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retrofit '79

Retrofit '79
Proceedings of a Workshop on Air Gasification

SERI

Sponsored and Organized by:
The Solar Energy Research Institute

Seattle, Washington
February 2, 1979

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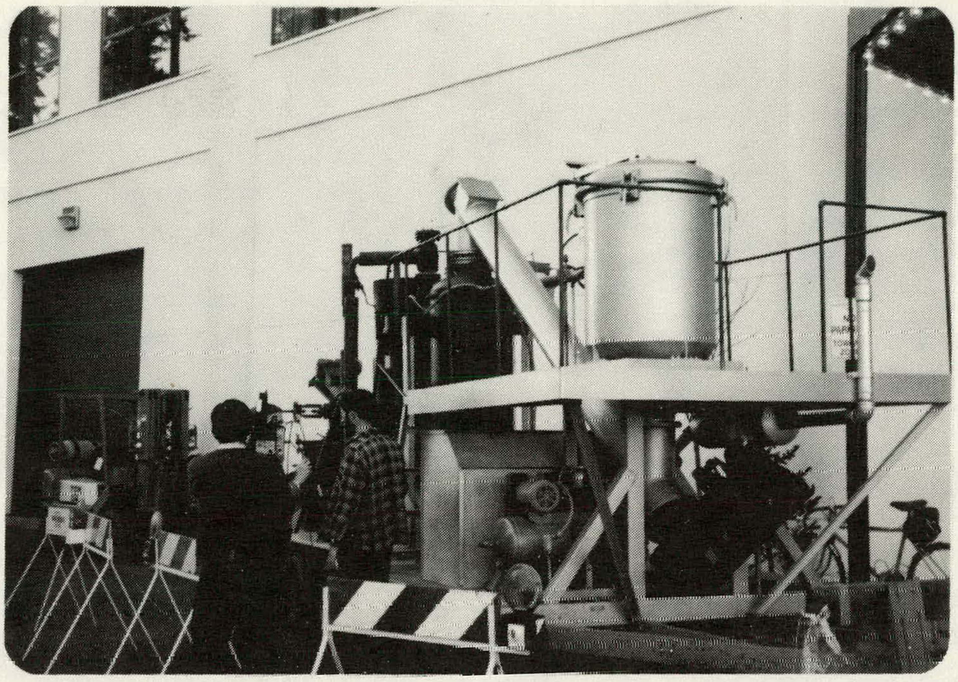

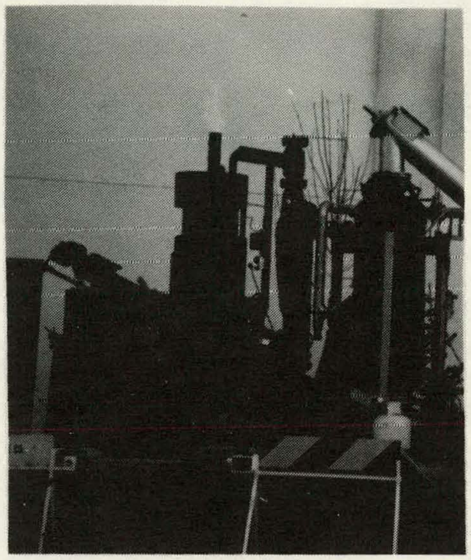

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SECTION 1.0

INTRODUCTION

AIR GASIFICATION WORKSHOP - WHY, WHERE, WHAT?

T. B. Reed and D. E. Jantzen

A biomass gasifier is a device that converts wood, residues and other biomass forms to a gas which can be burned in existing gas/oil burners for heat and power or in engines for power or transport. We presently have in the U.S. roughly 10 quads (10×10^{15} kjoules (Btu)) of such residues, so clearly gasifiers could be important in replacing fossil fuel with biomass.

Our purposes in holding this workshop were:

- o to identify present manufacturers of gasifiers and their products;
- o to give these manufacturers a forum for discussion where they could meet and discuss their common problems;
- o to determine the areas of general agreement on the value and characteristics of gasifiers;
- o to disseminate scientific information to the manufacturers;
- o to determine areas requiring further development;
- o to identify possible areas requiring research;
- o to develop contacts between manufacturers and institutional moieties; and
- o to determine areas in which federal and state governments could accelerate the introduction of gasifiers as appropriate.

The workshop was held in Seattle at the Red Lion Sea-Tac Inn on February 2, 1979 following the much larger Forest Products Research Institute annual convention, "Hardware For Energy Generation in the Wood Products Industry". Although it was originally hoped to limit the attendance to about forty persons representing manufacturers, research and institutional interest, 107 attendees actually registered (Section 12). In spite of the large attendance there was a sense of keen participation by all present and a number of groups were still talking intently when the meeting officially closed at 10:00 p.m. An informal poll of the attendees showed that:

- o 33 attendees had actually been involved in gasifier design and construction;
- o 40 attendees had had "hands on" experience in gasifier operation;
- o 102 attendees had actually seen gasifiers operate.

The papers contained in these proceedings discuss in detail the characteristics of various gasifiers. It is appropriate to answer two questions:

- o Why use gasification instead of direct combustion?
- o How does gasification differ from pyrolysis and combustion?

Complete combustion has been an ally to the human race for 10,000 years at least, and we burn wood in fireplaces, stoves, furnaces, and boilers with no great difficulties. Gasification was developed early in the last century and was also a well developed field as attested by the "gasworks" in most U.S. cities until natural gas displaced manufactured gas. Most of our parents knew and used this manufactured gas for cooking and lighting, but found it too expensive for heating so used coal or wood instead.

However, we have now become accustomed to and dependent on the convenience and high efficiency of gas or oil combustion. We also have equipment that will only burn gas/oil and would need to be replaced if we turned back to wood or coal. The principal justification for developing gasification today is that it would permit a retrofit of existing oil/gas combustion equipment and immediate use of existing biomass supplies as shown in Figure 1. We have appended a recent paper examining the relative economics of retrofit using gasifiers vs. conversion to solid fuel combustion. This paper shows that the cost of retrofit is about two-thirds the cost of a new solid fuel installation. The results also suggest that it may ultimately be always more economical to use a gasifier/gas boiler compared to solid fuel combustion.

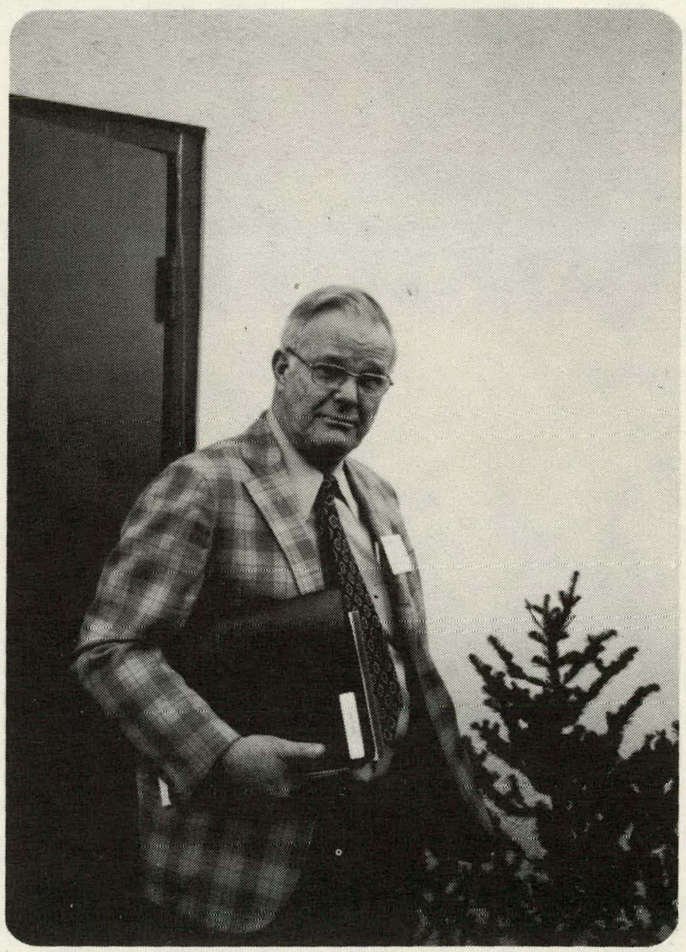
Two other factors make air gasification for existing boilers an attractive option today. Gasifiers typically have low particulate emissions because the particulates are removed in the gasifier before passing to the combustion unit. Even if some further cleanup is required, the volume of gas from the gasifier requiring cleanup is typically less than a quarter of the final flue products from combustion and the gases are much cooler.

Another factor which may soon favor gasification is the ability of gasifiers to burn a wide range of biomass residues, at least if used in association with densification. Densification (pelleting, briquetting, extrusion, etc.) can convert residues which have no commercial value as a fuel to a superior fuel approaching coal in combustion properties and without the pollutant emissions of coal. Densified biomass seems to be an ideal feedstock for gasifiers.

A more compelling reason for gasification when liquid fuels become too scarce/expensive is that the gas can be used to operate spark or diesel engines for power generation, transportation, and heavy machinery. This aspect is particularly covered in the paper by Eric Johannson of the Institute For Agricultural Machinery in Sweden.

There is currently some confusion between the terms pyrolysis, gasification, and combustion and we would like to close this discussion with some recent results we have obtained which puts these three processes into perspective. The principal distinction between these processes is the amount of air used relative to quantity of fuel.

The temperatures resulting from the reaction of biomass (here taken to have the molecular formula $C\,H_{1.4}\,O_{0.6}$) with varying amounts of air or oxygen are shown in Figure 2. (The equivalence ratio $\emptyset$ is the fraction of the theoretical oxygen or air required for complete combustion which is actually used.) The resulting gas compositions



for reaction of dry biomass with air are shown in Figure 3 while the heating value of the gas is shown in Figures 4 and 5. (We would like to thank Dr. Ray Desrosiers for making these calculations.) It should be stressed that these are the equilibrium temperatures and compositions given by the various air fuel ratios. We believe that they are a close approximation to the gas produced in downdraft and fluidized bed gasifiers where the gas is equilibrated at a high temperature, but less representative of updraft gasifiers.

It can be seen in Figures 2 and 4 that for an equivalence ratio (Ø) below about 0.2 (20% of the theoretical air required for total combustion) that a high energy gas is formed along with char. This we define as the pyrolysis range, and though gas is produced, the principal product is char (and sometimes oil) which often has a high sale value. For quantities of oxygen/air where Ø is between 0.25 - 0.5, (about 0.25) all char is consumed resulting in a medium energy gas with oxygen or a low energy gas with air. We define this as the gasification range. Finally, for Ø values of 1.0 - 2.0, all of the chemical energy in the gas is converted to thermal energy and we call this the combustion range. Thus, we see that the air (oxygen)/fuel range adequately distinguishes between pyrolysis (lower or no air) and combustion (excess air) processes.

We hope that these proceedings will be of benefit to all those interested in the field of air gasification and we wish to thank the participants in this workshop for their enthusiastic help.

U.S. Biomass Industries

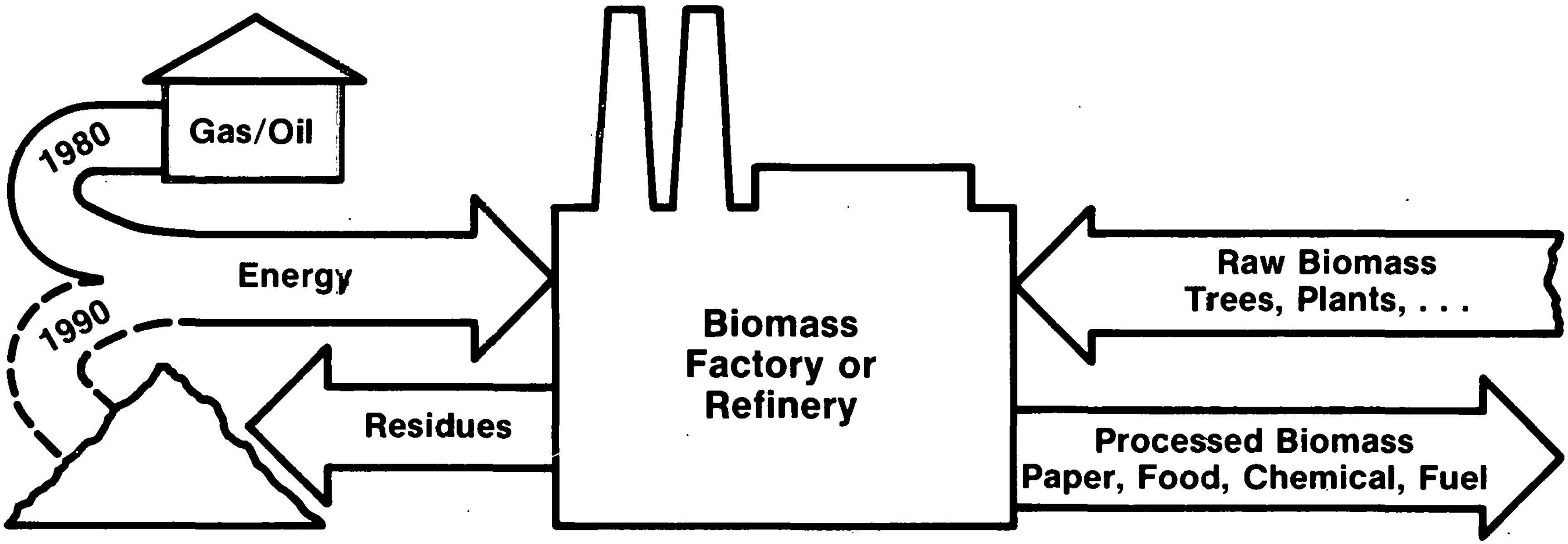


Figure 1

Wood Adiabatic Reaction Temperatures

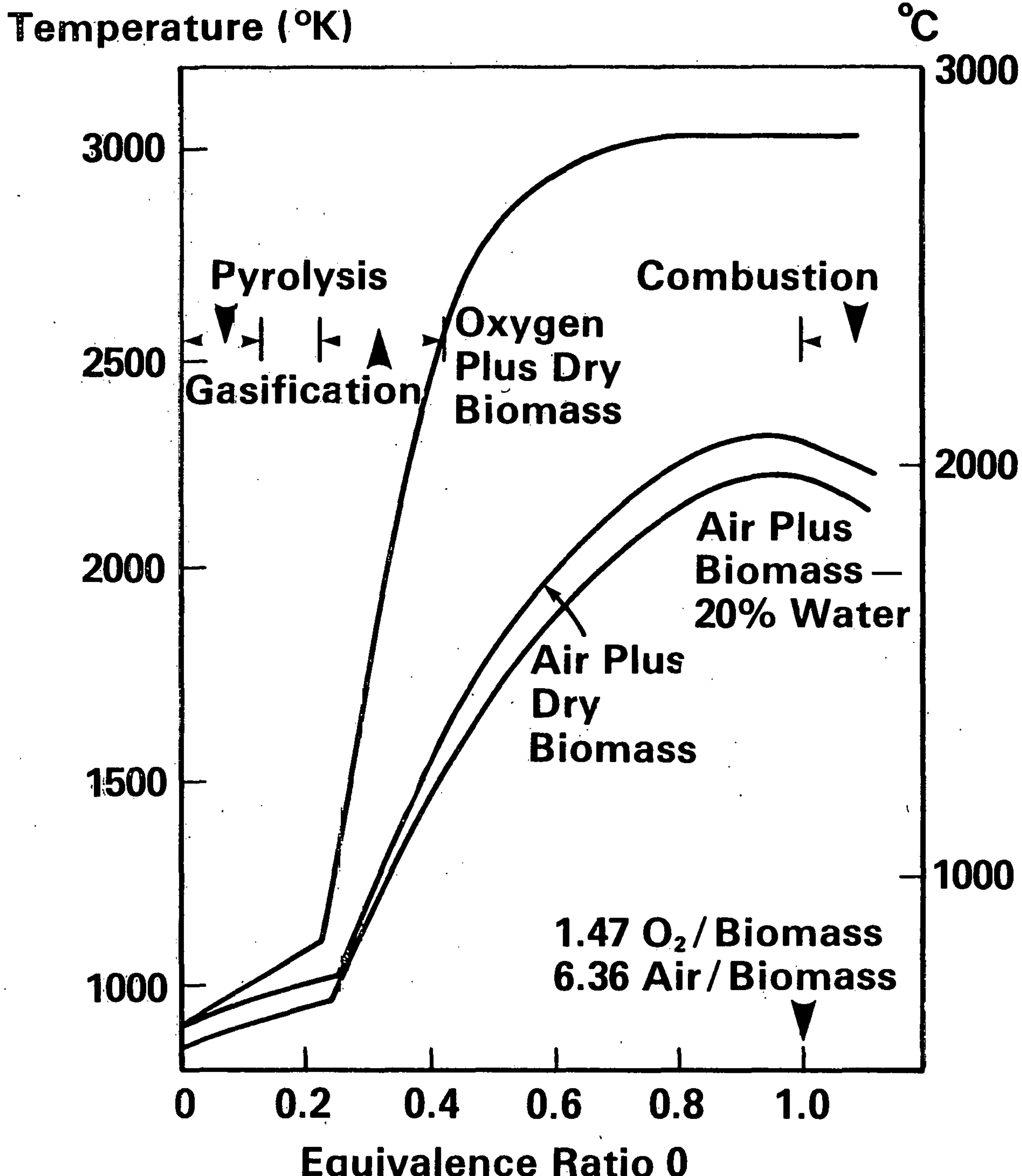


Figure 2

Equilibrium Composition for Adiabatic Air/Biomass Reaction

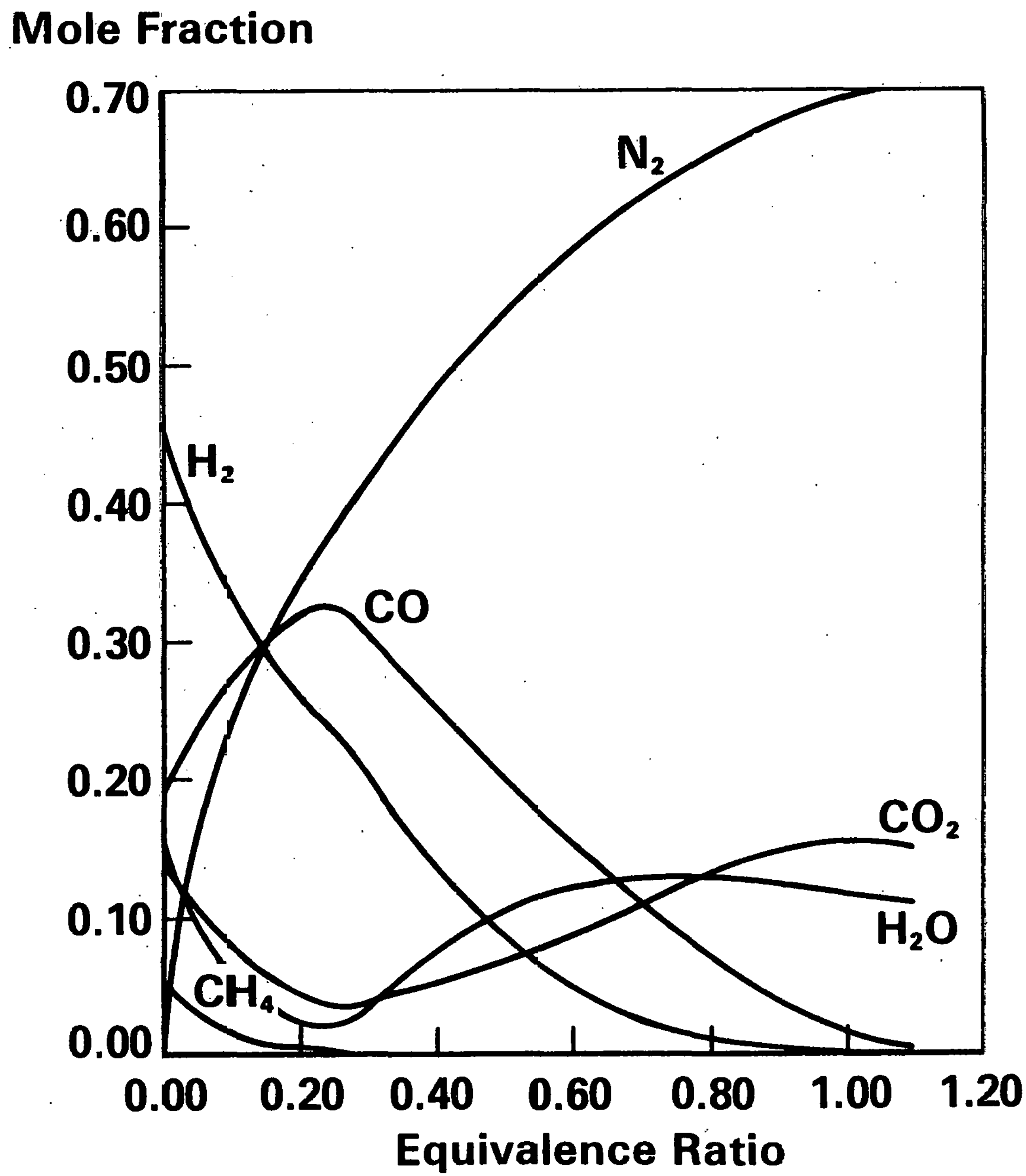


Figure 3

Low Heating Value for Dry Equilibrium Gas for Air/O_2 — Biomass Reaction

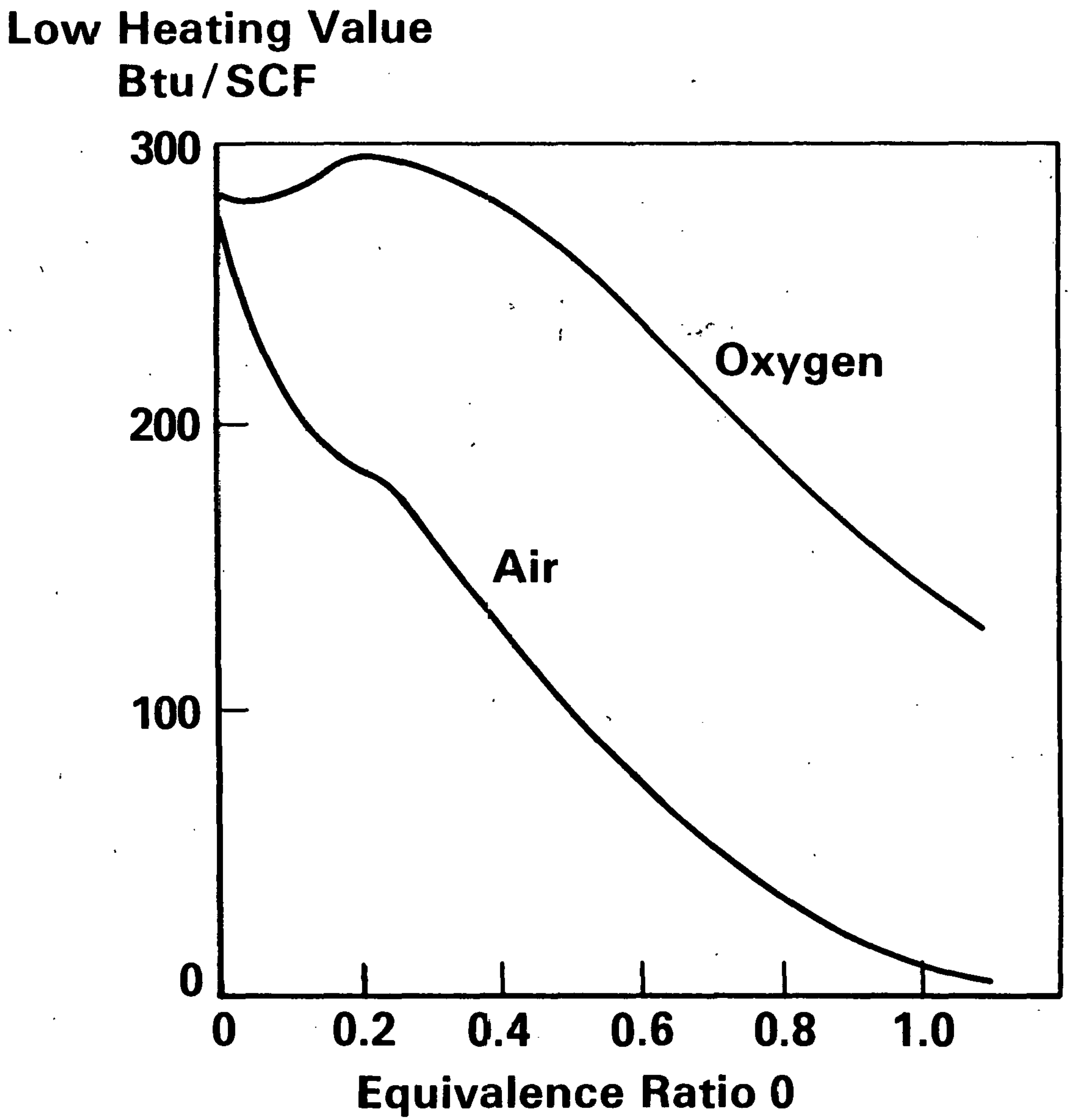


Figure 4

Gas and Char Energy Content for Oxygen and Air/Biomass Equilibrium

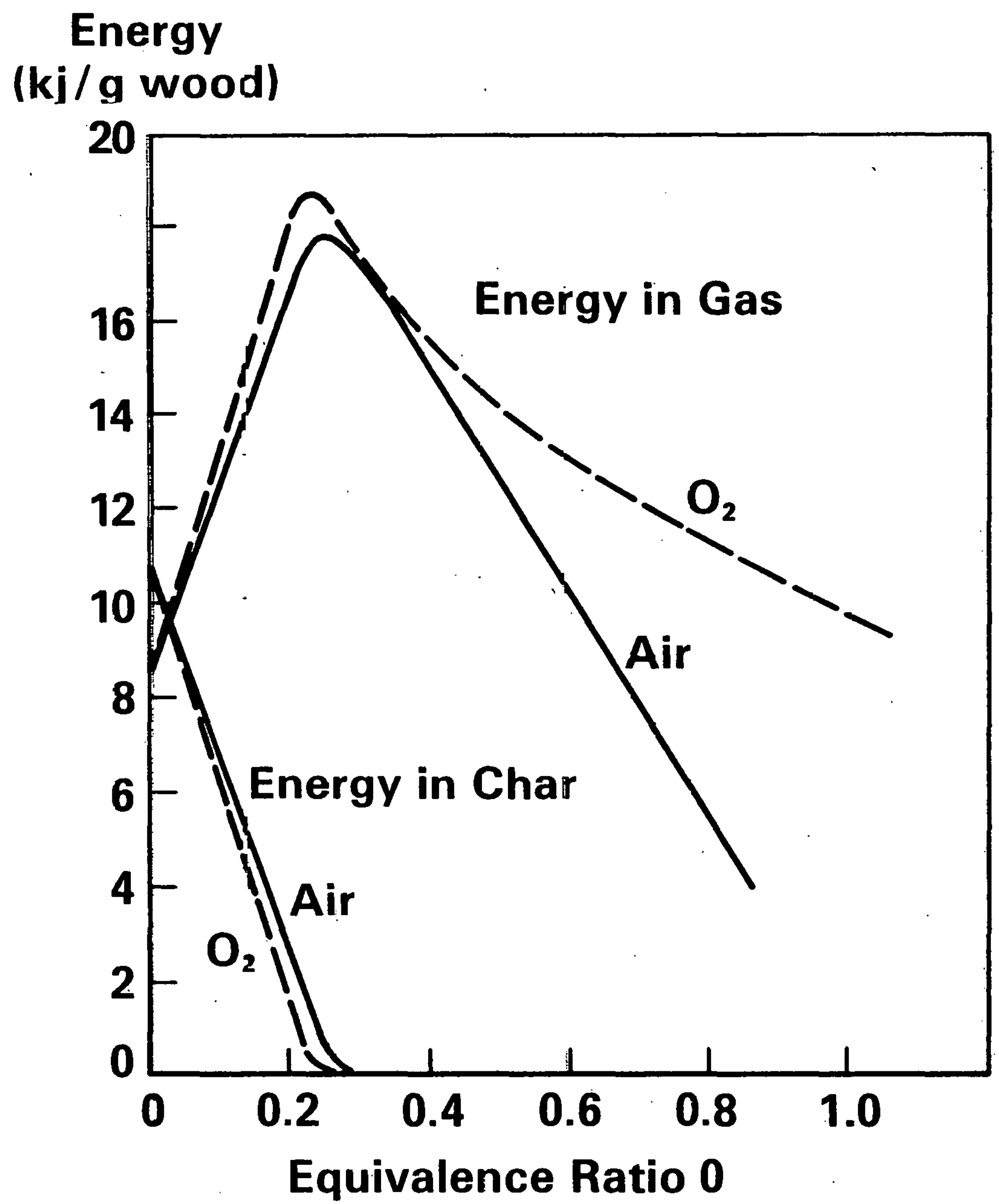


Figure 5

SECTION 2.0

RETROFIT '79

A WORKSHOP ON AIR BIOMASS GASIFIERS TO REPLACE GAS/OIL FUELS*
SPONSORED BY THE SOLAR ENERGY RESEARCH INSTITUTE (SERI)
Golden, Colorado

To be held on February 2, 1979 at the Red Lion Inn in Seattle in conjunction with the conference "Hardware For Energy Generation in the Forest Products Industry", January 30 to February 1.

Session A: Background Information On Air Gasification

8:30 a.m.	Welcome from SERI and opening remarks on Purpose of Workshop T.B. Reed, SERI
8:50	History and Present Potential of Air Gasifiers Brian Horsfield, Weyerhauser Corporation
9:20	Fundamental Principles of Air Gasification: Gengas I and II Survey Dan Jantzen, SERI
9:40	Coffee and Private Discussions

Session B: Case Histories of Operating Gasifiers

10:00 a.m.	The Updraft Gasifier John Burton and Al Fernie Westwood Polygas Ltd., Vancouver, Canada
10:25	The Downdraft Gasifier John Goss, Univ. of California, Davis
10:50	Fluidized Bed Gasifiers Richard Assaly, Alberta Industrial Developments Ltd. Edmonton, Canada
11:15	Gasification Experiments Using Pellets and Oxygen Enrichment Dick Bailie, Univ. of West Virginia, Morgantown
11:40 a.m.	Swedish Experience Operating Tractors and Trucks on Producer Gas Eric Johansson, National Swedish Testing Institute for Agricultural Machinery, Uppsala, Sweden
12:15 p.m.	LUNCH (Private Discussions)
2:00	Panel on Introduction of Air Gasifiers Bob Hodam, Moderator, California Energy Commission

3:00	Coffee and Private Discussions
3:20	Manufacturer/Researcher Panel on Technical Improvement of Air Gasifiers Tom Reed, Moderator, SERI
6:30	Cocktails (Cash Bar)
7:30	DINNER
8:30	Dinner Speech "Biomass — Who Needs It? Canada!" Ralph Overend, Chief Renewable Energy Resources Branch Energy, Mines, and Resources, Canada

SECTION 3.0

GASIFICATION - AN OVERVIEW

Ralph Overend
Biomass Program Director
Energy Project
National Research Council of Canada

Introduction

The upgrading of relatively low grade fuels such as lignite, peat, and wood residues to produce a clean gaseous fuel has been used several times in recent technological history. The stimulus to utilize these fuels has been the unavailability of demonstrably more convenient fuels such as hard coal, crude oil and its derivatives, or natural gas. The two world wars and "colonial" fuel needs occasioned widespread adoption of gasifiers to provide heat, illumination, and motive power when the supply of convenient fuels was not available. Figure 1 is a histogram of references to wood gasification in Chemical Abstracts in two-year periods up to 1976 along with the number of recent papers in the subject known to me. It is evident that interest in wood gasification is at an all time high as a result of the recognition that non-renewable resources are finite. Though the world will not run out of fossil fuels overnight, the combination of increasing world fuel demand and the increasing difficulties in securing supplies implies that alternative fuel substitutions will take place in the near and medium term. Given that the gasification of wood is an "old" technology, why should there be such research interest when theoretically at any rate, an off the shelf purchase of a World War II design should be possible?

Contemporary Gasifier Issues

Both public and private benefits can be seen to result from the substitution of easily available fuel wood and wood residues for fossil fuels in stationary applications such as: direct firing of dry kilns and lime kilns; the retrofit of a wood input to gas and oil fired boilers; space heating; and the generation of both shaft power and electricity. The extremely large investment in oil refineries and motor vehicle fuel distribution networks has forced the development of syncrudes from oil sands, heavy oils, coal, and shales so that the mobile gasifiers so common during the Second World War are unlikely to recur. The expectation that wood can be used in the above applications is tempered by the requirements that society has placed on all technologies for use in the last quarter of the twentieth century. The emphasis on safety, pollution control, efficiency, and reliability in a relatively low labor intensive environment combine to provide a far different milieu to the expediencies of war. It is these criteria which wood utilization by gasification has to meet over the next decade when the competition from the petroleum and natural gas economies will still be very strong. Extensive research and development is being conducted around the world to develop wood gasifiers to satisfy the needs above so that today there are pre-commercial units being demonstrated and units mainly derived from Second World War technology can be purchased.

WOOD GASIFICATION IN CHEMICAL ABSTRACTS

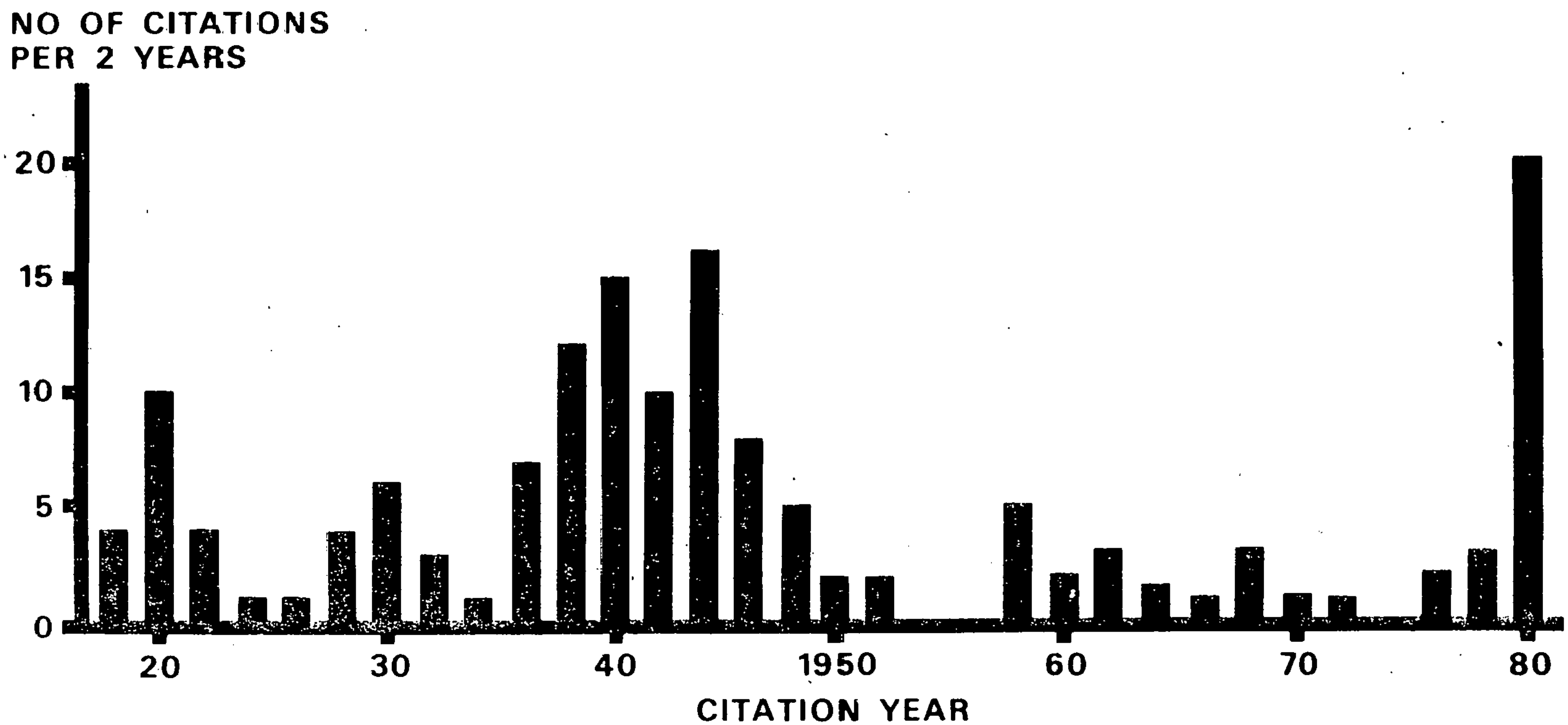


Figure 1

Principles of Wood Gasification

For the purpose of review, gasification is a process which converts a solid fuel into easily handled fuel gases. These gases are further defined as permanent gases and are non-condensible at ambient temperatures. Table 1 lists common gaseous products of gasification and their heats of combustion. The process of gasification can accompany other processes producing a liquid or a char as by-products though these will not be discussed here.

TABLE 1

Higher Heat of Combustion of Gases Produced in Wood Gasification (1)

		MJ/M3	Btu/Scf
Nitrogen N_2	Non Combustible	-	—
Carbon Dioxide CO_2	"	-	—
Water Vapour H_2O	"	-	—
Carbon Monoxide CO		12.6	322
Hydrogen H_2		12.8	325
Methane CH_4		39.8	1014
Ethane C_2H_6		70.4	1793
Ethylene C_2H_4		64.0	1630

The primary means of gasification available today are air driven oxidation/pyrolysis processes. This is not the only means by which a fuel gas can be obtained and further exploration is necessary.

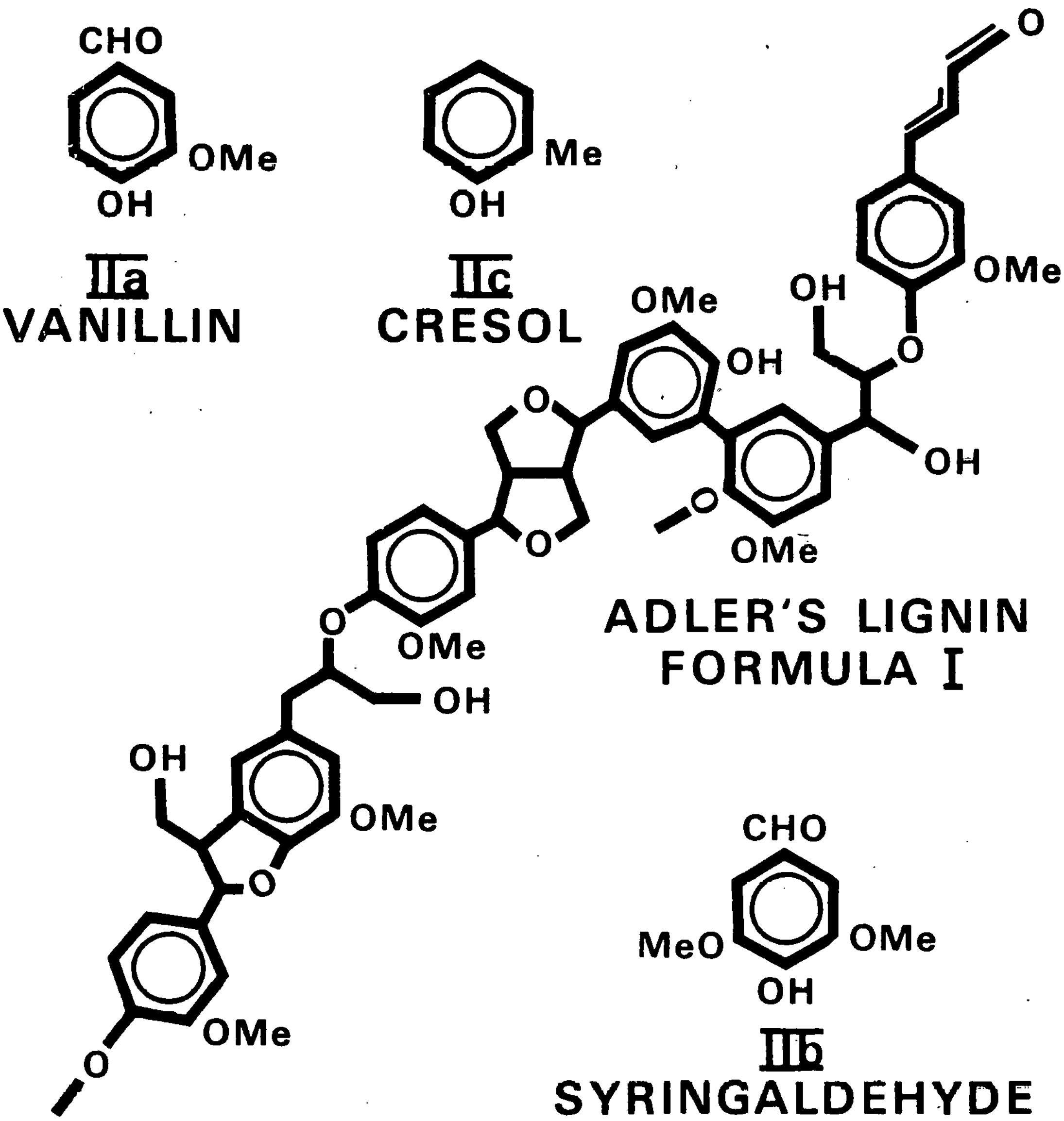
Pyrolysis - a thermal process conducted in the absence of oxygen to produce gas, oils, and char from a solid.

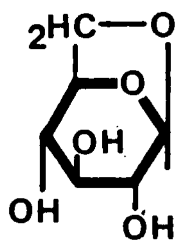
Wood Pyrolysis

When wood is heated in the absence of oxygen, a sequence of reactions take place the relative proportions of which depend on the rate of heating. For example, on heating wood slowly (2):

- Around 100°C there is a loss of water;
- From 100-250°C the wood loses mainly carbon dioxide and water;
- From 250-500°C a fairly rapid devolatilization of gases and tars takes place, leaving a solid char composed mainly of carbon.

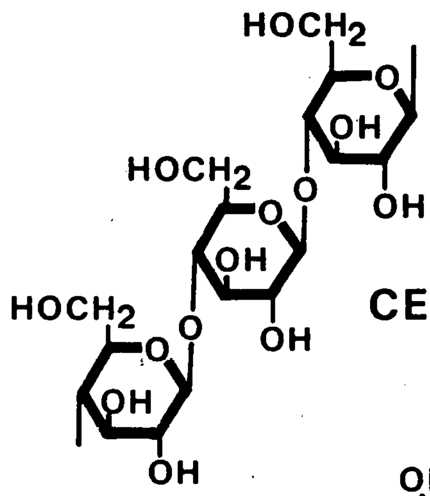
Wood is composed of three polymeric substances: lignin, hemicellulose, and cellulose. Each of these 3 polymers has a different chemical structure relating to their different functions in the living plant. The differences in structure also give rise to different pyrolysis products.


CHO
OMe
OH
IIa
VANILLIN
Me
OH
IIc
CRESOL
O
OMe
OH
OMe
OH
O
OH
O
O
OMe
O
OMe
OH
OH
OMe
O
OMe
ADLER'S LIGNIN
FORMULA I
CHO
MeO
OMe
OH
IIb
SYRINGALDEHYDE



LEVOGLUCOSAN

VI



CELLULOSE

V

H_2O

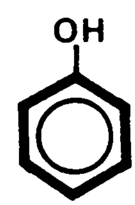
WATER

HOOC Me

ACETIC ACID

HCOOH

FORMIC ACID

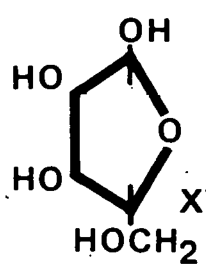


PHENOL

O=CH_2

FORMALDEHYDE

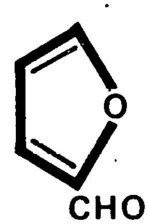
IVc



XYLOSE

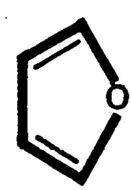
UNIT OF HEMICELLULOSE

III



FURFURAL

IVa



FURAN

IVb

Lignin has a structure I according to Adler (3) which is a large series of aromatic structures joined by either furan rings or ether linkages. On heating the relatively weak ether C-O bonds, they break to produce aromatic fragments such as vanillin IIa, syringaldehyde IIb, phenols and cresols IIc.

Hemicellulose III decomposes easily and the further decomposition of the pentosan manomer such as xylose is reflected by such products as furfural IVa, furan IVb, acetic acid and aldehydes IVc.

Cellulose pyrolysis has been studied exhaustively (4) and it is known that the polymer of glucosan units (V) is decomposed by internal hydrolysis and dehydration to give a large yield of levoglucosan (VI). This is stable at around 210° but at 270°C will also undergo decomposition to form water, formic and acetic acids, and phenols.

The complex bond breaking and rearrangement processes that the polymeric components of wood undergo on pyrolysis lead not only to a chaotic profusion of products 230 (5), but the relative proportions of these shows a high sensitivity to the rate of heating. For example, if the wood is finely divided and rapidly heated a higher proportion of gaseous products relative to char and oil are produced. Conversely, slow heating of large pieces of wood will maximize the production of charcoal at the expense of gas and oil production.

Gasifier Configurations

In the gasification systems to be discussed, the pyrolysis processes are heated by the oxidative combustion of the char in situ. While there are pyrolytic gas producers they nearly all require external heat sources such as a means of combusting one of the non-gaseous products (the char or the oil) and transferring this heat to the pyrolysis reactor. The majority of the systems available today are autogenous with the char oxidation and pyrolysis taking place in the same reactor. The archetypical gas producer which has been sold in the thousands since the early 1900's is a so-called fixed bed up-draft unit. A schematic of this is given in Figure 2. The fuel descends through the 3 zones illustrated and the air ascends through the oxidative combustion zone, the pyrolysis zone, and finally the drying zone before being taken off, cleaned as necessary, and used as a producer gas. The reactions occurring are:

Zone A
Drying at 100-200°C
Wet Wood + Heat → Dry Wood + Steam

Zone B
Pyrolysis at 200-500°C
Dry Wood + Heat → Char + CO + CO_2 + H_2O
+ CH_4 + C_2H_4
+ Pyroligneous Acids
+ Tars

Zone C
Oxidation of Char at 1100-1500°C
Char + O_2 + H_2O (steam either added or in fuel) → CO + H_2 + CO_2 + Heat.

