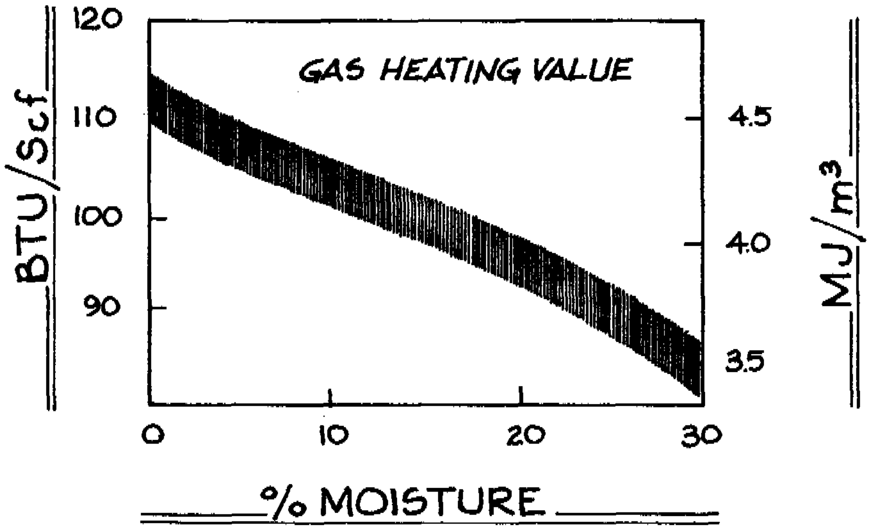

Figure 2.--Effect of moisture content on gas heating value for downdraft gasifiers. (Gumz 1950).

GASIFIER CONFIGURATIONS

Many different configurations have been used for gasifiers and the main differences are where the air is introduced and where the resultant fuel gas is extracted. The classical gasifiers, the updraft and downdraft types, are shown in figures 3 and 4. In the updraft gasifier, the air is introduced into the combustion zone immediately above the ash pit. Oxidation reactions 1 and 2 (table 1) occur, generating CO and CO_2 plus a great deal of heat. These gases pass upward through the biomass and their temperature is continually reduced. Some of the gases further react and generate H_2 and additional CO. Volatile oils are driven from the incoming biomass and these, along with the moisture, leave the gasifier.

The downdraft gasifier differs in that the reduction zone is the last one encountered by the existing gas. This process results in much lower volatile oil and tar content of the gas since these compounds crack into gases as they pass through the hot reduction zone. The reaction zones and predominate reactions that occur there are shown in figure 5 for a downdraft gasifier.

There are many variations on these basic designs. Biomass gasifiers range in size from 10^5 Btu/hr to 10^8 Btu/hr. The system design is highly dependent upon the end use and the desired or required heat content of the gas.