The first two processes are driven by the heat given out in the oxidation zone. The detailed thermo-chemistry of gasification can be summarized in Table 2.

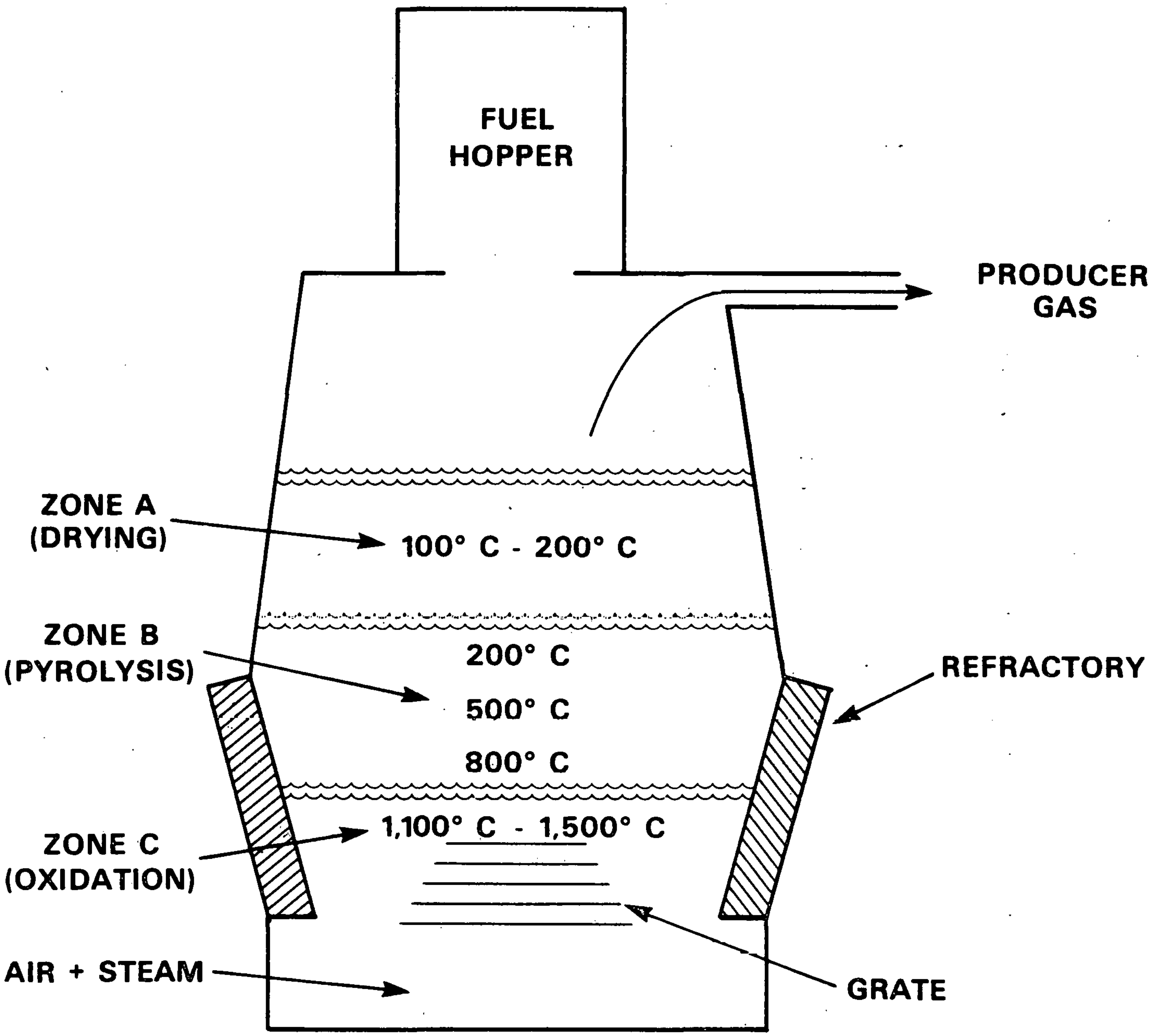

FUEL
HOPPER
PRODUCER
GAS
ZONE A
(DRYING)
100° C - 200° C
ZONE B
(PYROLYSIS)
200° C
500° C
800° C
REFRACTORY
ZONE C
(OXIDATION)
1,100° C - 1,500° C
AIR + STEAM
GRATE

Figure 2

TABLE 2
Thermo-Chemistry of Gasification

Reaction		Thermochemistry at 500° C H°/KJ/mole	
1)	$2C + O_2 \rightleftharpoons 2CO$		
2)	$C + O_2 \rightleftharpoons CO_2$	-394	Exothermic
3)	$C + CO_2 \rightleftharpoons 2CO$ Boudouard Reaction	+172	Endothermic
4)	$H_2O + CO \rightleftharpoons CO_2 + H_2$ Water Gas Shift	+2.85	Endothermic
5)	$H_2O + C \rightleftharpoons CO + H_2$	+175	Endothermic
6)	$C + 2H_2 \rightleftharpoons CH_4$	-75	Exothemic

*This reaction is not favoured at high temperatures or low pressures.

Reaction 1 therefore is the sole source of heat to drive the process and explains why the efficiency of gasification will not exceed about 70% (cold gas basis) since some part of the fuel input is required to maintain the high temperatures of the pyrolysis zone. Reference in the old literature is often given to the use of steam to regulate the bed temperature and to improve the product gas. In the case of the Crossley Gasifier a note is made that while wood does not require steam addition, the use of coal in the same gasifier does, in order to prevent burning out the grate. The key is the endothermic reaction 4 which subtracts heat from the reaction zone while converting the steam to hydrogen and carbon monoxide fuel gases.

The Down-Draft Gasifier

In many respects this gasifier is very different from the previously described up-draft reactor. Whereas the up-draft will always produce tars from wood so that the gas has to be extensively cleaned for engine use, the down-draft configuration is designed so that the tars and other gases all have to pass through the hot oxidation Zone C. As can be seen in Figure 3 the gases produced by the combustion and "cracking" of the tars are then passed along with solid carbon into the reaction Zone D. This zone serves to reduce carbon dioxide and water vapour to carbon monoxide and hydrogen by means of the reactions 2 and 4 above.

Before reaching Zone D, the reduction zone, ideally all of the oxygen from both the wood and the air is in the form of carbon dioxide and water after passing through Zone C so that the reactions:

$$H_2O + \text{Char} \rightarrow CO + H_2$$

and

$$CO + \text{Char} \rightarrow 2CO$$

These reactions are endothermic and eventually they cool the charcoal and ash to below 600° Celsius and the reaction then almost ceases so that the reduction "freezes" at the final gas composition. The reduction zone places two significant restrictions on the wood fuel composition. Firstly, the fuel should carbonize to a fairly strong structure with a sufficiently large particle size so that the gases will flow easily through the reduction zone. Secondly, because of the heat removal effects of water vapour both by chemical reactions 3 and 4 as well as the physical evaporation of water in Zone A, there is a limit to the water content of the feedstock of around 25%. This is illustrated in Figures 4 and

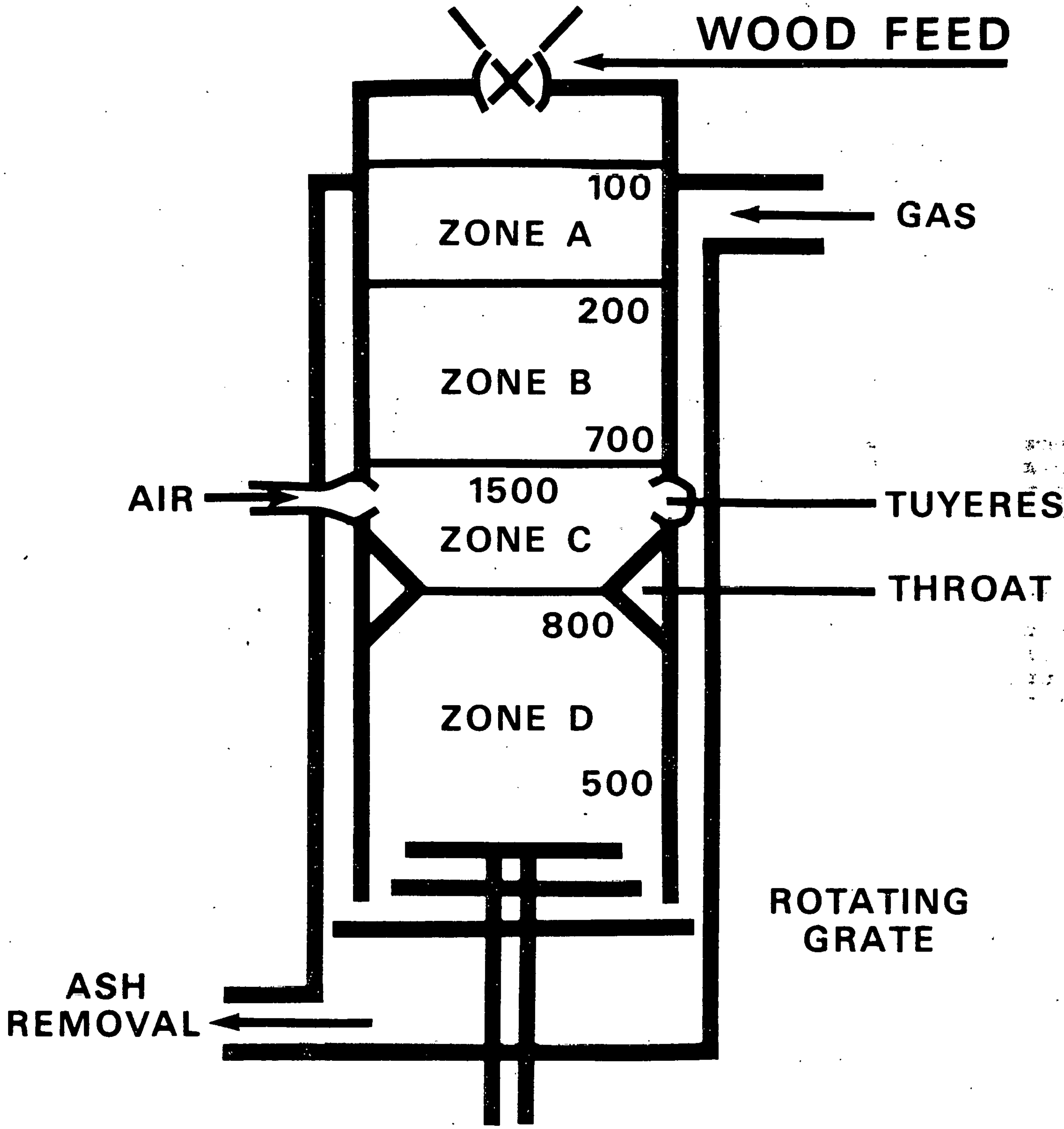

WOOD FEED
100
ZONE A
GAS
200
ZONE B
700
AIR
1500
TUYERES
ZONE C
THROAT
800
ZONE D
500
ROTATING
GRATE
ASH
REMOVAL

Figure 3

5 in which the effect of hardwood moisture content on gas composition, gasification efficiency, gas heating value, and the temperature of the reduction zone are shown from calculations by Gumz (6). The gas quality at 30% moisture content can be significantly improved by applying a preheat to the air or by improving heat transfer from the gases leaving the reactor. As calculated by Gumz (6) the effect of an external heat supply raising the temperature to 650° Celsius would be to produce a gas of 7.2 MJ/m3 compared with the dry gas value of 4.04 MJ/m3 for a 30% moisture content feed stock at a reaction temperature of 555° Celsius (in British units to 193 from 108 Btu/Scf dry gas basis). Among others, this type of gasifier is the basis of the Swedish "Gengas" unit as well as of the Imbert design.

The Fluidized Bed Gasifier

The fluid bed consists of an inert mass of a powdered material such as sand which is suspended by a fast flow of gas up through it. At the appropriate flow rate the individual sand particles are separated from one another and the whole bed appears as though it is boiling with large turbulent currents moving the sand particles around very rapidly. If other substances are introduced into the fluid bed they will appear to float or sink depending on their density and size, but at the same time they will be in contact with many sand particles. Fluidized bed gasifiers use sand and char as the fluid medium and can be air or oxygen blown. The wood is admitted either onto the surface of the bed or under the surface. The reactions described above now take place at the surface of the particle which is heated very rapidly by the hot sand particles. The result is that there is a very rapid pyrolysis of the wood and the gas given off contains high concentrations of methane and other small pyrolysis product hydrocarbons. The heat is supplied by the oxidation of the char and at any given moment the fluid bed will contain only a small proportion of fuel. The time taken by a piece of wood to be completely converted to gas is very short, taking only minutes instead of the hours required for other gasifiers. Because of the highly mixed nature of the fluid the throughput is a function of the volume of the fluidized bed. Traditionally, the fluid bed has a 10:1 ratio of height to diameter on account of the disengagement section above the bed to remove the fluid bed medium. The traditional gasifiers usually have a H/D ratio of less than 3:1.

Other Co-current Reactors

The cross-flow reactor is one in which air is admitted opposite to the gas exit with the fuel admitted from either above or the side. The reactions taking place are similar to those in the down-draft reactor. The British Columbia research council has developed a co-current reactor which is partially fluidized using the ash and char as the fluidizing medium. Unlike the true fluidized bed, this reactor has quite large temperature and concentration gradients. However, it still produces a good fuel gas with a reduced tar concentration, though enriched in methane, and it has the rapid load following characteristics of the fluid bed.

On a very large scale the Koppers-Totzek reactor (7) is an example of an entrained flow co-current reactor in which pulverized fuel, such as wood, is blown along with air through a large reaction chamber. In the reaction chamber, combustion and then reduction takes place to produce a gas composed only of hydrogen and carbon monoxide as fuel components.

Figure 6 is a summary of the different gasifier reactor types and their performance variables. From the reaction temperature plots it can be seen that the up-draft unit has

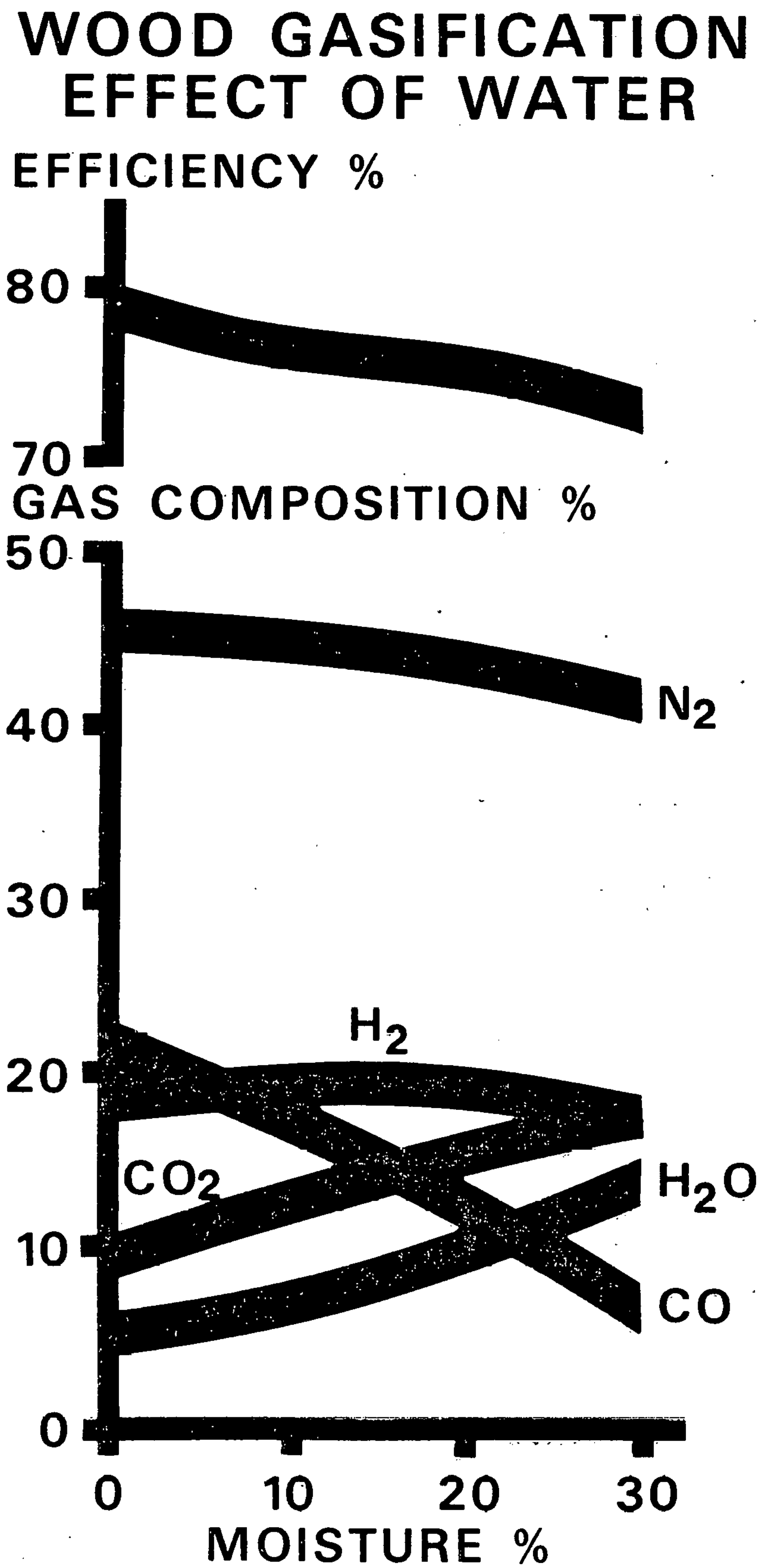

WOOD GASIFICATION
EFFECT OF WATER
EFFICIENCY %
80
70
GAS COMPOSITION %
50
40
30
20
10
0
N2
H2
CO2
H2O
CO
0
10
20
30
MOISTURE %

Figure 4

WOOD GASIFICATION EFFECT OF WATER

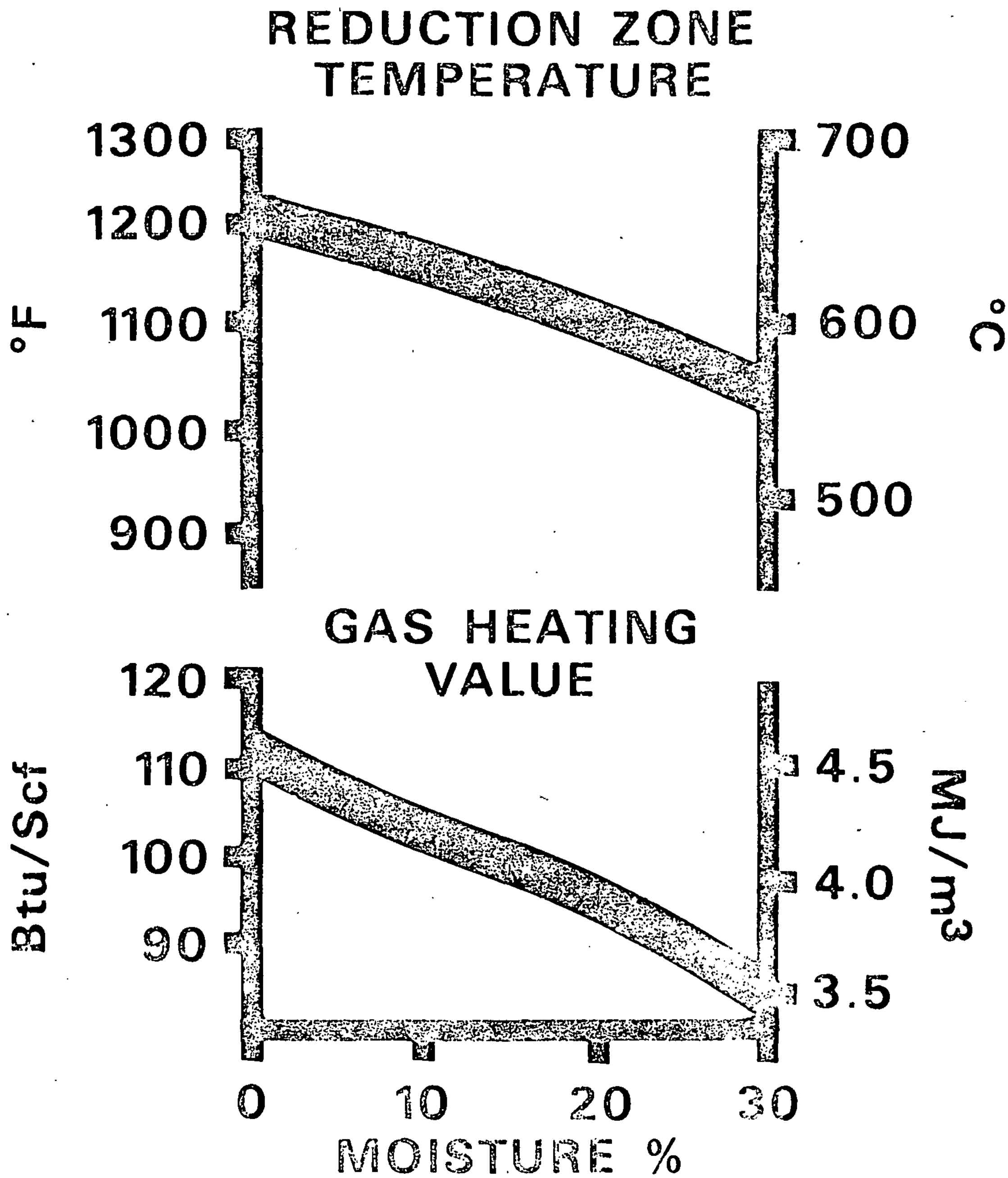


Figure 5

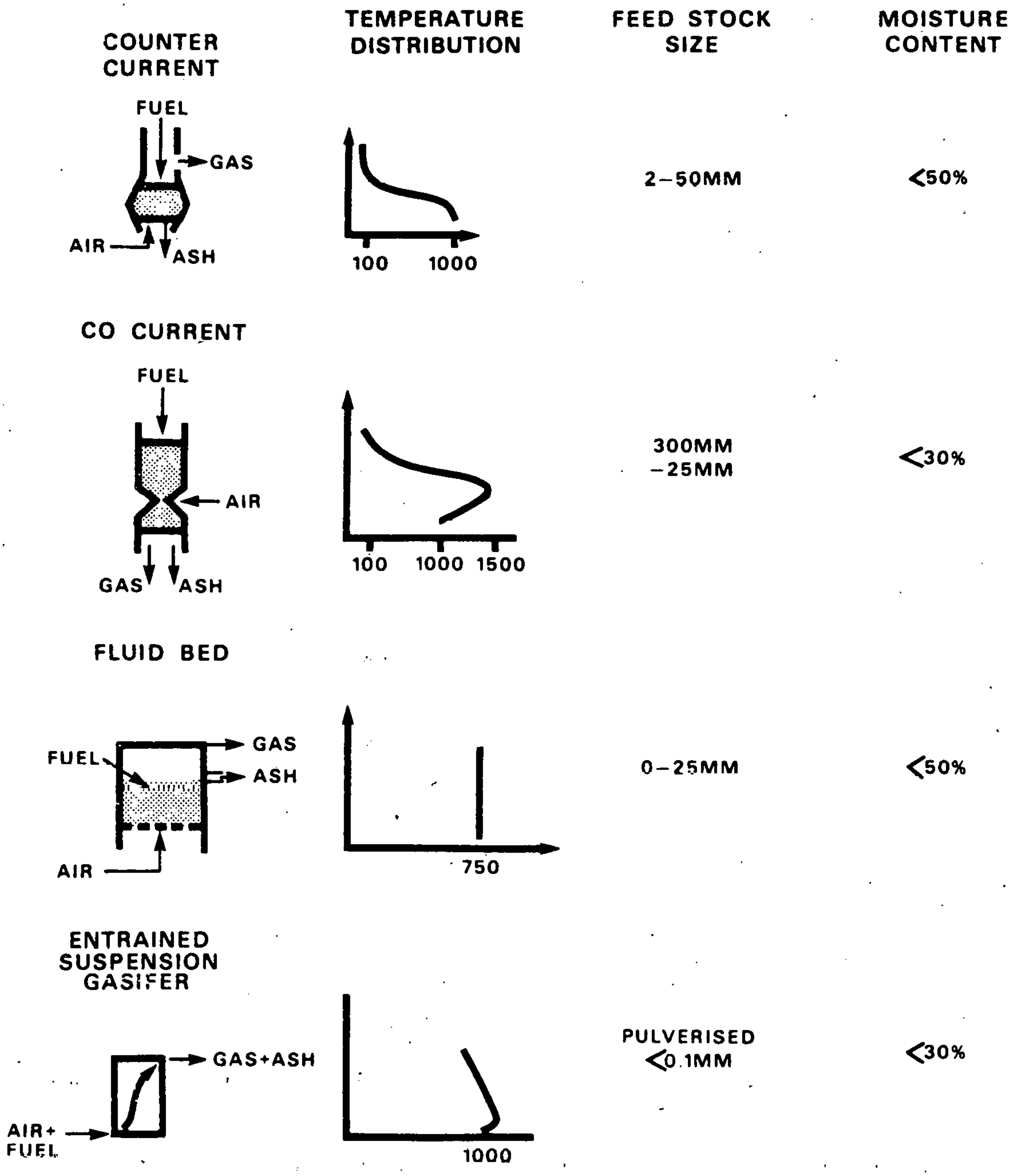

COUNTER CURRENT
TEMPERATURE DISTRIBUTION
FEED STOCK SIZE
MOISTURE CONTENT
FUEL
GAS
AIR
ASH
100
1000
2–50MM
<50%
CO CURRENT
FUEL
AIR
GAS
ASH
100
1000
1500
300MM
–25MM
<30%
FLUID BED
FUEL
GAS
ASH
AIR
750
0–25MM
<50%
ENTRAINED SUSPENSION GASIFER
GAS+ASH
AIR+
FUEL
1000
PULVERISED
<0.1MM
<30%

Figure 6

excellent heat transfer characteristics from the gas stream to the descending fuel. All of the other configurations will require some form of heat recovery from the leaving gas for efficient performance in applications other than the direct coupled dirty gas use.

Table 3 is a sample of the gas analyses of the different gasifier types. The nitrogen content is around 50%, the carbon dioxide content is around 10-15%, and the remainder is comprised of the fuel gases on a dry gas basis. The higher heating value of any gas mixture can be calculated from the heats of combustion of each component as given in Table 1. The gas produced will contain water vapor, reducing the apparent heating value significantly.

TABLE 3

Producer Gases from Wood

Gas Analysis — Oxygen and moisture free

Gasifier Type	CO_2	N_2	CO	H_2	CH_4	Unsaturates
Up-draft						
"Suction Gas"	13.7	52.1	17.4	9.8	4.6	2.4
"Westwood Polygas"	11.5	47.0	22.0	16.0	2.5	1.0
Down-Draft						
"Imbert"	11.2	49.3	20.5	17.0	2.0	-
"Fouchet"	16.0	46.8	13.3	21.0	2.6	0.3
"Duvant"	15.0	48.0	15.0	20.0	2.0	-
Fluid Bed						
"BC Research"	11.2	53.3	15.8	13.1	3.7	1.6
"Eco Research	16.52	44.7	14.8	16.9	5.7	1.4

Gasifier Ratings and Performance

The scale of gasification envisaged ranges from a throughput of 5kg/hour for small scale agricultural units to greater than 10 tonne an hour for large scale applications. At 80% thermal efficiency to a hot gas application, these extremes are equivalent to 22.5 kW_t to 45 MW_t or, in British units, 80,000 Btu/hr to 150 million Btu/hr. A very approximate energy and wood equivalence (at 100% efficient conversion) within 10% of units and ratings is as follows:

$$1{,}000{,}000 \text{ Btu/hour} = 300 \text{ kW}_t = 50 \text{ kg/h} = 100 \text{ lb/hour of oven dry wood}$$

Gasifiers are rated on the throughput of wood per unit time per unit area of the grate. This is not entirely correct for a fluid bed which depends on the working volume. However, for all of the other gasifiers, the working volume is extremely shallow and the rating is a function of the cross-sectional area. Typical ratings are given in in Table 4.

TABLE 4

Gasifier Ratings

REACTOR Configuration (Reference)	THROUGHPUT OF DRY WOOD lb/square foot/hour	$kg/m^2/h$
Up-draft (8)	20 - 40	100 - 200
Down-draft (9)	60 - 100	290 - 490
BC research (10)	60	290
Fluid Bed (11)	300 +	1500 +

These ratings can be taken as an approximate figure of merit for the different systems. The different throughputs arise from the mechanism of gasification. In the temperature ranges of gasifier operation the rate determining factors are not equilibria or chemical kinetics, but rather the rates of heat and mass transfer. The astonishingly high throughput of the fluidized bed reactor is caused by the enhanced contact between the gas flow and the wood. In the case of the up-draft units the rate of gas flow is limited because the fines and other fuel particles will blow out of the reactor and channeling will occur. The down-draft type has the gas flow and gravity working in the same direction so that a higher gas flow can be achieved. This is not without limit, however, since too great a pressure drop will result in channeling, and unreacted gases and wood will pass through.

Construction and Ancillary Requirements of Gasifiers

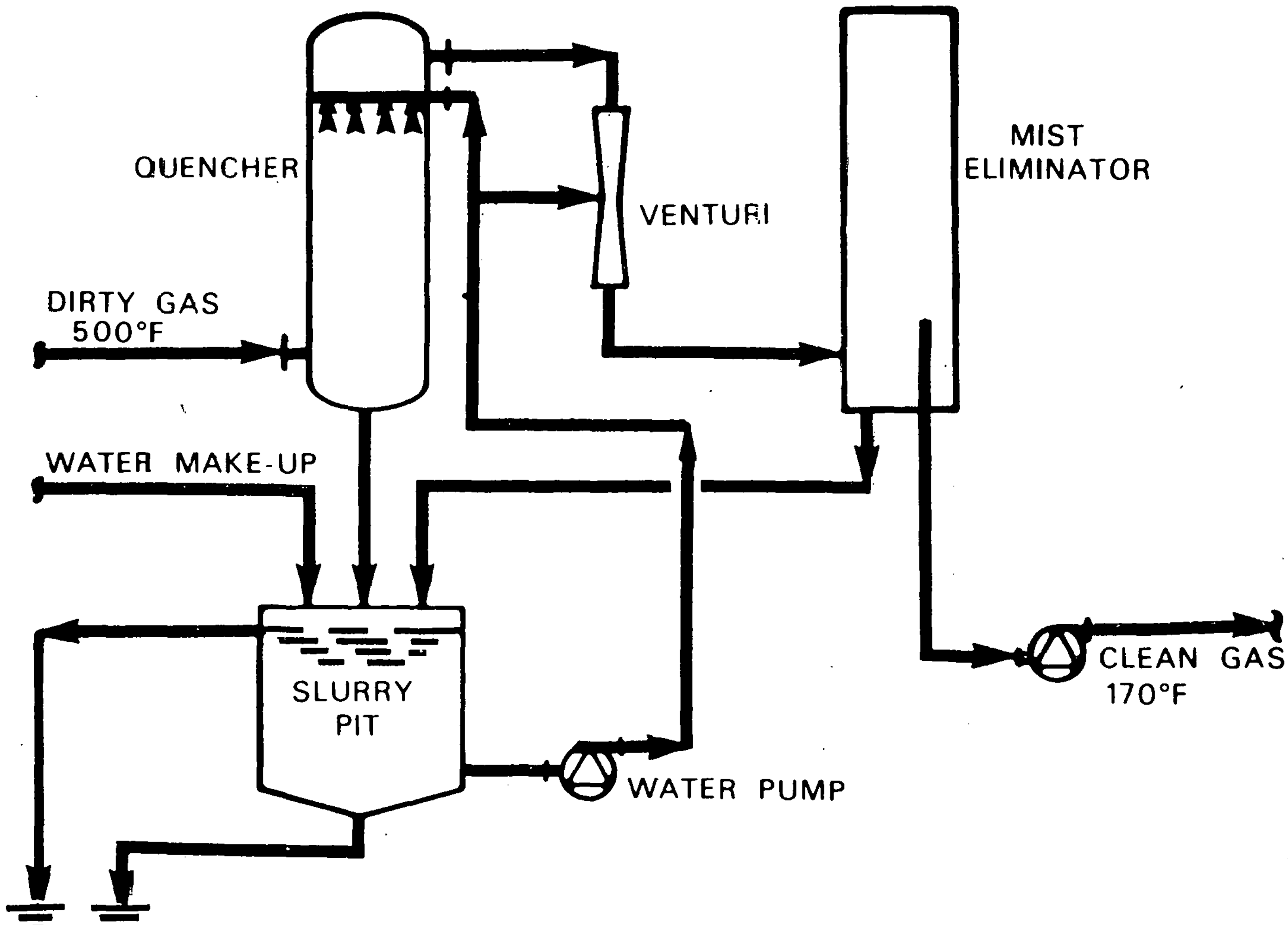
Gasifiers will be shop assembled and shipped out to the site. Depending on the diameter of the grate and the appropriate figure of merit from Table 4, the size restriction of around 3 m for the transportation of shop assembled reactors restricts the maximum size to 0.7, 2.1, and 10.6 tonne per hour for up-draft, down-draft, and fluid bed gasifiers respectively.

The materials of construction are mild steel shells with refractory or special steel liners. The refractory lining will probably be installed onsite either in bricks or cast in place. High temperature nickel alloy steels are generally used in the grate assembly.

The gasifier will also require:

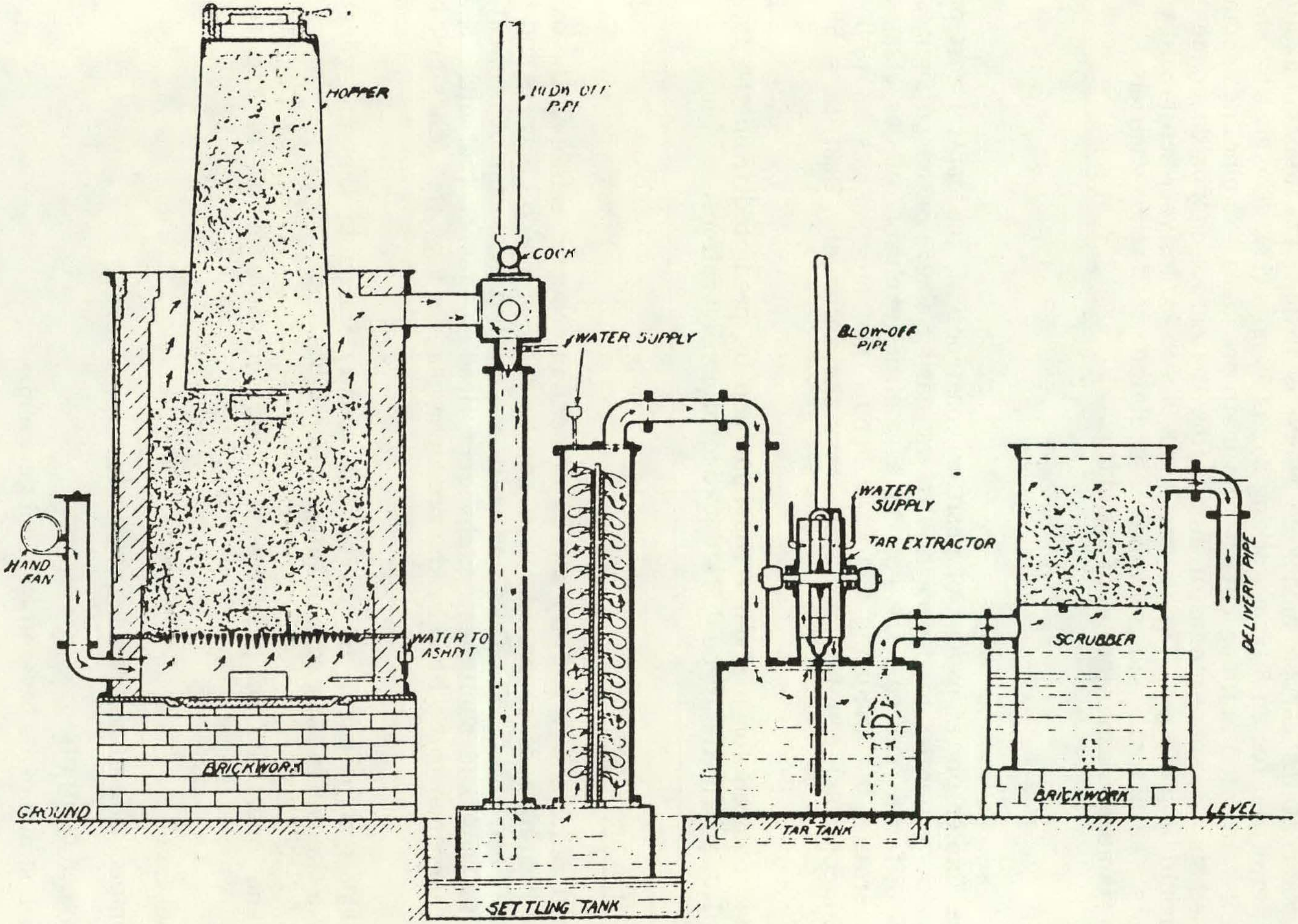
- o equipment for feedstock preparation including comminution and drying;
- o piping for the air and gas lines and their associated blowers;
- o ash handling facilities and disposal; and, depending on the application,
- o gas cooling and cleaning equipment.

The precise requirements are obviously a function of the site and the application. All of the equipment is commercially available with the exception of the gas cleaning equipment which is designed for the given application. Figure 7 illustrates the gas clean up train both ancient and modern.



PROCESS FLOW DIAGRAM-GAS SCRUBBER SYSTEM

Figure 7


HOPPER
COCK
WATER SUPPLY
BLOW-OFF PIPE
WATER SUPPLY
TAR EXTRACTOR
HAND FAN
WATER TO ASHPIT
SCRUBBER
DELIVERY PIPE
BRICKWORK
GROUND
SETTLING TANK
TAR TANK
BRICKWORK
LEVEL

All producer gas contains carbon monoxide which is toxic. The maximum allowable concentration permitted for an 8 hour working day is 50 ppm (12). The gasifier should be housed in a well ventilated building outside the main premises. If pipelines should pass through enclosed spaces, some means of monitoring the carbon monoxide concentration in the space should be provided. The producer gas is also explosive when mixed with air so that motors, actuators, and switches associated with the gasifier should be constructed to flame-and explosion-proof standards.

Costs

Because of the "boiler plate" aspect of gasifier construction, the capital cost per unit throughput can be expected to decrease with increasing size. Based on figures made available by 5 different sources, the cost of a gasifier (exclusive of gas clean-up and feedstock preparation but including the feed hopper and mechanisms as well as gas circulators and controls) can be predicted from the formula: $\text{Cost/k\$} = 80 - 160\ (\text{area*}/\text{m}^2)^{0.7}$.

The grate area required for a given throughput can be predicted from the figures of merit given in Table 4 for the three different reactor configurations.

Gasifier Operation and Controls

The gasifier will require an auxilliary source of heat in order to establish the oxidation zone. Electric heating rods, propane burners and torches, or fuel oil burners and torches are used in fixed bed units. The fluid bed units are ignited by means of preheating the fluidizing air in tube and shell heat exchangers fired by gas or fuel oil. The same preheater may continue to be fired by the producer gas if a very wet feedstock is being used.

The initial weak gas produced on start-up is usually flared in the emergency flare installed to take the gas in the event of interruption in its use.

The control and operation of gasifiers is based on some or all of the following parameters:

- the fuel level;
- the temperature of the various sections;
- the oxygen content;
- the carbon monoxide level in the fuel gas; and
- the pressure drop across the fuel bed.

In the main the primary control is by varying the air feed - in the operator's parlance— the "blast"—as well as the rate of addition of the wood. The turn up/down ratio achievable is in the range of 3 to 4; greater turn down is generally achieved by flaring some of the gas.

---

*The cross sectional area of the grate.

Ideally the fuel gas should be monitored continuously. However, during commissioning of the gasifier with the site fuel, a correlation will have been established between the fuel gas quality and one of the properties that can be monitored continuously such as oxygen, carbon dioxide, or carbon monoxide. On small gasifiers the method used before electronic chemical analysis came into being will probably be adopted. This method utilized a small burner running on the producer gas which was watched by the operator. A small flame implied a weak gas and thus called for remedial action.

The dynamic response of the various reactor types varies significantly. In the so-called fixed bed units the fuel may take up to 5 hours to pass from the feed hopper to the ash removal point. The slow movement of the fuel and the relatively small depth of the oxidation zone (Zone C) combine to give slow responses in moving from half load to full load. The fluid bed reactor has a very large inert thermal mass with a very small fuel loading of less than 2% by weight. The average life of a particle of wood is approximately 2 minutes resulting in a very rapid rate of response to changes in load. All gasifiers retain sufficiently high temperatures in the oxidation zone so that they can be quickly restarted after an 8 hour shut down.

Gasifier Applications

Direct firing, close-coupled applications without gas clean-up are usually retrofit applications in which natural gas, LPG, or fuel oil fired dry kilns or package boilers are modified to accomodate the low caloric value gas. These modifications normally include a heated burner shell to avoid the condensation of water vapor and tars along with a reduction in the air flow and an increase in the size of the fuel gas burner pipe to accomodate the very low air to fuel ratio of 1.2:1 compared with a ratio of 10.7:1 for natural gas (13). While the energy content of clean, cold producer gas is normally in the range 5-6 MJ/m^3 (130 - 150 Btu/Scf), the enthalpy content of the hot gas at 200°C and the vaporized tars bring the effective heating value to around 7.5 MJ/m^3 (200 Btu/Scf). This would serve to maintain the efficiency of a package boiler designed for the volume flow rate of natural gas firing.

In these applications the total efficiency, defined as

$$\frac{\text{heat from boiler}}{\text{HHV of wood to gasifier}}$$

will be at least 80% and more probably around 90%. If the fuel is dried with stack gases from the boiler, the combination of a pyrolysis gasifier and a package boiler will be more efficient than a wood-fired boiler according to Brink and Thomas (14), who calculate 80% vs 65% efficiencies for a hog fuel boiler. A study of the construction and operating costs of a fluidized bed gasifier of the BC research type with $9MW_t$ (or 30 million Btu/hr) output, close-coupled to a boiler (14), arrived at a total capital cost of $1,030,000. This figure is comprised of:

o Gasifier	339,000
o Scroll burner	65,000
o Civil Engineering	62,000
o Materials handling	150,000
o Contingencies	204,765

- o Electrical 57,235
- o Instruments 80,000
- o Ducting and piping 72,000

Annual operating costs including the very low price of $1 per unit of hog fuel (= 1 oven dry tonne) are 216k$ and resulted in the life cycle costs (calculated from Appendix 1) which are equal to those of natural gas at $2.10/103 Scf. The influence of discount rate and sensitivity to future gas price scenarios are shown in Figures 8 and 9 (16). The operating costs of 216k$ are broken down: labor 71%, maintenance 10%, hog fuel 8%, purchased power 3%, miscellaneous taxes and ash disposal 8%.

Similar conclusions as to the competitiveness of close-coupled gasifier retrofit to boilers are drawn by Reed et al (17) who also report on air emission data from tests conducted in California.

Environmental Impacts

There are no emissions from the close-coupled gasifier other than the stack gas from the boiler. The EPA data on the California experiments referred to by (16) showed that particulate, NO_X, and SO_2 standards are satisfactorily met.

The minor amounts of condensate that might accumulate in the lines are not considered to be a disposal problem.

Clean Gas Application

These applications require the gas to be cleaned and cooled so that they can be piped over some distance and then burnt in space heaters or boilers, or alternatively used to fire an engine to drive machinery or generate electricity. Cooling is necessary to remove the excess water vapor, which can amount to as much as 550 litre (120 Imperial Gallons) of tar-contaminated water for each tonne of green feedstock at 50% moisture content. The contaminated condensate will therefore represent a major disposal problem particularly since it carries a burden of phenolic compounds which are known to be extremely toxic to marine life. Solution of this problem still represents a major challenge and is the subject of research sponsored by the CEA with the Saskatchewan Power Corporation. The use of dry fuel reduces this problem and mobile gasifiers used on vehicles in wartime gasified either very dry hardwood or charcoal to minimize water and tar production (9). The down-draft gasifier will not tolerate more than 25-30% water and, because of the tar reforming capability, was the preferred unit for engine applications. The low tar potential of the fluid bed gasifier using dry fuel along with the tendency to higher concentrations of methane makes it an excellent candidate for this application also.