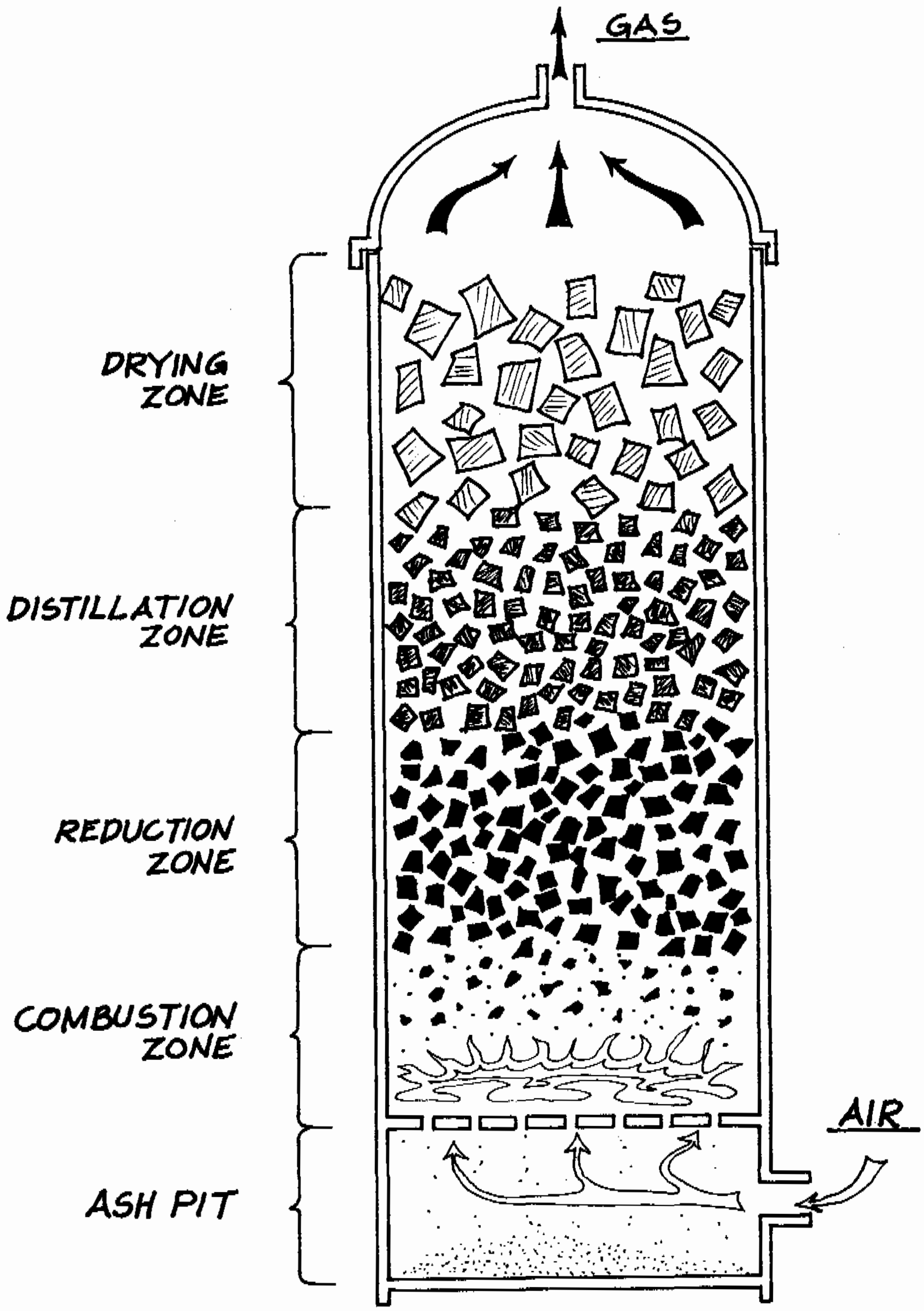

Figure 3.--Updraft gasifier.

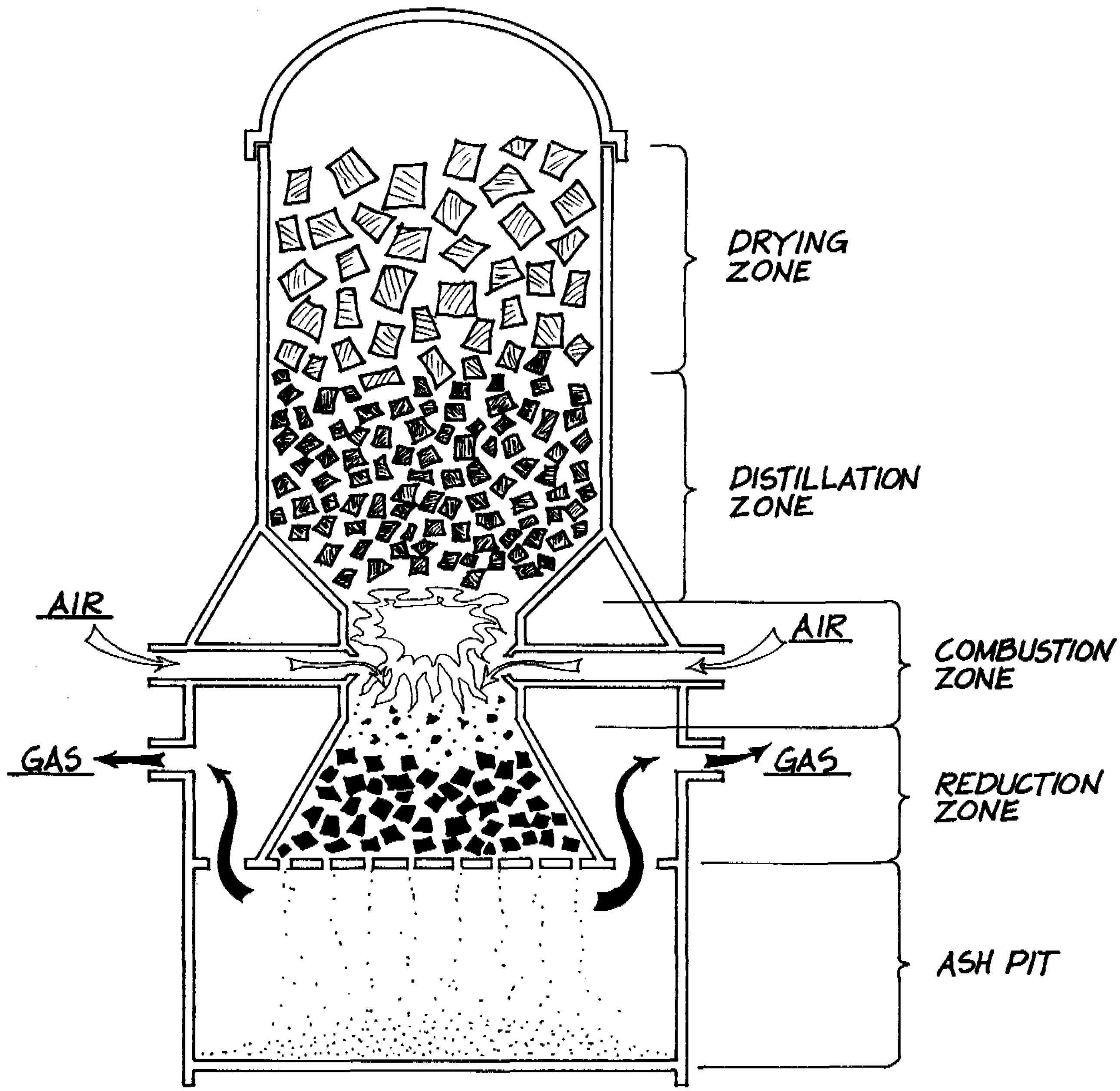

Figure 4.--Downdraft gasifier.