The engine applications today are for diesel engines with about 10% diesel oil as the ignition for producer gas aspirated or carburetted into the engine. Traditionally, spark ignition engines were used. However, the relatively poor heat rate of 30 MJ/kWh (compared with 20-22 MJ/kWh for a dual fuel diesel engine on producer gas diesel ignition), coupled with the wide-spread use of large stationary diesel engines has displaced the SI engine. Two European companies, Imbert and Duvant (18, 19), market gasifier/diesel electric generating sets in a variety of sizes. Very approximately, the

SENSITIVITY OF LIFE CYCLE COSTS TO DISCOUNT RATE AND REFERENCE GAS PRICES

(1978 Gas Price = $1.64/MM Btu)

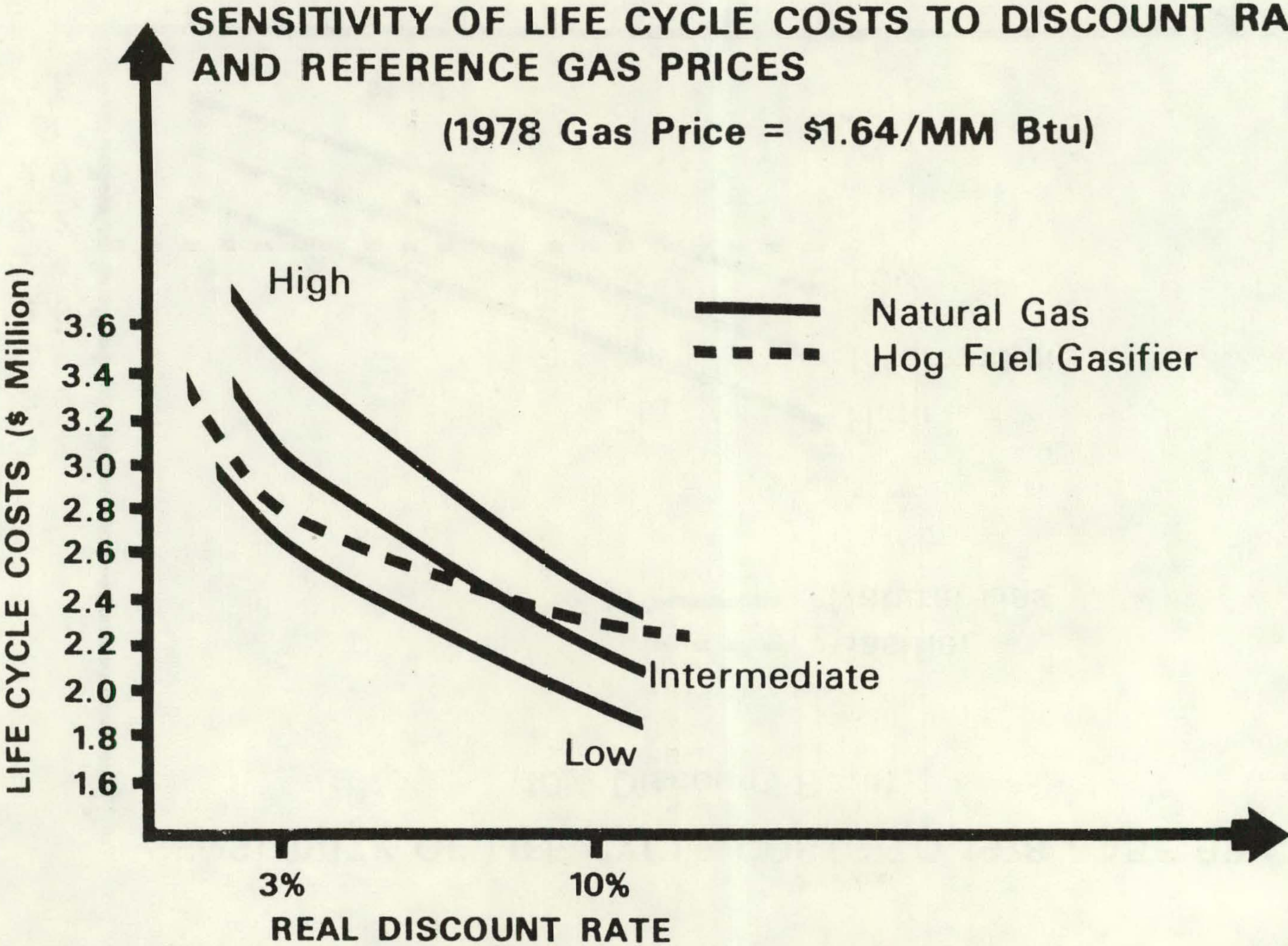


Figure 8

SENSITIVITY OF LIFE CYCLE COSTS TO 1978 BASE PRICE.
(10% Discount Rate)

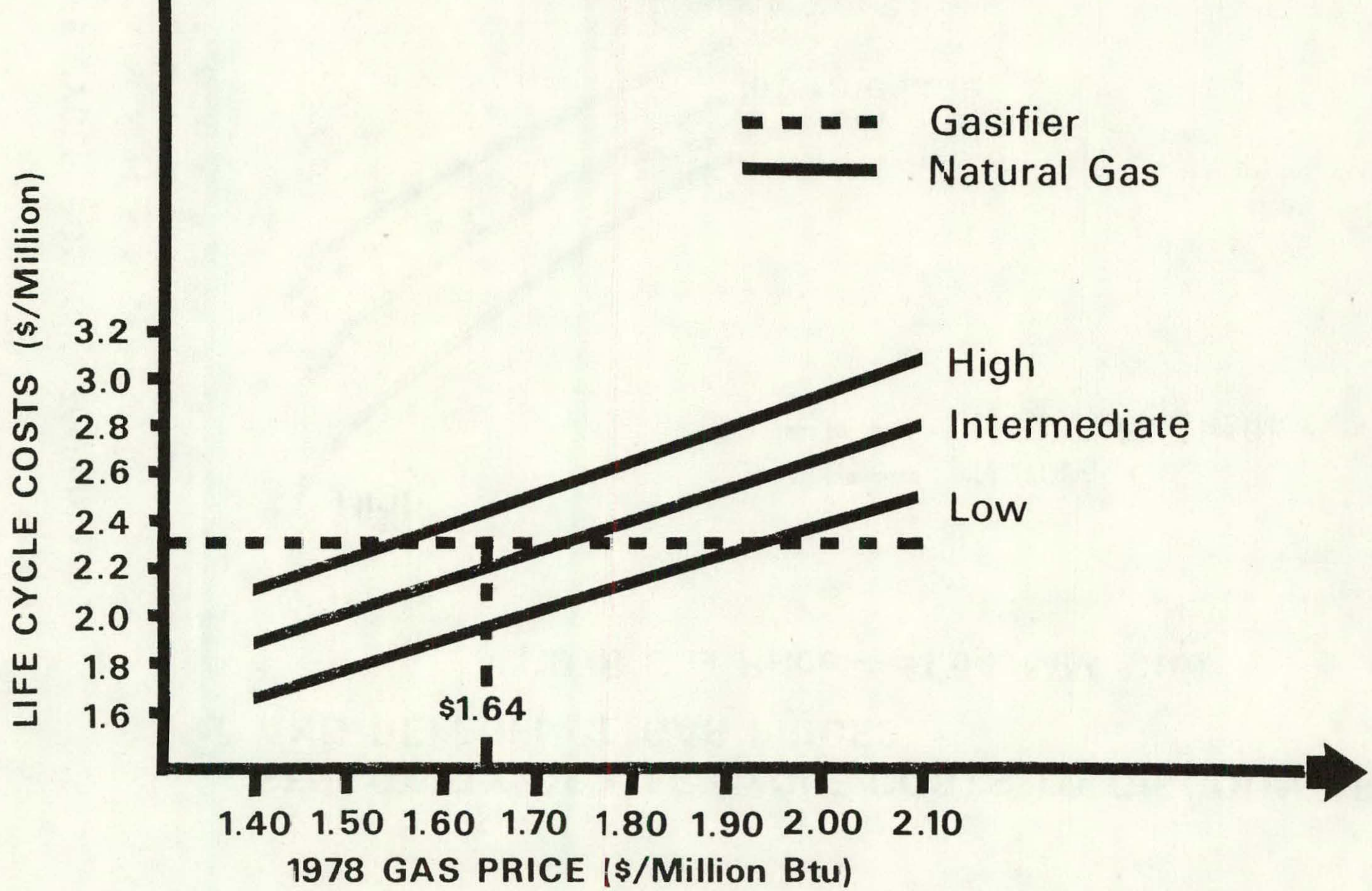


Figure 9

cost of these is around $800,000 for a 1 MW_e installation with a cost distribution of about 30% for the gasifier and clean up plant, 40% for the modified fuel engine, and 30% for the electrical generator.

Competing technologies

The concept of the close-coupled gasifier can be extended by constructing an integral gasifier and combustor and piping the hot gases to the drying kiln, lime kiln, or boiler. A representative of this form of gasification is the Lamb-Cargate Industries' Wet Cell Burner (20) illustrated in Figure 10. In this combustor, the primary air gasifies a pile fed from the bottom which receives heat by radiation from the secondary zone combustion. Like the close-coupled gasifier, the wood is effectively combusted with high efficiency because of the low excess air required.

In the generation of electricity the steam boiler turbine combination is available, though in this area the gasifier has an edge up to about 5 MW_e by virtue of the high efficiency of the diesel over the rankine cycle in small scale applications as well as steam's large requirement of condensor cooling. In Canada, the legal requirements of manning a boiler of greater than 50HP rating with a stationary engineer has generally prevented the use of steam even in the 10 MW_e scale because of the resultant high operating costs.

Future Prospects

The traditional up-draft and down-draft gasifiers are probably at the limits of their technological development. The former was available from Siemens after 1860 and the latter reached a high degree of development over 40 years ago. The combination of high throughput and relatively lower capital cost of fluid-bed gasifiers coupled with their good gas quality make them the best candidates for further technological improvement. As a result of the uniform temperature and reaction conditions in a fluid-bed, it is relatively easy to scale the design up or down with little of the risk associated with the other two types of gasifiers. Because the mass transfer in a fluid-bed is very much higher than in so-called fixed-bed types, the gasifying agent could be a mixture of oxygen and steam and the whole reactor could be pressurized. It is anticipated that the throughput will be linearly dependent on the oxygen pressure so that an existing air blown reactor that can process 1 tonne/h through an effective grate diameter of 1 meter could handle 5 tonnes with oxygen and steam at one atmosphere and 100 tonnes/h using the same mixture at 2 MPa (20 atmospheres). Such a throughput would of course pose formidable problems for the materials handling facilities which are a costly and relatively undeveloped component of present day gasifiers. The excellent mass-transfer of fluidized beds also holds the potential for the use of catalysts to modify the gas composition for use in chemical synthesis applications.

The traditional gasifier reactor configurations are being perfected using modern constructional materials and are being manufactured commercially in several countries. The initial markets of sawmill and remote region electricity generation, close-couple dirty gas applications in kiln firing, and for the retrofit of oil- and gas-fired boilers are well identified. Given the availability of wood residues at costs of less than $1/GJ ($\$1/10^6$ Btu) or 15-20 $/dry tonne, the technology is cost competitive with the offshore price of crude oil or about $16/bbl.

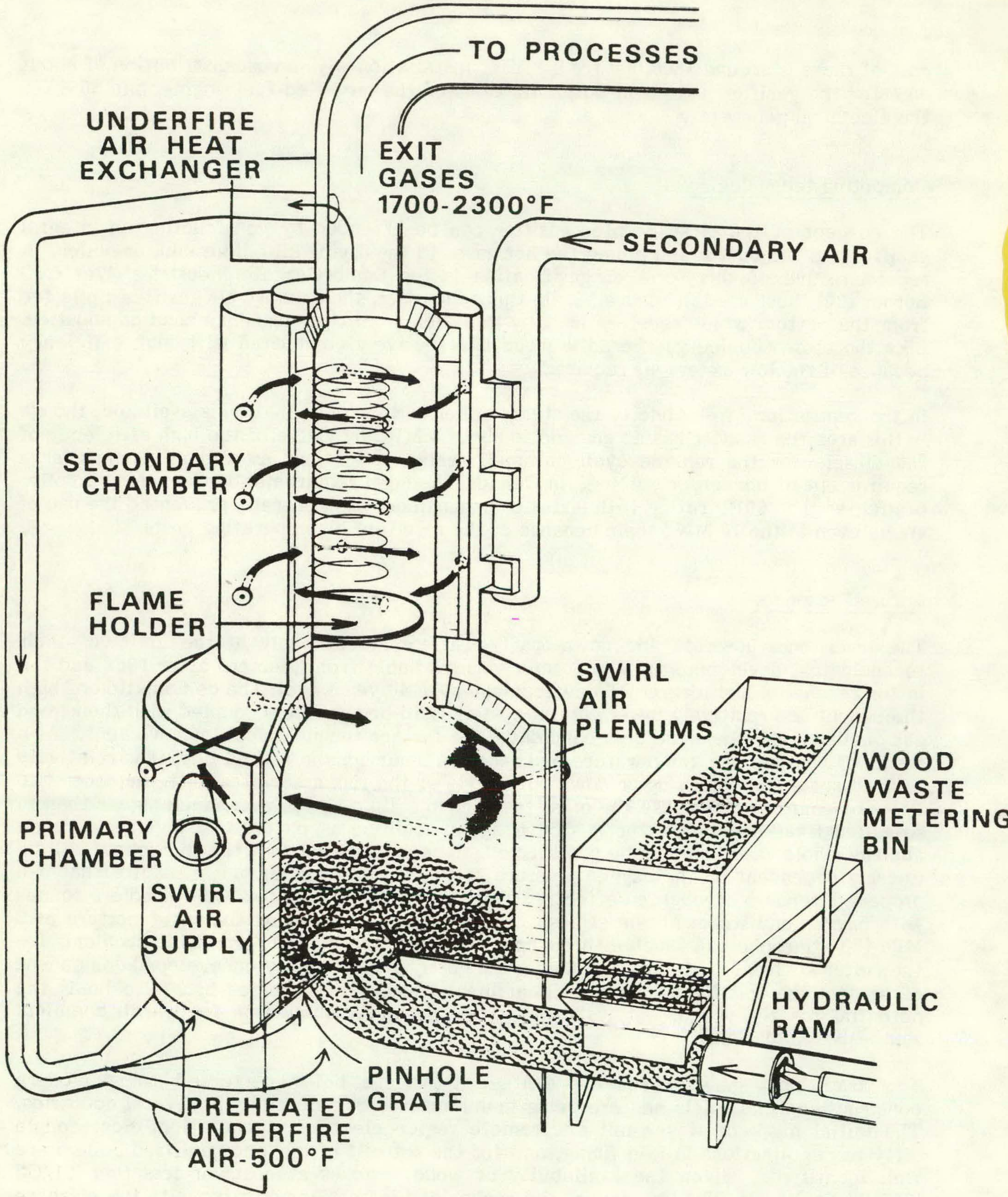

TO PROCESSES
UNDERFIRE AIR HEAT EXCHANGER
EXIT GASES 1700-2300°F
SECONDARY AIR
SECONDARY CHAMBER
FLAME HOLDER
SWIRL AIR PLENUMS
WOOD WASTE METERING BIN
PRIMARY CHAMBER
SWIRL AIR SUPPLY
HYDRAULIC RAM
PINHOLE GRATE
PREHEATED UNDERFIRE AIR-500°F

Figure 10

The generation of electricity from wood gasification is likely to change significantly from the present diesel engine to a gas turbine as the prime heat engine. The gas turbine offers lower cost with increased reliability and the high temperature exhaust can be integrated with gasifier preheating, fuel drying, and space and process heating in co-generation applications.

Further down the road will be the use of fuel cells to generate electricity. Using hydrogen and air, electricity can be generated at high efficiencies without the Carnot cycle restrictions of heat engines. The wood gasifier followed by a catalytic convertor to produce hydrogen from carbon monoxide by reaction 3 will be ideally suited to this application which could offer a heat rate of 10 MJ/kWh which is better than half of the diesel/producer gas rate.

The initial oil/gas-fired boiler retrofit market is likely to expand to include off-the-shelf package units of close-coupled gasifiers and boilers designed for producer gas firing. The present indications are that the gasifier/boiler configuration offers higher efficiency than the traditional hog fuel fired boiler with appreciably improved environmental benefits.

Appendix I: Life-cycle Costing and the Rational Conserver

The comparison or capital-intensive (gasifier, solar, insulation . . .) and fuel-intensive (most conventional) energy systems require calculation of all costs over the whole life cycle of the system. The life-cycle cost of any energy system can be calculated from the following:

$$LCC = K_o + \sum^{n} \frac{E_t}{(1+i)^t} + \frac{RV_n}{(1+i)^n}$$

where:

t	= 1	
LCC	= life cycle cost ($)	
k_o	= initial capital expenditure ($)	
RV_n	= residual or scrap value in year n ($)	
n	= lifetime of systems (years)	
i	= discount rate (percent)	

and,

$$E_t = K_t + (1 - F)\, D_t\, P_t + M_t$$

where:

K_t	= capital expenditure in year t ($)
F	= fraction of total heat demand provided by system in question (percent)
D_t	= heat demand in year t (GJ)
P_t	= net delivered cost of fuel in year t ($/GJ)
Mt	= operation and maintenance cost in year t ($)

This equation is merely the net present value of the stream of costs involved, over time, of providing energy. The tricky parts have to be done before the calculation begins, as it is necessary to project the real (not inflated) prices of conventional fuels over the life of the system. If the system has an expected lifetime as long as a mortgage, one has to make a guess about the course of oil, gas, and electricity prices over a period of time which has fooled many experts in the past.

The lifecycle costs of a hog fuel gasification system are compared with the purchase of natural gas. The data for the 9MWt gasifier is described above. Table 1 illustrates the two alternatives under consideration and their costs. Both alternatives assume the same end-use of the energy in firing a boiler.

TABLE 1

ALTERNATIVES

	Natural Gas	Hog Fuel Gasifier
Annual Heat Requirements	167,532 Btu	167,532 Btu
Captial Costs	-	$1,055,000
Annual Operating Costs	$275,766	$209,415
Unit Cost of Fuel ($1978)	$1.64/million Btu (increasing)	Unspecified

The conventional system uses 167,532 Btu of purchased natural gas, priced at $1.64/million Btu, for an annual operating cost of $275,766. The hog fuel gasifier requires a capital cost of $1,055,000 and an annual operating cost of $209,415 to produce the equivalent amount of low-Btu gas.

Considerable uncertainty exists in future long-term gas prices. It is convenient to present a wide band of prices and then conduct a full sensitivity analysis. Three reference scenarios are shown in Table 2: high, intermediate, and low. Since the intermediate projection is no more likely to occur than the high or low ones it is important to use all three projections to determine the sensitivity of the results to different levels of energy prices.

TABLE 2

REFERENCE PRICES OF NATURAL GAS*
(Annual percentage rate of change - Industrial Sector)

	High	Intermediate	Low
1978-82	5.4	2.6	1.4
1982-85	5.4	2.6	0.9
1985-1990	3.6	0.3	2.4

Results

Calculations of life-cycle cost of energy for the two alternatives are carried out according to standard discounted cash flow techniques and based on the following assumptions:

*These are hypothetical reference prices and do not reflect government policy.

	Gasifier	Natural Gas
Lifetime	20 years	N/A
Residual Value	10% of Capital Cost	N/A
Rate of Discount	10% real	10% real

In all the calculations the 1978 base price of natural gas was assumed to be $1.64/million Btu. This price was assumed to change according to the three scenarios in Table 2.

The comparison of life-cycle costs is shown in Table 3, and illustrates that the hog fuel gasifier is cost-competitive with conventional gas supply only under a high gas price scenario.

TABLE 3

LIFE CYCLE COST COMPARISON*
Future Gas Price Scenario

	High	Intermediate	Low
Conventional Gas Supply	$2,416,000	$2,200,000	$1,950,000
Hog Fuel Gasifier	—	$2,316,765	—

*10% discount rate, $1.64/million Btu 1978 gas price.

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12) O.S.H.A. standards. The TLV is subject to constant assessment and the value should be obtained from the provincial or state workers insurance and compensation board.

13) Page 253 of Reference I.

14) The Pyrolysis - Gasification - Combustion Process: Energy Effectiveness using oxygen vs air with wood fueled systems, D. L. Brink, J. F. Thomas and G. W. Fallico, p. 141 of "Thermal Uses and Properties of Carbohydrates and Lignins", F. Shafizadeh, K. Sarkanen and D. Tillman Eds., Academic Press 1976.

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17) Technology and Economics of Close-Coupled Gasifiers for Retrofitting Gas/Oil Combustion Units to Biomass Feedstock, T. Reed, et al, IBID.

18) Imbert Energietechnik
5760 Arnsberg 2.
Steinweg 11
Frances

19) Duvant Moteurs Diesel
Boite Postale 599
59308 Valenciennes
Frances

20) Lamb-Cargate Industries Ltd.
New Westminster, B.C.

SECTION 4.0

HISTORY AND POTENTIAL OF AIR GASIFICATION

by
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Weyerhaeuser Co., Tacoma, Washington

HISTORY OF GASIFICATION

A very brief look at the history of gasification (producer gas) technology shows a continuous development up until the end of World War II. After the war, inexpensive petroleum became plentiful and the economics of gasification became unfavorable, resulting in lack of interest on the part of both researchers and manufacturers. A very thorough bibliography by Nowakowska and Wiebe [1] covered the development of gas producers up through 1944.

Stationary gas producers, using coke or coal for fuel, were first developed in Germany when the Siemens brothers constructed a step grate producer in 1857. From that modest beginning, technological advances were made such that around the turn of the century gas producers were reliable enough to be used for ship power [2].

Efforts were also made to gasify fuel other than coal or coke. By 1923, stationary gas producers had been designed for and operated with just about every conceivable form of cellulosic residue including rice hulls, olive pits, straw, camel dung, cotton seed hulls, sawdust, walnut shells, and many others [3]. Power-Gas Company was very active in the design and installation of gas producers using a variety of crop residues and wood and installed these in countries where coal and oil were scarce [4]. Mining operations in Africa and Australia utilized a variety of vegetative material as fuel for gas producers for many years [5].

Research and development work in Europe accelerated during the 1940's with the advent of war and the impending fuel shortages. Both stationary and portable gas producers were manufactured. Small stationary producers were used by manufacturing firms to insure a consistent supply of gas [6]. Portable gas producers or suction gas generators were used for trucks, buses, and automobiles. During World War II perhaps as many as 700,000 vehicles were adapted to producer gas and they used many forms of fuel including charcoal, wood, and coconut husks. In Sweden, where automobiles were extensively powered with wood, one trailer-mounted gas producer was tested and the results indicated that 220 lb (100Kg) of wood was equivalent to 20 gallons (76 L) of gasoline [7]. Agricultural tractors also employed gasifiers and, in one instance where straw was being used as the fuel for a track-laying tractor, it was reported that 6.6 lbs (3 Kg) of straw produced 1.3 hp hr (1 KWh) [8].

In the United States very little research effort was devoted to gasification of crop residues; however, in 1948 Porter and Wiebe [9] tested a small gasifier at the USDA Laboratory in Peoria, Illinois. When coarsely ground cobs were tested, a gas of 159 BTU/cu ft (5,920 KJ/m^3) was produced from cobs that had a heat content of 8,000 BTU per oven dried Lb (18,610 KJ/Kg).

Designs

There are three common types of gas producers: 1) updraft, 2) downdraft, and 3) crossdraft. The updraft design was the most common in stationary gas generators (see Figure 1). This design produces a gas with a high tar content because the hot gases flow counter to the fuel and in doing so, pyrolize a portion of the fuel. This is not a problem if the fuel is going to be burned close to the gas producer, but if it is to be piped any considerable distance the gas will cool and the tars will condense, gradually plugging the pipe.

If an updraft gas producer is used with biomass to produce gas for an internal combustion engine, considerable care must be used to clean the gas. Updraft producers were used on vehicles only with tar-free fuels such as coke or charcoal. In a stationary application, cleaning can be done with a pray tower.

Downdraft gas producers have the potential to eliminate most of the tar from the gas and are probably better adapted to some forms of biomass. In a 1947 issue of Diesel Progress, Lustig describes a stationary downdraft gas prducer using ground up vegetable matter to supply fuel for dual fuel engines [10]. This gas producer is shown in Figure 2. It was built by the Wellman Engineering Company (now McDowell-Wellman) of Cleveland, Ohio, and a long series of tests were carried out using a Bruce MacBeth 4-cycle engine. It is noted in this article that "... Brazilian engineers attended the tests on the gas producer, anxious to find an effective means of utilizing waste vegetable matter."

The downdraft design requires a fuel that is fairly uniform in size and has a consistent and low moisture content. The updraft design, on the other hand is more flexible both in fuel size distribution and moisture content.

Crossdraft gas producers are the simplest of all designs, but are usually limited to relatively small sizes. They were particularly popular on motor vehicles when fueled with tar-free fuels such as charcoal or coke. They could, of course, be used with crop residue in situations where the gas was to be burned adjacent to the producer.

Gas producers have been made in a large range of sizes from as little as one foot (.3 m) in diameter, consuming only 40 lbs/hr (18 Kg/hr) to as large as 12 feet (3.7 m) in diameter, consuming 5,500 lbs.hr (2,500 Kg/hr) or more. In addition, there does not appear to be any great difference in thermal efficiency as related to size.

Small gas producers can be extremely simple in design, having essentially no moving parts and having the fuel batch fed and the ash batch removed. Figure 3 is a small downdraft gas producer for application to motor vehicles.

Applications

The resulting gas can either be burned directly without cooling and cleaning or it can be cooled and cleaned and used to fuel spark ignition engines, dual fuel diesel engines, or perhaps turbines. It is difficult to store.

Gas for Heating

Little evidence was found in the literature where biomass had been gasified for the purpose of supplying gas for heating. Coal, on the other hand, was gasified for both hot,

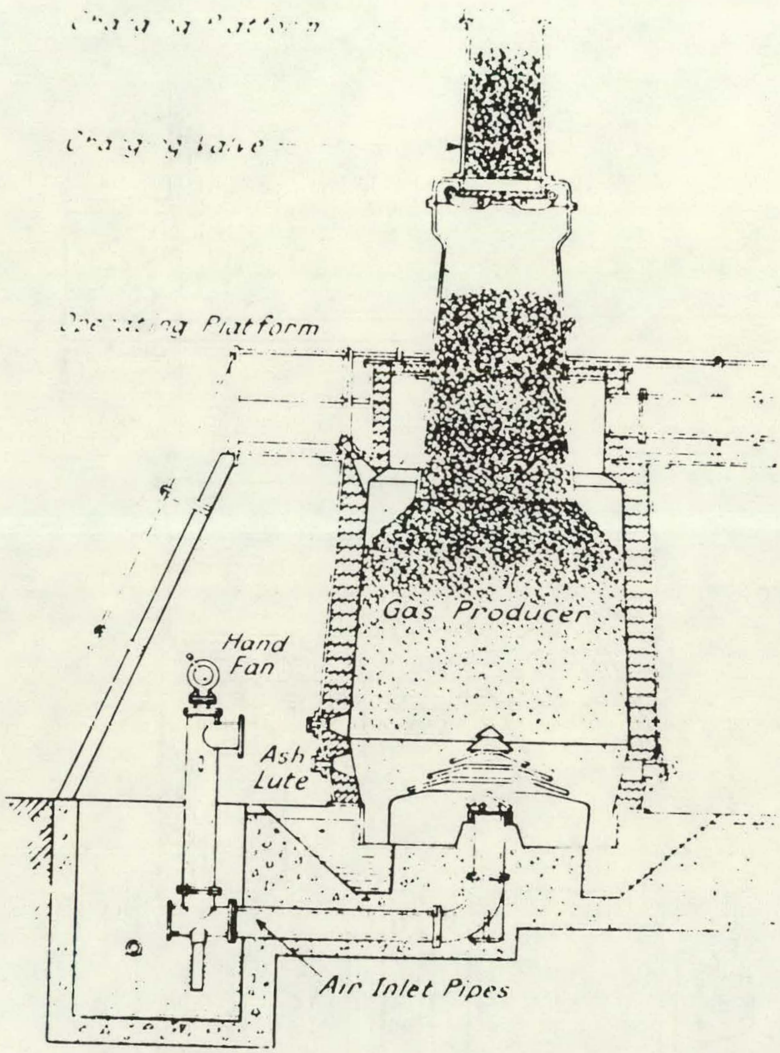

Fig. 16.10 Power Gas Generator for Waste Fuel

Fig. 1. Updraft gas producer using crop residue as a fuel (Ref. 4)

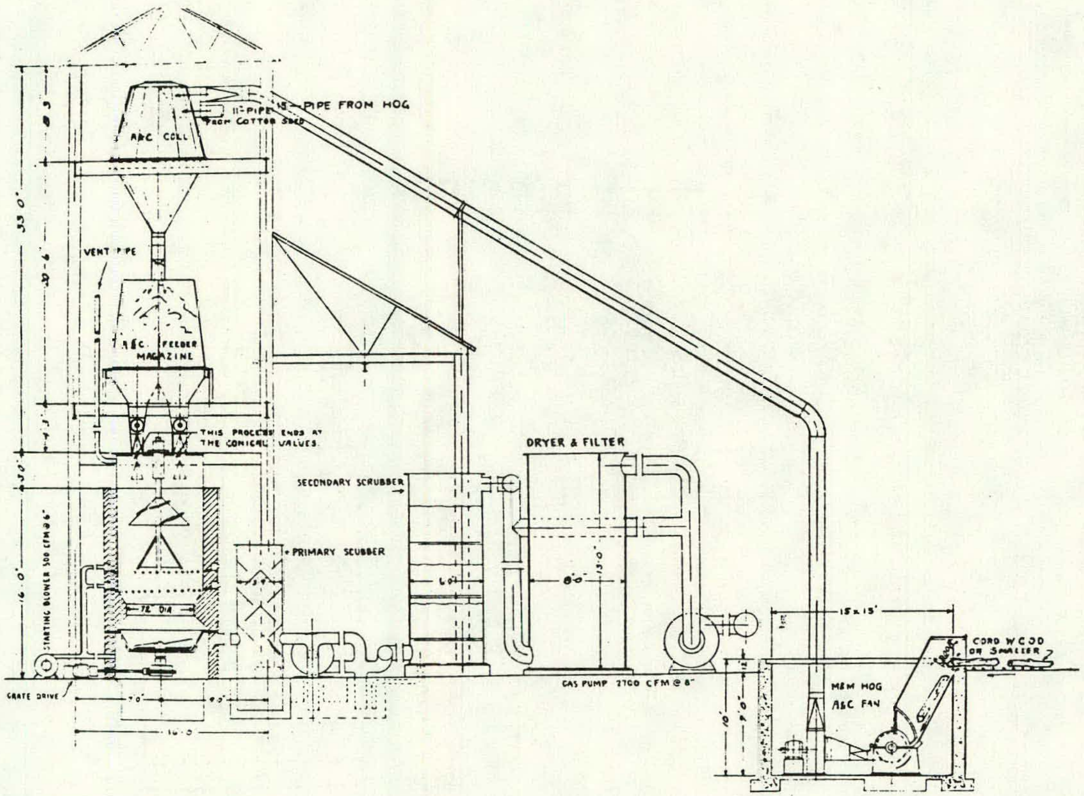

Fig. 2. 600 H.P. downdraft gas producer using crop residue as fuel. (Lustig, 1947) (Ref. 10)

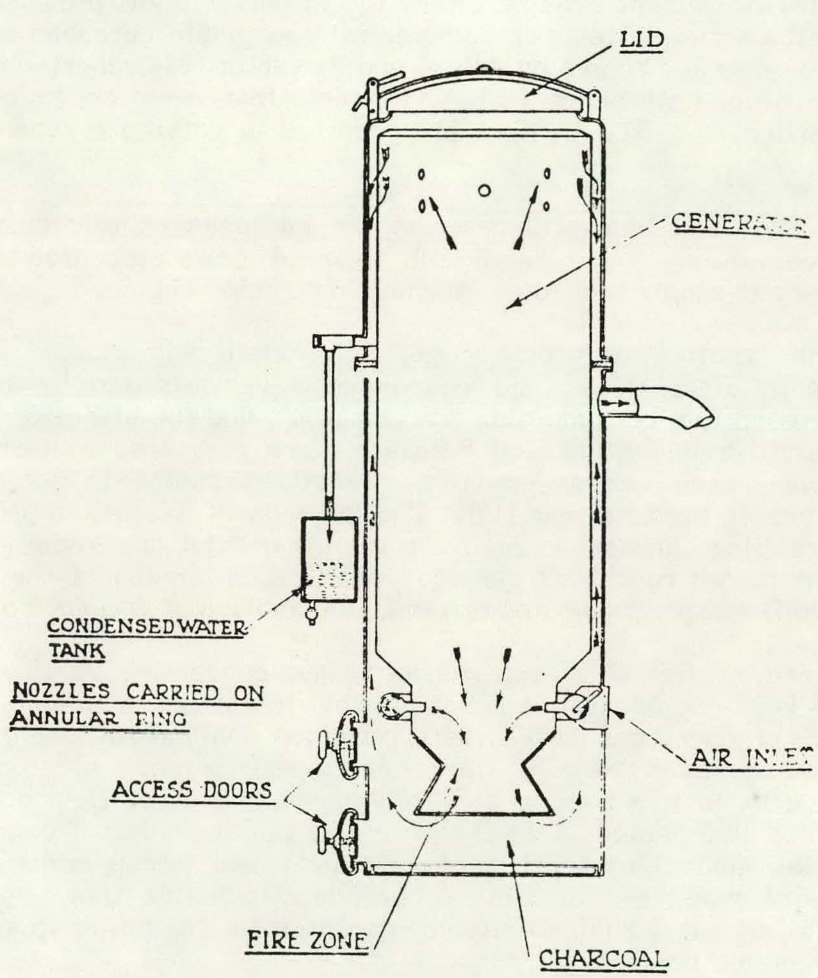

Fig. 3. Imbert downdraft gas producer for use with motor and cars and trucks. (Lowe, 1940) (Ref. 11)

raw gas and cool, clean gas. Hot, raw gas was used extensively in the steel industry and cool, clean gas was substituted for town gas in England during World War II. There appears to be few restraints when substituting cool, clean producer gas for natural gas or propane, provided the burner is of a proper design.

Gas for Engines

Considerable attention has been given to the development of gas producers for cars, trucks, and buses. A review of some eight different gas producers appears in Automobile Engineer [12]. A thorough discussion of gas generation principles and the application to small gas producers was given by Lowe, who also detailed several commercial models [11]. The Canadian Government became interested in portable gas producers and, as a result, commissioned a series of tests on commercially available European models. As a further result, a very detailed report by Allcut and Patten in 1943 reported on a study of 12 gas producers in which both bench tests and vehicle tests were conducted [13]. Gas generation, composition, and BTU content are reported in detail for repeated tests on each producer.

A recent book by Skov and Papworth describe the European experience with vehicle mounted gas producers during World War II [14]. Figure 4 shows a gas producer and other components necessary to supply fuel to an internal combustion engine.

Conversion of farm tractors to producer gas was extensively studied in Australia. Operational problems, field trials, and economics were discussed by Roberts [15]. Bowden, et al, discussed fuel consumption, power output, and the effect of high and low compression pistons. Producer gas and kerosene were compared in terms of power output, cylinder wear, and economics [16]. Freeth discussed in some detail the conversion of tractors to producer gas [17]. The majority of Australian producers were crossdraft producers using charcoal as fuel. On the other hand, the Soviet gas producers used wood or straw fueled downdraft gas producers. A discussion of the evolution of these Soviet downdraft gas producers appears in a 1945 edition of Gas Oil Power [18].

Reduction in horsepower has been experienced when converting gasoline engines to producer gas. This is simply because it is not possible to get the same amount of energy into a cylinder with producer gas as it is with gasoline. Typical reduction ranged from 40% to 50%. Two common ways of increasing power were: a) to increase the compression ratio, and b) to supercharge. In a theoretical study Heywood thought by increasing pressure to 20.5 psi (141.4 KPa) absolute at the beginning of compression, the horsepower would be equivalent to that of gasoline when not supercharged [20]. In discussing the use of wood gas in Finland, Branders indicated that a supercharging pressure of about 6 psig (41.4 KPa) totally compensated for the power loss [19]. He did not report on the vehicles' compression ratio.

For some applications, increase in compression ratio may be simpler. It has been reported that for an engine having a compression ratio of 4.7:1, the power can be increased to 70% of gasoline power by raising the compression ratio to 10:1 [21].

In all likelihood, large stationary engines will be compression ignition and not spark ignition engines. Diesel engines can be converted to spark ignition without changing the compression ratios. In an article in Gas and Oil Power, a conversion is discussed and it is noted that the change-over reduced the output from 40 B.H.P. to 32 B.H.P. in an engine with a compression ratio of 13.5:1 [22]. In an article appearing in the Commercial Motor,

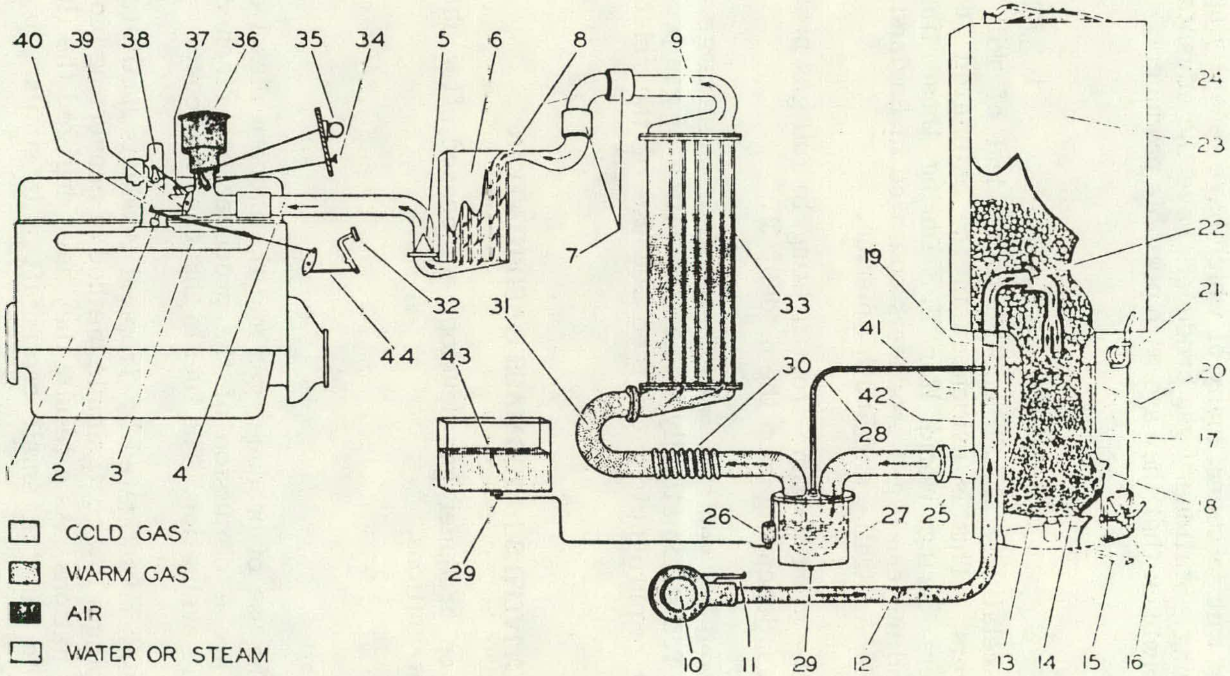

Fig. 4. The Swedish Svedlund gas producing systems applied to motor cars and trucks. (Branders, 1941) (Ref. 19)

the benefits of feeding producer gas directly into diesel engines and injecting small quantities of fuel oil for ignition purposes are discussed [23]. The importance of unrestricted air intake is emphasized. Bench tests indicated that with the gas-diesel oil mixture power was reduced from 60 to 40 HP at 1,200 rpm but that diesel oil consumption was reduced from 1.55 pints/hour (5.46 L/hr) to 2.43 pints/hour (1.15 L/hr) when augmented with producer gas.

Filtering of producer gas prior to its use in internal combustion engines, of course, is essential to avoid excessive wear. In all likelihood the gas can be cleaned to satisfactory standards by simply using a wet scrubber, many of which have recently appeared on the market for stack gas cleaning. Stationary gas producers have the advantage that bulky, wet cleaners are not the drawback that they are with portable producers.

Operations

Start-up and operation is relatively simple and no great deal of skill is required to operate small gas producers. This is evidenced in the estimated 700,000 vehicles converted to gas producers during World War II. During these times of limited manufacturing facilities and material, gas producers operated in England and Europe as well as in the Pacific Islands, Australia, and South America.

For small gas producers, the start-up time from lighting to full gas production ranged from 1 minute to 10 minutes, depending upon the model [13].

Although gas producers used on vehicles were batch fed, most large stationary gas producers using coal were fed automatically. The application of gas producers to crop residue would most likely require automatic feed because of the relatively low bulk density of the material.

CURRENT EUROPEAN ACTIVITIES IN BIOMASS GASIFICATION

Although nearly all work on producer gas development ceased after about 1945 there have been some recent contributions.

England

A 1956 report discusses the use of producer gas and the modern diesel engine for road transport [24]. Included are a discussion of the producer and cleaners, a road test evaluation, and an economic evaluation. The fuel in this case was coke.

Biomass gasification is being investigated by Tropical Products Institute, in Berkshire. Their interest is in developing a low cost, simple method of converting biomass into shaft horsepower for developing nations. As a result, they have engaged the firm of Neal and Spencer of Leatherhead to build a small crossdraft unit similar to the ones they manufactured in World War II.

A. J. Brockwell, a consulting engineer in Darlington, is currently promoting updraft gasifiers with biomass. Mr. Brockwell was formerly with Power Gas Company and, in that capacity, designed and constructed a number of updraft gasifiers using cottonseed husks, sawdust, olive residue, and bagasse as fuel.

France

DuVant Motors manufacture diesel-electric sets which can be dual fueled on producer gas. They have a number of installations including some in the Ivory Coast where gas is made from coconut husks. Their plants range is size from 400 to 1,000 Kw and operate on a fuel intake of about 10% diesel fuel and 90% producer gas at a thermal efficiency of 36% to 38%. The controls allow the engine to go from dual fuel to pure diesel under load with no variation in power output.

Distibois in Orchamps has a large gas producer fueled on wood. This gas producer not only supplies gas for a 1,000 Kw diesel-electric set but also produces high quality charcoal used for home heating. Figure 5 is an incomplete diagram of their producer which is 98 ft (30 m) high and about 10 ft (3 m) in diameter. It is lined with light duty fire brick and had operated 30 years before the lining was replaced.

This type of gas producer is often referred to as a 2-stage or dual mode gas producer. Its unique characteristic is that it can produce a completely tar-free gas simply because the flow from the combustion chamber is split in such a way that approximately 1/3 of the gas moves up or countercurrent to the fuel flow and 2/3 of the gas moves downward. The movement of the hot gas upwards countercurrent to the fuel flow pyrolizes the wood and moves the volatile material upward. This volatile material is then mixed with incoming air and burned in excess air under controlled conditions such that all the heavier hydrocarbons are destroyed. The resulting gas then enters the main body of the gas producer and the 2/3 that moves down undergoes reduction, thus producing the carbon monoxide. The off-gas temperature is an indication of the progress of the endothermic reactions.

The 1,000 KW dual fuel diesel was manufactured by Societe Alsacienne de Constructions Mecaniques. This firm is apparently a competitor of DuVant Motors.

Sweden

The National Swedish Testing Institute has been active in producer gas design and testing since approximately 1957. This extensive and long-term research program was initiated after the Suez crisis when Sweden again realized that they were totally dependent on foreign oil.

Mr. Nordstrom's work is reported in a lengthy 5-chapter report of which, unfortunately, only 20 copies were produced. The research topics included physical dimensions of the gas producer, characteristics of the fuel including experiments involving effects of fuel size and the potentials for cubing and briqueting, and a large section on gas cleaning. A summary of his work was published in 1960 [25].

Current research work in Sweden is being carried on gas producers of the downdraft type and are quite similar to the Swedish downdraft gas producer shown in Figure 6. The filtering of this gas, however, is somewhat unique. The filters are made of woven fiberglass and are operated in such a way as to maintain a temperature between 480-660°F (250-350°C). This high temperature assures that no tar condenses on the surface. Cleaning of the filters to remove dust particles are accomplished by tapping or banging the frame to which the fiberglass is attached.

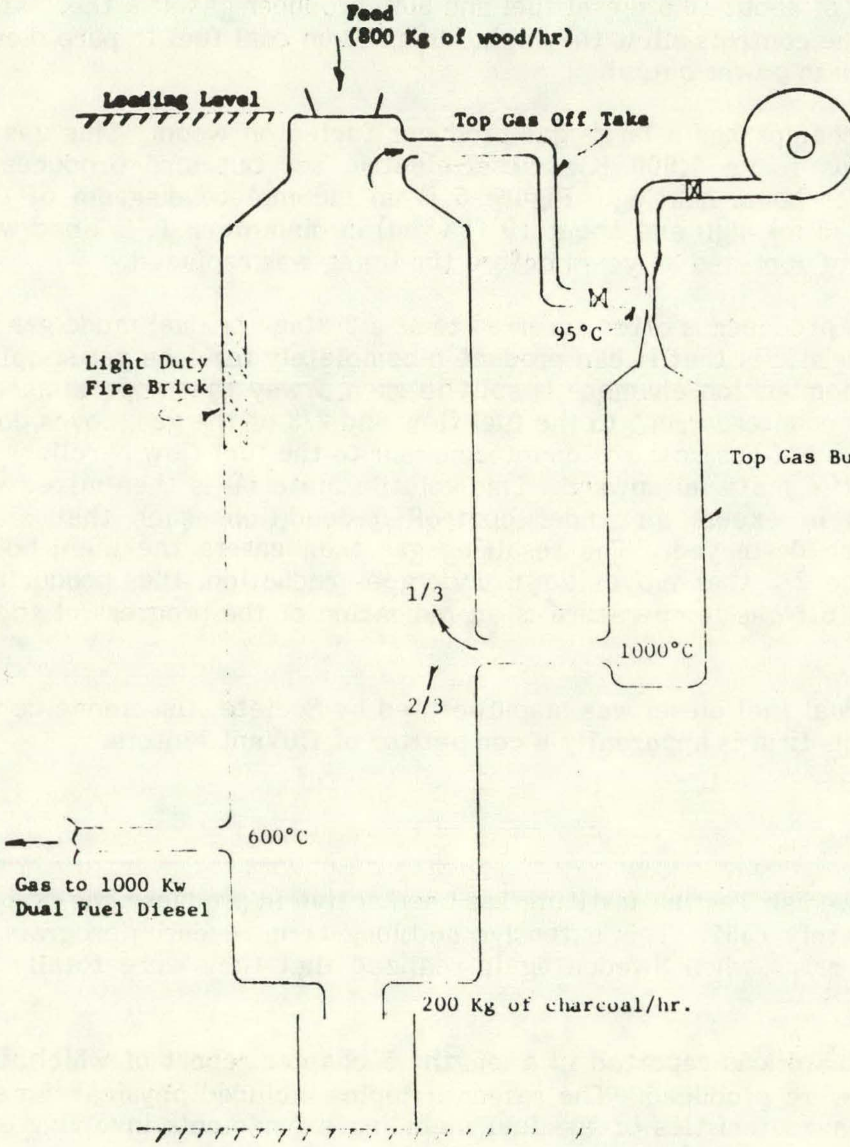

Fig. 5. Dual flow gas producer for producing charcoal and powering a 1000 kW dual-fuel diesel.

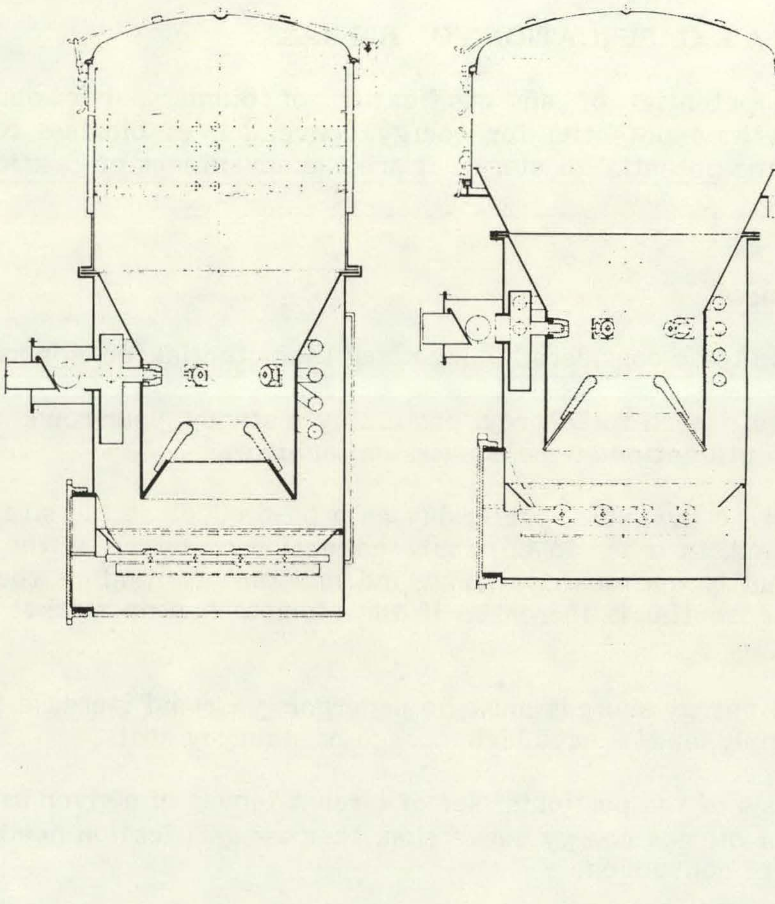

Fig. 6. Modern downdraft gas producers developed in Sweden for use with wood. (Nordstrom, 1960) (Ref. 25)

The starting procedure for gas producers mounted on vehicles consisted of draining both the condensors, removal of the ash from the ash hopper, and then filling the ash hopper with chips. The stand pipe valve was then opened, a large match placed in a holder, the match lit, and the holder shoved in a small opening in the gas producer so that the match was positioned at the center of the tuyeres. Immediately the match hole was shut, the small starting fan connected, and smoke began to pour from the stand pipe. After approximately 3-5 minutes the smoke became noticeably less opaque at which point a lighter was used to ignite the producer gas emitting from the stand pipe. The ignition of the gas indicated the gas producer was working properly. The start fan was disconnected, the stand pipe sealed, and the engine then started on straight diesel fuel. As soon as the diesel engine came up to temperature, the throttle from the gas producer was opened and the gas mixture adjusted. Under these circumstances, the tractor engine then became a dual fuel diesel.

POTENTIAL FOR AIR GASIFICATION FOR BIOMASS

In assessing the potential of air gasification of biomass, two questions must be answered: 1) Is there potential for energy conversion of biomass regardless of the method and 2) if the potential exists, what are the advantages of gasification over other technologies?

Potential for Biomass

Three aspects need to be considered in assessing the potential for biomass conversion:

1. There must be a need for energy, preferably a steady, year-round need, in order to maximize the utilization of the conversion facilities.

2. Biomass must be available, preferably as a by-product at the site where energy is being consumed, in order to eliminate collection costs and so the user has control over the quantity and quality. Size and moisture content of the biomass is also important. Potential is increased if the biomass has no market value and has a disposal cost.

3. Conventional energy sources must be undergoing a rapid increase in price, have an unreliable supply, and/or have high storage or standyby costs.

If, after an analysis of the particular set of circumstances of a given user, there appears to be potential for biomas energy conversion, then air gasification needs to be compared with other forms of conversion.

Potential of Air Gasification

There are several characteristics of air gasification that may make it competitive with other conversion methods.

1. The form of energy. The output, of course, is hot gas containing some condensibles. This gas can be transported a short distance and therefore used to convert existing gas and oil burners in boilers, heaters, or dryers. Or the gas can be cooled and cleaned then distributed within a plant and also put into short-term

storage (i.e., water displacement tanks).

The energy from direct combustion is difficult to distribute directly and storage is all but impossible. If low-temperature heat is required (for drying), direct combustion would require a heat exchanger whereas it may be possible to dry directly using the products of combustion of producer gas.

2. Gas can be used directly in spark ignition or compression ignition (diesel) engines for conversion to shaft horsepower. In this application, gasifier size is important. Because a gas producer can be sized to supply gas to an engine of just a few horsepower to one of thousands of horsepower, the process can be used to supply shaft horsepower in a range that is not presently commercially available with steam turbines. The fact that internal combustion engines and the service network that accompanies them are so readily available makes them very attractive. It also appears that the thermal efficiency in small internal combustion engines is not as adversely affected as it is in small steam turbines.

   For direct combustion to produce shaft horsepower, high pressure steam is necessary. Because of the safety aspects of high pressure steam, a qualified boiler operator usually must be in attendance.

There are several drawbacks to gasification. These include:

- A poisonous gas is being produced (CO).
- If cold, clean gas is required, the tars must be disposed of properly. Perhaps design innovations can solve this problem.
- If downdraft producers are to be used, fuel of uniform size and low-moisture content is required.
- The biomass gasification equipment industry is not mature and needs a good track record.

Some of the above comments can be expanded upon by reviewing a few potential applications.

Specific Applications

1. Rice milling. During rice milling, approximately 20% of the incoming weight is removed as rice husks. Gasification and internal combustion engines would allow the extraction of useful energy from the rice husks for operation of the rice milling plant. These plants potentially can run year-round. Rice husks, however, already have a market.

2. Lumber milling. Gasification and internal combustion engines would offer an alternative to boiler and steam turbines for small lumber mills and would provide a use for wood residues that may otherwise have to be disposed of by burning of landfill.

3. Cotton ginning. In the preparation of cotton lint, approximately 140 to 180 lbs of cotton gin trash is produced per bale. Disposal of this cotton gin trash is a serious

problem because when it is burned in the open, it causes severe air pollution. Cotton ginning requires electric energy as well as a substantial quantity of heat for drying cotton in preparation for ginning and a preliminary heat balance indicates that the energy content of the cotton gin trash could supply both the power and the heat energy required for cotton ginning. Cotton ginning is, however, a seasonal operation.

4. Corn drying. An estimated heat equivalent of 10 million barrels of oil is required to dry the U.S. corn crop each year. Gasification would provide the technology to convert a small portion of the corn cobs to a useful gas that could be simply adapted to existing corn drying facilities, thus eliminating an extensive use of propane and making corn farmers independent of fossil fuel for drying [26].

5. Fruit and vegetable dehydration. Fruits and vegetables are dehydrated to make them storable and many of these dehydration operations have ready access to crop residues. For example, dehydration of prunes takes place adjacent to orchards where annually large amounts of woody material are removed while pruning the trees. These prunings could be readily stored during the summer and then used as fuel for the gasification process to provide energy for prune dehydration. The same is true of raisin dehydration and walnut drying. The cost of collection appears to be a deterrent.

6. Pumping irrigation water. If crop residues can be conveniently and inexpensively collected at the farm level, gasification could be used to convert the crop residues to a useful fuel for internal combustion engines, which in turn could be used for irrigation pumping.

7. Mobile equipment. The potential here seems small. Intensive use of the equipment is required. Space for the gas producer must exist and payload cannot be an important factor. The vehicle should have a travel pattern that allows it to cycle past the fuel supply every few hours. An example might be a log stacker working two or three shifts that has access to kiln dried mill ends that have no market.

CONCLUSION

Gasification is a proven technology. To be economically viable requires a unique set of circumstances. The gasification equipment industry needs to understand the extent of these unique sets of circumstances and if the market exists, develop the necessary equipment along with the sales and service network.

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SECTION 5.1

THE DOWNDRAFT GASIFIER

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ABSTRACT

The state of the gasification art and the gasification process are briefly discussed with emphasis on the downdraft gasifier. The development and description of the UCD/SERCDC pilot plant downdraft gas producer are presented. Some design particulars are given but construction details have been omitted. The gas producer has been operated for a total of 705 hours, 328 1/2 of which were continuous. Fifteen observed and calculated data items are presented for two 12 hour periods and one 3.8 hour period when wood chips were gasified at 453, 678, and 682 pounds wet weight/hour. Calculated heat output in the hot gas stream was 2.7 and 4.4 million BTU/hr. Process energy transfer efficiency from fuel to hot gas ranged from 82.8 to 84.7 percent. Heating value of the gas ranged from 184 to 190 BTU/ft^3 (NTP).

STATE OF THE ART†

Rambush reports [1] that the first stand-alone gas producer was constructed by Bischof in Germany in 1839. This producer was followed by one built in France in 1840 and another one built in Sweden in 1845. The two Siemens brothers patented their first combined gas producer and regenerative furnace in 1861. This development started the use of hot raw gas for heavy furnace work.

The development of the gas producer can be traced along two different paths. Stationary producers were first used in the last half of the nineteenth century to gasify coal or coke. Producers of this type were usually "updraught" in operation, with air blown into the bottom of the fuel bed and producer gas discharged at the top. The gas was either fired directly in steam boilers or furnaces, or cleaned, cooled and used as fuel for gas engines. In the latter case, manifold vacuum was used to move air and gas through the entire system. It was found that low grade coal and eventually wood waste and other vegetable refuse could be successfully gasified. The development of these residue-fueled, stationary, updraft gas producers ceased in the 1940's and 50's.

†This section adapted from [2].

In addition to stationary producers, portable units were developed for transport use. During the 1940's, with petroleum fuel shortages, research into portable gas producers increased. During WW II about 70,000 road vehicles were adapted for use with producer gas by Nazi Germany. Coal, coke and charcoal were generally used as fuels; wood and crop residues received limited use. Three types of portable producers were developed. Updraught design -- the same as in stationary producers -- had the disadvantage of generating a gas with high tar content. This was caused by the hot gases flowing counter to the fuel and in doing so they pyrolyzed a portion of the fuel. Downdraught producers had the potential to eliminate tar from the gas and were better suited to crop residues. Crossdraught producers combine some of the desirable updraught and downdraught characteristics, by the introduction of combustion air at the side of the lower level of the fuel or through an inclined grate.

The Imbert, downdraught gas producer was one of the most successful of the portable designs used by Nazi Germany during WW II. Although most producer development work ceased at the end of WW II, Nordstrom and other workers in Sweden continued investigation of the Imbert producer. The result was a highly successful, batch-fed, downdraught gas producer for use on agricultural tractors and transport trucks. It was fueled with sized wood chips dried to about 20% or less moisture content. The tractors and trucks were equipped with dual-fuel, naturally aspirated diesel engines. Standard engines were modified to operate in the dual-fuel mode or switch back to normal diesel operation. About 10 percent diesel fuel was used to ignite the low BTU gas.

Stationary, residue-fueled, updraught producers were manufactured by the Power Gas Company in England until about 1950. DuVant Moteurs in France still manufactures gas-producers and diesel engines which operate in dual-fuel mode with producer gas. Internal combustion engines running on producer gas are still to be found in operation in France, Italy, and in a number of Third World Countries.

Gas, from stationary updraught producers required extensive cleaning before use in heat engines other than boiler fire boxes. This was accomplished in a rotary tar extractor and by scrubbing with water. The tar and scrubbing water, high C.O.D., were not without disposal problems. The development of coal gasification has continued and renewed interest has been generated in this concept.

From the above paragraphs, conclusions can be drawn as to the current state of gasification development. Small portable downdraught producers have been developed to a high level of reliable operation. The emphasis has been on lightness, simplicity, accessibility and the need to provide a clean fuel for engines operating under variable conditions.

Large, stationary updraught producers have been successfully operated on crop residue. Disposal of the relatively small waste streams from gas cleaning could be handled by landfilling. Gasifiers for use with coal are currently being operated in the United States. These are very large, expensive units which are probably inapplicable to crop residues because of differences in physical and chemical make up of coal and crop residues. Availability of satisfactory gas clean up equipment in the United States is still a problem for large coal gasifiers.

Improved performance and clean operating gas producer designs can be achieved with the application of current technology and selection of components and materials from the available wide range of off-the-shelf items. Development engineering and applications research are needed to determine which component or material will perform optimally in the gasifier. Automation of all gasification processes and continuous optimized performance can be achieved by the design and application of advanced computerized process control and instrumentation systems. Longer capitalization life can be had by the use of special alloy metals and energy losses reduced by using efficient, high temperature insulation. Advanced electro-mechanical level detectors for particulate matter are essential elements of automatically controlled fuel feed and ash removal. All of these features except computerized process control have been incorporated into the design and construction of the pilot plant gas producer.

THE GASIFICATION PROCESS

The flows of Fuel In, combustion Air In, Gas Out and Solid Refuse Out are shown in Figure 1. The first important phase of the gasification process takes place in the upper fire box area where the air being pumped in sustains partial burning of the fuel at temperatures above 2000°F. Carbon dioxide, water vapor, volatile hydrocarbons and a downward moving bed of incandescent carbon result from this incomplete burning of the fuel. As the gases rush through the hot bed of moving char, hence the name down-draft gasifier, carbon monoxide, hydrogen and gaseous hydrocarbons, mostly methane, are produced and exit out the Gas Out port at temperatures ranging from about 500°F to above 800°F depending primarily on the moisture content of the fuel. The drier the fuel, the higher the exit gas temperature.

The heating value of these combustible gases, at 68°F and normal atmospheric pressure ranges from 125 - 200 BTU/ft^3 depending on the kind of fuel fed into the gasifier. For a mixture of several types of wood chips at an average moisture content of 19%, wet basis, continu-

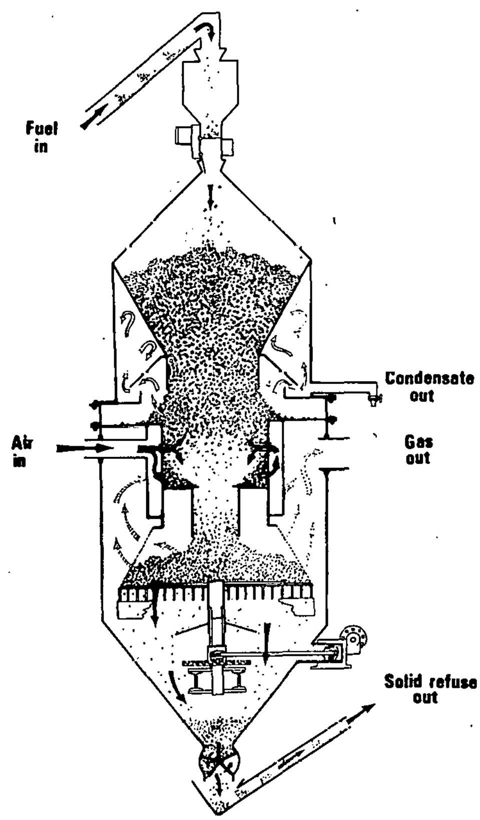

Figure 1. Schematic of an early design of the Pilot Plant Gasifier.

ous flow gas analysis instrumentation gave the following average values for two sets of readings taken 1 1/2 hours apart. CO @ 19.7% v/v x 321.8 BTU/ft^3 = 63.4 BTU/ft^3. H_2 @ 16.2% v/v x 275.0 BTU/ft^3 = 44.6 BTU/ft^3. THC (total hydrocarbon) @ 9.3% v/v x 949.4 BTU/ft^3 = 88.3 BTU/ft^3. Total combustible gas heating value at NTP = 196.3 BTU/ft^3. The content of the THC was assumed to be 95% methane @ 913.1 BTU/ft^3 and 5% ethane at 1641 BTU/ft^3. Figure 2 is a diagramic representation of the gasification process taken from Reference [3] which gives an expanded discussion of the gasification process.

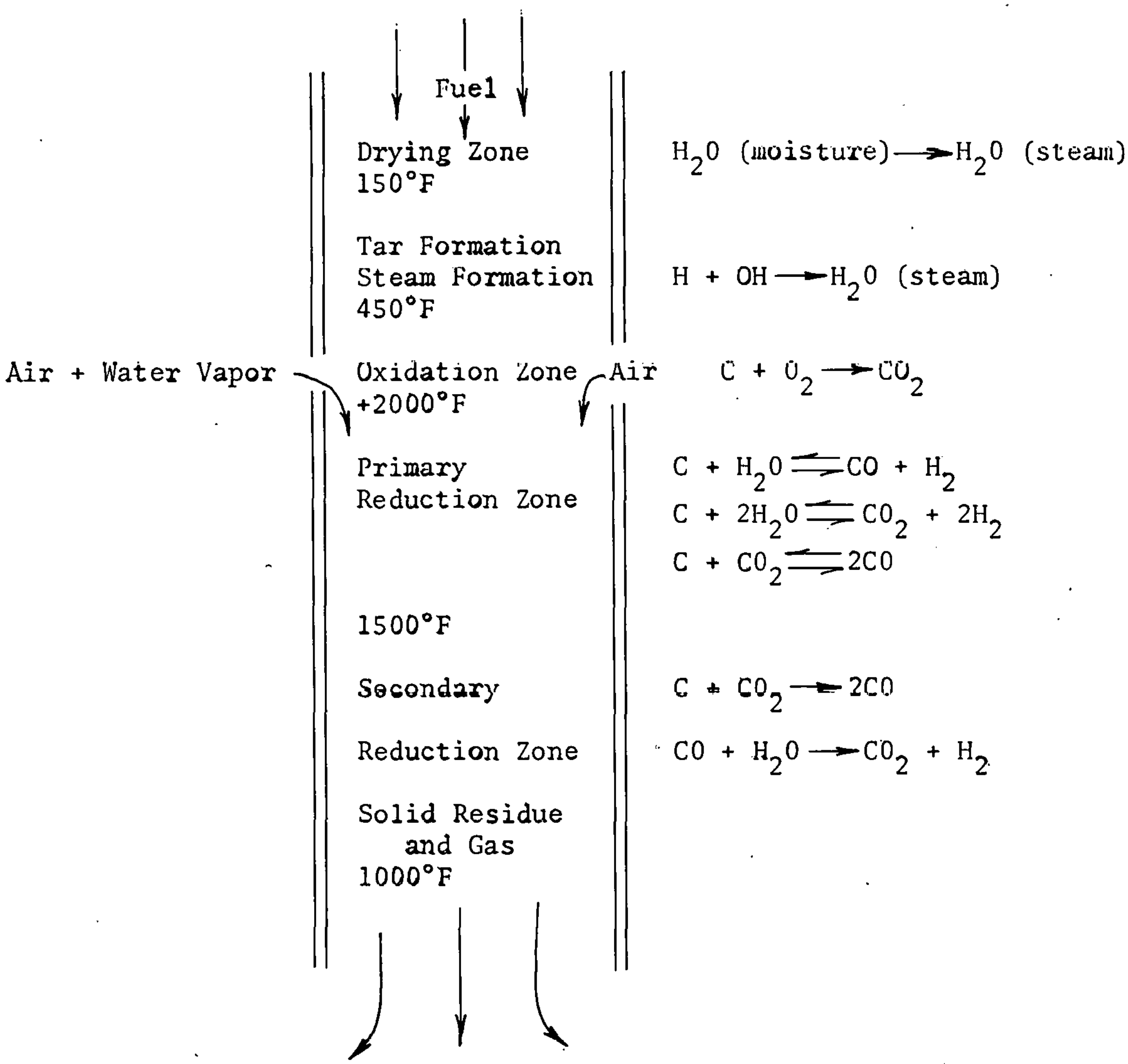

Figure 2. Reaction zones in a downdraft producer.

DEVELOPMENT OF THE UCD/SERCDC PILOT PLANT GAS PRODUCER

Early in 1975 a project was formulated in cooperation with Diamond/Sunsweet, Inc., Stockton, California, to gasify the mulled walnut shell from the processing plant in a downdraft gas producer. The low-BTU gas would be burned in the fire box of a steam boiler which was to be equipped with a center-fired, low-BTU gas burner positioned at the center of the existing natural gas ring burner. When low-BTU gas was being combusted in the fire box, the natural gas supply would be modulated to meet boiler demand but always maintain a low flame level to sustain ignition of the low-BTU gas. A proposal to provide a major portion of the funds for the project was submitted to and funded by the California Energy Commission.

The initial activity of the project was a preliminary design study to obtain information on the gasification characteristics and requirements for mulled walnut shell. Drawing upon technical literature and previous experience with a small gas producer, a laboratory scale gas producer was designed and constructed to investigate fire-box and ash grate configurations for the gasification of mulled nut shell. From the results of this work a scale-up design from a 1-foot diameter fire box to a 4-foot diameter fire box was made for the pilot plant gas producer. A special ash grate design was evolved and tested satisfactorily in the laboratory model to deal with the high bulk density and small particle size of the mulled shell (about 35 lb/ft^3 and all shell passing through a No. 4 Tyler sieve and retained on top of a No. 14 Tyler sieve). The ash grate consisted of a perforated stainless steel, truncated conical basket attached to the base of the cylindrical fire box. Char was moved through the basket perforations by a powered knife-wiper blade rotating just above the base of the perforated basket bottom. This design required much greater torque than indicated by scale-up from the laboratory model and other considerations. The combination of the ash grate design and physical characteristics of the mulled shell resulted in much higher static gas pressures (3 to 5 psi) in the bonnet of the pilot plant than in the laboratory model. Consequently, the fuel feed gate assembly was unsatisfactory for injecting fuel and gas leakage while combustion air was supplied to the producer. Gas production was satisfactory for a batch-mode operation, i.e., no fuel feeding during gas production.

These difficulties not-with-standing, the California Energy Commision provided additional funding to modify the pilot plant and conduct test-demonstration work on the gasification of wood chips and agricultural residues. The results for operation on mulled nut shell and the successful design, construction and testing of a downdraft gasifier, somewhat smaller than the pilot plant unit, producing low-BTU from corn cobs were used to design and install new ash grate and fuel feed systems in the pilot plant gas producer.

DESCRIPTION OF THE UCD/SERCDC PILOT PLANT GAS PRODUCER†

Figure 3 is a view of the producer at its last installation site and Figure 4 is an assembly drawing of the producer tankage. The gas producer shell is in five sections, which are connected together by

†This section adapted from [2].

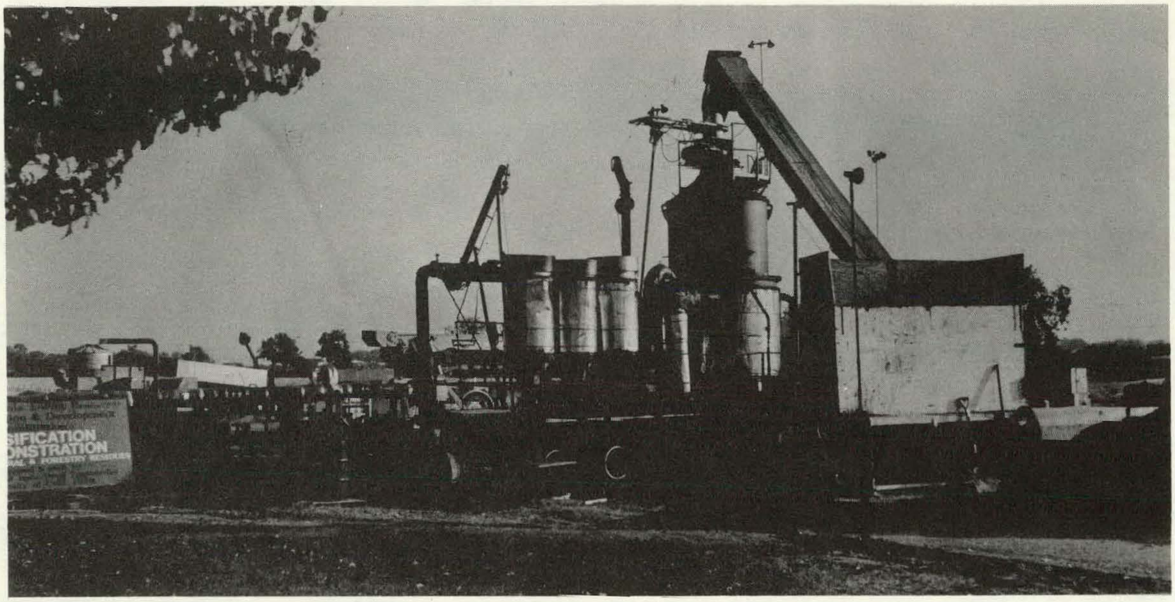

Figure 3. Pilot plant at its last installation site. Fuel hopper mounted on platform scales in foreground. Mounted on the semi-trailer to the left of the producer is first the hot gas cyclone and then three hot gas fiberglass sock-type filters. Combustion air, positive displacement blower with gasoline engine drive are located on the ground at the rear of the trailer.

bolted flanges. Inside the shell, the fuel hopper, fire box and perforated char basket with augers are arranged so that internal configuration can be altered as desired. The producer is designed to operate in downdraught mode with provision to convert it to an updraught producer should the fuel characteristics require such a change. The entire pilot plant has been made portable by mounting it on a flatbed semi-trailer, and by providing a boom for assembly/disassembly of the major sections of the producer. Partial disassembly achieves a height limit of 13' 6" which is necessary during transport.

The volumetric capacities of the fire box and basket are 38 cubic feet and 143 cubic feet respectively. The ash pit has a capacity of 69 cubic feet, although much of this space is taken up with support beams for the producer shell, fire box and char basket. The entire unit, excluding the fuel feed and ash removal systems, weighs 3.9 tons and is 17 1/4 feet high. Above the top of the basket, the producer will hold about 54 cubic feet of fuel and char when full. The basket floor diameter is 76 inches. The upper half of the producer was fabricated from 10 gauge 1020 sheet metal. The lower half of the shell and fire box was made from A515 steel plate.

For experimental purposes, the producer was equipped with a scale to weigh feed fuels and instrumentation for monitoring combustion air

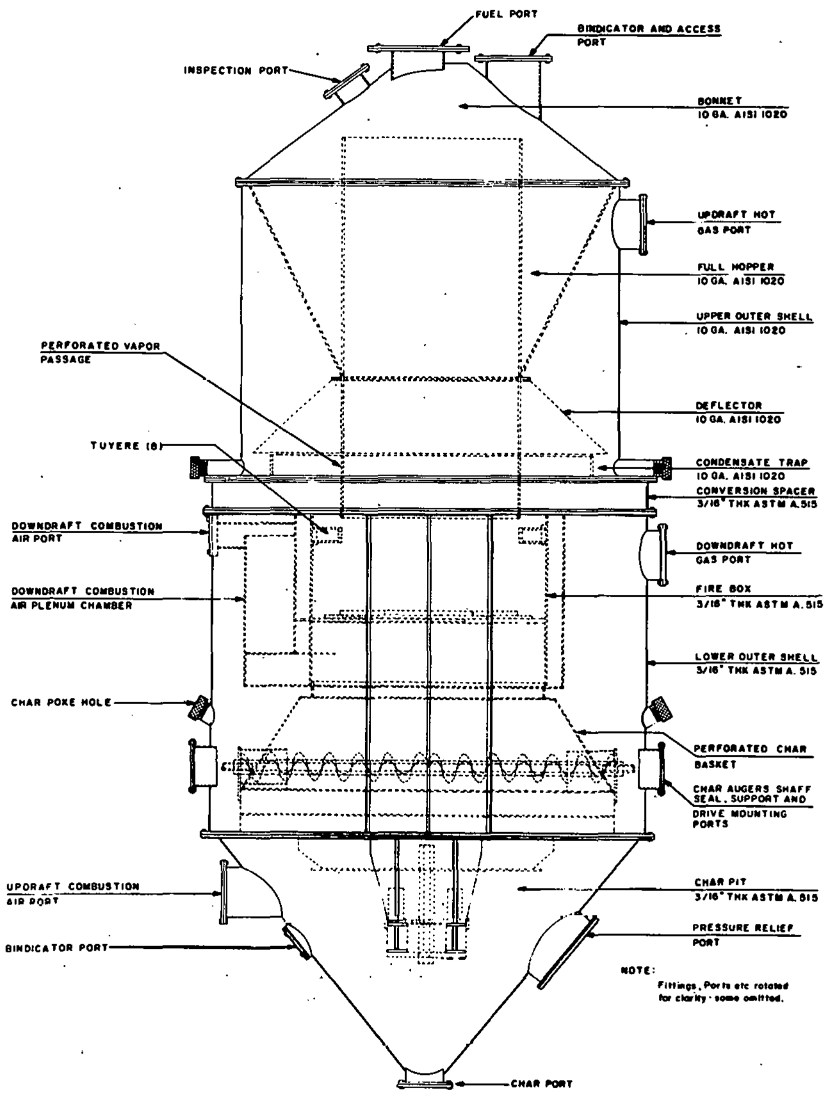

Figure 4. Schematic of the Pilot Plant Gas Producer. Scale reference: Upper outer shell diameter is 6 feet.

rate, temperature, pressure, and gas composition. The entire pilot plant can be monitored and controlled from the instrument cabin mounted on rubber pads at the front of the trailer.

Combustion air was supplied by a gasoline-engine driven, positive displacement blower. The intake air was cleaned by passing through a 2-inch thick fiberglass filter. A pressure relief valve was placed in the 5-inch air line immediately after the blower to bypass pressurized combustion air should high gas flow resistance develop in the producer and when the manual butterfly valve in the air line about 6 feet before the producer combustion air port was partially or completely closed. The combustion air was fed into the top of the fire box through 8 tuyeres from a pressure balancing plenum chamber, completely surrounding the outside wall of the fire box.

The fuel feed system consists of a fuel hopper box with drag chain, fuel elevator, fuel feed chute and tramp iron magnet, knife gate and rotary airlock feeder. Char is removed from the base of the producer with a rotary airlock and conveyed by a char auger to a disposal pile. Both the ash pit and fuel cylinder are equipped with level detectors to automatically start and stop the fuel feed and ash removal systems. These systems are equipped with motion detectors and automatic/manual controls to effectively deal with stoppages of the rotary airlocks. The fuel hopper box has a capacity of 64 cubic feet. The rotary airlock feeder can deliver 45 cubic feet/minute and the fuel elevator is rated somewhat less than this. The solid refuse rotary airlock has a capacity of 2 cubic feet/minute.

The grate consists of a conical basket, fabricated from 3/16" perforated stainless steel. Solid char is removed from the basket by 3 parallel and fully exposed stainless steel augers. The augers are right- and left-hand pitched to move char from the center of the basket along the bottom to openings in the side wall of the basket. Auger shaft support and drive are external to the producer. Solid particulates in the hot gas exiting from the producer are removed by a conventional air-handling cyclone. The cyclone is equipped with a knife gate and quick detachable, gas-tight dust bin for servicing without shuting down the producer. The cyclone is wrapped with fiberglass building insulation and jacketed with a single wrap of thin aluminum roof flashing.

The instrument control panel located in the cabin mounted on the front end of the semi-trailer contains a schematic diagram of the producer on which is located component status lights, pressure gauges, temperature meters, various electrical and pneumatic switches, and gas analysis meters. Chromel-alumel thermocouple wire is used for all temperature measurements. Gas constituents monitored on a continuous volumetric basis are CO_2, CO, O_2, H_2, and total hydrocarbon as carbon in CH_4. The instrument panel temperature meters were paralleled to a recording potentiometer which recorded each temperature on a strip chart once every six minutes. An event recorder was used to document the operational status on a timed basis of such components as the fuel elevator and ash removal gate. Hour meters and watt-hour meters were provided to record cumulative operational time and power consumption.

RESULTS FROM SELECTED TEST PERIODS†

The pilot plant has been set-up and operated in four locations in Northern California: Diamond/Sunsweet, Inc., Stockton; Department of Agricultural Engineering, University of California, Davis Campus; State Printing Plant, Sacramento and The California Primate Research Center, University of California, Davis Campus. Total gas producer operational time at these four locations since it was first fired in January, 1977, is 705 hours. One-hundred-fifty-eight hours were accumulated at the State Printing plant and 531 at the Primate Research Center from June through November 8, 1978. At this last location, expect for one 45-minute stoppage to repair a component in the producer fuel feed system and a 7-hour break to replace the portable electric generator, the gas producer was operated continuously for 328 1/2 hours. Table 1 contains results for selected operational periods at the Primate Research Center.

TABLE 1. OBSERVED AND CALCULATED DATA
GAS PRODUCER OPERATION AND PERFORMANCE
THREE SELECTED TEST PERIODS [2]
(Tabulated values are averages for the Test Periods)

1.	Run period	7 p 10-26 7 a 10-27	6 p 11-1 6 a 11-2	7:34 - 11:22 p 11-12
2.	Fuel	mix. chips	mix. chips	mix. chips
3.	Fuel moist. W.B. %	19.2	13.8	13.8
4.	Wet fuel rate lb/hr	453	678	682
5.	Refuse rate lb/hr	38	43	53
6.	Cyclone dust rate lb/hr	.75	1.4	1.5
7.	Condensate rate lb/hr	none	none	none
8.	Gasification rate lb/hr	414	634	628
9.	Hot gas discharge temp. °F	743	745	706
10.	Heat in dry fuel BTU/hr	3,267,000	5,242,000	5,283,000
11.	Enthalpy of water in fuel and combustion air BTU/hr	4,000	4,400	9,900
12.	Total heat input BTU/hr	3,271,000	5,246,000	5,293,000
13.	Heat loss: refuse, shell, gas leakage BTU/hr	561,000	800,000	895,000
14.	Energy transfer eff. %	82.8	84.7	83.0
15.	Gas value (NTP) BTU/ft^3	189	190	184

CONCLUSIONS

1. Down-draft gasifiers with this pilot plant or similar designs are restricted to fuels with low ash contents and fuel moisture contents that are estimated to be 20 percent or less.
2. The design concepts in this gasifier appear to be sound for long-term continuous or short-period discontinuous operation.

†This section adapted from [2].

3. Gas leakage levels at the fuel feed and refuse removal points are the result of high internal producer gas pressures. Reducing these to satisfactory level is likely to increase the capital cost of the producer.
4. The two sources for the high pressure drop across the producer are the amount of fines in the wood chips as received from the suppliers and the perforated ash basket design. The latter is believed to contribute most to the high pressure drop.
5. As a test and demonstration unit, the pilot plant gas producer has served a useful purpose. Further operation to acquire additional operational data will require substantial funds and installation space.

ACKNOWLEDGEMENTS

The opportunity to prepare this paper and present it at the Biomass Air Gasification Workshop held in Seattle, Washington on February 2, 1979, has been supported by the Solar Energy Research Institute, Golden, Colorado. I wish to thank Thomas B. Reed and Dan Jantzen of the Institute for their invitation to participate in the Workshop.

Many members and students of my Department, other Campus units, and Robert Hodam and Richard C. Lang of the California Energy Commission have contributed extensively to these investigations since I became project leader in January, 1977. Because of the dedication of each of these individuals, a great deal of information on downdraft gasification of agricultural and forest residues has been acquired in a very short time. This paper is a limited treatment of only the gas producer. For all who have labored on this project, I am certain they will agree, that special thanks and highest appreciation must be given to Mr. James J. Mehlschau, Development Engineer, who above all others made it possible to accomplish the project objectives.

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SECTION 5.2

GASIFICATION SYSTEMS—A CASE HISTORY

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ABSTRACT

The gasification system—case history pertains to the Westwood Polygas full-scale prototype plant located at Ainsworth Lumber Company in Chasm, British Columbia, Canada.

This plant has, over the past three years, operated periodically for a total of one thousand hours and has undergone modifications to overcome many operating difficulties.

The gasifier is a fixed bed system, air blown with some steam addition for combustion zone control and water gas production. The flow of air/gas is counter-current to the vertical gravity fuel bed. A saturated cool 140-160 Btu gas is taken off the reactor vessel top.

The gasifier is simple, requiring no auxiliary fuels, special subsystems or expensive fuel preparation and can be operated by mill personnel.

The Westwood Polygas process and the Ainsworth gasifier are in the last stages of a Canadian Government assisted research program and by mid-1979 Westwood Polygas hopes to have developed a process and necessary hardware technology for building a commercial fixed-bed gasifier.

INTRODUCTION

To make a case history complete it is useful to know something of the background as well as the present status of the continuing development of the Westwood Polygas Gasification Program.

Approximately six years ago, Moore Dry Kiln Company of Canada Ltd., undertook, with the assistance of the Canadian Government, the design and construction of a fixed-bed type gasification pilot plant. The objective of this program was to demonstrate the gasification of sawmill woodwaste to produce low Btu usable gas for lumber drying and other thermal requirements within a mill complex.

The pilot plant was operated frequently over a period of two years and much information was developed. Interest in the idea of obtaining usable energy from woodwaste led to the design and construction of a full-scale prototype two-reactor plant for Ainsworth Lumber Company who were building a new mill at Chasm, B. C.

The prototype plant was in the preliminary commissioning stage when for corporate reasons Moore of Canada had to withdraw from the gasification program which left Ainsworth Lumber Company with a nonoperating gasification plant. Subsequently, Ainsworth Lumber Company, Wright Engineers Limited, and Intercontinental Engineering joined forces under the name of Westwood Polygas to carry on the development work started by Moore of Canada.

The Ainsworth Lumber Company plant is located a considerable distance from a source of natural gas which led to the choice of the gasification process to supply fuel to fire the dry kilns. Until the gasifiers are working reliably, the kilns are being fired by Number 2 fuel oil and the woodwaste is being consumed by a teepee burner.

This paper is a case history of the gasifier and does not deal with the gas cooling and cleaning train as this equipment is proven and its selection is dependent on the end use of the gas.

The gasification plant envisaged is not intended to replace the large, efficient, well proven hog fuel boilers. The gasifiers are being developed for application on a modular basis for sawmill operations which have a need for fuel and at the same time have to dispose of in excess of 30 units of woodwaste per day.

The most effective use of the gas produced is for direct combustion in dry kilns, pulp mill lime kilns, or boilers.

Given the economic climate, scrubbing equipment can be installed to make the gas suitable to fire an internal combustion engine for power generation.

To date the program has amply demonstrated the process of making an acceptable combustible gas for direct firing. The reactor has been plagued with mechanical problems, the last of which we hope to have designed out of the plant by mid-1979.

BASIC PRINCIPLES

The gasifier/reactor is a ten foot diameter by approximately 20 foot high, double walled vessel with an inverted tapered liner. The bottom part of the lining is refractory, designed to withstand reaction temperatures which can reach 3000° F.

The fuel (woodwaste) is fed through a rotary lock feeder at the top of the vessel, and ash/clinker is removed from the bottom.

The flow of air/gas is counter-current to the vertical gravity fuel bed and is introduced through the ash bed which acts as a diffuser.

The bed profile commences at the bottom with an ash bed on top of which is the high temperature combustion zone, followed by a carbon/char reduction and pyrolysis zone, and drying layers from which comes a saturated, "cool" 140-160 Btu gas which is discharged from the reactor vessel top cone.

The throughput of woodwaste in the reactor and the gas make are linked by moisture content and quality of fuel (largely bark, versus planer shavings and clean sawdust) and by the quantity of air and steam introduced.

The volume of air introduced is relative to the size of the combustion zone and the amount and frequency of steam addition is dictated by the combustion zone temperature.

FIXED BED REACTOR ADVANTAGES

There are a number of woodwaste energy conversion systems available as commercial units, and many more in the development stage such as the Westwood Polygas gasifier. A number of the systems developed will find specific areas of application in the forest industry.

The Westwood Polygas fixed-bed system has some distinct advantages over other gasification systems being developed. Some of the more outstanding points are as follows:

(a) No auxiliary fuel or catalyst is required for the process and once the fire has been started it is self sustaining with the addition of preheated air and steam.

(b) A "cool," 180-200° F top gas is produced making it easy to handle with minimum cooling required to make the gas combustible (140-160° F).

(c) No strict limitations are placed on moisture content of the fuel feed. The normal mill waste produced in the interior of B.C. runs approximately 40-50% moisture on a wet basis. The reactor functions better when the fuel is not too dry.

(d) The system will accept hog fuel with a wide range of particle size. It has been found that stringy bark and branches, as well as sticks such as 2x4's and larger, should be reduced in size to allow physical handling without creating mechanical problems.

(e) The gasifier can be close coupled to standard gas scrubbing and cooling systems designed to clean the gas suitable for its intended use.

(f) Tars and particulates are readily separated from the condensate which is circulated to the cyclone and scrubber. The tars and particulates are returned to the gasifier for a second pass through the combustion zone.

(g) The reactor operates at a very low pressure (1-2 psi), therefore, no special boiler certification is required for the operator or the unit.

(h) There is no "stack" cleanup required as the particulate emissions are well below the acceptable standards.

(i) The gas plant is not complicated to operate and can be maintained by millwrights and electricians normally associated with a sawmill.

OPERATIONS

A great deal of experience has been gained operating a full-size prototype gasifier. Much of the information obtained from the smaller scale pilot plant has been duplicated on the prototype plant, however, scale-up problems have occurred and a number of serious mechanical difficulties have been encountered with equipment designed into the prototype which was not part of the pilot plant.

Three major test runs were made in 1978 producing considerable process data relative to mode of operation, sensitivity to fuel characteristics, combustion zone control, fuel flow, and other problems associated with ash handling and condensate disposal.

The development program has been slow by necessity. Working with a full-size plant makes the modifications large and expensive. The principle being followed is to make a few major changes at a time, and by trial run to check their effectiveness before proceeding with further modifications.

The first run in 1978 was in the freezing cold of January/February. Much attention was given to keeping the plant operating and checking out the modifications. Energy and material balances were made and gas samples taken and analyzed using a chromatograph. Little emphasis was placed on process control or operating procedures.

The winter operation gave an opportunity to test the process under difficult conditions. As a result, much was learned for inclusion in design parameters.

The second run was in July after numerous modifications were carried out following the January operation.

This test was plagued with mechanical problems and was run under very hot climatic conditions. This tremendous contrast from the January run gave us more valuable data for our design input.

During this test more attention was given to obtaining process data and carrying out on-stream surveys. Gas analyses including composition and moisture were taken frequently. A sampling train using impingers was employed to take gas stream particulate emissions.

In order to complete the data collection on particulates, a cascade impactor was employed to obtain particle size distribution in the stream. This included the tar and nontar particulates.

This test terminated by mechanical malfunction. It was planned to stop the gasification reaction by purging the reactor with nitrogen to complete this run.

A tanker of nitrogen was standing by, and discharged 180,000 ft^3 into the reactor over a period of 17 hours. The nitrogen arrested the reactions in the combustion zone rapidly and cooling of the combustion zone and carbon bed reduced the temperatures below the auto-ignition temperature of the fuel. The reactor remained sealed until cool, and was opened and hand excavated to reveal the actual bed profile which up to this point had been a matter of assumption and speculation as to its character.

The third run was in September which turned out to be the best gas making performance to date with steady state conditions. The steady operation allowed pressure and velocity surveys to be taken in the streams, physical poking of the bed to locate the combustion zone, and operating procedures to be applied over a number of shifts.

A better understanding of the process variables and their control was gained during this test run and will contribute to increased effectiveness of operation in future tests.

Further mechanical modifications are being made and a tapered refractory lining will be installed to replace the temporary stainless steel liner used to test out the effect on fuel flow.

When the modifications are complete, testing will continue in the spring of 1979 with gas being produced and fired in the dry kiln.

OPERATIONAL PROBLEMS

(a) Fuel flow was the most severe problem within the reactor. Hog fuel builds natural arches and can easily span over a ten foot diameter. In addition to the arching characteristics of hog fuel in the bed, the counter-current air blast assists in holding up the fuel bed.

Modifications were made to the reactor to overcome the fuel flow problem and at this time we are not in a position to elaborate on the measures taken but we can say that the reactor is no longer subjected to fuel falls and severe channeling. Particulate carryover can be a problem when the woodwaste is too dry or frozen. When the wood fines are very dry and dusty, condensate is sprayed on the fuel prior to entering the reactor. When the fuel is frozen, the condensate separating tank must be capable of handling the particulate load for return to the reactor.

(b) The major mechanical problem causing operational malfunction has been in the area of the rotating hearth. Due to failure of the rotating element seals and the inability of the wraparound chain drive to withstand the high temperature and hostile environment, it has not been possible to achieve long term continuous operation. Maintenance shutdowns varied in duration from one hour to one day before resuming operations. Recovery of gas production after these shutdowns was rapid but time was required to stabilize the process.

(c) Ash content of woodwaste is extremely small resulting in very gradual ash buildup in the base of the reactor. The process can run for days without ash removal. As a result, the ash is fused and re-fused until a large clinker is formed making removal difficult and reducing the effectiveness of the ash bed as an air/steam diffuser. In order to make ash, gravel was added to the fuel feed, which contributed three positive improvements in the reactor's performance.

(i) The gravel improved the bed porosity.

(ii) The gravel added weight to the fuel bed.

(iii) Ash removal was possible on a scheduled basis relative to the amount of gravel being added. Much of the gravel removed from the ash bed was in its original condition and suitable for recirculation.

(d) Expansion of the combustion zone when starting up the reactor was uncontrolled and from the very beginning the fire propagated in the direction of airflow which found the path of least resistance through the ash bed. In order to get rapid horizontal expansion of the combustion zone in all directions, fuel oil is now added to the starting fuel bed in a ring which assists the fire in growing to a large diameter rapidly and brings the reactor up to gas production within four hours.

The above descriptions highlight the major problems and some of the solutions tried and proven to date. The only major area of concern which has not been tested to achieve confidence is the ash removal system. It is generally felt that a complete revision of this system will be required to give long term reliable performance.