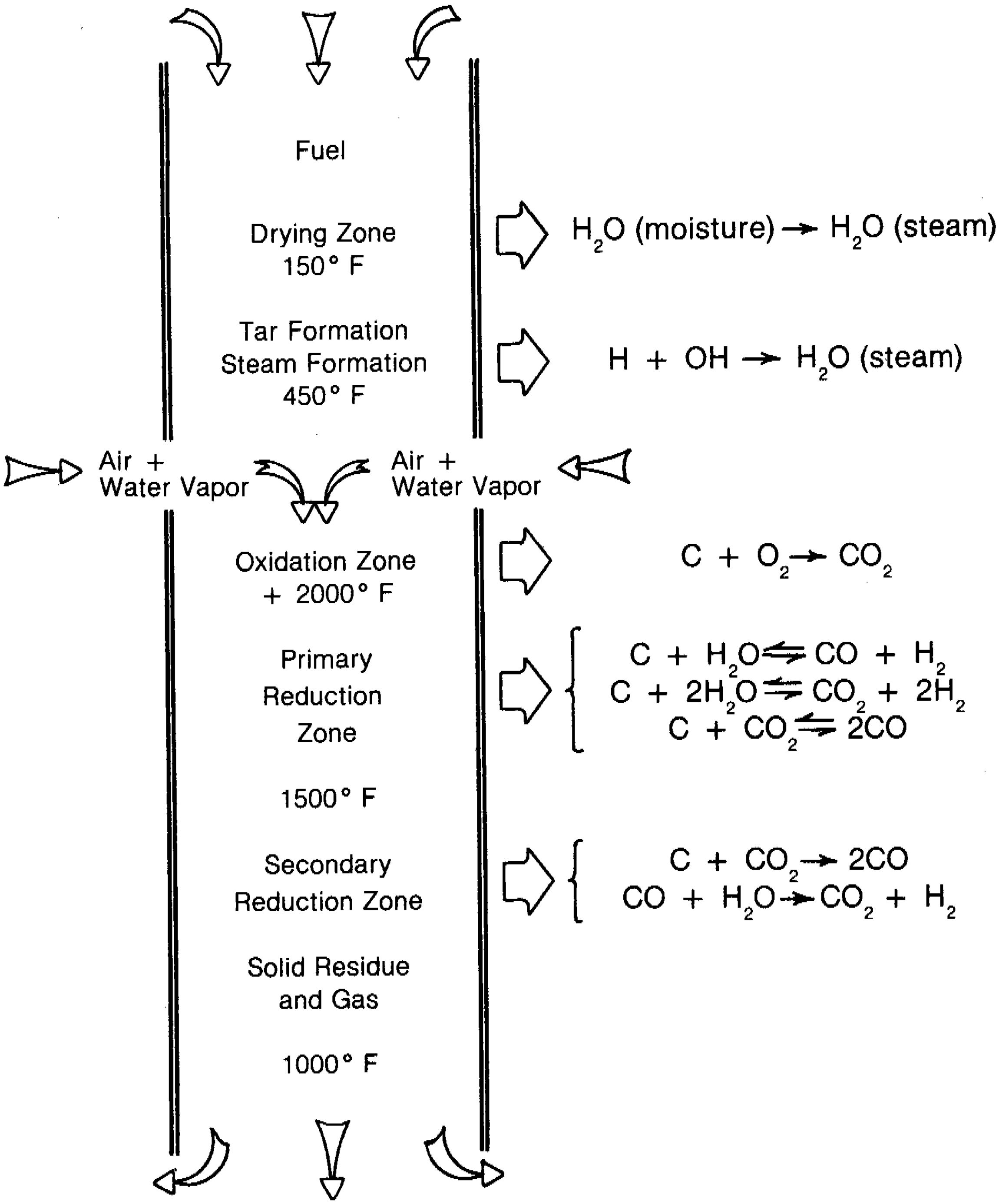

Figure 5.--Reaction zones in a downdraft gasifier.

APPLICATIONS

Gasification of organic materials for power and fuel have been utilized since 1857 when the Siemens brothers in Germany developed a successful gasifier using coke for fuel. By 1923, stationary gasifiers had been designed for and operated with many forms of cellulosic residue. During World War II, up to 700,000 vehicles were equipped with gasifiers to meet the problem of liquid fuel shortages. Today gasifiers are being developed for applications ranging from home heating systems to portable and stationary electrical generators.

One of the most efficient uses of a gasifier is to produce gaseous fuel for an existing gas burner. As shown in figure 6, a boiler's efficiency depends upon the energy content of its fuel. However, for gases with a heating value greater than 200 Btu/scf, the efficiency is essentially constant and equal to that for natural gas. By close coupling the gasifier to the boiler all of the generated fuel gas as well as the sensible heat of the gas stream is utilized. Of course, the size of the fuel line would have to be increased since the fuel gas only has about 150-200 Btu/SCF compared to natural gas with 1000 Btu/SCF.