OPERATING OBSERVATIONS

(a) From the operating experience to date, we confirm that the gasification plant can be automated with only part-time supervision from an operator who is connected with the equipment utilizing the gas.

(b) The Btu content of the gas is variable and can over a short period of time, range from 120 to 170 Btu's. This is not critical to firing a kiln, but could be a problem in other gas applications. A gas holder or accumulator may be required for some applications.

(c) Make gas is influenced markedly by fuel addition to the bed. From experience it has been found that fuel should be introduced on a closely timed cycle and not be allowed to lag for more than 40 minutes. If the interval between fuel loading extends to an hour, the chances of running into an upset condition become likely as gas production will drop significantly when a large quantity of fresh fuel is added, and the fuel bed will suffer from compaction.

(d) Make gas is also influenced by steam addition which has an effect on the combustion zone temperature. If the steam purges the bed bringing the temperature below the water gas reaction level, gas production falls off rapidly.

(e) It has been found possible to control the position of the reaction zones in the vertical bed by careful removal of ash.

(f) The plant has turned down capability of 4:1.

The reactor can be turned down to zero gas production by cutting off the air supply and can rapidly recover to full production after a period of up to a week.

On the other hand, a minimum of one week is required to reduce the bed and allow cooling time to enable maintenance to take place within the reactor vessel or ash removal system.

(g) From experience it has been found that gas quality can be monitored visually by examination of the flare or by a calorimeter. In a fully automated plant it would be necessary to have some type of broad spectrum on-stream analyzer for process control.

EMISSION AND WASTE CONTROL

The only aromatic emission is fumes from the condensate tank, which in a commercial plant would be contained and vented to the flare for disposal.

When flaring total gas production there is no visible plume or incandescent particulate emission from the flare. Emissions are well below 0.100 gr/sdcf. Stack emissions were taken on the pilot plant and were below 0.010 gr/sdcf.

Condensate, which is primarily the water removed from the wood along with some light oils and tar, is being produced at a rate of about 3 to 5 g.p.m., depending on the moisture content of the woodwaste. The oils, tar and particulate carryover are readily separated and all solids can be returned to the reactor for further reduction. Condensate disposal at the present time is by incineration in the excess gas flare. It is recognized as an inefficient means of disposal, but until a proven process is found for safe disposal, it is the best way to handle the problem. Ash removed from the reactor is primarily dirt and gravel which was entrained in the bark from the mill yard. The normal wood ash component is a very small part of the total. The ash is completely inert and would provide good road base material.

ECONOMICS

The economics of a total gasification plant cannot be defined in simple terms. Each application must be examined and the variables quantified to determine the overall economics. Some of the variables which influence the cost of gas production are:

(a) End use of the gas.

(b) Total energy requirements versus energy produced.

(c) Woodwaste availability and type.

(d) Cost of fuel being replaced, i.e., gas or oil.

(e) Cost of woodwaste or conversely disposal cost of woodwaste.

One of the critical factors in determining the economics of a gasification plant is the level of efficiency at which it can be operated. The efficiency in the case of the gasification plant is defined as the ratio of the energy available in the the produced gas to the total energy input including woodwaste feedstock, air, steam, and power consumed in running the plant.

The largest single factor affecting the efficiency of the plant is the amount of energy required to evaporate condensate; this is illustrated on the accompanying graph which shows a significant drop in efficiency when large quantities of condensate must be disposed of. The exit gas temperature should be kept as high as other considerations will allow and a minimum of gas condensate removed.

To outline an economic evaluation, the following parameters will apply:

(a) A single reactor plant.

(b) Zero cost for run of the mill woodwaste.

(c) Minimum gas cleanup.

(d) Gas fired direct to a kiln.

(e) Heat output at 60% efficiency.

(f) Plant operation three shifts, five days per week.

Using the above factors, a natural gas equivalent energy cost of $1.50 per million Btu's would result.

From the above example it can be seen that in an application where a negative fuel cost is introduced, an incentive to install a gasification plant would apply, as the current price for interruptible natural gas is $1.50 per million Btu's.

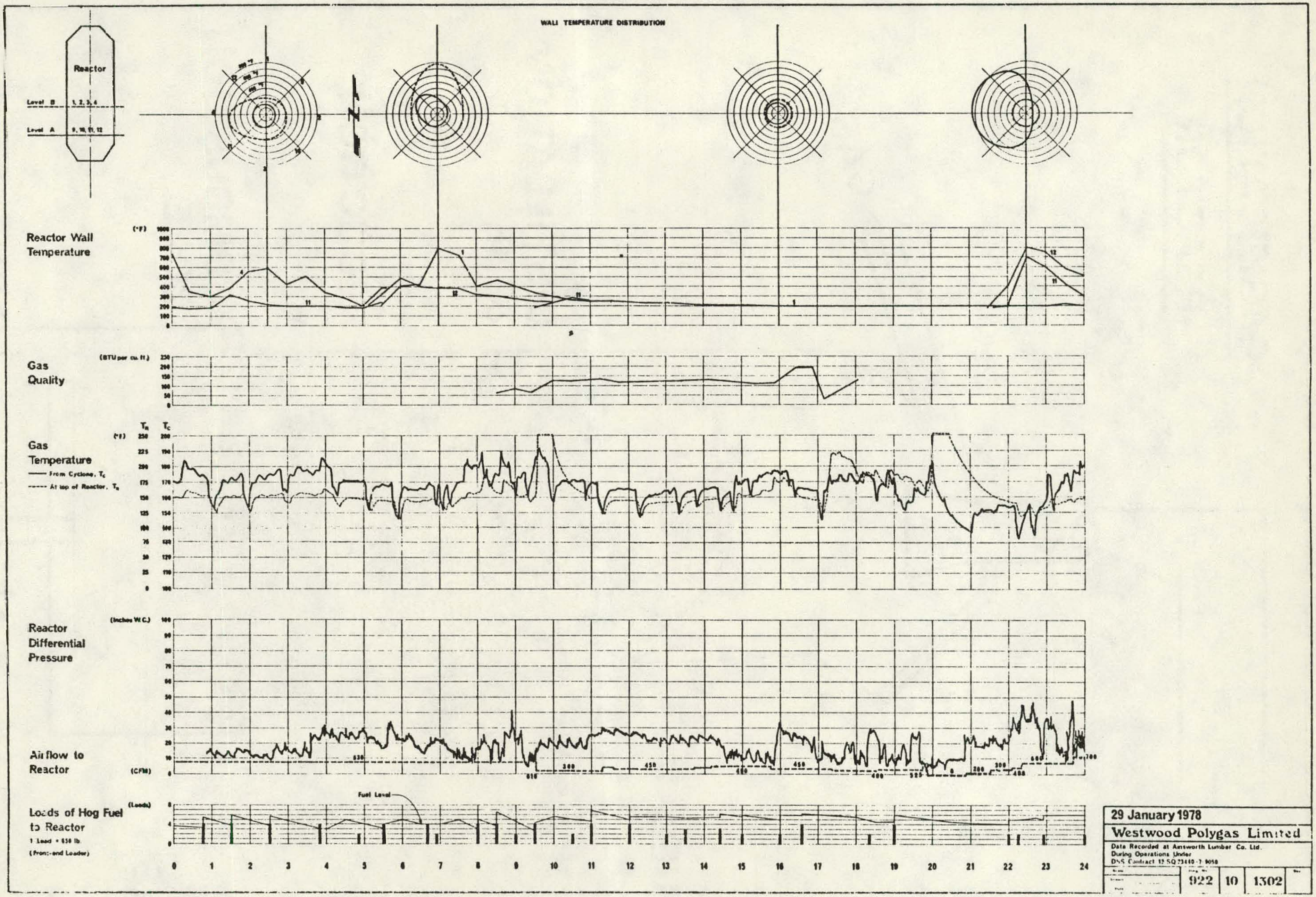
MAINTENANCE

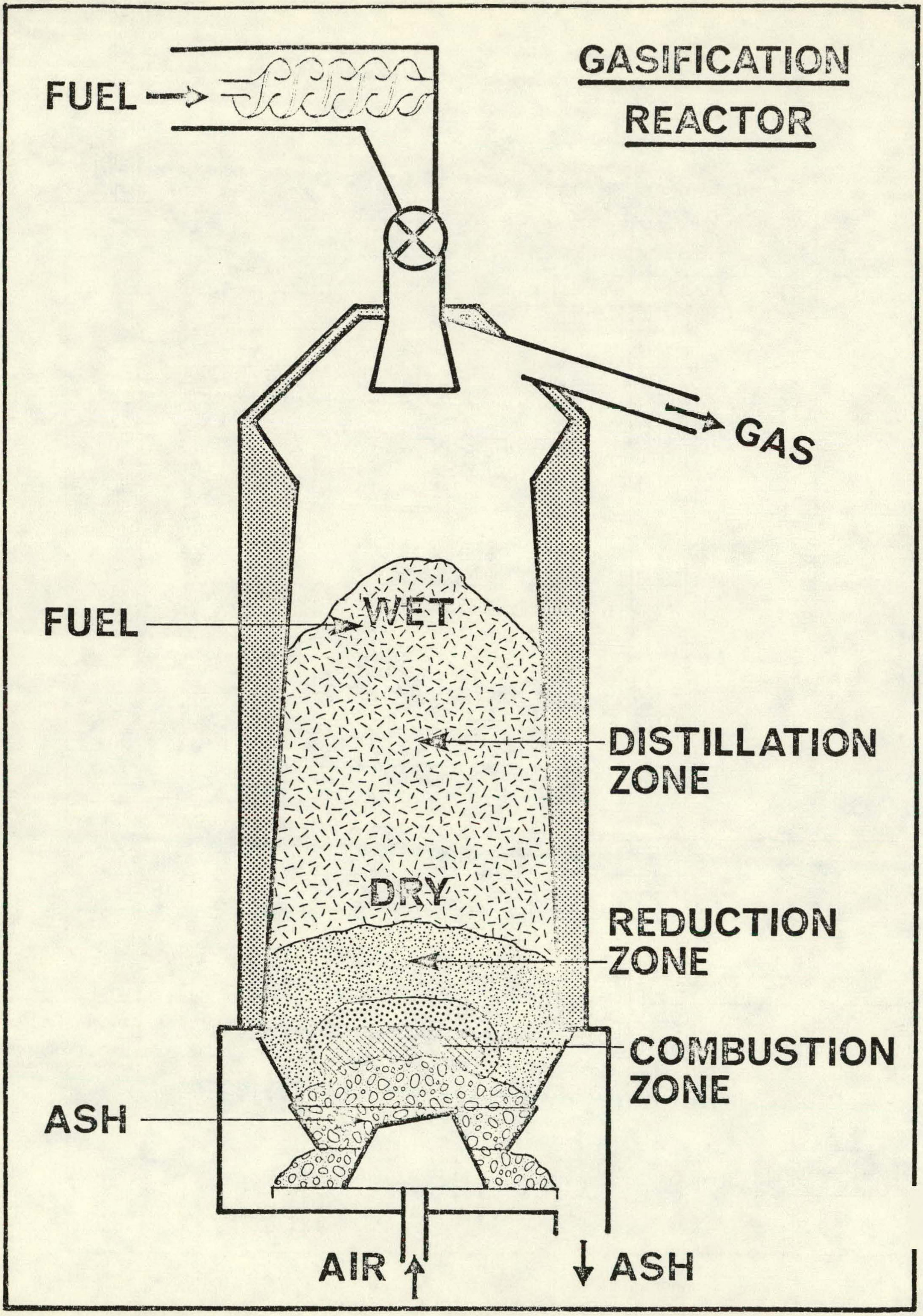
The prototype plant has not run long enough to determine long term effects on the various components in the system.

The frequency of maintenance within the reactor vessel and the internals of the ash removing system is anticipated to be once a year, and within the mill complex could be scheduled for the summer period when kiln drying is greatly reduced over a period of several months. If the gasification plant were being used for power generation and heating, the difference between peak and minimum capacity would have to be at least one reactor's output to allow scheduled maintenance.

The areas which will require running maintenance will be the instrumentation, valves, and thermocouples. Refractory maintenance should be required only on an annual shutdown basis; similarly, any wearing surfaces or parts in the ash removal system would be repaired or replaced on an annual basis.

Other points of running maintenance such as bearing lubrication, pump seals, gland packing and so forth, are no different than any other industrial plant. The simplicity of the gasification plant allows this type of maintenance to be carried out by the oilers, millwrights, and electricians who are normally available in the mill.


WALL TEMPERATURE DISTRIBUTION
Reactor
Level B
1, 2, 3, 4
Level A
9, 10, 11, 12
Reactor Wall Temperature
(°F)
Gas Quality
(BTU per cu. ft.)
Gas Temperature
From Cyclone, T_C
At top of Reactor, T_R
T_R
T_C
Reactor Differential Pressure
(Inches W.C.)
Airflow to Reactor
(CFM)
Loads of Hog Fuel to Reactor
(Loads)
1 Load = 630 lb.
(Front-end Loader)
Fuel Level
29 January 1978
Westwood Polygas Limited
Data Recorded at Ainsworth Lumber Co. Ltd.
During Operations Under
DSS Contract 12 SQ 23440-7-9050
922
10
1302


GASIFICATION
REACTOR
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COMBUSTION
ZONE
ASH
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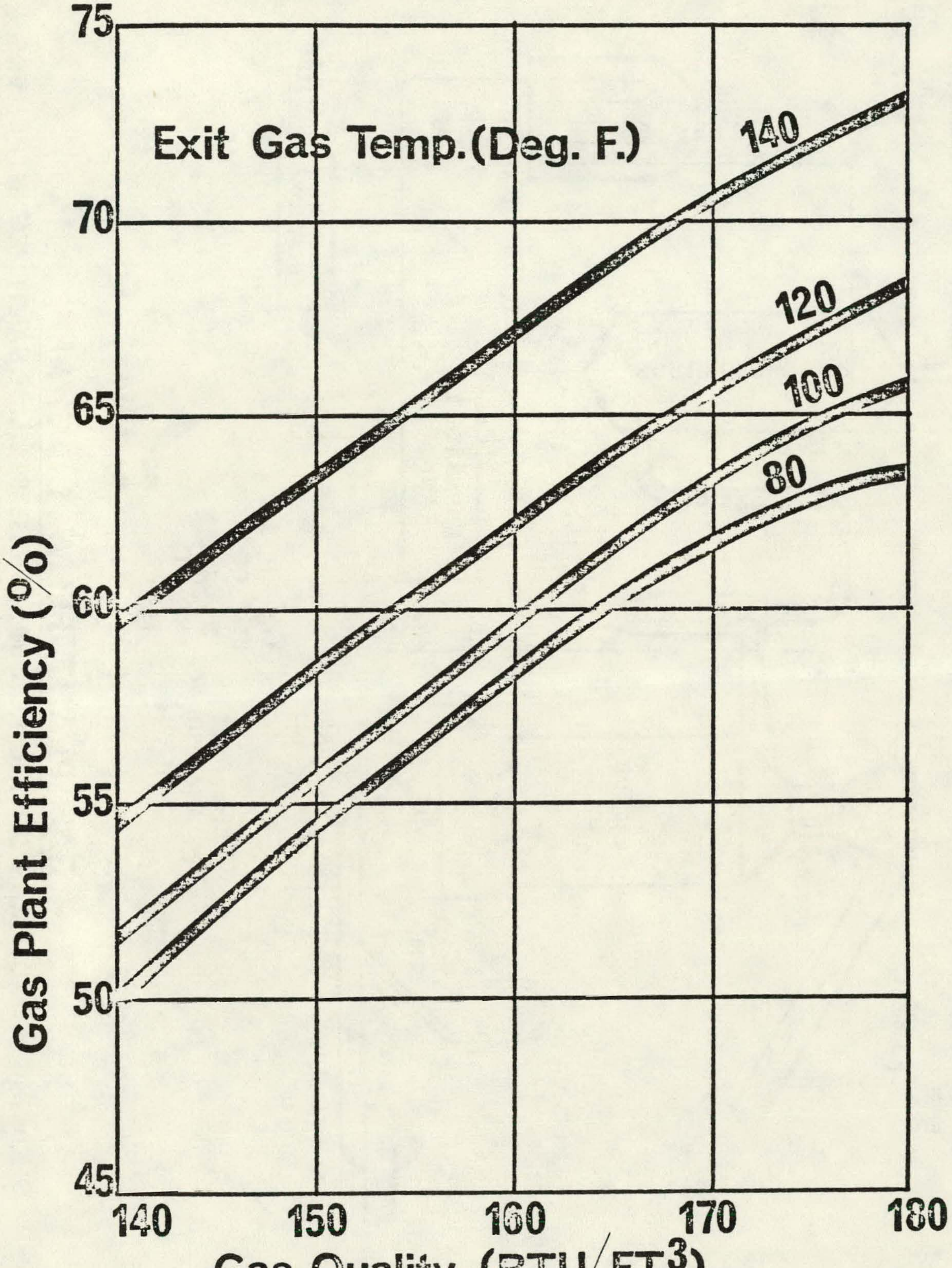
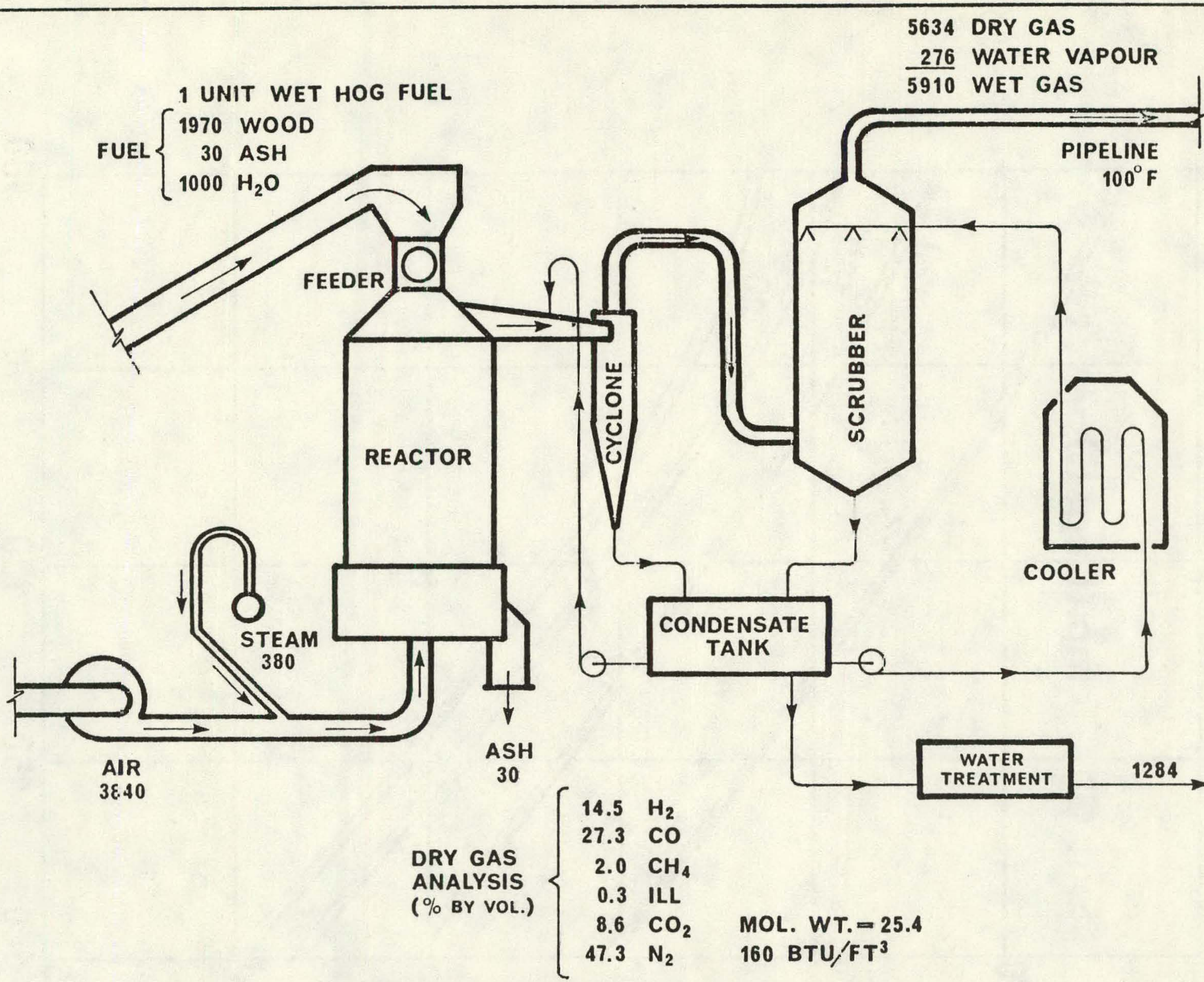
ASH



GASIFICATION EFFICIENCY WITH
DISPOSAL OF CONDENSATE BY EVAPORATION



GAS PLANT FLOW DIAGRAM

SHOWING CONDITIONS DURING RUN IN SEPT. 1978. ALL QUANTITIES IN POUNDS

SECTION 5.3

FLUIDIZED BED GASIFIERS

by
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INTRODUCTION

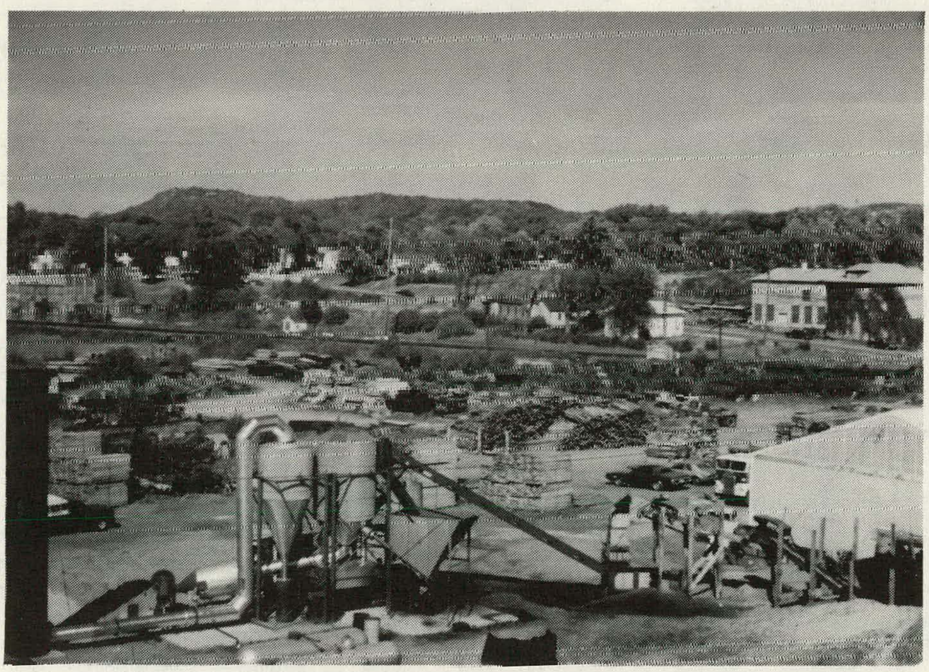
A new solution to the organic waste disposal problem for the forest and agricultural industries is the Thermex-Reactor, a fluid-bed gasification process, the first in this advanced technology, developed over the past seven years by Alberta Industrial Developments Ltd., of Edmonton, Alberta, Canada.

With today's rapidly rising cost of fossil fuels, and the ever-increasing concern of pollution, environment, and conservation controls, the Thermex-Reactor suits the needs of those industries. Utilization of waste is a prime concern to the forest and food processing companies who are large energy consumers and produce an abundance of biomass energy, a renewable source.

The Thermex-Reactor was orignally developed for the production of charcoal in an oxygen-free atmosphere, essentially baking the raw material. An outgrowth of this process is the Thermex-Reactor fluid-bed process for total gasification using air.

The Thermex-Reactor is so flexible it can be operated to maximize the production of gas or charcoal as desired.

Thermex-Reactor



First Thermex-Reactor pyrolysis plant operations at a sawmill site on a continuous basis.

COMPARATIVE GASIFICATION PROCESSES

The production of gas by decomposition of the solid carbonaceous material (wood particles) takes place at high temperatures in a controlled atmosphere with limited oxygen.

Gasificiation is a pyrolysis process. Pyrolysis of biomass is a destructive distallation process which is on balance endothermic. Pyrolysis is usually perfomed under atmospheric pressure and at temperatures up to 2000 C. The high temperature and lack of O_2 results in a chemical breakdown into several component streams. These are:

Wood Gas - composed of CO_2, CO, CH_4, C_2H_4 and higher molecular weight hydrocarbons.

Distillates - composed of insoluble tar (phenolics) and pyroligneous acid, the latter containing acetic acid, methanol, acetone, esters, aldehydes, and furfural.

Solid Phase - consisting of ash and charcoal.

The higher the pyrolysis temperature, the greater the amount of gaseous product formed and smaller amount of tar and charcoal formed. At certain temperatures, depending on the type of equipment used, direct gasification of wood into gaseous fuel is possible. Other factors which influence the composition and yield of the products are rate of heating, the oxygen content of the atmosphere, type of wood, and pressure attained.

Pyrolysis may be carried out by heating biomass directly or indirectly in either a fixed-bed, an entrained bed, or a fluidized-bed reactor, and in either countercurrent or co-current mode in the fixed-bed.

In the countercurrent fixed-bed process, the raw material is fed into the top of the reactor. Air flows upward through the bottom of the reactor. As the raw material moves slowly downward, it is dried, distilled, reduced, and oxidized. It is finally discharged from the reactor as ash or charcoal and ash depending on temperatures in the reactor.

The advantages of a fixed-bed process are high energy conversion efficiency, low particulate emission, and the ability to process fuel with a high moisture content. However, the process suffers from ash removal and channelling problems. In addition, the countercurrent mode maximizes the production of tars in the gas, thus requiring an elaborate cleaning facility. The fixed-bed temperature in the combustion zone is in the range of 1300 C to 2000 C.

Relatively low bed temperatures prevent sintering and agglomeration of ash and thus simplify ash removal, saves on costly shutdown conditions which extend reactor life, minimize the formation of tars, and reduce gas cleaning requirements.

Moisture content in the wood removed within the reaction center reduces thermal efficiency, reduces operating temperature, and affects the dynamics of the reaction, consuming energy for water evaporation. All systems operate best with an evenly sized raw material with a consistent moisture content. Raw material sizing and moisture reduction equipment would be desirable unless sufficient raw material of a consistent dry nature is available.

All by-products can be cooled, cleaned, pelletized, stored, or utilized directly for energy consumption in boilers, kilns, dryers, electric generator sets, and space heating.

Gases utilized directly, without scrubbing and cooling, have a higher heating value and cause less problems with tar storage or tar utilization as well as being less costly to install.

ALBERTA INDUSTRIAL DEVELOPMENTS LTD.

Alberta Industrial Developments Ltd. (A.I.D.) was formed in 1972 with the purpose of specializing in the field of process equipment for conversion of wood residue into usable by-products.

A.I.D. then obtained the licensing rights from the British Columbia Research Center for the development of a patented charcoal and wood gasification process, then designed, built, and operated a pilot plant at B. C. Research from 1972 to 1974. These results led to a scale-up from an 18" diameter reactor with an input of 300 lbs. per hour to an 8' diameter reactor with an input of 6000 lbs per hour. This reactor was designed, fabricated, and field tested at a sawmill site in Edmonton.

The monitoring and analysis of this scale-up reactor was done with the assistance of Alberta Research and Northwestern Utilities Ltd. Several species of wood and wood waste were utilized. The production balance of charcoal and producer gas proved to be commercially viable. The equipment was then shipped to Wisconsin for production of charcoal for briquetting. The outcome of this move resulted in modifications to the system to maximize either charcoal or producer gas. In order to develop the reactor commercially, an engineering team experienced in the charcoal industry and gas utilization have re-designed and developed ancillary equipment for the process. The incorporation of these engineering and fabrication recommendations have resulted in an advanced system far exceeding the orginal concept.

This prototype plant was operated over a four year period utilizing most species of North American wood, wood waste, and bark with varying sizes and moisture content. The plant has approximately 6000 hours of use.

A.I.D. with their experience over the past years on the system have now developed the reactor and ancillaries to peak performance producing low BTU gas.

THE THERMEX-REACTOR PROCESS

The basic process in the Thermex-Reactor consists of distilling and gasifying cellulosic particles varying from very fine material to particles of approximately one inch in size. Larger materials are shredded or broken into particles small enough to be used in the process.

Raw material is conveyed or blown to the ractor feed bin, as produced from the mill or stock piles, manually or automatically. The size of the feed bin will determine the intervals of loading.

Particles are directed to a bed of hot glowing charcoal in a closed chamber where wood particles are quickly distilled and gasified. Both oxygen-containing gas and evolved gases are present in sufficient quantity to maintain the charcoal and particle bed in a turbulent of "fluidized" state, resulting in a uniformly high temperature throughout.

Charcoal is continuously formed in the process. A certain amount is burned by oxygen and removed along with accumulated ash. Evolved gases, acids, alcohols, and tars rise through the hot charcoal body. The tar mist is cracked by heat to form lower molecular weight hydrocarbons. The crude gas passes through a disengagement zone in the chamber above the charcoal bed before it is withdrawn from the apparatus.

The unit is thermally self-sustaining while gasifying as the required process heat is supplied by the partial combustion of carbon. Fuel gas is produced by rapid decomposition in a continuous fluid bed gasifier.

The solids remaining in the hot bed of the reaction zone and those collected by the cyclones are continuously withdrawn from the reactor as ash or charcoal, depending upon the operating mode.

The solids which exit through the bottom of the reactor pass through a holding gate and into a continually moving screw conveyor. This conveyor is a conditioning unit which cools the solids with or without water, therefore preventing hazardous hot carbon or ash from entering the waste bins or piles. This removal is continuous.

If charcoal is to be withdrawn as a major by-product of the process, then a simple adjustment to increase the raw material feed input will automatically decrease the temperature of the reaction zone and increase charcoal production.

The best results are obtained with particles that are dried and pre-heated to the point of thermal decomposition. However, the reactor is designed to accept a moisture level of up to 55% wet basis.

Where moisture levels are higher than 55% (wet basis) drying should be applied. This can be accomplished with an attached flash drying system. Either exhaust gases can be withdrawn for this use, or alternately the gas can be cooled and scrubbed and the tars can be utilized in a combustion furnace for drying. The flash dryer system would be part of the blower feed system. An attached flash drying system is relatively inexpensive and is recommended for consistent feed stock as it serves to prevent material handling problems and reduction in reactor size as well as utilization of external rather than internal heat for drying. When raw material is pre-dried there is more heat available in the hot gas. This also reduces the heat loss required for drying internally.

The relationship between reactor temperatures and moisture content of the feed is the minimum temperature at which most of the wood fed will gasify. Higher temperatures will assure gasification but will lower the B.T.U. content of the dry gas, as more of the carbon burns to carbon dioxide.

In general, the reactor must be run at higher temperatures to minimize charcoal production and maximize gas production, but at lower temperatures to maximize overall thermal efficiency. For good operation, the reactor should be kept betwen 950°F and 1650°F.

In comparison to the conventional co-current fixed bed gasifying operation, the Thermex-Reactor is able to produce a larger yield of fuel gas with a higher heating value, from 157 to 200 BUT/SCF as compared to other systems of 97 to 132 BTU/SCF.

Gas production on cold start-up with raw material will take a few hours. Once a bed of charcoal has been produced in the reactor, shutdown and re-starting will be a matter of minutes.

Re-starting after shutdown can take place without the start-up furnace. Air from the air pump is all that is required for start-up. The insulated refractory-lined reactor and the charcoal act as a heat sink which would take several days to cool.

Personnel required can perform other duties on the site or use others who may already be employed for other purposes. One person can operate one or more modules.

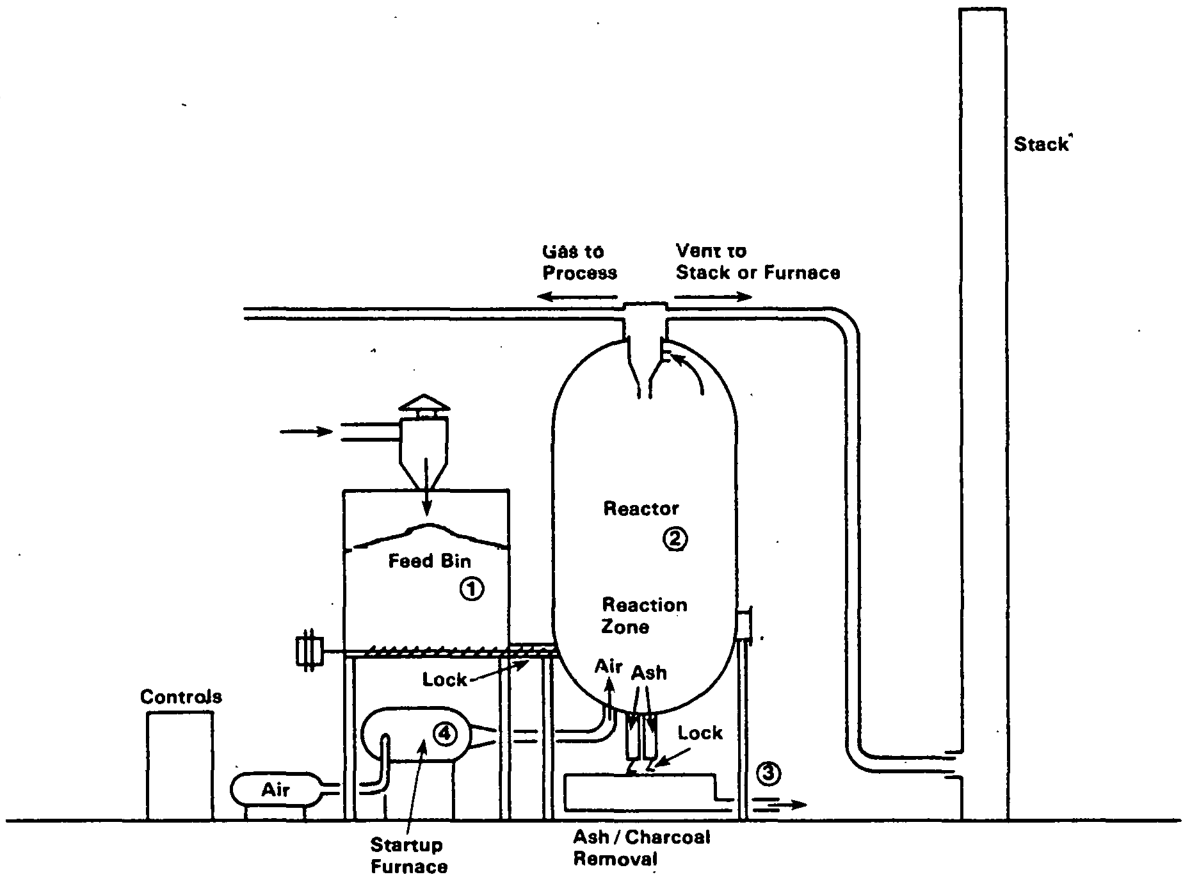
Little maintenance will be required, as there are few moving parts. Regular greasing and oiling of the components should be maintained.

The reactor should be opened every month or two to check for sinter above the grates. This may not be necessary with inter-connected sawmill plant installations operating on a continuous basis.

Although modual reactor sizes can be purchased for manual operation with loading equipment, we suggest that for best economics, units should be designed to suit the mill waste production for automation. In this manner, material handling of the waste is minimized and total utilization of the residue is achieved.

In the case where more waste is produced than the mill can consume in energy, excess gases can be burned cleanly to the atmosphere or, alternately, charcoal can be produced for storage or resale to other consumers.

In most cases equipment will be assembled prior to shipment for ease of installation at the site. Subject to plant size and equipment required, approximately two weeks will be necessary for technology transfer.



EQUIPMENT LIST AND DESCRIPTION

(1) Feed bin and structure with screw conveyor bottom, operates continuously by hydraulic variable speed motors. Feed bins can be varied in size, subject to operation, and can be fed automatically by different material-handling systems.

(2) Refractory-lined and insulated reactor, size to be designed to suit mill requirements. Internals of stainless steel and particulate collecting cyclones. Includes structures ready for inter-connection.

(3) Ash or charcoal conditioning conveyor, with water nozzles and air-cooling devices, valves, compressors, pumps, motorized for continuous operation.

(4) Start-up furnace and controls with all instrumentation, recording devices for temperature control, all motor starters, and safety devices, provided for manual or automatic operation.

(5) Control cabin, gas pipeline and gas burning furnace or stack will be provided on request, subject to end use.

(6) Other components, engineering requirements, design work, will be provided, subject to the mill site and available auxiliary equipment at the site.

SUMMARY PERFORMANCE

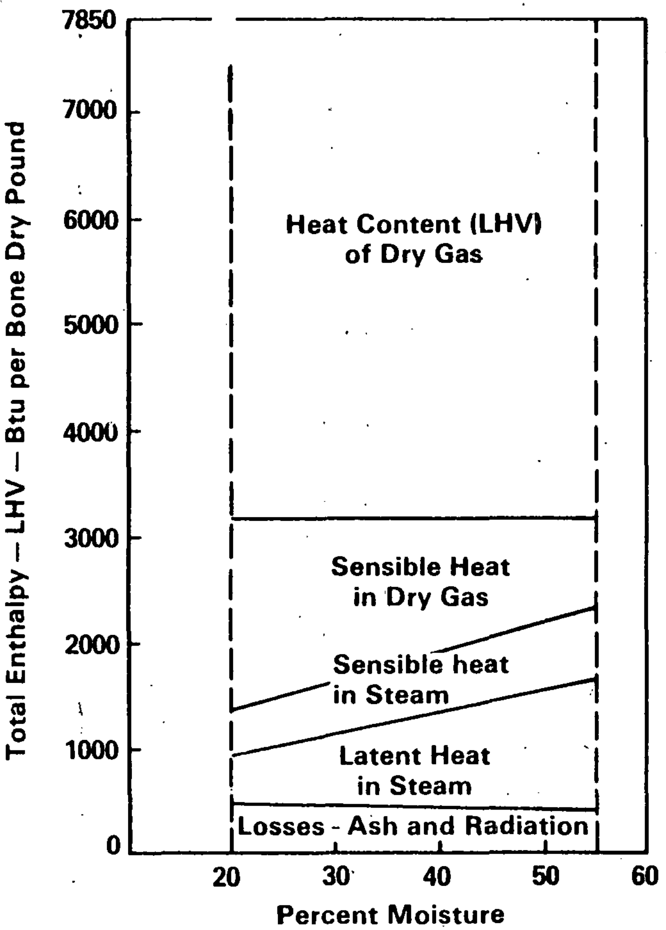
Feed Stock - Wood Raw Material (of varying sizes, species, moisture and operating temperatures) (corn husks, rice hulls, coconut shells, other nut shells, etc., can be utilized)

	Range	
Operating Temperatures	800°F	1700°F
Moisture (Wet Base)	14%	55%
Material Size		± 1"
Material Bulk Density (Gravity Packed)	6 Lb./Cu.Ft.	22.5 Lb./Cu.Ft.
Feed Rate (Bone Dry Basis with moisture)	50 Lb./Sq.Ft.	200 Lb./Sq.Ft.
Turn Down Ratio	3 to 1	
B.T.U./S.C.F.	157	200
Emissions	0.090	0.127
Flue Gas (CO_2)	5.4%	16%
Horse Power (8'-16' Reactors)	40 H.P.	65 H.P.
Heat Loss (Shut Down)/ Hour	8°F	14°F
Start Up (Gas Production) Cold	5 Hrs.	12 Hrs.
Start Up (Gas Production) Hot		± 1 Minute
Flame Temperature	1500°F	1750°F
Residue Ash	0.05%	5.0%
Production Charcoal	5.0%	35%

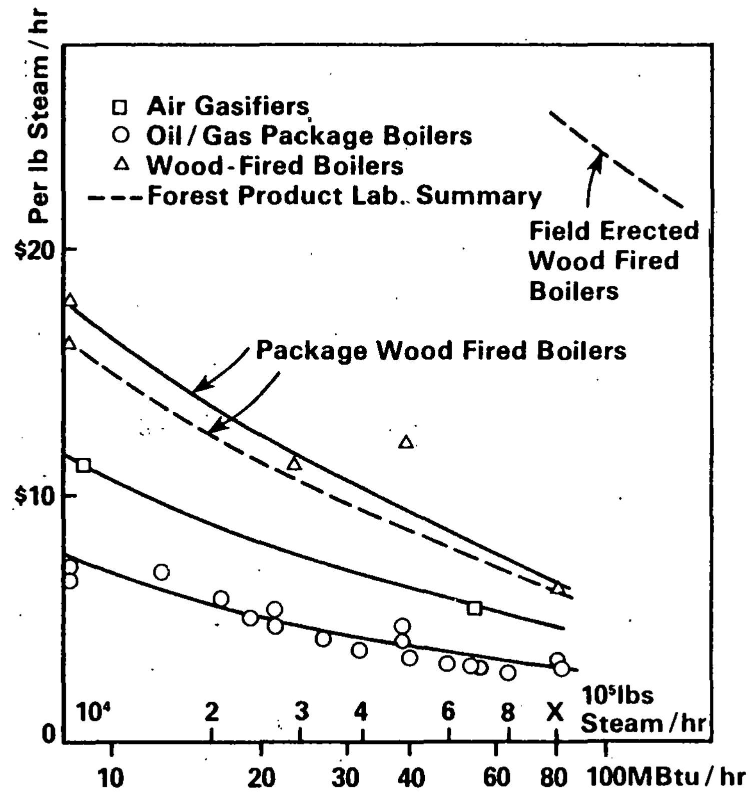
Gas Composition (Typical)

H_2 - 18%/O_2 - 1.9%/N_2 - 46.2%/CO - 18.3%/CE_4 - 4.1%/CO_2 - 10.3%/C_2 - 1.2%: Total B.T.U./S.C.F. 178.

Does not include probable calorific value of tars and other distillates.



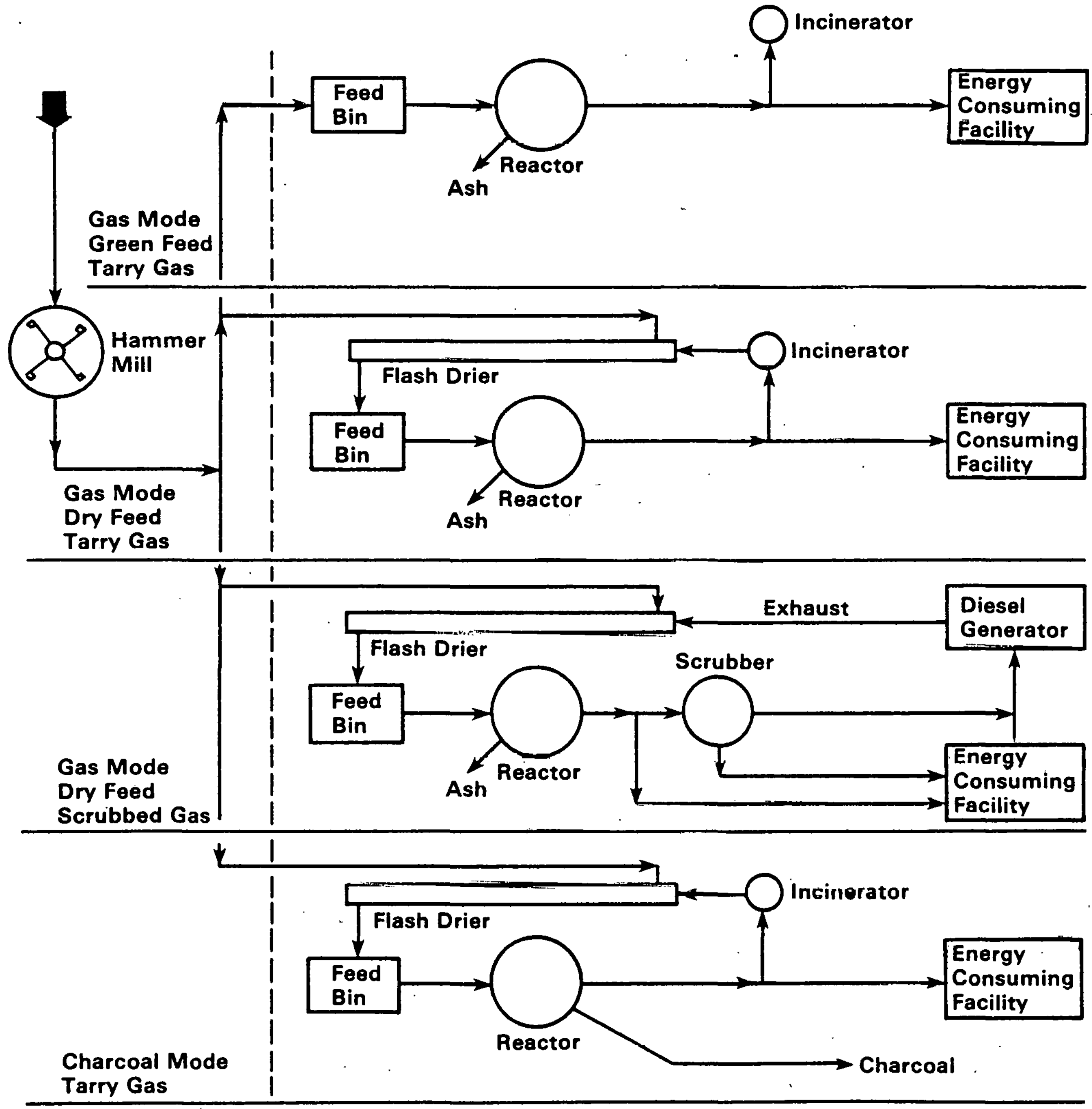
Total Enthalpy — LHV — Btu per Bone Dry Pound
7850
7000
6000
5000
4000
3000
2000
1000
0
Heat Content (LHV) of Dry Gas
Sensible Heat in Dry Gas
Sensible heat in Steam
Latent Heat in Steam
Losses - Ash and Radiation
20
30
40
50
60
Percent Moisture



Per lb Steam / hr
$20
$10
0
Air Gasifiers
Oil / Gas Package Boilers
Wood-Fired Boilers
Forest Product Lab. Summary
Field Erected Wood Fired Boilers
Package Wood Fired Boilers
10⁴
2
3
4
6
8
X
10⁵lbs Steam / hr
10
20
30
40
60
80
100MBtu / hr

OPERATIONAL SYSTEMS (TYPICAL)

Direct firing, close-coupled, utilizing green fuel for production of low 150-200 B.T.U. gas for boilers, dryers, conditioning vats, etc. All systems can produce charcoal for storage or resale.



ESTIMATED CAPITAL AND OPERATING COST

EXAMPLE

Basis	
Higher Heating Value	8500/B.T.U./B.D.P.
M = 1 Million B.T.U.	
Efficiency	
Heating Value including Sensible Heat	86%
Heat Loss - Ash and Radiation	6%
Heat Loss of Evaporation	8%
	100%

Efficiency will vary subject to type of fuel material, moisture, material size, and mode of operation.

Plant Size	
Thermex-Reactor	8' Diameter
Raw Material	Sawdust
Moisture	25%
Feed Stock Dry Matter 75%	3000 Lbs./Hr.
Feed Stock Wet Matter 25% (H_2O)	4000 Lbs./Hr.
Higher Heat Value (3000 Lbs. x 8500 B.T.U.)	25.5 M/B.T.U./Hr.
Heating Value including Sensible Heat	21.5 M/B.T.U./Hr.
Captial Cost	
Gasification Equipment	$160,000.00

Annual Operating Cost		
Depreciation	10%	$16,000.00
Maintenance	6%	3,200.00
Utilities	$ .03 KWH (8000 Hrs.)	8,000.00
Operating Labor	Chargeable to System	14,000.00
Insurance and Taxes	2%	1,600.00
Interest	10%	16,000.00
Total		$66,800.00

Annual Gas Produced (8000 Hrs.) 170,000 M/B.T.U./Yr.

Gas Cost $0.39/M/B.T.U.

No consideration is taken for cost of fuel as this varies from region to region.

Material handling or sizing equipment cost is not included as these items may be available at the plant site. Additional cost for gas transfer may be required subject to distance of utilization.

Total installation and energy requirements for specific sites should be reviewed for precise cost as support equipment will be required.

Equipment Cost of Different Sizes

35/M/B.T.U./Hr. 12'Reactor 8000 Lbs./Hr./40% (Moisture) $264,000.00

61/M/B.T.U./Hr. 16'Reactor 14000 Lbs./Hr./40% (Moisture) $420,000.00

(B.T.U./Hr. Production = Higher Heating Value plus Sensible Heat of Wet & Dry Gas)

ADVANTAGES OF THE THERMEX-REACTOR PROCESS

- o makes use of waste material which formerly had little or no value;
- o quality gas (or charcoal) can be produced from any species of cellulosic material;
- o saves on fossile fuel and land-fill costs;
- o low capital and operation cost;
- o low air, power, and maintenance requirements;
- o can be accurately controlled to produce the desired by-products;
- o can be shut down and started up rapidly, suitable for shift operations;
- o continuous process ensures constant quality of all products;
- o higher B.T.U./S.C.F. values than other processes;
- o the equipment requires no housing other than controls;
- o few moving parts guarantees continued low cost performance;
- o tar, oils, and carbons can be stored with the addition of auxiliary equipment;
- o plant expansion requires only a simple addition of module units;
- o module units can be cut from the system operation without seriously affecting gas operation;
- o factory-assembled for quick installation;
- o can be easily re-located;
- o only one skilled laborer is needed to operate several reactors;
- o burn-off of excess gas meets clean air standards;
- o gas production can be interconnected and utilized in package oil or gas burning equipment, drying raw materials, boilers, kilns, buildings, or other related purposes;
- o flexibility of design allows for adaptation to a variety of industries;
- o ash or charcoal is removed continually;
- o the process will accept all fines; and
- o controlled temperatures prevent sintering and fusion.

SECTION 5.4

RECENT OPERATING EXPERIENCE WITH A SMALL DOWN-DRAFT WOOD GAS GENERATOR

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ABSTRACT

Hardwood blocks, softwood blocks, wood pellets, and charcoal were gasified using various oxygen-air mixtures. The gasifier system used was a Swedish Hessleman Model 50/13 generator. The unit ran on all feeds and oxygen concentrations from 21% (air) to 100% without alteration. The gas produced was burned in a standard North American industrial burner with no modifications. It was also used to fuel a modern Datsun 510 (100 hp.) internal combustion engine. The heating value of the gas produced ran 110+, 200+, 260+ Btu/ft^3 (4.10 x 10^6, 7.45 x 10^6, 9.69 x 10^6 joules/m^3) for oxygen concentrations of 21, 50, and 100%.

Compared to the up-draft gas generator the down-draft generator

*Produces a gas containing less liquid and tar products.

*Is considerably smaller for the same output: 3 x 10^6 Btu/ft^3 reactor volume (112 x 10^9 joules/m^3) and 3 x 10^6 Btu/ft^2 of hearth (34 x 10^9 joules/m^2)

*Is as efficient for close couples systems.

It can be mass produced at modest cost for 20-500 hp engines (14,500-363,000 watts) and 50,000 to 1,250,000 Btu/hr burners (14,500-363,000 watts). Some modifications are necessary for a continuous feed system.

INTRODUCTION

The number of gas generators in Sweden at the end of World War II was about 100,00, of which about half were wood-gas generators [1]. Gengas [1] states that in a wood gas generator a down draft system must be used, and the hearth should have a constriction in the passage area so that high temperatures are obtained. This causes the distillation products which are harmful to the engine to be completely burned or decomposed [1]. This hearth design limits down-draft generators to the modest sizes of 20 to 500 hp or 50,000 to 1,250,000 Btu/hr (14,500-363,000 watts). These units had a low cost because of their size, relative simplicity, and mass production. Table 1 presents some of the common sizes of wood gas generators.

Table 1
SOME SWEDISH WOOD GAS GENERATORS

Manufacturer	Model Number	Overall Height (mm)	Diameter (mm)	Throat Diameter (mm)	Hopper Capacity (hl)
Hesselman:	50/13	1850		130	2,0
do	55/15	1850		150	2,7
Bolinder/Trim:	13/50	1850		130	2,0
do	15/55	1850		150	2,7
do	17/55	1850		170	2,7
do	17/75	2330		170	6,0
do	17/75	1600		170	3,2
Imbert:					
Wulf & Co	130/550/170	1700		130	2,4
do	150/550/170	1700		150	2,4
do	150/650/210	2100		150	3,4
do	170/650/210	2100		170	3,4

Source: Gengas [1].

A Hessleman gas generator was obtained by the Department of Chemical Engineering, WVU from Sweden several years ago. It was learned of from two Swedish railroad buffs seeking narrow gage steam locomotives in the coal areas of W.Va. In their search for engines in Sweden they came across four units in a round house that had been crated and stored. They were built to provide feed to an internal combustion engine that ran a 50 Kw electric generator. The units were first generated by undergraduate students in the department as a part of a national competition (SCORE - Student Competition On Relevant Engineering) on use of underutilized feeds to provide power. It was then set aside and only recently re-comissioned.

This Hessleman generator was tested in 1978 at Environmental Energy Engineering's commerical testing facility near Morgantown, West Virginia. This system was tested because in the United States little attention has been given to the down-draft concept. This system also permitted easy extenstion to oxygen enriched air operation and the use of wood pellets.

DESCRIPTION OF HESSLEMAN

The gas producer used was a Hessleman Vedgasverk, Type T-500. This is a suction type gas producer with a throat diameter of approximately five inches (0.130 m.). For the tests performed at EEE the gasifier was not operated as a suction system but was blown with air or oxygen enriched air. Figure 1 is a sketch of the gasifier with some of the significant dimensions. The gasifier had five air nozzles equally spaced around the circumference of the generator. The gasifier top is sealed with a spring loaded door which keeps the unit air tight. This top acts as a relief valve if an explosion should occur and permits easy opening for charging fuel to the gasifier. The product gases leave the gasifier by passing up through the annulus and out near the top. The gas immediately enters a cyclone for removal of some of the entrained solids.

DOWN-DRAFT VERSUS UP-DRAFT

Figure 2 compares the up-draft, conventional down-draft, and the Hessleman generators. In the up-draft generator the distillation occurs in the top of the fuel bed and the distillation products leave with the product gas. In the down-draft generator the distillation also occurs in the top of the fuel bed but the distillation products must pass down through the combustion and reduction zones. This results in a greater decomposition of the condensables. The Hessleman generator is a down-draft generator with a constriction in the hearth. This constriction results in higher temperatures which helps to decompose the tars and condensables [1]. Some of the advantages of the up-draft system are:

* Simplest design.
* Most of the sensible heat in the product gases is used to dry, preheat, and distill the fuel.

Some advantages of the conventional down-draft system are:

* Design simplier than the Hessleman but provisions for air distribution should be included.
* More of the tars are decomposed.
* Less clinker formation [2].

Additional advantages of the Hessleman down-draft system are:

* Even more of the tars are decomposed.
* Some of the sensible heat is transferred to the fuel bed as the gases leave through the annular space.

In close-coupled systems where the gases are used in burners there is no difference in the efficiencies, because the sensible heat in the down-draft gases is also used. For systems which are not close-coupled this sensible heat is lost but the tars from the up-draft generator condense and are lost. In internal combustion engines the up-draft generator gas must have the tars removed to protect the engine and the down-draft generator gas must be cooled to permit a sufficient quantity of gas to enter the engine cylinders. Figure 3 indicates the amounts of tars that must be lost in an up-draft system to equal the amount of sensible heat lost in the down-draft system.

PRESENT STUDIES

The studies at E.E.E. operated the Hessleman generator on the following

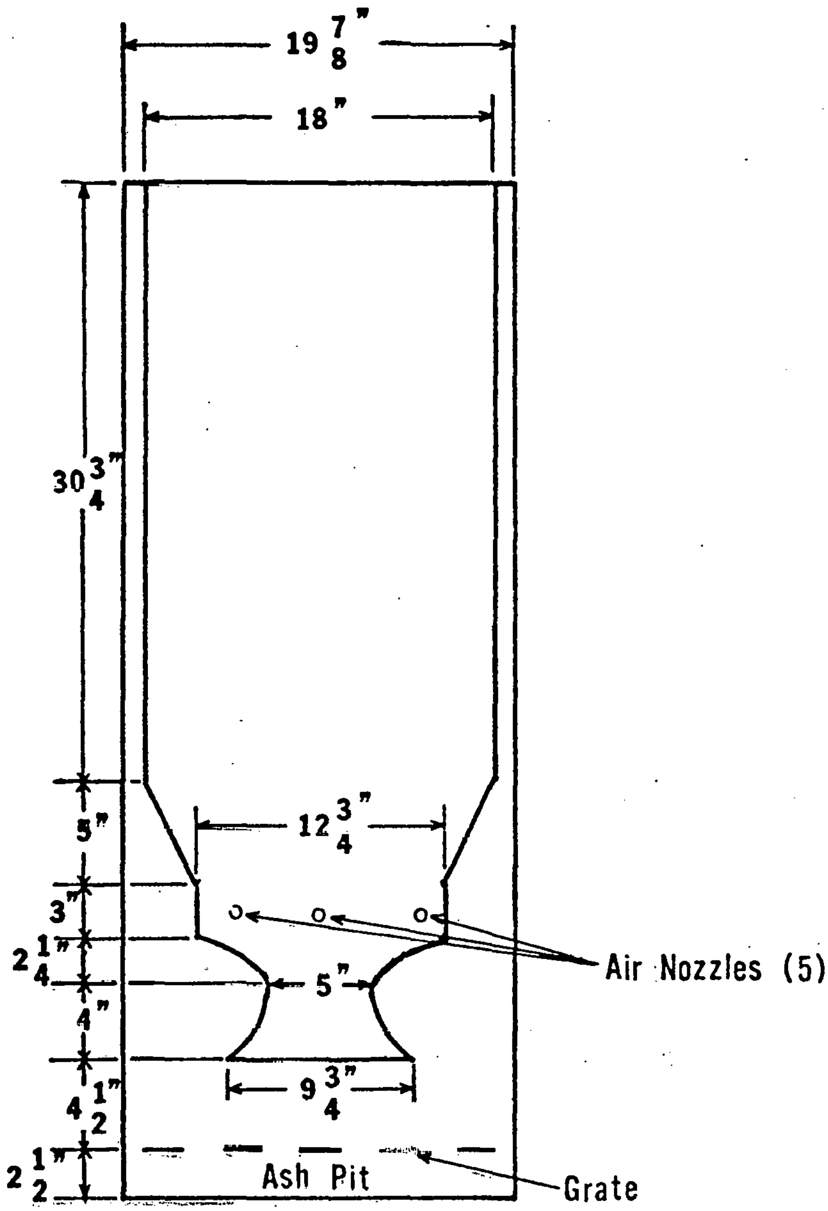

FIGURE 1. HESSLEMAN GAS GENERATOR

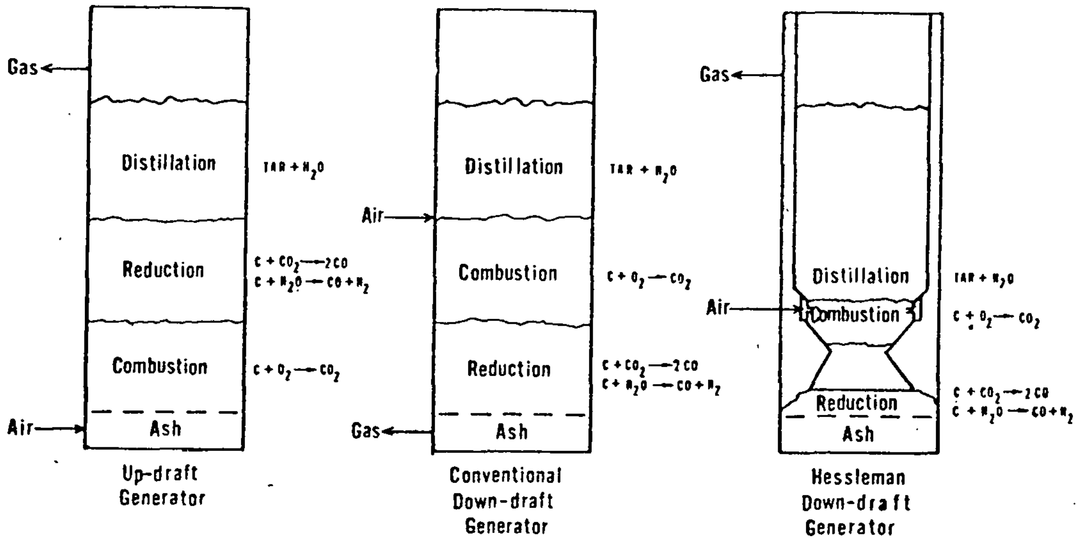

FIGURE 2. COMPARISON BETWEEN UP-DRAFT AND DOWN-DRAFT GENERATORS

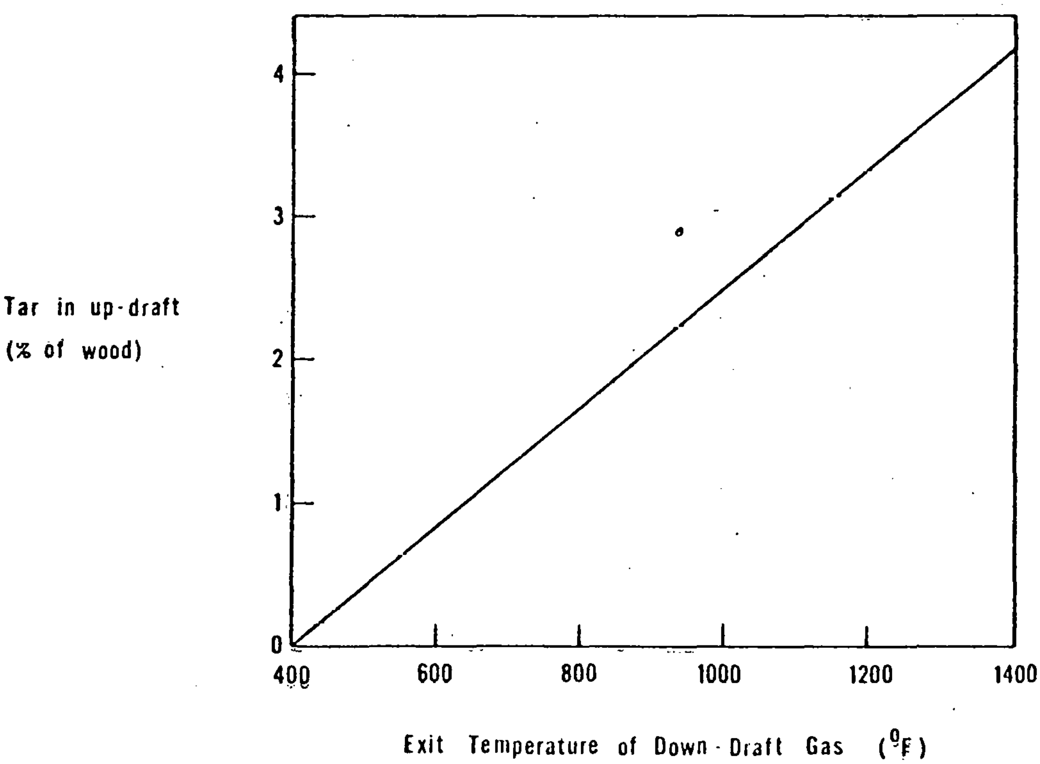

FIGURE 3. CONDITIONS FOR EQUAL EFFICIENCIES

fuels:

* Charcoal briquets.
* Unprocessed charcoal (as received from a charcoal kiln).
* Hardwood blocks -- slab wood cut into 1 in. x 1 1/2 in. x 3 in. (25 mm x 37 mm x 76 mm).
* Softwood blocks -- 2 in. x 4 in. lumber cut into 1 in. x 1 1/2 in. x 3 in. (25 mm x 37 mm x 76 mm).
* Wood pellets -- Compressed sawdust 1/4" D x 3/4" long (6 mm D x 19 mm long).

The generator was blown with air, oxygen enriched air, and pure oxygen.

The generator gas was successfully used in an industrial burner and an internal combustion engine. The industrial burner was a North American Series 4422 XS Air Burner. The burner designation is 4422-7A. No modifications of the burner were needed. The internal combustion engine was a Datsun type PL-510. The engine capacity was 1595 cc and had a maximum horsepower rating of 100 at 6000 RPM (SAE). The engine was operated with no load. The only modification necessary to operate the engine was to install a gas carburator, which was obtained with the generator.

PERFORMANCE

Figure 4 presents a temperature profile along the vertical axis for the gasifier. The fuel was wood pellets and the gasifier was air blown. An attempt was made to measure this temperature profile for a 40% oxygen blown test, but the thermocouple probe was melted. This occurred in the air nozzle plane and suggests that the temperature was above 2550°F (1670°K).

Figure 5 presents the effects of the oxygen concentration on the CO, H_2, and CH_4 concentrations in the generator gas. Figure 6 gives the effect of the oxygen concentration on the heating value of the generator gas. As would be expected the concentrations and the heating value increase as the oxygen concentration increased.

The engine was operated without a load but the power loss due to using generator gas was deduced from the gas heating value. Figure 7 presents the power loss for different oxygen concentrations of the blown gas. These curves are based on the generator gas being burned stoiciometrically and the gasoline being burned stoiciometrically, and with 10% and 20% excess air. Complete combustion of the gasoline should require more excess air than will be required for the generator gas. These curves show that operating the generator with oxygen enriched air reduces the power loss of the engine.

EPRI [3] has determined the effect of the heating value of the gas on burner efficiency. This is shown in Figure 8. The efficiency of the burner increases as the heating value increases until a heating value of 225 Btu/ft^3 (33.3 x 10^6 joules/m^3) is reached. The efficiency then decreases as the heating value increases. Two other factors to consider are the amount of air required by the fuel and the amount of

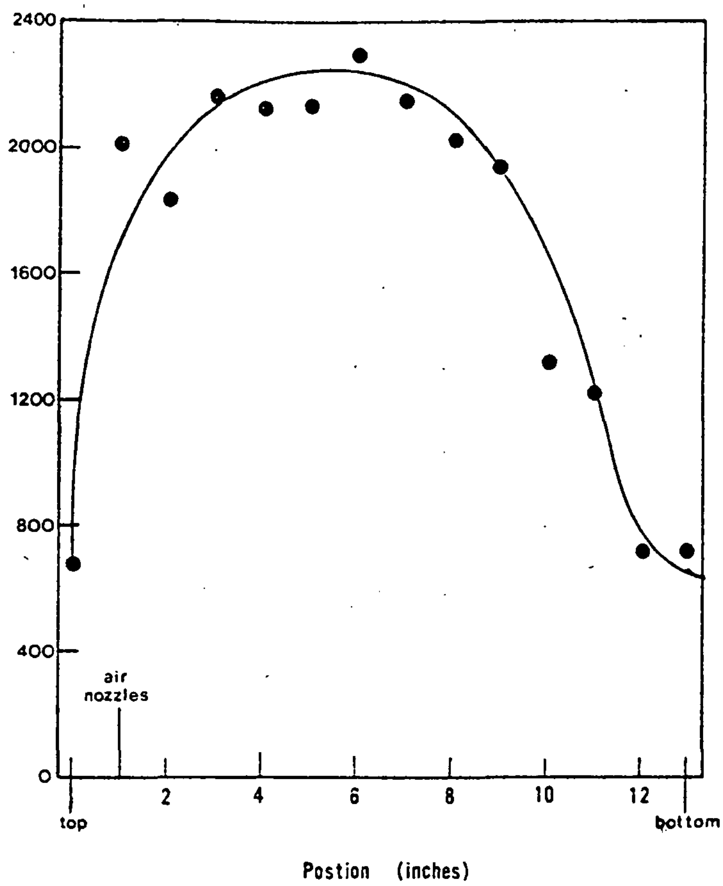

FIGURE 4. TEMPERATURE PROFILE FOR AIR BLOWN TESTS

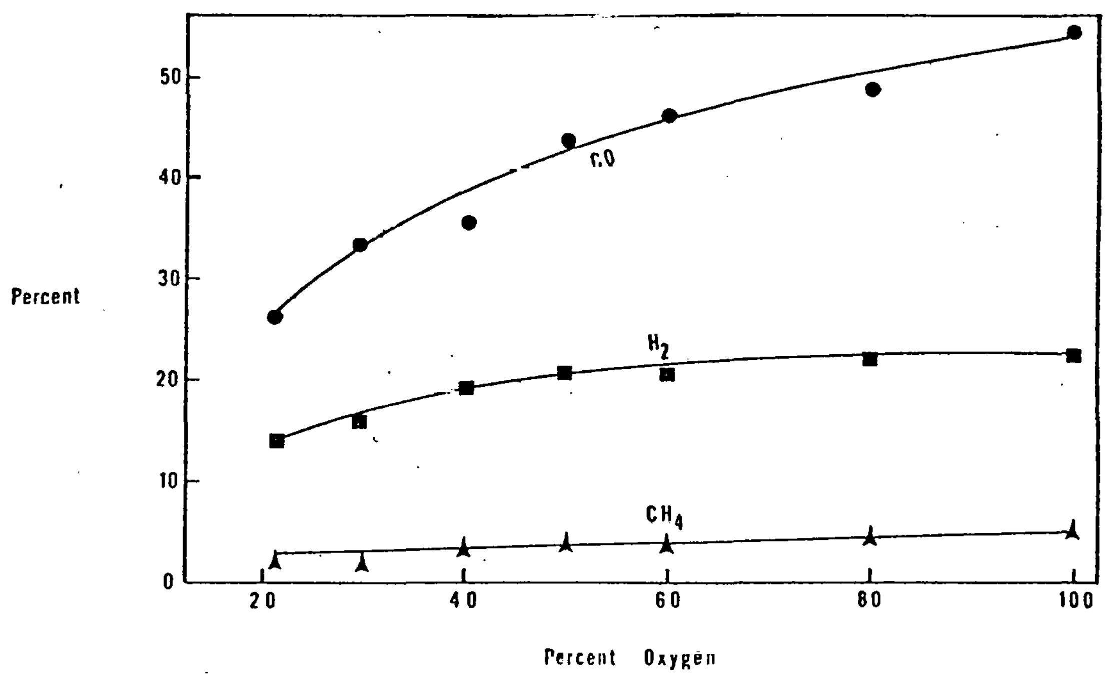

FIGURE 5. EFFECT OF OXYGEN CONCENTRATION ON GAS COMPOSITION

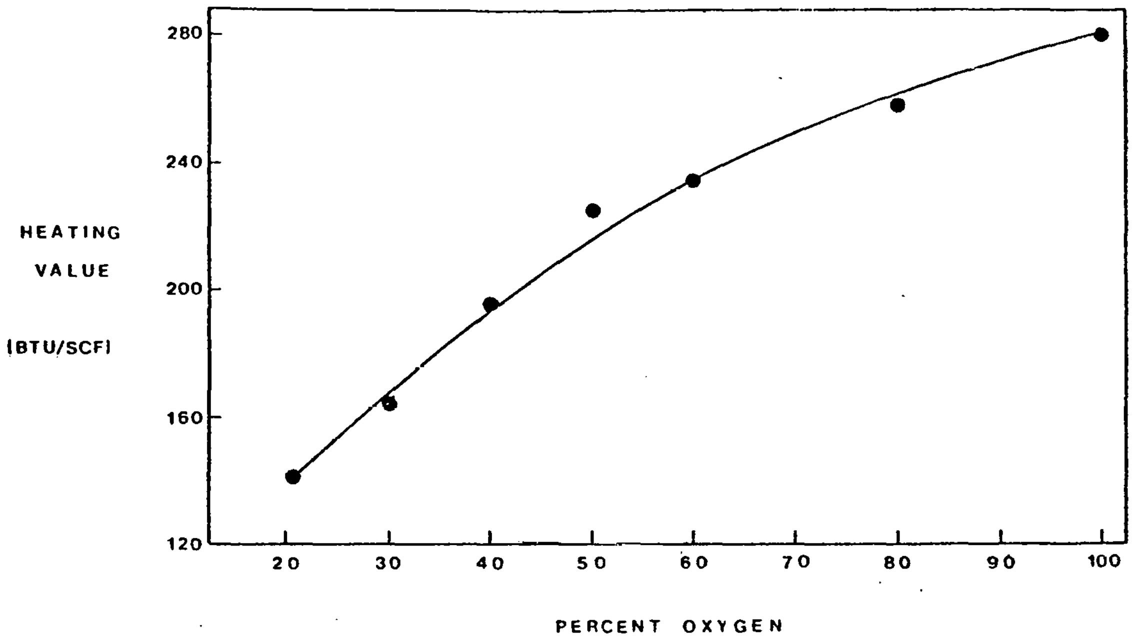

FIGURE 6. EFFECT OF OXYGEN CONCENTRATION ON GAS HEATING VALUE

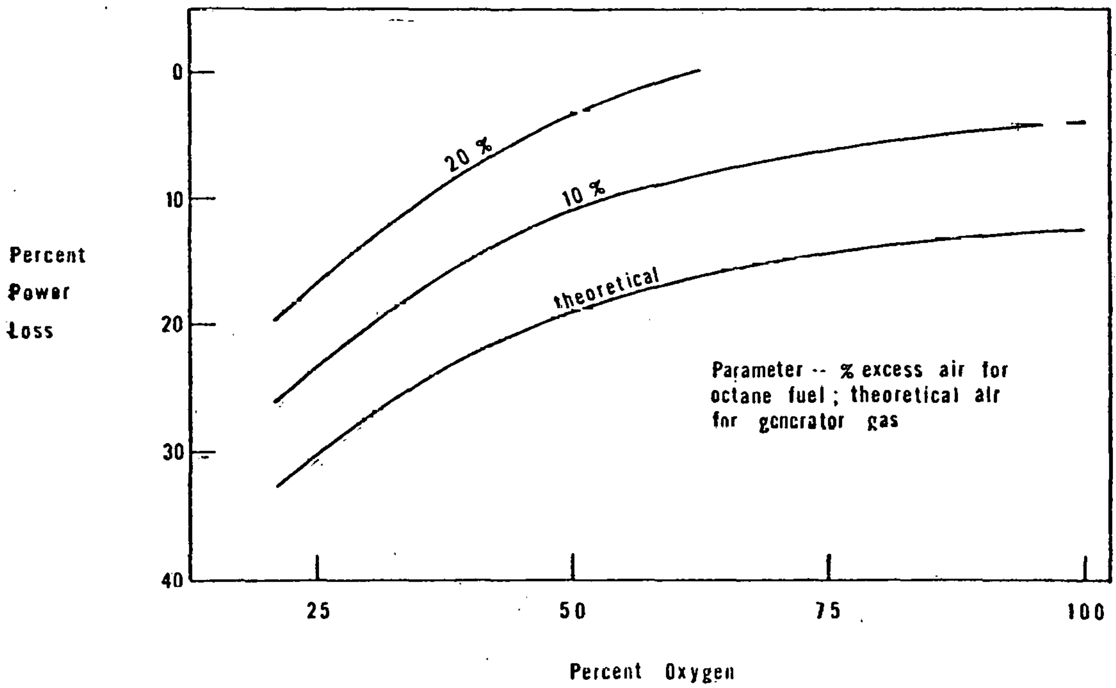

FIGURE 7. EFFECT OF OXYGEN CONCENTRATION ON ENGINE POWER LOSS

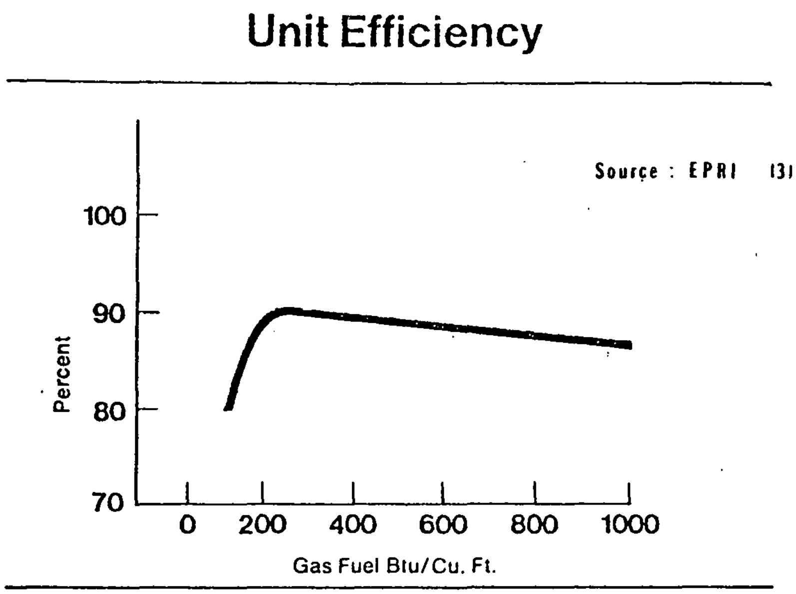

FIGURE 8. UNIT EFFICIENCY

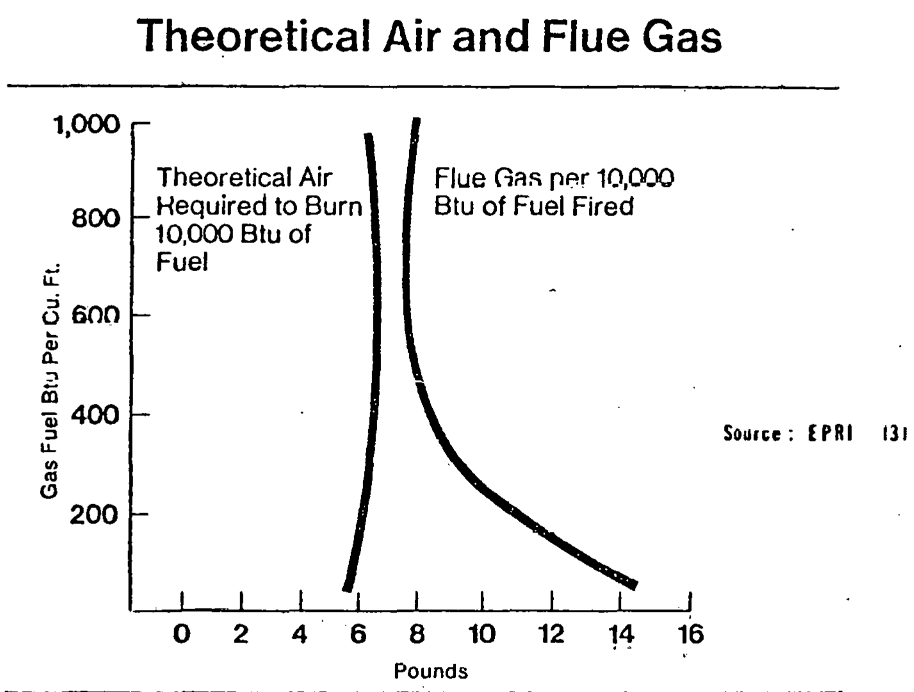

FIGURE 9. THEORETICAL AIR AND FLUE GAS

flue gases produced. These are shown in Figure 9. The amount of air required to burn 10,000 Btu (41.9 x 10^6 joules) of fuel does not depend much on the gas heating value. The amount of flue gas is also fairly independent of the heating value of the gas for values greater than 300 Btu/ft^3 (44.4 x 10^6 joules/m^3). The amount of flue gases then increases as the heating value decreases. For example the amount of flue gases for 200 Btu/ft^3 (29.6 joules/m^3) gas is 44% greater than that for 1000 Btu/ft^3 (148 x 10^6 joules/m^3).

CONCLUSIONS

* Can oporate a burner with no modifications.
* Can operate an internal combustion engine with the only modification being in the carburator.
* Can handle enriched oxygen.
* Should have a relatively low cost.
* Can handle a variety of fuels.
* Compared to up-draft the gas has much less tar.
* The close-coupled efficiency of the up-draft and down-draft should be the same.
* Should be able to be fit with a stoker for continuous operation.
* Has a high turn down ratio-about 12 to 1.

ACKNOWLEDGEMENTS

This study was carried out under a Solar Energy Research Institute contract number AH-8-1077-1. Gratefully appreciated is the invaluable help given by the SERI personnel, including the translation of the Swedish book "Gasogens". Alos apprcciated is the help given by Chuck Clovis and Preston Todd in preparing the fuel and operating the gasifier.

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SECTION 5.5
VEHICLE GASIFIERS

by Eric Johansson
Director of the National Swedish Testing Institute for Agricultural Machinery

ABSTRACT

The pioneer work of the use of producer gas as a fuel for internal combustion engines was carried out in Great Britain, Germany and France.

Basic research work in the design of gasifiers was done already during world war I by Mr Axel Swedlund in Sweden.

The most important feature of the producer gas in Sweden is to serve as a fuel substitute at a shortage in the supply of liquid fuel.

Recent research and development work at the National Swedish Testing Institute for Agricultural Machinery has been devoted to the converting of the generators to suit modern diesel engines and to improve the gas cleaners.

VEHICLE GASIFIERS

The use of producer gas as a fuel for internal combustion engines is not a new approach from a technical point of view. Gasifiers were thus both designed and put into practical work as early as the beginning of the 20th century. The pioneer work was done in Great Britain, Germany and France. Anthracite, brown coal, peat and wood were used as fuel.

In Sweden a considerable interest was paid very early to the production of producer gas. Basic research was carried out by Axel Swedlund, who already during world war I designed a gasifier for stationary work. The Swedlund-system was then further developed during world war II.

During world war II the import of liquid fuel to Sweden was very limited. The practical use of vehicle gasifiers became then very important. The numbers of designs and manufacturers were large. Already at the beginning of 1940 more than 1 500 vehicle gasifiers were in practical service. This number grew rapidly and reached 75 000 at the end of the war 1945. At that time we had at least 500 different designs. Some of these dominated the market. Besides System-Swedlund we had Imbert, Hesselman, Lion, Källe and Betz. System-Swedlund was made in appr. 35 000 copies.

After world war II the vehicle gasifiers disappeared just as rapid as they had been put into use. The use of producer gas as a fuel for internal combustion engines was no longer of interest when we once more got free access to cheap liquid fuel. The drawbacks in the shape of decreased power performance, tedious work and the risks of carbon-monoxide poisoning were evident. The most important feature of the producer gas was thus to serve as a fuel substitute at a shortage in the supply of liquid fuel.

The increased mechanization of both agriculture and forestry together with the very rapidly growing numbers of diesel engines in tractors, trucks and combines have required new research and development work in the field of wood gasifiers. Since the beginning of the 1950th the National Swedish Testing Institute for Agricultural Machinery has been responsible for all official work in this field in Sweden. The larger part of this research has been devoted to the converting of the generators to be used together with diesel engines.

Due to the fact that the numbers of vehicles have increased more than 10 times since world war II, the switch over to producer gas to be used as an engine fuel has become a question of mass production. In the year of 1978 we had approcimately 3 000 000 cars and trucks besides 250 000 tractors. The corresponding figure for the total number of vehicles in the year of 1940 was 250 000.

It has therefore been necessary to modify the present gasifier - designed for research work - to be suitable for regular massproduction. Swedish authorities have therefore made an agreement with Volvo and Saab-Scania to develop a standard design of wood gasifiers in co-operation with the National Swedish Testing Institute for Agricultural Machinery.

Wood as an engine fuel

Wood is at present the only Swedish alternative to liquid fuels that will last for a long time. The wood must either be chipped or cubed. Chipped wood is planned to be produced in large scale at different paper mills while cubed wood is planned to be made locally for instance at the regular farms. Spruce, pine, birch and beech are examples of trees that will give wood suitable for gasifiers.

The function of the gasifier

A PRINCIPAL DRAWING OF A GAS GENERATOR

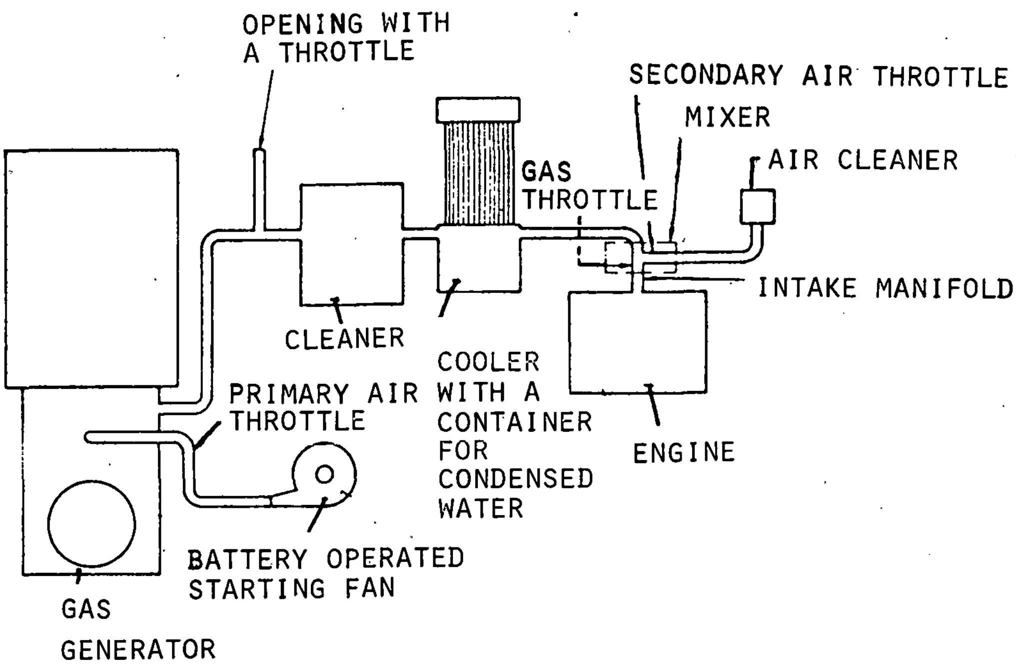

Figure no 1. A gasifier or generator is required to make producer gas suitable as engine fuel. A complete gasifier consists of a generator, cleaner, cooler and mixer.

WOOD GASIFICATION

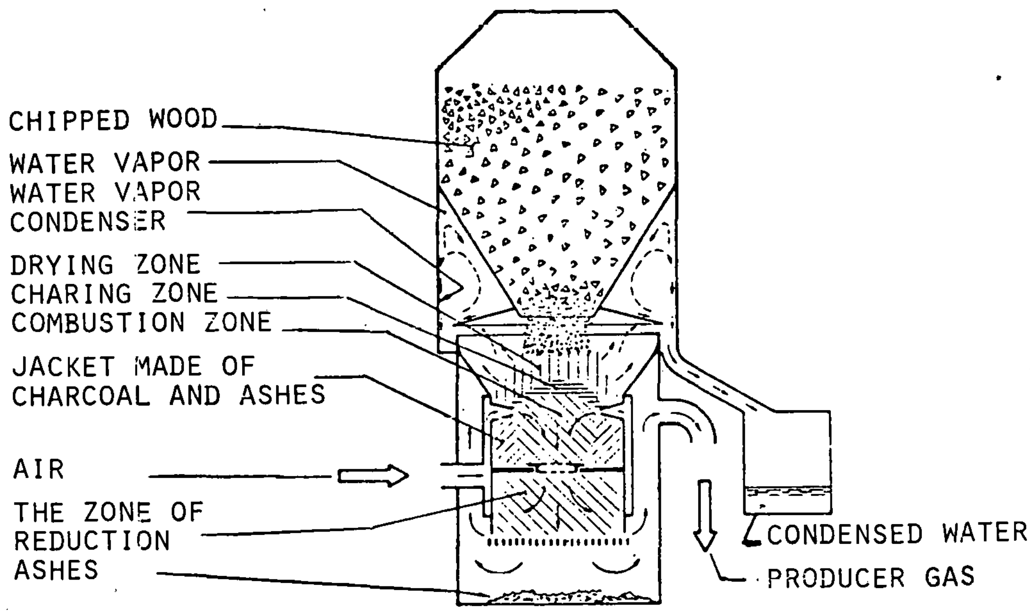

Figure no 2. The producer gas will be formed through combustion of wood at restricted air supply in a gasifier.

A GAS GENERATOR FOR CHIPPED WOOD

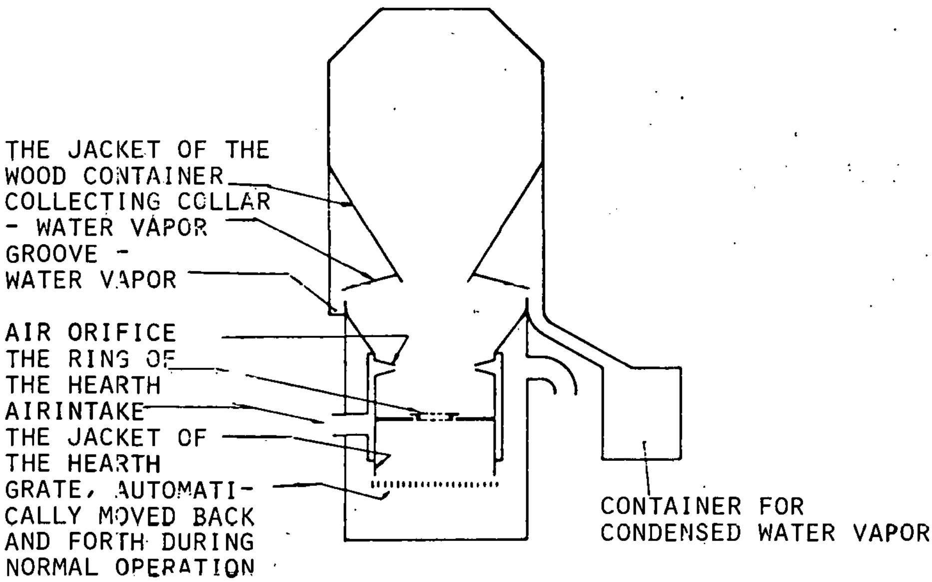

Figure no 3. The components of a wood gasifier for chipped wood. A movable grate is required when chipped wood is used. Considerable design effort has also been payed to the design of the hearth.

The components of producer gas

The producer gas contains besides carbon monoxide and hydrogen also other combustible components such as small amounts of methane and some heavy hydrocarbons.

The noncumbustible components are nitrogen, carbondioxide and water-vapor.

The residues consists of ashes and soot.

An analysis of producer gas originating from wood with a moisture content of 12 - 20 % shows the following components.

Combustible components (volume %)

Carbon monoxide, CO	17 - 22 %
Hydrogen, H_2	16 - 20 %
Methane, CH_4	2 - 3 %
Heavy hydrocarbons, C_nH_m	0,2 - 0,4 %

Noncombustible components

Carbondioxide, CO_2	10 - 15 %
Nitrogen, N_2	45 - 50 %

EQUIPMENT FOR THE AUTOMATICALLY OPERATION OF A GRATE MOUNTED TO A GASGENERATOR DESIGNED FOR CHIPPED WOOD.

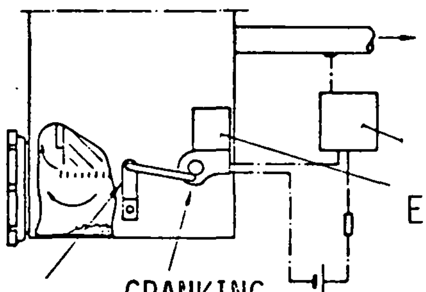

Figure no 4. The automatic operation of a grate mounted to a gas generator which is designed for chipped wood.

Function: When the charcoal bed in the zone of reduction chokes up the producer gas in the outlet pipe gets a still lower pressure than normal. This low pressure will influence the pressure gauge which will switch on the electric motor whose cranking movement is converted to a movement of the grate back and forth. After a short while the charcoal bed will become soft.

The pressure gauge will again stop the movement of the grate as soon as the pressure reaches its normal level.