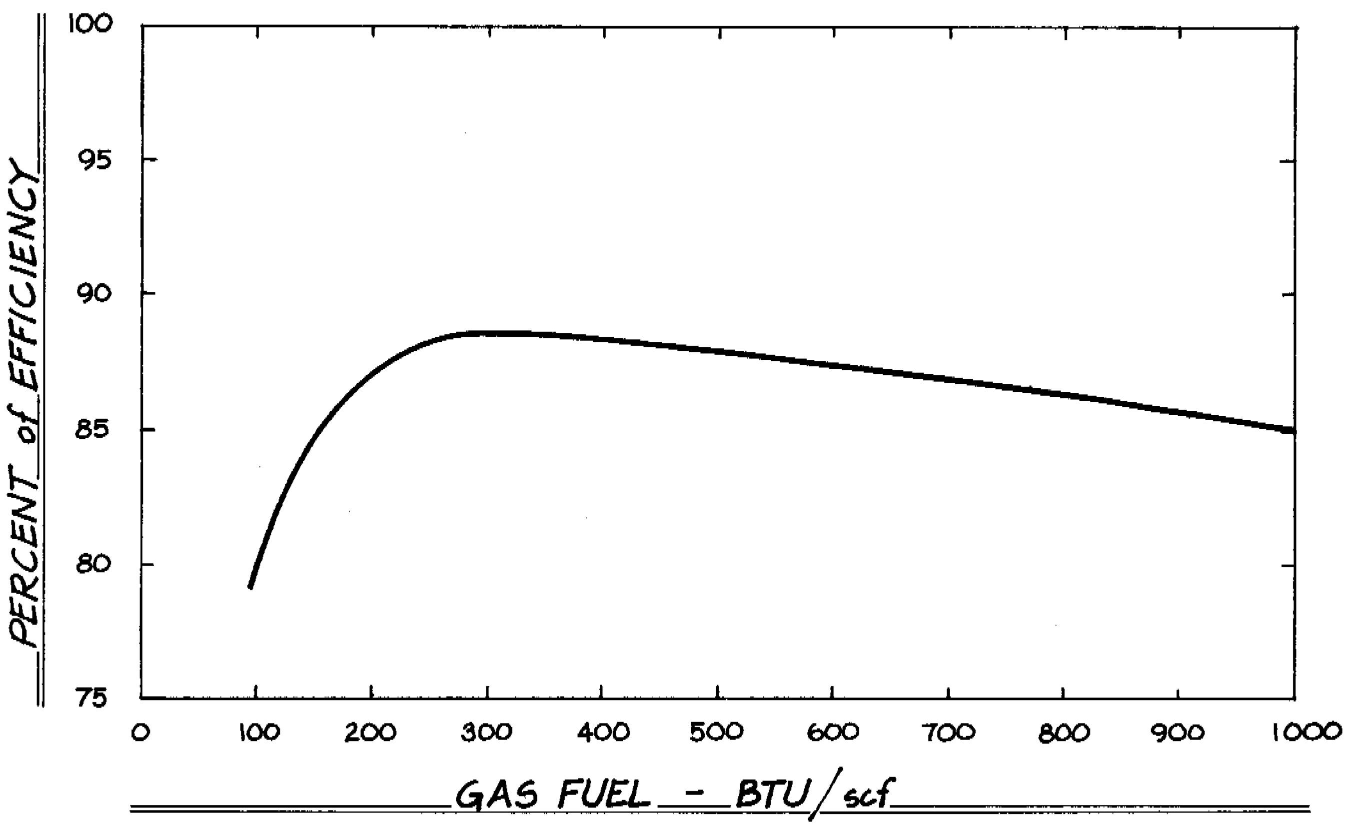

Figure 6.--Gaseous burner efficiencies (Bechtel 1975).

Another application of biomass gasifiers is to produce fuel for an internal combustion engine, either spark or compression ignition types. The Swedish experience with gasifiers providing fuel for vehicles shows both the technical feasibility as well as the many drawbacks. Thus it is not expected that gasifiers will find much general acceptance for mobile applications.

In general, though, there is a great deal of interest in developing and testing biomass gasifiers. Appendix A lists biomass air gasifiers research, development, and demonstration programs around the country. The University of California - Davis gasifier has been demonstrated at the state heating plant in Sacramento as well as at the Diamond/Sunsweet walnut processing plant as a source of fuel for steam generation. Moteurs Durant units have been delivered and installed in Europe, Africa, Asia and Central America to provide electrical power from biomass via an air gasifier.

ECONOMICS

The accurate determination of fuel gas costs from a biomass gasifier is a very complicated exercise. The capital cost for the gasifier is probably the easiest parameter to determine, but the cost of capital, which depends on many arbitrary decisions, is very difficult to determine. For the purposes of this review paper, only the operating cost of gasification will be compared with that of natural gas. In this analysis, assumptions must be made, including an assumed cost of the biomass feedstock (table 3).

Table 3.--Assumptions used to determine operating cost of gasifier.