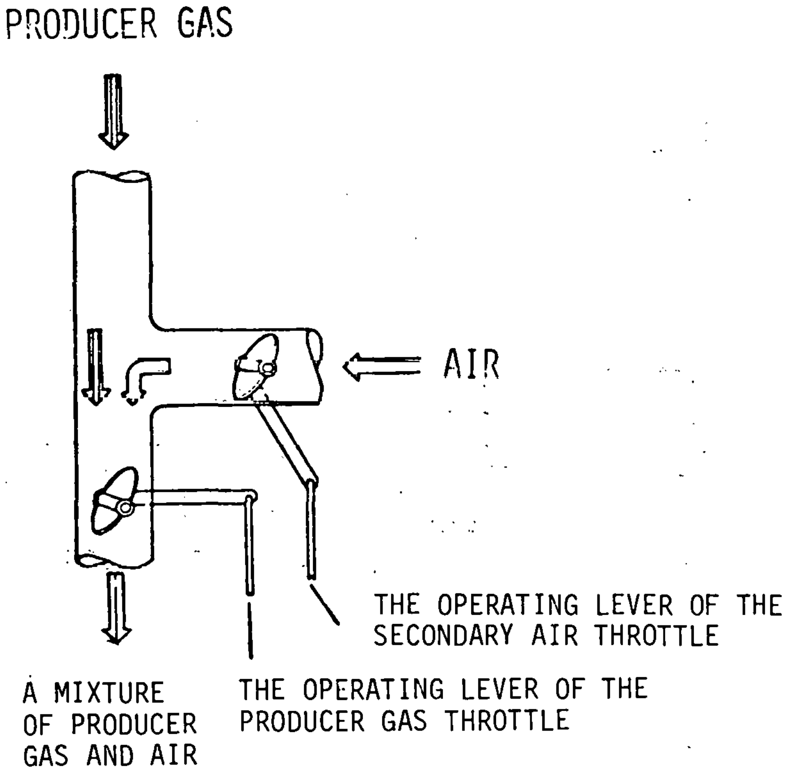

Figure no 5. The device for the mixing of air and producer gas.

Safety aspects

Producer gas is poisonous due to its content of carbon monoxide. This gas neither smells nor does it tastes. The inhilation of carbon monoxide can be very dangerous. It is therefore very important that a person who operates a vehicle running on producer gas is well informed and properly trained and thus aware of the actual safety rules.

SECTION 6.0

SUMMARY OF REMARKS

OF A PANEL ON COMMERCIALIZATION OF AIR GASIFIERS

A panel of representatives of various institutional organizations was convened under the direction of Mr. Robert Hodum from the California Energy Commission to discuss possible ways in which the introduction of air gasification could be accelerated. The members of the panel were: Victor Engleman (Science Applications, Inc.), John Calhoun (Forest Fuels), George Finney (Halcyon Co.), Howard Ammundson (Century Research), John Stafford (Guarantee Fuel).

Each panel member made a statement of his own activities and answered questions from the floor. The remarks are summarized here from recordings made at the time.

ROBERT HODUM: California has had an ongoing program of demonstration of the feasibility of gasification, especially at the University of California in Davis, and John Goss, Brian Horsfield, Robert Williams and others have worked on that program. (Bob Williams has now formed a company to manufacture gasifiers and the gasifier was demonstrated Tuesday through Thursday afternoon before the conference.) Several long-term demonstrations were operated last year at state power plants. California (1) is now buying gasifiers for state heating needs and (2) has appropriated $500,000 to co-fund gasifier and other biomass conversion equipment with industry. In the first RFP there were no purchasers for gasifiers due to the novelty and questions of reliability of gasifiers still remaining in the minds of purchasers. Another RFP will be issued in July. These incentives are also available to suppliers of biomass.

VICTOR ENGLEMAN: It is necessary to match the application to the need, and gasifiers have wide but not universal applicability. Some markets are limited, e.g., there are only two major seed corn driers in the United States.

There is still a 'show me' attitude among U.S. customers since there has been no past history of gasifier use in the U.S. as there was in Europe. Maximum market penetration will only occur when one can produce a satisfied customer. The oil industry has had fifty years to develop its refineries, and no doubt there were technical problems to resolve. However, these problems were worked out in the privacy of the companies. If gasifiers are developed on public monies, the problems will be given wide publication and slow down commercialization.

Customers tend to want a complete package installation on gasifiers, including wood delivery and handling. Yet various options are available for each piece of the package. This leads to confusion in the customers' mind which in turn leads to inactivity.

Incentives are needed to convince customers to burn less convenient fuels such as biomass, and gasifiers will have to have more than a 10% initial economic edge as long as natural gas is available to overcome initial reluctance. However, when gas or oil becomes unavailable, the customers will turn to biomass which they can control themselves.

Hodum commented that he is in continual debate with the California Legislature as to whether it is better to provide incentives or run demonstrations. He believes there is a place for both.

JOHN CALHOUN (Forest Fuels) commented that even a 50% federal subsidy is often not sufficient to convince the customers to buy a gasifier which he considers to be unproven. However, GEORGE FINNEY (Halcyon Company) believes that the use of gasifiers will develop purely on their economic merits, and he is now installing two gasifiers in Maine and in Atlanta (25 MBtu/hr) on this basis. Finney wants no part of federal government help or interference. He will guarantee less than 0.025 grains of particulate levels. He has met difficulty with the State of Georgia. It took three months to complete the plant engineering and four months to obtain the purchase order through the state legislature. Cost of complete gasifier (minus wood handling ancillaries) is $220,000 for a 25 MBtu/hr gasifier.

HOWARD AMMUNDSON (Century): How can the large investment in a gasifier be amortized over 10 to 20 years in these changing times? (Century has been making gasifiers ranging from automotive gasifiers to 80 MBtu/hr gasifiers for crop production for 40 years in Taiwan for firms in the Far East.)

BENDERSKI (Pyros): The 1978 Agricultural Act of the U.S. Department of Agriculture, while initially intended to support gasohol plants, could in principle also be used to give loan guarantees for gasifier installations. It gives a firm commitment of low-interest loans to the buyer/seller.

JOHN STAFFORD (Guarantee Fuel): We are now negotiating two $6 million loan guarantees for making pelletized fuels under a similar arrangement.

FINNEY (Halycon): Another problem is establishing a long-range supply of fuel. We now have orders for six plants in Massachusetts if we can guarantee a continuing supply of fuel. How can we overcome this barrier?

HODUM: In California, the State is acting as a customer for biomass fuels to even out the supply. For instance, a 1500 MW coal power plant is being constructed in an area with large quantities of biomass. We are encouraging them to install biomass co-firing capability on the boiler.

REED (SERI): This is related to the "Golden Garbage Syndrome" discovered by Wheelebrator-Frye. Any municipality now paying $12/ton to dispose of its garbage would be delighted to have you haul it away - until you volunteer to do so. Then you can't have it. Wheelebrator-Frye overcomes this problem by forming a joint parternship with the town and keeping open books showing only a fair profit.

SECTION 7.0

SUMMARY OF REMARKS OF A PANEL ON TECHNICAL ASPECTS AND RESEARCH NEEDS OF AIR GASIFIERS

A panel of representatives of various gasifier manufacturers and research organizations was convened to discuss technical problems of air gasifiers, and to consider areas where further research is needed to improve gasifier performance. Dr. Tom Reed served as moderator of the discussion.

Each panel member briefly introduced himself and his involvement with air gasifiers before the discussion was thrown open to the entire workshop. The discussion is summarized here from recordings made of the meetings.

Stan Bozdech, DeKalb Ag Research

Six years ago DeKalb decided to try to use their corncobs for drying seed corn, which presently requires liquid propane. After trying several direct combustion processes unsuccessfully, they began a program to develop a corncob gasifier. They have a gasifier which they used to dry seed corn and are considering building a number of larger units.

Howard Ammundson, Century Research

Century Research has been involved with gasifiers in Taiwan and before that in China. In the 1940's they built and repaired gas producers. They operated a 85 MBtu/hr gasifier in Taiwan before natural gas was discovered and made gasification uneconomic.

John Calhoun, Forest Fuels

Forest Fuels has built several sloping grate gasifiers over the last four years, and has several units running including one firing a 12 MBtu/hr kiln. The Department of Energy states that half the energy in the United States is burned in units smaller than 10 Btu/hr, so they are comfortable to be in that market.

Richard Bailie, Environmental Energy Engineering

EEE does commercial testing of gasification units, but has no products or units to sell.

Amil Chatterjee, Stanford Research Institute

Before joining SRI, Amil Chatterjee worked for Torox Systems where he built, tested, and installed the Torox gasifier which gasified municipal solid waste. SRI is involved with Biomass studies for DOE. He believes there is still analytical and research work to be done to optimize the design of gasifiers. The definition of the combustion, pyrolysis, and reduction zones, and the way these zones vary with time, moisture, contact, etc., need further attention, in order to make a scientific design of a gasifier.

There was considerable discussion as to whether future advances in gasification technology will be due to computer modeling studies of the gasification reactor, or due to "hands on" hardware development by persons experiencing the problems or operating the present generation of gasifiers. One group maintained that a relatively small effort aimed at better understanding of the gasification reaction would prevent costly mistakes in the development of hardware. A second group maintained that no combustion system had ever been designed satisfactorily by computer simulation, and warned the conference against calling for even more computer studies. Perhaps Dick Bailie had the last say when he stated that both types of research are necessary, with the function of computer simulation being to indicate to the researcher the direction in which breakthroughs might occur, and that then these areas had to be explored with actual hardware to confirm the computer analysis.

Howard Ammundson suggested that we need to emphasize fuel handling systems and fuel preparation. When fuels are properly prepared, many of the operating problems do not arise. John Calhoun said that the paper companies have had many years of experience handling wood materials, and that much of the same technology works for fuel woods.

Bob Williams asked if anyone had suggestions on how to interest the American engine manufacturers in developing engines suitable for power generation with gasifiers. He said "when I call Peoria and Waukesha, their engineers say yes, Bob, we are interested in what you are doing, but they really aren't much help to us." Tom Reed suggested that if we tell them about the Duetz engine being imported for a 1 MW plant in Prince Edward Island, and the Duvont engines being imported to the United States, they will be more interested in protecting their markets. Bob Williams said he had tried to blackmail them that way, but until they can see large markets for their engines they just are not interested.

Amil Chatterjee asked if anyone had experience with gas turbines operating on low Btu gas and what the future of gasifiers coupled directly to a turbine was. Ralph Overend said that in Europe the off-gas from blast furnaces is used in gas turbines. This gas is somewhere around 90 Btu/Scf. Pete Stranges from United Technology said they have run gas turbines on low Btu gas from coal. United Technology had to modify the combuster a bit but otherwise the turbine worked fine. UT is concerned about the particulates. The gas clean-up is important. UT has limited experience: maybe 10 hours of running time, but sees no major difficulties.

Tom Reed asked how much economic penalty there is in operating if the gas is at 1 atmosphere pressure. What advantage is there for pressurized gasifiers? Pete Stranges replied that normally gas turbines operate at 10-15 psi, and expand to 1 atmosphere. They will lose a lot of performance if they don't operate the gasifiers at pressure.

Dick Bailie thought we were confusing the issue by discussing the use of gasifiers for turbines. Gasifiers should be used for what they do best: that is, produce a gas that burns. Burn it in cement kilns, for crop drying, or in a furnace. If we go to these complicated units we will have to wait five years to see the first units in operation.

Amil Chetterjee asked what the advantages of pelletized fuel for a gasifier were and whether a better Btu gas was obtained. Dick Bailie replied that a better Btu gas was not obtained. Sawdust cannot be burned in a gasifier, because the void space in the bed is needed to push the gas through. Pelletized sawdust works fine. The same may be true for other potential fuels.

(These comments are a paraphrased and condensed version of the overall discussion, which lasted for 1 1/2 hours. Although considerable discussion of a non-technical nature also took place, it has not been included in this summary.)

SECTION 8.0

TECHNOLOGY AND ECONOMICS OF CLOSE-COUPLED GASIFIERS FOR RETROFITTING GAS/OIL COMBUSTION UNITS TO BIOMASS FEEDSTOCK*

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Solar Energy Research Institute
Golden, Colorado

ABSTRACT

Close-coupled air gasifiers can be used to convert existing gas/oil boilers to burn biomass. The gasifiers are relatively simple units operating at 85 to 90% thermal efficiency. The gas contains CO, H_2, hydrocarbon gases and vapors with N_2, H_2O, and CO_2 dilutents, and has a heating value of 140 to 200 Btu/scf when burned hot without scrubbing. Use of this gas in existing boilers may cause 5 to 10% derating. Recent tests of a 14 MBtu/hr gasifier coupled to a power boiler in California over a 158 hour period gave satisfactory results with low emissions and only minor technical difficulties.

The economics of two gasifiers reported in the literature are analyzed with respect to fuel cost as a function of capital and operating costs. The gas is estimated to cost $1.40 to $2.70/MBtu for biomass feedstocks costing $10 to $20/dry ton. The capital costs of retrofitting existing gas/oil boilers are approximately two-thirds the cost of new installations of package wood-fired boilers. Although gasifiers larger than 100 MBtu/hr are not now available, they could probably be used to convert larger field-erected boilers to biomass more economically than construction of new wood-fired boilers. The cost of construction of a new wood-fired package boiler is estimated to be about the same as the cost of a gasifier plus a conventional gas/oil package boiler.

*Presented at "React '78," The Biomass Energy Institute, Winnipeg, Canada, October 3-4, 1978.

INTRODUCTION

Industrial concerns will need 20/20 foresight to cope with the increasing energy problems in our society. Many, who converted from coal to natural gas or oil during the last decade to meet more stringent emission requirements, are faced now with much higher fuel prices and the possible curtailment or total interruption of supply. The most obvious course is conversion of those boilers originally using coal back to coal or wood, or the replacement of the new oil/gas package boiler with a new coal/wood installation. Both of these options are relatively expensive and will also require new emission controls.

A less obvious option is the use of a biomass (or coal) gasifier to retrofit the existing gas/oil boiler to an intermediate energy gas generated in situ, using the close-coupled gasifier. We shall examine the technology and economics of biomass gasifiers, and compare the economics of retrofit with installation of complete combustion installations for biomass.

HISTORY AND STATUS OF GASIFIERS

The term "gasification" refers to the thermal conversion of biomass (or coal or petroleum) to a gas to be used for heat, power, or chemical synthesis. "Pyrolysis" actually implies production of charcoal or oil as well. A recent worldwide survey lists 55 commercial or demonstration gasification and pyrolysis projects in North America.[1] In the 1930's, most cities of the United States had a "gasworks," gasifying either coal or wood to provide gas for cooking and lighting. These units have been closed down in the United States due to the availability of low cost natural gas and oil, but gasification of biomass has been widely used in other parts of the world.[2] Small portable gasifiers were widely used during both World Wars to drive cars and trucks.[3, 4]

Although we will probably not use gasifiers for transportation in the United States in the near future, we can use these simple devices to provide gas for retrofitting gas- or oil-fired boilers. This will eliminate the necessity of replacing the entire system, which would be required for conversion to a solid fuel such as wood or coal. In fact, many industries have waste biomass which is presently a disposal problem, but which would provide necessary process heat if suitable size gasifiers were installed.

TYPES OF GASIFIERS

There are dozens of types of gasifiers ranging in size from 100,000 Btu/hr to 100 MBtu/hr and yielding a gas with energy content from 90 Btu/scf to 1,000 Btu/scf. The various methods for gasification are shown in Figure 1. We wish to focus here on the simplest type of gasifier: the air-blown, close-coupled gasifier accented in Figure 1 in which a relatively low energy content gas is manufactured on site and burned in existing equipment a few feet away. This is the so-called "close-coupled" mode of operation. In this case, there is no need to cool and scrub the oils from the gas as would be required for use in engines or pipelines. This greatly reduces the cost and increases the simplicity and efficiency of the apparatus.

The two principle types of close-coupled gasifiers are the updraft gasifier and the downdraft gasifier, shown diagrammatically in Figure 2, (a) and (b). (Other types include crossdraft and dual mode gasifiers.) In an updraft gasifier, air first contacts a bed of

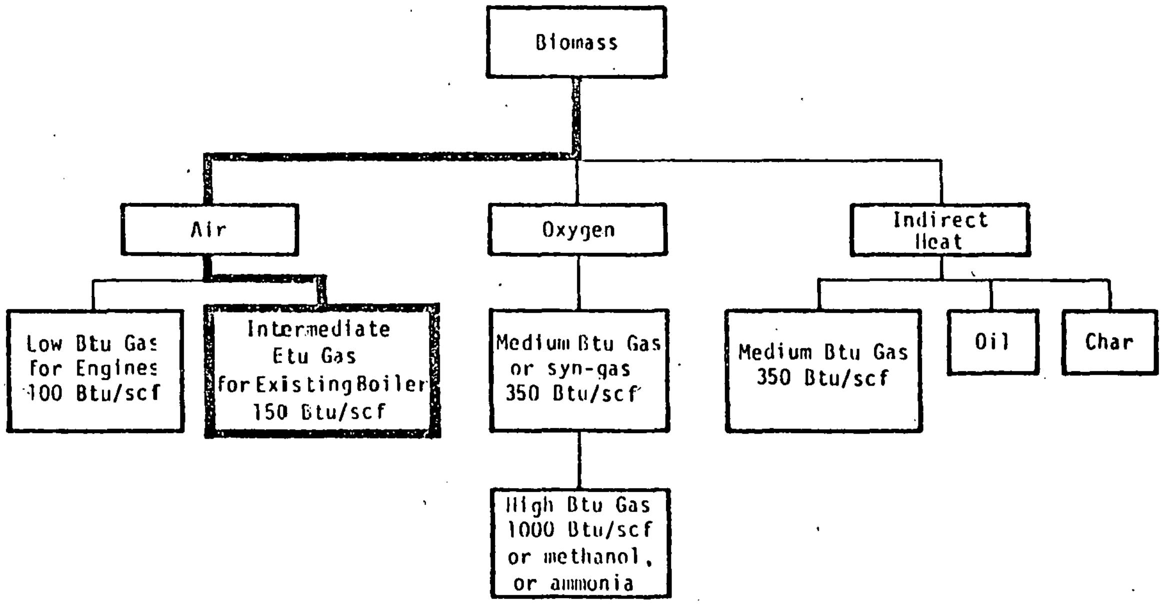

Fig. 1. Close-Coupled gasification and other gasification paths

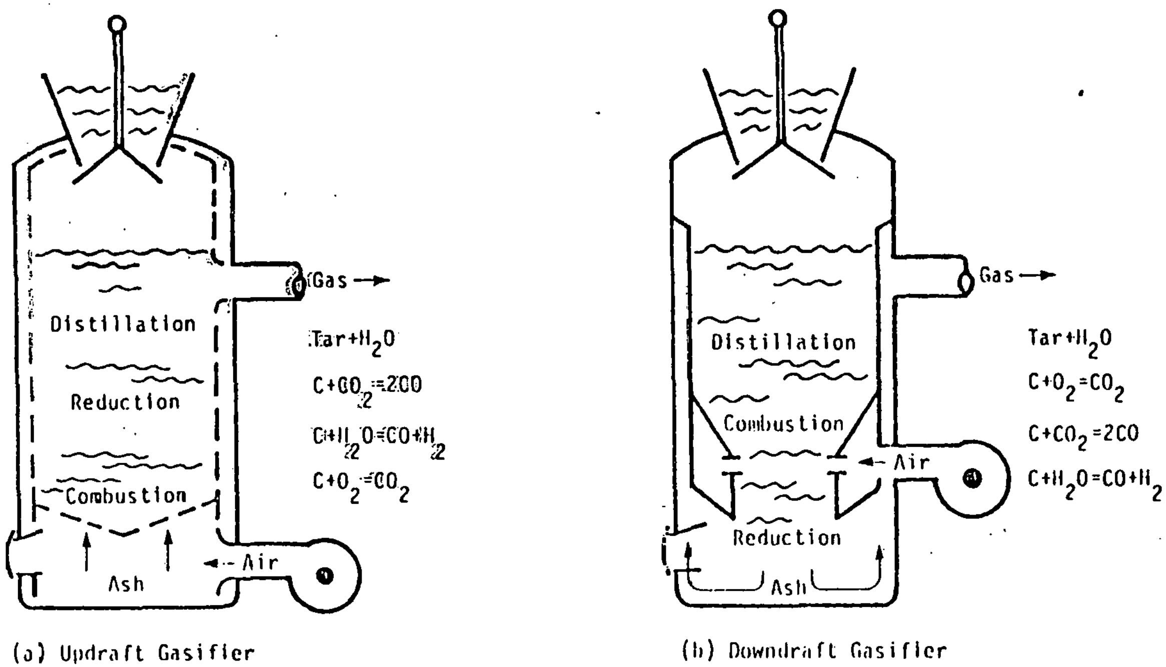

Fig. 2 Updraft and downdraft gasifiers and their associated reactions

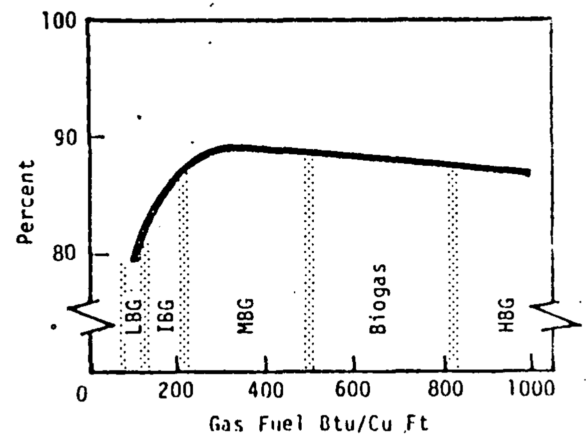

Fig. 3 Boiler efficiency vs Gas energy content

burning charcoal, generating hot CO and CO_2. These gases pass successively through the incoming biomass, first pyrolyzing it to form volatile oils and finally drying it. The gas is diluted by any moisture in the feedstock, but the energy content is enhanced and the burning characteristics are improved by the high molecular weight oil vapors.

In a downdraft gasifier, the air is injected through nozzles into the hottest portion of the charcoal fire and is drawn down through the charcoal bed along with the tars and moisture from the fuel in the higher regions. This causes the oil vapors to crack into gases, primarily CO and H_2. Downdraft gasifiers are especially useful for producing gas to be used in engines, because the oil vapors will clog the engine intakes. At present, both types are being used for retrofitting gas/oil boilers to biomass.

A preliminary list of manufacturers of gasifiers suitable for conversion of gas/oil boilers is given in Table 1. This table also shows the type, size, and some preliminary costs of gasifiers obtainable from the manufacturer. This will be dicussed below.

Gasifier Fuels

In principal, gasifiers can operate on any carbonaceous solid fuel such as coal, lignite, or biomass. In practice, however, the satisfactory operation of any particular gasifier will depend on its design relative to the fuels used, and depends in particular on the fuel density, moisture content, ash fusion temperature, particle size, etc.

The satisfactory operation of a gasifier depends on a free and uniform passage of the gas through the fuel bed. Therefore, satisfactory biomass fuels should be relatively uniform in particle size so that the gases do not form channels. Particle size should be greater than about one-quarter inch so that there is not too much back pressure, paticularly in updraft gasifiers. Dusts and fines are particularly troublesome. The charcoal which forms on pyrolysis should have moderate physical integrity to prevent collapse and plugging of the bed.

For these reasons, wood chips and bark make excellent fuels for gasifiers. Gasifiers have been run satisfactorily also on shells, pits, and corn cobs. However, other fuels such as straw, cotton gin trash, food residues, etc., may require densification (cubing, pelleting, briquettting, extrusion, etc.) in order to be used satisfactorily in gasifiers.

Biomass has many attractive features as a fuel, including very low sulfur, renewability, low cost in many cases, and no increase in long-term atmospheric CO_2. However, biomass occurs in a wide variety of forms and is often too wet to burn and too bulky to ship. Recently, a number of companies have begun to make densified fuels, "DBF", to overcome this handicap and create a uniform commodity fuel selling for $20 to $30/ton. The cost of drying and densifiying is approximately $6 to $15/ton and must be weighed against the value of the biomass with and without densification.[5] A number of gasification tests have been run on pellets and they are found to be quite satisfactory.[6-8]

DBF has typical particle densities of 0.8-1.3, while wood chips (dry basis) have densities of 0.4-0.5, and most other biomass is even less dense. Therefore, a further advantage of densification before gasification is that the capacity of the gasifier is increased due to the higher energy density at the grate.

The energy content of the gas produced in gasifiers is low because of the dilution effect of the nitrogen content of the air used in gasification. In addition, it may be even lower due to water vapor in the gas. Therefore, it is desirable to keep the water vapor in the fuel to a minimum. Some gasifiers can operate with up to 30% moisture content, but gas quality is degraded at higher moisture levels. It is necessary to reduce moisture content from 10% to 20% before densification and the result is DBF with an attractively low moisture content.

Properties of Producer Gas

The gases produced in the gasifiers shown in Table 1 contain CO, H_2, and hydrocarbon gases as their principle fuel ingredients. In addition, they contain N_2, CO_2, and H_2O as dilutents. If the gases are cooled and scrubbed for use in engines or a pipeline, they have a typical energy content of 90 Btu/scf and are called by the names: low Btu gas (LBG), producer gas, Gen-gas, or generator gas. A typical analysis (Davis Gasifier, Walnut shells) shows: CO = 20.5%; H_2 = 15.3%; CO_2 - 7.4%; O_2 = 1.4%; hydrocarbons = 8.1%; N_2 = 47.4%.[6]

If these gases are to be used for heating, it is not desirable to remove the pyrolysis oil vapors and the sensible heat. Then these same gases have an effective heat content of 140 to 200 Btu/scf, depending on temperature, feedstock, type of gasifier, etc. We propose the name "intermediate Btu gas" (IBG) for this type of gas with an energy content of 140 to 200 Btu/scf.

Efficiency of Combustion of IBG

The energy content of a gas is very important if the gas is to be shipped by pipeline. However, the flame temperature and flue gas mass produced varies very little with energy content because large quantities of air must be added for combustion. The relative efficiency of boilers using gases of various energy content are shown in Figure 3 as a function of energy content of the gas.[9] Here it can be seen that capacity is actually higher for the medium Btu gases (MBG) (with energy content around 350 Btu/scf) than it is for high Btu gas (HBG) with energy content about 1,000 Btu/scf. The efficiency falls rapidly below about 200 Btu/scf. It can be seen that there is little loss for intermediate Btu gas (IBG), but considerably more for low Btu gas, (LBG).

Scale of Close-Coupled Gasifiers

It can be seen from Tables 1 and 2 that there are a number of close-coupled gasifiers being developed in the range 1 to 100 MBtu/hr. There may also be some need for even smaller gasifiers, for instance, for heating apartments and shopping centers. At present, there are no proven biomass gasifiers for operation above 100 Btu/hr and there would seem to be a need for this size for large process steam installations expecially in the paper industry. However, coal gasifiers have been built at this larger scale and there seems to be no technical barrier to scaling gasifiers to larger or smaller sizes.

Efficiency of Close-Coupled Gasifiers

Since all the gas generated is burned and the sensible heat of the gas stream is also conserved, close-coupled gasifiers can have very high efficiencies. Essentially complete combustion of the resulting gas is easily achieved, as a result of the two-stage combustion in the gasifier and boiler. The only heat losses in the gasifier are the losses from the outer surfaces and loss to the ash which is negligible. The Century gasifier is reported to have a thermal efficiency of 90%[8,10] while the Davis Gasifier operates at a typical efficiency of 85%.[8] The early gasifiers used for transport in Europe had thermal efficiencies of 80% even after cooling and scrubbing the tars.

Retrofitting Existing Boilers to Close-Coupled Gasifiers

The gases produced in the gasifiers of Table 1 can be burned in existing oil/gas installations, and a number of commercial installations have been made. The gas is somewhat more difficult to burn than natural gas and will require insulated piping to prevent condensation of pyrolysis oils and tars. A gas pilot flame or flame holder will be used to insure combsution. However, the conversion problems are minimal.

In general, the modifications needed for retrofitting existing boilers are not documented, but a recent feasibility study at the California State Central Heating and Cooling Plant in Sacremento used the Davis Gasifier to power one of it's boilers[7] for 158 hours. The gasifier is 8ft in diameter and 15ft tall and produced 16 MBtu/hr. Tests were run using three fuels: kiln dry wood chips purchased for $9/ton or $12.50/ton delivered; and pelleted white fir sawdust purchased for $22.50/ton or $35/ton delivered. The heating value of the gas varied from 182 to 206 Btu/scf. Emissions were: 0% SO_2 observed (0.2% allowable); 130 ppm NO_x (200 ppm Federal Standard); and 0.703 lbs/hr particulates (4.09 lbs/hr allowable). There was some condensate, tar, and charcoal collected. The Division of Water Quality concluded that they would not be a serious disposal problem.

Minor problems encountered during the test runs included the burning out of an auger motor and some tar buildup in the delivery line. Most of the problems were associated with the temporary nature of the hookup for testing and should be no obstacle to commercialization. There was no noticeable deterioration of the metal parts. (Gasifiers are still in operation that were built 60 years ago.) During these tests, the gasifier production rate was controlled manually by controlling intake air. It is expected that gasifiers will be characterized by fast response time to changes in load, since they have been used to operate trucks, cars, and tractors.

ECONOMICS OF RETROFITTING GASIFIERS TO EXISTING BOILERS

Two manufacturers with commercial experience have projected costs for commercial sized units and their assumptions and costs given are shown in Table 2.[8, 10] The gas costs dereived ($0.73 and $1.06) are attractive relative to natural gas costs. However, they are not directly comparable to each other because of different assumptions used and the different size of the units.

In order to make these costs more directly comparable with each other and with other energy costs, we have used the cost analysis methodology developed at the Electric Power Research Institute (EPRI) for the Energy Research and Development Administration (ERDA).[11] This methodology was initially developed for comparison of fossil and nuclear steam and power costs. The methodology has recently been used at the Solar Energy Research Institute (SERI) to develop a computer program for comparison of various solar energy costs as well.[12] The program uses certain assumptions (see Table 3) to determine anticipated capital flows and operating costs over the lifetime of the facility. These costs are then used to derive a first-year fuel cost for the first year of the application and also a levelized cost over the assumed lifetime of the facility.*

We have used the EPRI/ERDA/SERI program to determine the cost of gas produced in the gasifiers of Table 2 as a function of input fuel cost. These first year fuel costs are shown in Table 3, derived from the assumptions listed. The levelized fuel cost is also shown in parentheses. In order to show the sensitivity of gas cost to the fuel, operating, and capital costs, these factors are shown separately in Table 4 for a fuel cost of $20/ton. Since the gas cost depends linearly on fuel costs, the gas cost can be computed for any other input fuel cost by multiplying the fuel contributions shown in Table 4 by the fuel cost and dividing by 20. Gas costs for other capital or operating costs can also be determined in the same manner.

It can be easily seen from Tables 3 and 4 that the principle factor determining gas cost is the cost of the biomass fuel used, with operating costs and capital costs contributing much less. Thus, gasification of low cost forest and agricultural wastes (costing $0 to $15/ton) is less attractive in comparison with today's natural gas costs, but may soon be competitive. Other advantages for the use of gasifiers is that they can be operated intermittently when gas or oil is not available and depending on spot prices for both gas/oil and biomass. Also, they perform the additional function of disposal of the biomass which sometimes gives the biomass a negative fuel value.

COMPARISON OF ALTERNATE FUEL CONVERSION OPTIONS

If it is difficult to establish cost guidelines for retrofitting gas/oil boilers with close-coupled gasifiers, and it is even more difficult to compare their costs with other conversion options in a time of rapidly changing costs and variable availability of fossil fuels. In a recent study on wood combustion economics made by the Forest Products Laboratory (FPL), the authors explained that "the procurement cost of combustion equipment options is a dominant factor in their selection. In a combustion equipment survey, cost data were found to be very difficult to obtain without establishing point designs. Repetitive contact with manufacturers and review of published data ultimately resulted in a set of cost curves."[13] We have used similar methods here to evaluate the use of gasifiers to retrofit existing gas/oil installations and to compare these costs to other options.

The options available for conversion away from gas/oil today are:

1. Reconversion of an orginally solid fueled installation (which had been converted for gas/oil) back to solid fuel. Where possbile, this is probably the most economical conversion—yet, often the solid fuel handling equipment will have been scrapped, new emission control equipment will have to be added, and the existing boiler is likely to be old and inefficient.

2. Replacement of the existing gas/oil boiler (often relatively new) and installation of a new solid fuel system burning coal, wood, or other biomass. This will cost on the order of $8 to $30/lb st/hr and will require installation of new emission control equipment.

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*The levelized cost is the constant price at which the gas must be sold over the life of the project to produce the required rated return.

3. Installation of a close-coupled gasifier to operate the existing gas/oil equipment. This will cost on the order of \$4 to \$9/lb st/hr (see Tables 1 and 2) and makes use of much of the existing installation. It also permits using gas/oil where and when they are available and economic. It permits use of biomass wastes that would not have other value as fuels.

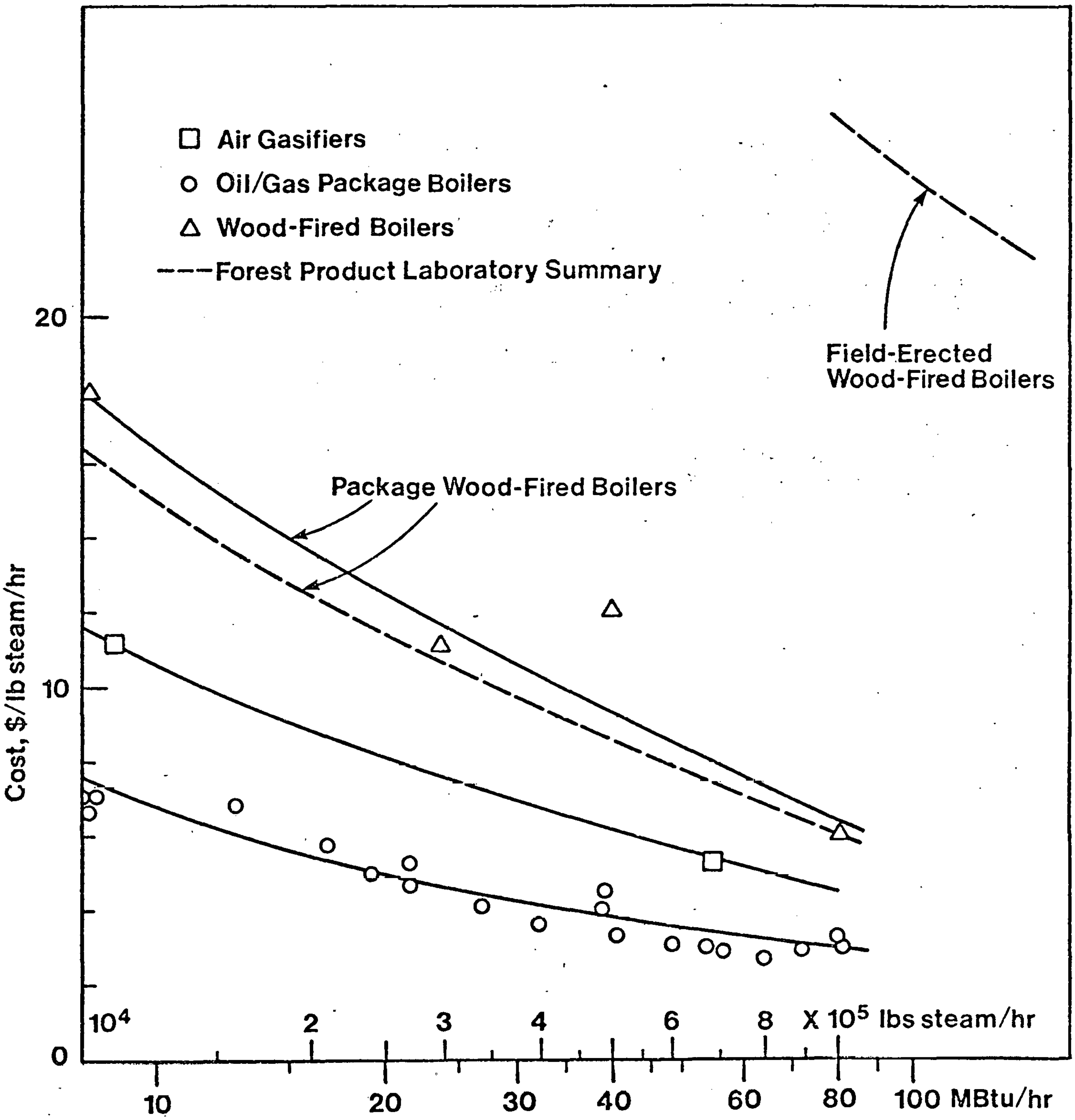
The data shown in Figure 4 compares the costs of these options. The costs obtained from a number of manufacturers for gas/oil package boilers are shown as open circles as a function of plant size. The costs of wood-fired package boilers obtained from several manufacturers along with the FPL results of 1975 (Option 2) are shown as open triangles. The costs of the two gasifiers presented in Table 2 are shown as open squares (Option 3). From these figures, it seems that the cost of adding a gasifier to an existing package boiler is about two-thirds of the cost of installing a new package wood-fired boiler (Option 2).

In general, the cost of package wood-fired boilers (\$8 to \$18/lb st/hr) is considerably less than that for field-erected boilers (\$15 to \$25/lb st/hr) which are required for generation of steam in excess of about 10^5/lb st/hr as shown by the FPL results in Figure 4.[13] In an early study for some paper industries in Maine, the advantages of close-coupled gasifiers for retrofitting the very large existing boilers (typically 2-10 x 10^5/lb st/hr) with gasifiers were pointed out.[14] At present, this attractive option for larger boilers is not available because no gasifiers over 10^5/lb st/hr are available, but development of such a gasifier would permit conversion of the paper industry away from gas/oil at minimum cost.

COMPARISON OF NEW CONSTRUCTION ECONOMICS

If gasifiers are cheaper for retrofit, one may ask whether their combination with a cheap gas/oil boiler (two-stage combustion) may also be preferable to conventional package wood-fired boilers for new installations. Addition of the lower two curves of Figure 4 gives prices for a complete new gasifier-boiler system of \$6.9-\$19.0/lb st/hr to compare to \$6.2-\$18.0/lb st/hr for conventional package wood-fired boilers. The closeness of these numbers is probably fortuitous and it is too early to conclude that the two-stage combustion option using a gasifier is superior to the conventional package wood-fired boiler. Yet, this cannot be ruled out and should be further investigated. The economics which could favor the gasifier-boiler combination are the very low price of conventional gas/oil boilers compared to wood boilers and the relative simplicity and low cost of gasifiers compared to wood furnaces. In addition, the emissions from gasifiers may turn out to be lower than for conventional wood firing, and the turn-down ratio of gasifiers may be superior to that for wood firing. Use of gasifiers would permit return to fossil fuel (dual fuel capability) where that was feasible.

A recent study on a fluidized-bed medium Btu gasifier now under development suggests that the combination of this more expensive technology with package boilers is at least comparable in cost to installation of solid fuel combustion equipment.[15]



Air Gasifiers
Oil/Gas Package Boilers
Wood-Fired Boilers
Forest Product Laboratory Summary
Field-Erected
Wood-Fired Boilers
Package Wood-Fired Boilers
Cost, $/lb steam/hr
20
10
0
10^4
2
3
4
6
8
X 10^5 lbs steam/hr
10
20
30
40
60
80
100 MBtu/hr

Figure 4

CONCLUSIONS

1. Wood and biomass gasifiers are now being developed for retrofitting existing boilers in the 10^4-10^5/lb st/hr (10-100 MBtu/hr) range to use wood and biomass residues.

2. The cost of gas from these gasifiers is estimated to be $1.40-$2.79/MBtu biomass feedstock costing $10 to $20/ton.

3. The addition of a close-coupled gasifier to an existing gas/oil boiler will cost on the order of two-thirds the cost of installation of a new package wood-fired boiler.

4. Although gasifiers larger than 100 MBtu/hr (10^5/lb st/hr) are not presently available, they could probably be used to convert existing field-erected gas/oil boilers to biomass more economically than construction of new wood-fired boilers.

5. The use of a gasifier plus a low cost gas/oil type boiler for new construction is comparable in cost to wood package boilers and should be investigated for future installations, particularly where dual fuel operation is desired.

TABLE 1

PARTIAL LIST OF BIOMASS GASIFIER MANUFACTURERS IN THE UNITED STATES

Name	Type	STATUS(1)	SIZE(2) MBtu/hr
Applied Engineering, Orangeburg, SC	Updraft	D	8
Biomass Fuel Conversion, Yuba City, CA	Downdraft	D	14
Century Research, Gardena, CA	Updraft	C	85
Davis Gasifier, U. of Calif., CA	Downdraft	D	14
Dekalb Agricultural Research, Dekalb, IL	Updraft	D	1.7
Forest Fuels, Keene, NH	Updraft	C	1-12
Foster-Wheeler, Livingston, NJ	Updraft	D	50
Halcyon, E. Andover, NH	Updraft	C	8
Pioneer Hi-Bred Inst., Johnston, IA	Updraft	D	7
Woodex Corp., Eugene, OR	Updraft	C	10

(1) Status of project: C, Commercial - at least one unit in field
D, Demonstration, Testing

(2) Fuel Consumption in tons/hr is approximately MBtu/hr, 16 MBtu/dry ton.

TABLE 2

OPERATING COST OF GASIFICATION

	GASIFIER A[1]		GASIFIER B[2]	
Fuel	Walnut Hulls		Chaparral	
Rated Gas Production (Btu/hr)	14.1 M		85 M	
Rated Feed Rate (ton/hr)	1.19		7.87	
Capital Cost	$125,000		$350,000	
Efficiency	85%		90%	
Annual Operating Costs:				
Depreciation	(10%)	$12,580	(10%)	$35,000
Repairs & Maintenance	(3%)	3,774	(3%)	10,000
Utilities (Water, Power)		—		38,795
Operating Labor	(250 days)	6,000	(365 days)	14,600
Taxes & Insurance	(2%)	2,516		—
Interest	(7%)	8,806		—
Profit		—		—
Gasification Cost		$33,676		$98,895
Fuel Cost	($4/ton)	$ 28,571	($10/ton)	$689,450
Total Operating Cost		$62,247		$788,345
Annual Gas Production (MBtu)		85,000		744,600
Gasification Cost ($/MBtu)		$ 0.40		$ 0.13
Gas Cost ($/MBtu)		$ 0.73		$ 1.06

(1) Goss, J. R. "Food, Forest Wastes = Low Btu Fuel." Agricultural Engineering. January 1978. p.30. (Davis Gasifier).

(2) Amundsen, H. R. "The Economics of Wood Gasification." Chaparral for Energy Information Exchange Conference. July 22, 1976. Pasadena, CA. p. 118. (Century Gasifier).

TABLE 3

GAS COSTS

	Biomass Cost-$10/ton	$20/ton	$30/ton
Gasifier A 14 MBtu/hr	1978 Cost $1.41 Levilized Cost (2.08)	$2.58 (3.78)	$2.74 (5.49)
Gasifier B 85 MBtu/hr	1978 Cost $1.44 Levilized Cost (2.12)	$4.72 (3.99)	$3.99 (5.86)

Assumptions:

1. 20-year life of project.
2. Capital and operating costs are given in Table 2.
3. Plant capacity factor - 0.92.
4. Tax and insurance rates:

Effective Federal Income Tax Rates	0.48
Other Taxes	0.82*
Insurance Premiums	0.0025*

*fraction of present value of capital investment

5. Capitalization Ratios:

		Rate of Return
Debt	0.50	0.08
Common Stock	0.40	0.12
Preferred Stock	0.10	0.08

6. Rates of Inflation:

General Economy	5%
Capital Costs	5%
Operating Costs	6%
Maintenance	6%
Fuel Costs	7%

TABLE 4

Detail Cost Breakdown For $20/Ton Fuel

Gasifier "A"	Gasifier "B"			
	1978 cost	Levelized Cost	1978 cost	Levelized Cost
Operating Costs	$0.11	0.15	0.13	0.19
Capital Costs	0.06	0.09	0.13	0.19
Fuel Cost	2.55	3.75	2.32	3.40
Total Costs	2.72	3.99	2.58	3.78

Assumptions: Same as Table 3.

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4. Brian Horsfield, "Current European Activities in Gasification," 1976. Available from University of California, Agricultural Engineering Department, Favis, CA 95616 along with 12 publications 1976-1977 from B. Horsfield, J. R. Gross, F. Jenkins, H. Doster, R. Peart, R. D. Williams, and R. Hodman.

5. T. B. Reed and B. Bryant, "Densified Biomass: A New Form of Solid Fuel," SERI Report #35, The Solar Energy Research Institute, Golden, CO (July 1978).

6. R. O. Williams and J. R. Gross, "An Assessment of the Gasification Characteristics of Some Agricultural and Forest Industry Wastes,: Manuscript from Department of Agricultural Engineering, University of California, Davis, November 1977.

7. Feasibility Study: "Commercial Biomass Gasifier at State Central Heating and Cooling Plant," prepared by Fuels Office Alternatives Division, California State Energy Commission, Sacramento, (April 1978).

8. J. R. Gross, "Food, Forest Wastes = Low Btu Fuel", Agricultural Engineering, p. 30, (January 1978).

9. H. R. Ammundsen, "The Economics of Wood Gasification," in Chaparral for Energy Information Exchange Conference, Pasadena, CA, sponsored by PSW Experiment Station, Angeles National Forest. July 22, 1976, p. 118; also various publications available from Century Research, Gardena, CA 90247.

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11. "The Cost of Energy from Utility-Owned Solar Electric Systems: A Required Revue Methodology for ERDA/EPRI Evaluation," Jet Propulsion Laboratory, California Institute of Technology, No. JPL 5040-29, June 1976.

12. "Levelized and Energy Inflating Model: ECOST 1," Bob Witholder, Solar Energy Research Institute, September 25, 1978.

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SECTION 9.0

RESEARCH NEEDS IN AIR GASIFICATION

The biomass thermal conversion research section of SERI undertook this workshop in air gasification in part to determine whether there is a need for further research in air gasification before commercialization proceeds. It is clear from the comments in the panel discussion and the section on governmental action that research is not high on the priority list of most of the participants.

We have recently published a translation of the book "Generator Gas - The Swedish Experience from 1939-1945", initially published by the Swedish Academy of Engineering in 1950. This 329 page book, (available from NTIS for $12) contains a wealth of information on both the scientific principles of gasification and the practical aspects of fuel preparation and operating gasifiers. We recommend this book to anyone interested in the principles and practice of air gasification.