Peak demand for heat	15×10^6 Btu/hr
Capital Cost of gasifier and installation (ref. 6, 7)	$340,200
Cost of Capital	15%
Operating Costs (ref. 6, 7)	$37,010/yr.
Operating Cost inflation factor	7%
Heat content of feedstock	17×10^6 Btu/ODT
Gasification efficiency	80%
Yearly heat demand	118.8×10^9 Btu
Feedstock inflation factor	10%

The most sensitive economic factor in all end uses of biomass is the cost of biomass feedstock. This is true for gasification processes as well as ethanol production from grain. There have been many studies of the cost of delivered forest residues (Pratt 1978, Johnson 1978, Mattson 1978) and the values range from $15 to $35/ODT.

Figure 7 shows the operating cost of gasification for three selected biomass feedstock costs as a function of year. Compared to each feedstock cost are the future prices of firm industrial natural gas assuming various rates of increase. The 24 percent increase per year reflects the history of natural gas prices over the past nine years (Montana Power 1979). As illustrated, the cost of gas from biomass gasification is less than the industrial rates for natural gas for all years at a feedstock cost of $20/ODT. However, for a feedstock cost of $45/ODT, the crossover points are 5 to 10 years into the future before gasification can compete with natural gas.

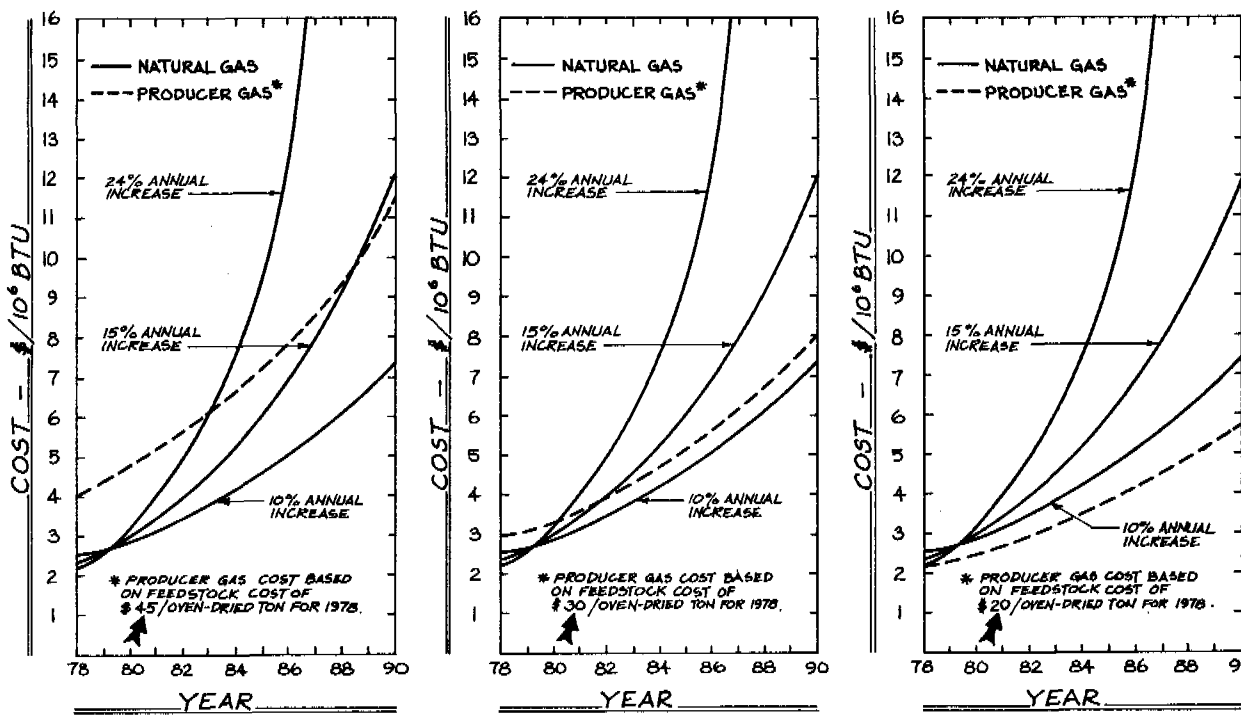

Figure 7.--Cost comparison curves, natural gas and producer gas.

In any event, each potential user of biomass as a fuel must determine his own economic situation and operating costs. There are many factors to consider from both a technical and an economic viewpoint.

CONCLUSION

1. The gasification of forest residues is a proven technology.
2. Commercial biomass gasifiers are available but not yet widely accepted.
3. Low Btu-gas can be used for heating and for power end-uses.
4. The cost of gas from biomass gasifiers is strongly dependent upon the cost of biomass feedstock.

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APPENDIX

Biomass Gasifier Projects

Organization	Status
Alberta Industrial Developments Ltd. 704 Cambridge Building Edmonton, Alberta Canada T5J 1R9 (403) 429-4094	Fluid bed reactor 30×10^6 Btu/hr Prototype ready for commercial use.
Applied Engineering Co. Orangeburg, SC 29115 (803) 534-2424	Updraft, 5×10^6 Btu/hr commercial demonstration.
Bio-Solar Research & Development Corp. 1500 Valley River Drive Eugene, Oregon 97401 (503) 686-0765	Updraft, small pilot scale.
P.C. Walkup Battelle - Northwest P.O. Box 999 Richland, WA 99352 (509) 946-2432	Updraft, commercial and research stage.
B.C. Research 3650 Wesbrook Mall Vancouver, B.C. Canada V6S 2L2 (604) 224-4331	Fluidized bed, 10^6 Btu/hr, research.
Department of Agricultural Engineering University of California Davis, California 95616 (916) 752-1421	Downdraft, 6×10^6 Btu/hr, demonstration.
Century Research, Inc. 16935 S. Vermont Avenue Gardena, California 90247 (213) 327-2405	Updraft, 50×10^6 Btu/hr, commercial.
Davy Powergas, Inc. P.O. Box 36444 Houston, TX 77036 (713) 782-3440	Updraft, commercial.
John Deere & Company Technical Center 3300 River Drive Moline, Illinois 61265 (309) 757-5275	Downdraft, 100 kW generator, research.

Eco-Research, Ltd. P.O. Box 200, Station A Willodale, Ontario Canada M2N 5S8 (416) 226-7351	Fluidized bed, 15 x 10^6 Btu/hr pilot plant.
Environmental Energy Engineering Inc. P.O. Box 4214 Morgantown, West Virginia 26505 (304) 983-2196	Fluidized bed 3 x 10^6 Btu/hr pilot plant.
Forest Fuels, Inc. 7 Main Street Keene, New Hampshire 03431 (603) 357-3319	Updraft, 1-30 x 10^6 Btu/hr pilot-commercial.
Foster Wheeler Energy Corporation 110 S. Orange Avenue Livingston, New Jersey 07039 (201) 533-2667	Updraft, research.
Biomass Corporation 951 Live Oak Boulevard Yuba City, California 95991 (916) 674-7230	Downdraft, 1-15 x 10^6 Btu/hr commercial.
Engineering Experiment Station Georgia Institute of Technology Room 1512 A C&S Bldg. 33 N. Avenue Atlanta, Georgia 30332 (404) 894-3448	Updraft, 0.5 x 10^6 Btu/hr research.
Halcyon Associates, Inc. Maple Street East Andover, New Hampshire 03231 (603) 735-5356	Updraft, 6-50 x 10^6 Btu/hr commercial.
Imbert Air Gasifier 5760 Arnsberg, 2 Steinweg Nr. 11 Germany	Downdraft, 10-10,000 kW generator commercial.
Lamb-Cargate Industries 1135 Queens Avenue New Westminister, B.C. Canada V5L 4Y2 (604) 521-8821	Updraft, 25 x 10^6 Btu/hr commercial.
Moteurs Duvant Industrial Development & Procurement One Old Country Road Carle Place, NY 11514 (516) 248-0880	Downdraft, 1-8 x 10^6 Btu/hr 100-750 kW generator commercial.

Pioneer Hi-Bred International 4700 Merle Hay Road Johnston, IA 50131 (515) 245-3721	Downdraft, 9×10^6 Btu/hr research.
Vermont Wood Energy Corp. P.O. Box 280 Stowe, Vermont 05672 (802) 253-7220	Downdraft, 8×10^4 Btu/hr development.