Since over a million gasifiers were in use in Europe during World War II, it is clear that air gasification commercialization can proceed without further research. However, research can potentially increase the understanding of operation of gasifiers and lead to improvements in operation and efficiency.

We have formed a gasification research group at SERI to determine the principles and fundamentals of all gasification processes in more detail than they are presently understood. These same principles will also apply to air gasification, and it is to be hoped that they will lead to improvements in design. However, it may take a long time for new data and understanding to be assimilated; meanwhile, air gasifier operation is sufficiently satisfactory to be commercialized today. Individual companies will work hard on improvements specific to their own products, but further basic research needs have not been identified.

SECTION 10.0

GOVERNMENT AIDS TO COMMERCIALIZATION OF AIR GASIFICATION

INTRODUCTION

At the Air Gasifier Workshop "Retrofit - '79", February 2, 1979, a suggestion was made by Mr. Charles Bendesky, of Pyros, Inc., that there was a need for government-industry cooperation in the rapid development of gasification to replace gas and oil, and that the attendees would be in an ideal position to make such suggestions. With the help of Mr. Bendersky, we drafted a letter asking for suggestions for useful government action and sent it to the attendees. Mr. Bendersky and his staff at Pyros have made the enclosed summary of the suggestions received, and these are presented in Table 1.

TABLE 1

RETROFIT '79 — Follow-Up

"Appropriate Near Term Role of Federal Government and Other Actions to Support a US Air Gasifer Industry"

ORGANIZATION			**RECOMMENDATIONS**		
Name	**Type**	**Primary Interest**	**Federal Action**	**State/Local Action**	**Gen./Comments**
Arkansas Power & Light Co. Little Rock, Arkansas	User/Utility	Development of: solid fuel gasifier for cogeneration; close coupled biomass gasifiers; gasification system capable of switching from coal to wood. Concern: clean fuel availability	Improve flexibility of combining technologies		
Bio-Energy Council Washington, DC	Consultant	1. Fixed plant development. 2. Mobile-plant category	1. '77 Farm Bill, Sec. 1420 pilot project loan guarantee program - possible approach. 2. Direct grants for several small-scale demos (e.g., bus/truck, auto, boat). Perhaps SERI could initiate (Note: Attachment 1 is a list of general bioenergy commercialization incentive suggestions by Dr. Paul Bente.)	1. Market guarantees & major gasifier investment tax credit (e.g., EPA-California program.)	Bob Kennel/Ultrasystems has concept for "strike-force", i.e., forester, economist, plant engineer on demand make immediate recommendation on practical conversion of wood through direct burning or gasification.
Biomass Energy Institute, Inc. Winnepeg, Manitoba, Cana	Canadian Gov't.	General			1. Need to identify location and economic statistics of any commercially viable biome[illegible]gasifiers, not ju[illegible] hose in development

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
Biomass Energy Institute, Inc. (continued)					2. Need closer look at shortcomings of stationary-type gasification (automation, ease of control, long-term consistency of operation).
					3. Need active experimentation with rotary gasifiers, one of most constructive activities toward technology commercialization.
Century Research Inc. Gardena, California	Hardware developer/ manufacturer	1. Feedstock supply	1. Government documentation of availability of feedstocks, i.e. ag/animal/wood industry wastes, low-grade lignitic deposits, etc.		
		2. Importation of foreign technology	2. Encourage importation of foreign technology and related research, development, and engineering experience.		
		3. Financing for air gasifier installation	3. Legislation authorizing govt. guarantee of special type of mortgage loan.		

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
Richard Wright Energy Research Associates Monroe, Wisconsin	Manufacturer	Economic growth of industry - general		State funding/local sponsorship preferable — less cost and better able to meet local needs.	Favor "normal evolution", i.e., "hands off" by federal government. See Attachment 2 for specific recommendations.
Environmental Energy Engineering, Inc. Morgantown, West Virginia	Manufacturer	Biomass gasification development - general	US support of Sweden's already developed facility/staff. This, plus cooperation, will help move US to earliest possible commercialization.		1. Get units operating on modest scale to provide visual exposure — may require subsidy for extra labor needed.

ORGANIZATION			RECOMMENDATIONS		
Name	**Type**	**Primary Interest**	**Federal Action**	**State/Local Action**	**Gen./Comments**
Environmental Energy Engineering, Inc. (continued)					Concurrently with above, develop less labor intensive continuous units, larger units, and more effective units. 2. Establish environmental consequences associated with biogas utilization in small and large units. 3. Update Hessleman gasifier to a continuous operating & compact unit to serve as demo & operating unit for small scale uses — demo of engine operation & firing existing gas burners of right size.
Gorham International, Inc. Portland, Maine	Paper Mill/ (Consultant)	Wood harvesting & distribution	Specific: interest in in DOE funding of joint demo project, with an industrial partner, involving use of down draft gasifier chipper & dryer at or near harvesting site.(Industry partner to use chips himself or establish fuel distribution system for dry/graded chips.)		Attributes slow growth of industry to dependence of small scale in place gasifiers on <u>secondary</u> wastes (sometime negative value) — more rapid growth will require use of primary forest wastes as fuel. Need new/more economical harvesting methods, such as down-draft gasifier chipper/dryer described at left.

ORGANIZATION			RECOMMENDATIONS		
Name	**Type**	**Primary Interest**	**Federal Action**	**State/Local Action**	**Gen./Comments**
Halcyon Associates, Inc. E. Andover, New Hampshire	Hardware developer/ manufacturer	Economic growth of biomass gasifer industry - general			Technology advancing slowly largely due to lack of DOE aid to smaller companies doing actual inventing/design/development. Small companies have no "in" at DOE to obtain funding for efforts to prove feasibility/ practicality/economy in commercial applications. Technology design promotion—get number of units installed & operating, requires liaison with users. Small companies also hampered by terms, conditions, & guarantees required by purchasing agents & bureaucrats. In view of 'inevitable' lack of DOE or other federal support, as public attention turns to alternate fuels, small companies: (a) may form alliances with larger ones—which have "in" with DOE—to obtain funds; (b) go public to get venture capital

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
Lamb/Cargate Industries, Ltd. New Westminster British Columbia	Supplier (British Columbia)	Gasifiers in energy-saving related equipment	Federal role should be to reduce risks undertaken by supplier & purchaser of new technology. Canada has several such programs: 1. E.D.P. - govt. matches funds with supplier; income from sale divided equally between govt. & supplier. 2. Dept. Energy, Mines, & Resources (DEMR) - offer buyer 25% grant on cost of total energy saving system. 3. DEMR - one-time 66% loan guarantee for financing co-generation from wood (1 per province.)		DOE should reduce excessive time for processing applications.

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
National Center for Appropriate Technology Butte, Montana	Consultant	Air gasifiers - general	Should install units in government facilities. DOD - largest energy user - should be prime target. (Would aid self-sufficiency of military installations and be good PR).		Most private users taking "show me" attitude toward use of air gasifiers.
Pioneer Hi-Bred International, Inc. Des Moines Iowa	User/Developer (large seed and grain company)	General	In general, government should stay out and let profit-oriented private industry handle. However, tax credit for private industry's investment in technology development might be helpful, although documentation to satisfy tax authorities may be difficult		Feel their work (use of corn cobs as fuel) different from other alternate fuel projects & not practical to "wait" for government sponsorship. Time required to get govt. support too long.
Ripley & Sun Richland, Washington	?		Funding for development of portable/mobile equipment, and personnel training.		Vertical energy integration needed in agricultural, forestry, and municipal wastes. (areas where sources & potential uses physically close.) Ag - demo in larger agribusiness sector using available biomass resources, transport, & storage for use in air gasifiers to po farm machinery.

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
					Forestry - collect, transport, process, & transport processed fuel form to sites for use in stokers/gasifiers. Possibly use gen-gas fueled trucks for transport. Municipal wastes - similar to above.

ORGANIZATION Name	Type	Primary Interest	RECOMMENDATIONS Federal Action	State/Local Action	Gen./Comments
Stanford Research Institute Menlo Park, California	Consultant	Proper design rather than just building gasifiers, which is currently the case.	Federal funding of R&D required to make air-blown gasification commercially acceptable success. Suggestions: (1) technical & environmental evaluation of operating gasifier; (2) test varied feedstocks in commercial gasifier; (3) thermochemical modelling of data from #2 by computer; (4) cost analysis of biomass pretreatment and handling; (5) cost effective analysis of preprocessed vs. "as received" materials for gasification; (6) comparative cost benefit analysis of biomass gasifier vs. combustion unit for refitting gas/oil-fired industrial boilers; (7) study factors around biomass gasifier installation in terms of availability/quality/cost of feedstock, local air pollution & residue disposal regulations, tax incentives for producing syngas, and socio-economic impact of facility.		

ORGANIZATION			RECOMMENDATIONS		
Name	**Type**	**Primary Interest**	**Federal Action**	**State/Local Action**	**Gen./Comments**
Texas Tech University Lubbock, Texas	Research	Effective Utilization of gasifiers - general	Federal funding of information programs and demonstrations re: small gasifiers (for transportation and agriculture)—justifiable because small users can't make required technical/economic decisions themselves. Adapt World War II gasifier data to today's technology		See rather limited utilization of air-blown biomass gasifiers. Direct combustion most effective, for new construction, for using biomass to produce steam space heating, and electricity. See little need for govt. financial support & research in development and testing. Due to problems of high cost and fuel supply, govt. should not intervene but let marketplace determine outcome.

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
U.S. Forest Service, Forest Products Laboratory Madison, Wisconsin	Federal Government	General	Federal govt. could be helpful in moving gasification technology from pilot stage to commercialization. Specific suggestions: 1. Sec. 1420, '77 Farm Bill pilot project loan guarantees. 2. 1978 NEA - get clarification for manufacturers of how additional 10% tax credit for combustion units not using fossil fuels might apply to gasification units. (See Attachment 3 for summary of provision.) 3. Funding additional research to solve problems re: slag prevention & handling, tar cleanup, pressurization, fuel bridging in unit, fuel handling outside unit.		
Vermont Wood Energy Corporation Stowe, Vermont	Hardware developer/ manufacturer	Home heating size gasification units	Financial assistance for: 1. Development of small residential gasifiers (particularly where socio--economically beneficial, as in New England).		

ORGANIZATION			RECOMMENDATIONS		
Name	Type	Primary Interest	Federal Action	State/Local Action	Gen./Comments
			2. Development of retail fuel distribution system, via aid to interested individuals/groups.		
Washington State Energy Office Olympia Washington	State Government	General	1. Conduct gasification workshops every 6-8 months to introduce & educate new prospective private industry users to gasification products. Should also include how to handle dangers of gas use, potentially a significant barrier to commercialization. 2. Tax incentives, i.e. - rapid write-off of capital investment in gasification equipment.		

ORGANIZATION Names	Type	Primary Interest	RECOMMENDATIONS Federal Action	State/Local Action	Gen./Comments
Wood Energy Consultants, Ltd. Charlottetown, Prince Edward Is., Canada	Consultant (Canadian)	General	Sees major problem as lack of capital. Suggests Federal and/or state assistance by: 1. Purchase, by pre-payment, a number of gasifiers up to $250,000 per company. These gasifiers would be for future delivery at the stabilized production cost of the future. In the meantime, the manufacturer would have this money to finish development work and be capable of manufacturing units. 2. Loan guarantees to purchasers to buy units so that the financial risk of non-performance is on the government. With the massive importation of oil, the Federal government is spending much more money than they would ever lose by the failure of a few "prototype" gasifiers. These gasifiers would help replace oil that may not even be available within 30 years. These guarantees would be only to the extent of the cost of the gasifier. 3. The first installations should be in rural applications near sawmills, where the wood is readily available and the economics make most sense. After these successes the government can take its purchased units (prepaid as in #1) and retrofit the applicable government buildings. 4. At this point, with working models and successful applications of the technology, the government could order a large enough number to help the manufacturer establish his assembly line. The units under the government guarantee program could go to normal purchasers or the excess into government buildings.		

ATTACHMENT 1

From "Bio Energy Commercialization Incentives", luncheon address by Paul F. Bente, Jr., Executive Director, BioEnergy Council, at IGT-sponsored Conference on Energy Production from Biomass and Wastes, Orlando, Florida, January 23, 1979.

Keeping national goals and principles in mind, let us move on to several types of incentives that may be considered.

1. One type is to mandate achieving goals without specifying the means. This happened, for example, when the government told the auto industry that its cars had to reach increasingly higher mileage performance over given periods of time, without telling them what had to be done to achieve this end result. An analogy would be to mandate over a period of time the addition to gasoline of increasing amounts of alcohol fuel, regardless of origin, or perhaps even restricted to biomass origin.

2. Another approach is that of building a market by establishing economic subsidies which lower the price of a product to establish its use, much as our country now underwrites the cost of importing oil.

3. Yet another way involves offering incentives to overcome institutional barriers that are chiefly financial in nature. There are many such possibilities to consider, foremost of which are loan guarantees where bank or investor financing cannot otherwise be secured.

4. Loan guarantees have the effect of lowering the interest rate on borrowed money by about 2 percent. However, loan guarantees, though authorized, are not presently operative in the DOE budget. An amendment is needed to create a line-item in the budget for a loan guarantee program.

5. USDA, through its Farmers Home Administration, has an effective loan guarantee program. In addition, the Food and Agriculture Act of 1977 set up a $60 million loan guarantee program to guarantee loans of up to $15 million for four industrial production projects to be selected from competitive proposals.

6. About 30 requests for such assistance were received. On January 12 the Commodities Credit Corporation Board ruled on the first three firms to qualify for such assistance. A guarantee was awarded to ENERCO, Inc., of Langhorn, Pennsylvania, which has a mobile wood pyrolysis unit that can also produce hydrocarbons. The guarantee will cover about $5 million in loans for 45 mobile plants. A second guarantee was made to U.S. Sugars and Savannah Foods for a $15 million loan for facilities at Cleviston, Florida to conduct acid hydrolysis of bagasse to sugars that will be fermented to make alcohol. This will be located adjacent to a sugar mill. A third guarantee is being made to Guaranty Fuels, Inc. in Independence, Kansas for $5.8 million in loans covering 2 plants to pelletize forest wastes. Sometime next month the Board will select the fourth firm to be given a loan guarantee under this program. Let us hope that the interest rates which have soared dramatically will not be so high as to stop these projects from materializing.

7. Making direct government loans may even be necessary if a loan guarantee is not a sufficient incentive for lenders, or if interest rates from conventional sources of finance are too high, even with the lower rates made possible by guarantees.

8. Utilities are vitally concerned about being able to get financing for installation of biomass facilities. Offering investor-owned utilities government loans at reduced rates may be necessary to provide a significant incentive for their using biomass as fuel.

9. Another possibility is making an outright grant of funds, possibly on the condition that it must be matched by funds from other sources. This might be necessary to expand the resource of wood via cultivation, transportation, and energy conversion. Such a program should be applicable to public or private organizations as well as to individuals.

10. Another type of incentive is tax exemption. Under the IRS code, Economic Development Revenue Bonds of up to $1,000,000 are tax exempt if they are issued to finance the cost of some portions of "municipal solid waste facilities". It is considered legally possible to use this vehicle to finance wood-fueled electric generating plants. One such case has occurred, but it is questionable if others will. When and if tested, the IRS ruling will have to classify wood residues or wastes as "municipal solid wastes". Quite possibly this may not be the case. This situation could be clarified by amending the IRS act so that it clearly qualifies wood residues or wastes for such commercialization.

11. There are other taxes, such as the inventory tax and the capital gains tax, which can discourage production, harvesting, and use of biomass for energy. Amendments to exempt biomass from these taxes could help to spur commercialization.

12. There are still other possibilities to consider including amendment to the IRS code for allowing rapid amortization to be applied against the cost of retrofitting or converting an existing energy production unit to use of biomass as a source of energy.

13. Another example might be amending the National Energy Act to allow a 20 to 40 percent investment tax credit on the basis of capital costs incurred for converting biomass as a source of energy.

14. We have heard of the solar tax credit that just went into effect for those who install solar devices to heat water, to heat or air condition buildings, or to insulate them. Heating homes with wood, which is stored up solar energy, seems just as deserving and could have a far greater impact, for it is more readily put to use by Mr. Public. Hence, there is a possibility of increasing self-sufficiency of homeowners and reducing their use of gas and oil by amending the law to allow wood heating stoves to qualify under the solar tax credit.

15. Another incentive that would be both controversial and complicated to administer is redirecting funds used to pay farmers to set land aside in order to reduce production. Indeed, the funds could be used to pay farmers to produce biomass for fuel. This might be a bio-energy crop of trees, corn, or other crops for conversion to fuels and possibly other valuable coproducts such as feed supplements and fertilizers.

16. Another approach to incentives might be linked to environmental regulations involving the issuing of permits, including grandfathering arrangements. Combustion of biomass materials on a large scale will no doubt require emission control devices

which are expensive. Commercialization incentives might be offered by allowing quick amortization of capital expenditures for such equipment or by providing federal subsidies via procedures such as tax exempt industrial development bonds. Another possibility is to allow an investment tax credit, or to provide Small Business Administration loans of the economic injury type. These are designed to assist small industries that cannot benefit from the other procedures because they don't yet have enough cash flow to take a tax write-off or because they aren't yet making a profit.

Our government might emulate the commercialization effort being put forth by Canada. Canadians already use wood to the extent of 3-1/2 percent of total energy consumption. Their government desires to increase this several fold and last July launched a strong commercialization program earmarking funds to get industry to use more wood. Canada has launched 5 programs which commit over $300 million toward commercialization over the next 5 years.

The Forest Industry Renewable Energy (FIRE) program sets up $140 million to be used over a 5-year period to contribute up to 20 percent of approved capital costs of systems using wood as an energy form. A companion program, Energy from the Forest (ENFOR), provides $30 million over 5 years for a new contracted-out research program to implement large scale use of forests to provide greater amounts of transportable fuels that will substitute for hydrocarbon fossil fuels in the late 1980's.

To spur these two programs, a series of cost-shared, Federal-Provincial agreements will be set up involving a Federal contribution of $114 million allocated over the next 5 years to bring current expensive prototypes to full scale application. The Provincial contribution will be additional; but if this has been announced, I'm not aware of it.

In addition a loan guarantee program is being set up to encourage generation of electricity from wood and municipal waste. The first project of its kind in any province is eligible for a guarantee of 50 percent of loan capital for a direct generating station and 66-2/3 percent for a co-generating station.

With the aid of these programs, a 10 percent contribution to Canada's energy supply is considered possible by the year 2000.

ATTACHMENT 2

Specific suggestions of Richard C. Wright:

1. Improve accuracy of media releases. There has been too much controversial and misleading publicity.

2. Differentiate between air-blown coal gas producers and biomass gasifiers. These are entirely different devices.

3. Promote recognition of forest products as equally important for renewable energy sources as for pulp and timber production.

4. Encourage refining raw biomass into a uniform high-grade fuel. This is essential for optimum fuel utilization efficiency.

5. Sponsor voluntary grade or type specifications for refined biomass products. For example, indentifying specifications such as ASTM D-396 for fuel oil, or the now obsolete "Commercial Standards" such as CS-95, Anthracite coal size standards, etc.

6. Avoid massive financial grants for hardware development. Too much hardware is now being re-invented at public expense.

7. U.S. Federal support for a gasifier industry should be limited. Biomass gasification is now off to a good start. If left to serious competition in private industry, it will develop on a sound basis. Scientific help from a few well-qualified institutions, i.e. Georgia Tech, U. of C. - Davis, etc. will be an advantage. Government grants to more presently unqualified agencies are not desirable.

ATTACHMENT 3

Summary of provision under Energy Tax Act of 1978 (part of NEA) - from DOE Summary:

7. Business Energy Tax Credits

A variety of tax credits for investment by business is provided. An additional 10 percent investment tax credit (non-refundable except for solar equipment) is provided for investment in:

a. Alternative Energy Property: This applies to boilers and other combustors which use coal or an alternative fuel, equipment to produce alternative fuels, pollution control equipment, equipment for handling and storage of alternate fuels, and geothermal equipment. This credit compliments and provides a major economic underpinning for the coal conversion regulatory program. The credit is not available to utilities.

Directory of Air Biomass Gasifiers In the U.S. and Canada

Edited by:
T.B. Reed
D.E. Jantzen

retrofit '79

RETROFIT '79

A Collection prepared for

RETROFIT '79 - Workshop on

Air—Biomass Gasifiers

February 2, 1979
Seattle, Washington

Solar Energy Research Institute
A Division of Midwest Research Institute

BIOMASS AIR GASIFIER DIRECTORY

Organization
Alberta Industrial Developments Ltd.

Address
704 Cambridge Building
Edmonton, Alberta
Canada T5J 1R9

Personnel
Richard P. Assaly

Phone
(403) 429-4094

Type of Gasifier (up/down draft, size, fuel, application, etc.

Thermex-Reactor- (Fluid Bed) 70 ton/day
30 million Btu/hr. Design and module size unlimited.

Status (research, pilot scale, commercial, etc.)

PROTOTYPE - Now ready for commercial use.

General Information (description, photo, sketch, etc.)

Gas Generator Process by Fluid Bed (Pyrolysis) includes flash drier/ feed bin/gasifier (Thermex-Reactor) operates on air, close couple gas connection for boilers, driers, etc.

Process can maximize gas or charcoal production. High efficiency process with low operating cost system can operate on very fine raw material higher heating values of gas than other systems.

Plans for Future

Short Term - 1979-80 Three to six reactor installations up to 10 tons/hr.

Long Term - High pressure (400-600 GPSI) system for SynGas.

Name Richard P. Assaly Date January 16, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization
Applied Engineering Co.

Address
Orangeburg, S. C. 29115

Personnel
E. B. Rogers/R. M. Clement

Phone
803-534-2424

Type of Gasifier (up/down draft, size, fuel, application, etc.

Updraft Gasifier fueled on green, whole tree chips or similar free flowing feedstock

Status (research, pilot scale, commercial, etc.)

Commercial (demonstration)

General Information (description, photo, sketch, etc.)

Gasifier systems, including a proprietary burner head, have been developed and successfully tested in sizes up to 5 MM BTU/hour. Preliminary engineering completed for 15-20 MM BTU/hour design. Unique feature of system is proprietary burner which can burn both gasified products and pyrolytic oils without separation. Gasifier contains internal recycle flows for temperature control in grate region.

Plans for Future Ready to install prototype commercial installation.

Name R. M. Clement   Date 1-15-79

BIOMASS AIR GASIFIER DIRECTORY

Organization

Battelle-Northwest

Address

P.O. Box 999, Richland, WA 99352

Personnel | **Phone**

L.K. Mudge 946-2268

P.C. Walkup 946-2432

~~D.G. Ham 946-2083~~

Type of Gasifier (up/down draft, size, fuel, application, etc.

Updraft. Diameter: 1 ft; working bed height: 5 ft. Solids processed: corn stalks, grass straw, wood chips, wood pellets, industrial wastes, coke, ~~charcoal, coal~~

Status (research, pilot scale, commercial, etc.)

Operational at a small pilot scale.

General Information (description, photo, sketch, etc.)

The gasifier is refractory lined and is equipped with an eccentric, rotating grate and a mechanical feed distributor. Solid feed is introduced at the top of the reactor through a lock hopper and auger. A schematic of the gasifier is shown in Figure 1, and a photo is attached.

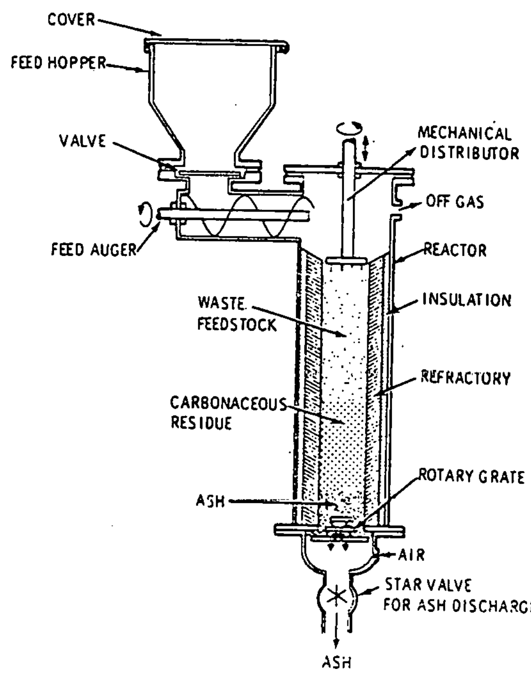

Figure 1 *Schematic of small gasifier*

Plans for Future

Continue operation of the gasifier to characterize gasification characteristics of different solids.

Name Lyle K. Mudge Date 9 January 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization
Bio-Solar Research & Development Corp.

Address
1500 Valley River Drive, Suite 220
Eugene, Oregon 97401

Personnel
35

Phone
(503) 686-0765

Type of Gasifier (up/down draft, size, fuel, application, etc.

Updraft, tank size 12' x 25', burns WOODEX® solid fuel pellets to produce gas for any heat application,

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Status (research, pilot scale, commercial, etc.)

Commercial and research

General Information (description, photo, sketch, etc.)

Bio-Solar Research & Development Corp. manufactures producer gas equipment burning WOODEX® pelletized solid fuel, and producing a gas of high heat value from a non-fossil derivative. The gas is called G-GAS, and a patent has been applied for. The gas can be used to produce heat for any purpose, and when cleaned by proprietary methods, can be used in glass smelting.

Plans for Future Bio-Solar Research & Development Corp. will continue to build WOODEX® plants with G-GAS producers providing heat for dehumidification of biomass in the manufacture of WOODEX® pellets. Gasifiers will also be utilized by joint-venture plants built with major companies and through license agreement.

Name Ted Carpentier   Date 31 January, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization B.C. Research

Address 3650 Wesbrook Mall
Vancouver, B.C. V6S 2L2
Canada

Personnel Dr. Douglas W. Duncan

Phone (604) 224-4331

Type of Gasifier (up/down draft, size, fuel, application, etc.

Fluidized bed wood waste gasifier using run-of-the-mill sawdust or hog fuel.

Status (research, pilot scale, commercial, etc.)

10^6 Btu/hr unit available at B.C. Research for research use.
$4x10^6$ Btu/hr unit at Saskatchewan Forest Products, Hudson Bay, Saskatchewan.

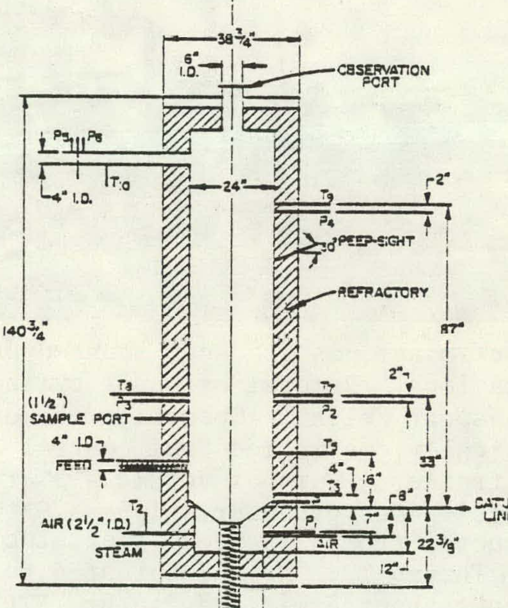
General Information (description, photo, sketch, etc.)

The B.C. Research unit has the dimensions shown in the attached sketch. Air is supplied below the pinhole grate by a 3 HP blower (150 CFM capacity). Run-of-mill hog fuel containing up to 50% moisture (total weight basis) is fed into the combustion zone just above the grate where the volatiles are driven off and consumed. The 5 ft bed consists of charcoal and ash. Surplus ash is withdrawn intermittently through the bottom of the unit. The raw gas (100-150 Btu/sdcf) exits via a port near the top of the reactor, passes through a dry cyclone to a furnace where it is burned.

The $4x10^6$ Btu/hr unit in Saskatchewan is similar except that the reactor has an expanded freeboard above the ash bed to aid in particulate removal and the raw gas exits from the top of the reactor where it passes through a cyclone and then through a gas cleaning system. The raw gas is intended to fire a diesel generator set.

The Btu gasifier is being commercialized by Lamb Cargate Industries Ltd., 1135 Queens Avc., New Westminster, B.C., V5L 4Y2.

Figure 2
B.C. RESEARCH FLUIDIZED BED GASIFIER



T = Thermocouple no.
P = Pressure port no.
═ = Orifice plate on pipe

Plans for Future

Continue research studies on research reactor. Generate financing to build $20x10^6$ Btu/hr prototype.

Name [signature] Date January 24, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Department of Agricultural Engineering

Address

University of California
Davis, CA 95616

Personnel

John R. Goss, Professor

Phone

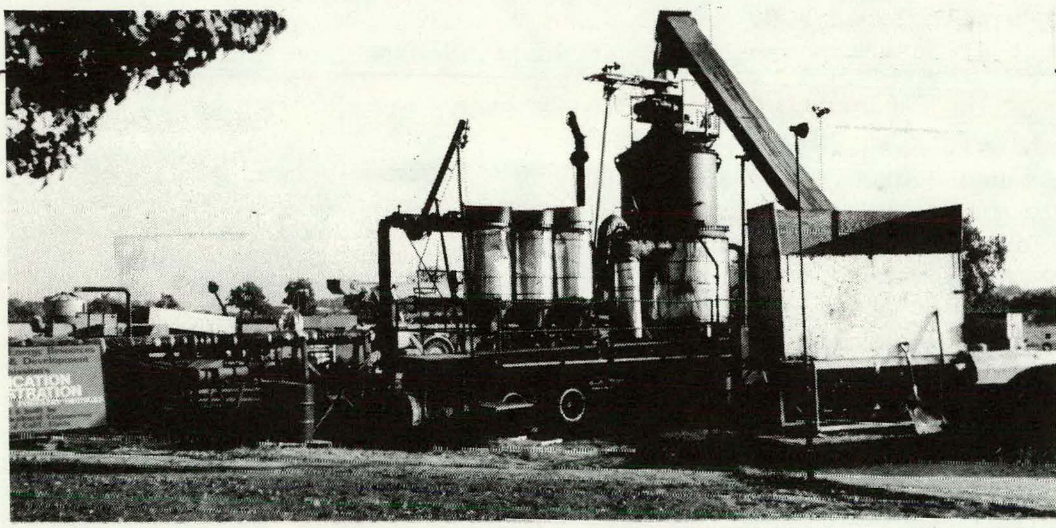
(916) 752-1421/0102

Type of Gasifier (up/down draft, size, fuel, application, etc.)

Downdraft, 4-foot firebox, 54 ft^3 fuel capacity including active firebox volume, 500 to 1100 lb/hr of hogged kiln dried lumber waste and other agricultural and forest residue.

Status (research, pilot scale, commercial, etc.)

Pilot scale for research and demonstration.



Pilot plant gas producer mounted on semi-trailer for transport to various test locations. Removal of upper cylinder and fuel feed assembly to meet 13 ft 6 inch transport height. Operation is monitored and fuel feed and ash removal automatically controlled from control and instrument panel mounted in cabin at front of trailer. Firebox volume - 38 ft^3. Ash grate basket - 143 ft^3. Ash pit - 69 ft^3. Gas producer weighs 3.9 tons. Firebox and lower outer cylinder constructed from A515 steel flat stock. Lower cylinder insulated with 2" thick J-M Thermo 12. Normal output 4 to 6 million Btu/hr on dry wood chips. Maximum output about 8 million Btu/hr (NTP) of combustible gases. To left of gas producer are the hot gas cyclone and three hot gas fiberglass bag filters. Combustion air blower and gasoline engine drive on ground at rear of trailer.

Plans for Future

Property of California Energy Commission awaiting further program development. Inquire Commission at 1111 Howe Avenue, Sacramento, CA 95825. (916) 920-6033.

Name John R. Goss **Date** January, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Department of Agricultural Engineering

Address

University of California
Davis, CA 95616

Personnel

Phone

Type of Gasifier (up/down draft, size, fuel, application, etc.)

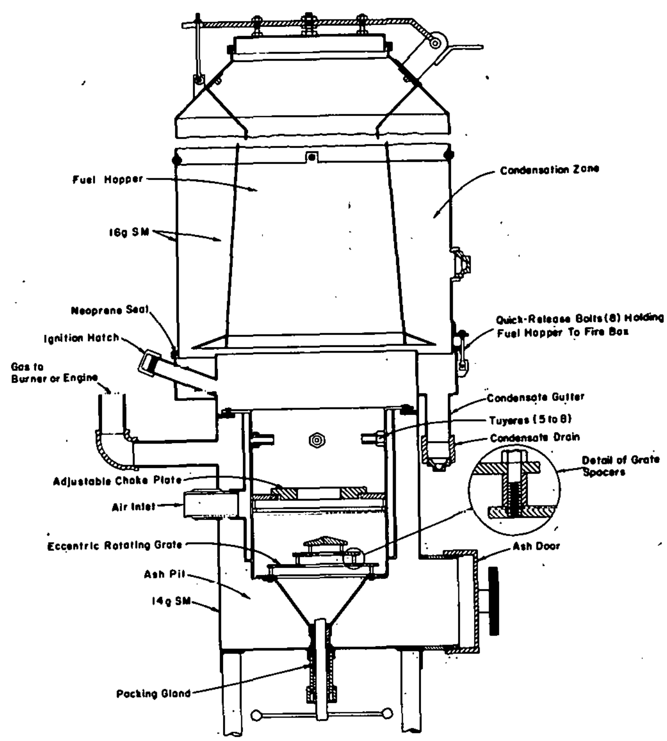
Downdraft, 12-inch firebox, 1.8 ft^3 fuel capacity, 30 to 80 pounds/hour fuel rate with agricultural and forest residues.

Status (research, pilot scale, commercial, etc.)

Laboratory scale gas producer to investigate gasification characteristics of fuels and test variations in design parameters.

General Information (description, photo, sketch, etc.)

The gas producer fuel is batch fed by opening the gasketed cover at the top. Fuel cylinders with different configurations can be inserted for particular physical characteristics of fuel. A fuel column 32 inches high is accommodated above the firebox. Tuyere nozzle sizes and lengths and elevation of choke plate and choke diameter can all be changed. Ash grates of various configurations can be interchanged with the one shown. Hand turning of the grate has been replaced with a small fractional horsepower motor, gear reducing box and roller chain drive.



Plans for Future

Continue investigating gasification characteristics of agricultural and forest residues and low-Btu gas utilization before and after solid particulate filtration and then after cooling and condensing.

Name John R. Goss Date January, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Century Research, Inc.

Address

16935 S. Vermont Avenue, Gardena, Calif. 90247

Personnel

Dr. Steve S. Hu
Mr. Howard R. Amundsen

Phone

(213) 327 - 2405

Type of Gasifier (up/down draft, size, fuel, application, etc.

up-draft, Layer-zoned, Oxi-reduction Minimax Gas Producer, 10 ft diameter for standard model, Fuel: animal waste, agriculture waste, forest waste, paper waste, etc. Gas fuel for electricity, steam, cement/brick plant, chemical feedstock for amonia/alcohol manufacturing

Status (research, pilot scale, commercial, etc.)

commercial

General Information (description, photo, sketch, etc.)

overall dimension of standard 10 ft diameter unit: 35 ft tall represented by 15 ft of hopper and gravity feed system, 10 ft of combustion chamber, and 10 ft of residue cone and residue discharge system.

The unit can process approximately 100 tons of feed stock per day and produce 50 to 100 million btu equivalent of producer gas per hour.

The producer gas is composed of approx. 20-25% CO, 10-15% H2, 2%± CH4, and 5 -10% CO2 and 50-60% N2 (by volume). It contains 125-165 btu per cu ft under std temp and pressure condition. It can reach 2700 deg F flame temperature.

A typical Century Research/ Bainien gassification plant is composed of 5 component systems: Frontend feed stock processing system, Gasification system, Test and automatic control system, Environmental cleanup system, and End product synthetization or utilization/application system.

Marketable product on the basis of 1978 calculations is priced at $2. to $2.50 per million btu.

Plans for Future

Development of semi-portable or portable version of the standard model, so that the gasifier can process lower daily tonage with high effciency and on site to site basis.

Name Steve Hu / Howard R. Amundsen Date January 16th, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Davy Powergas Inc.

Address

P.O. Box 36444
Houston, Texas 77036

Personnel

1500 in USA
Worldwide

Phone

(713) 782-3440

Type of Gasifier (up/down draft, size, fuel, application, etc.

Up draft fixed bed type, up to 13' 6" ø, producing both gas engine fuel and ammonia synthesis gas.

Status (research, pilot scale, commercial, etc.)

Commercial - More than twenty gasifiers built & operated

General Information (description, photo, sketch, etc.)

This fixed bed "Waste Refuse Producer" is an offshoot of the Powergas Corp. Ltd. fixed bed producer of which more than one thousand gasifiers were built and operated. This biomass unit has operated on wood, wood bark, cotton seeds, bagasse, etc. Most of these units have been shut down due to the availability of natural gas and oil. We believe that one or two are still operating in Southern Africa.

Plans for Future

Davy is still promoting biomass gasification with air and now with oxygen. We are presently proceeding with the design of a 2000 TPD methanol plant based on wood gasification.

Name Edgar E. Bailey
Edgar E. Bailey
Product Manager

Date June 16, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Deere & Company

Personnel

N. A. Sauter

Address

Technical Center
3300 River Drive
Moline, IL 61265

Phone

309/757-5275

Type of Gasifier (up/down draft, size, fuel, application, etc.

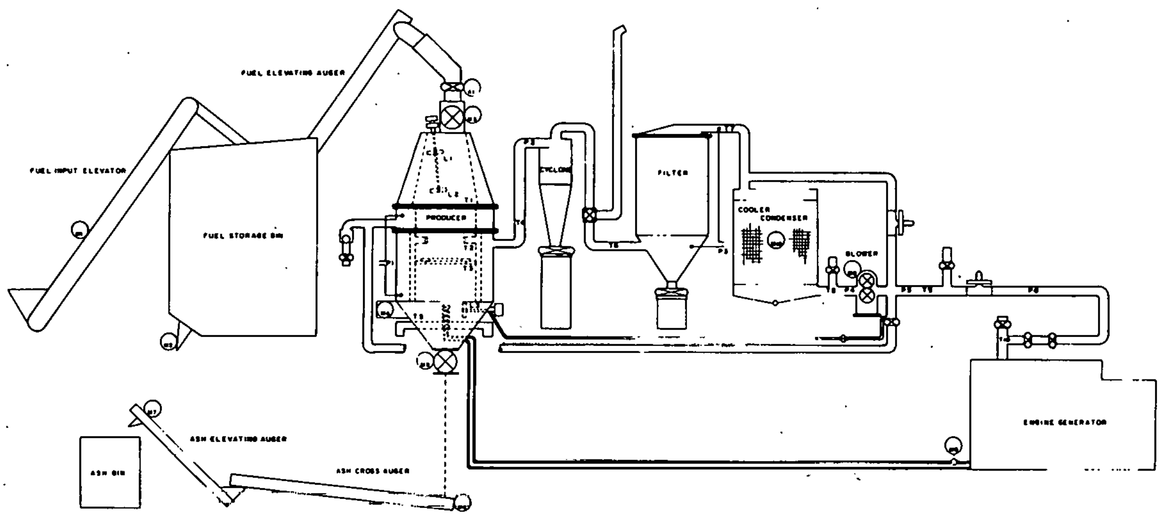
Continuous, portable, downdraft unit for converting agricultural residues to gas and to electricity via 100 kW diesel generator set

Status (research, pilot scale, commercial, etc.)

Research Tool

General Information (description, photo, sketch, etc.)

Unit is generally described in Chapter 8, Solid Wastes and Residues - Conversion by Advanced Thermal Processes, American Chemical Society Symposium Series, Washington, D. C. 1978.



Schematic of portable 100 w farm power plant

Plans for Future

Not currently active

Name [signature] Date 11 January 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Eco-Research Limited

Personnel

John W. Black

Address

P.O.Box 200, Station A
Willowdale, Ontario. M2N 5S8

Phone

416-226-7351

Type of Gasifier (up/down draft, size, fuel, application, etc.

Fluidized Bed Gasifier
Application - wood, municipal refuse

Status (research, pilot scale, commercial, etc.)

25 TPD pilot plant - ready for commercialization Sept.'79

General Information (description, photo, sketch, etc.)

The pilot plant started up in May '76 and has been used both as a combustion unit with in-bed steam generation and a gasification system for the production of a low BTU fuel gas. Materials gasified have included tires, wood, wood wastes, agricultural biomass and municipal refuse.

Plans for Future

Plans for the near term include a continuous demonstration test of about 3 months and oxygen gasification

Name John W. Black Date January 16, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Environmental Energy Engineering Inc.

Address

P.O. Box 4214, Morgantown, W.Va. 26505

Personnel

Dr. Richard C. Bailie

Phone

(304) 983-2196

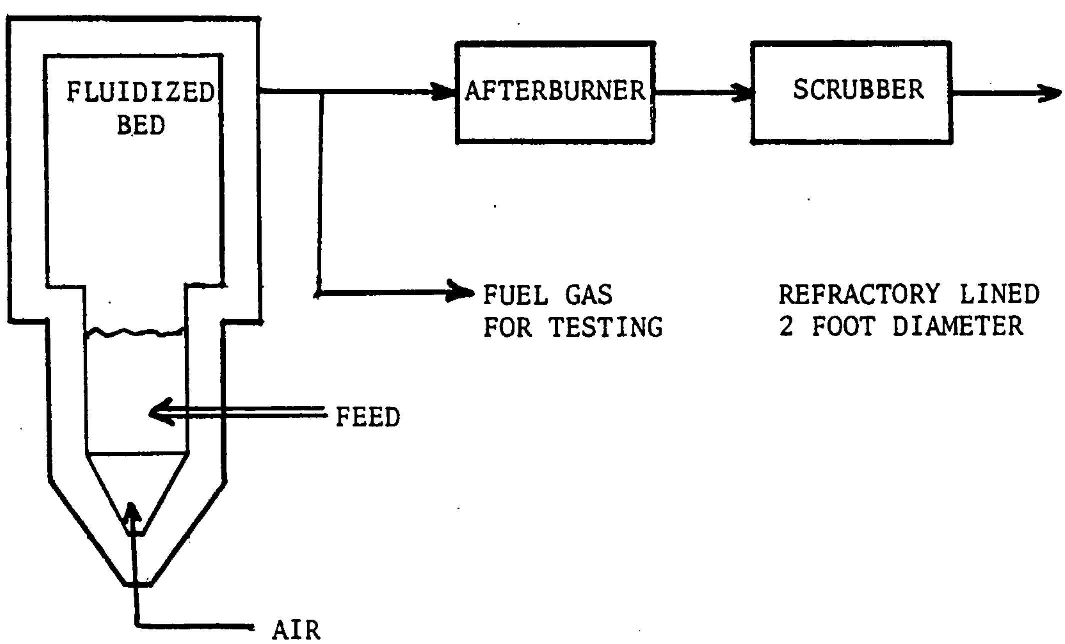
Type of Gasifier (up/down draft, size, fuel, application, etc.

Fluidized bed operating on wood blocks, sawdust or pellets. Operates commercial burner which can be used for crop drying, furnace industrial heat and internal combustion engine. Air blown, Cap. 3 x 10^6 Btu/hr.

Status (research, pilot scale, commercial, etc.)

Pilot plant test facility for different feed stocks.

General Information (description, photo, sketch, etc.)



Plans for Future

Available for commercial development.

Name R. C. Bailie   Date Jan. 24, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Environmental Energy Engineering Inc.

Address

P.O. Box 4214, Morgantown, W.Va. 26505

Personnel

Dr. Richard C. Bailie

Phone

(304) 983-2196

Type of Gasifier (up/down draft, size, fuel, application, etc.

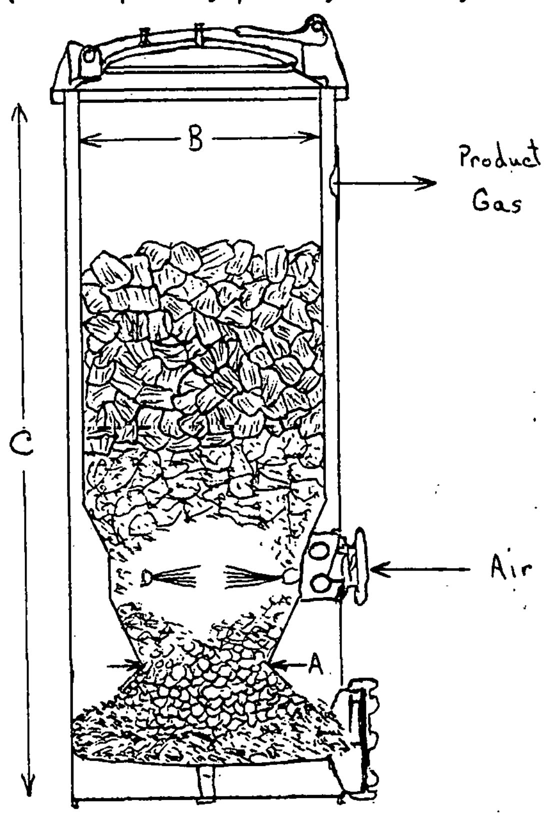
Downdraft gasifier operating on char, wood blocks or pelletized wood. Operates commercial burner that can be used for crop drying, furnace industrial heat and internal combustion engine. Cap. 100,000/hr to 500,000 Btu/hr.

Status (research, pilot scale, commercial, etc.)

Batch system ready for commercial application but no manufacturer exists. Continuous system requires additional development.

General Information (description, photo, sketch, etc.)

A = 5 in.
B = 18 in.
C = 50 in.



Plans for Future

Test in small commercial operations replacing natural gas. Test oxygen enriched air systems. Modify for continuous operation.

Name R. C. Bailie Date Jan 24, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Environmental Energy Engineering, Inc.

Address

P.O. Box 4214, Morgantown, W.Va 26505

Personnel

Dr. Richard C. Bailie

Phone

(304) 983-2196

Type of Gasifier (up/down draft, size, fuel, application, etc.)

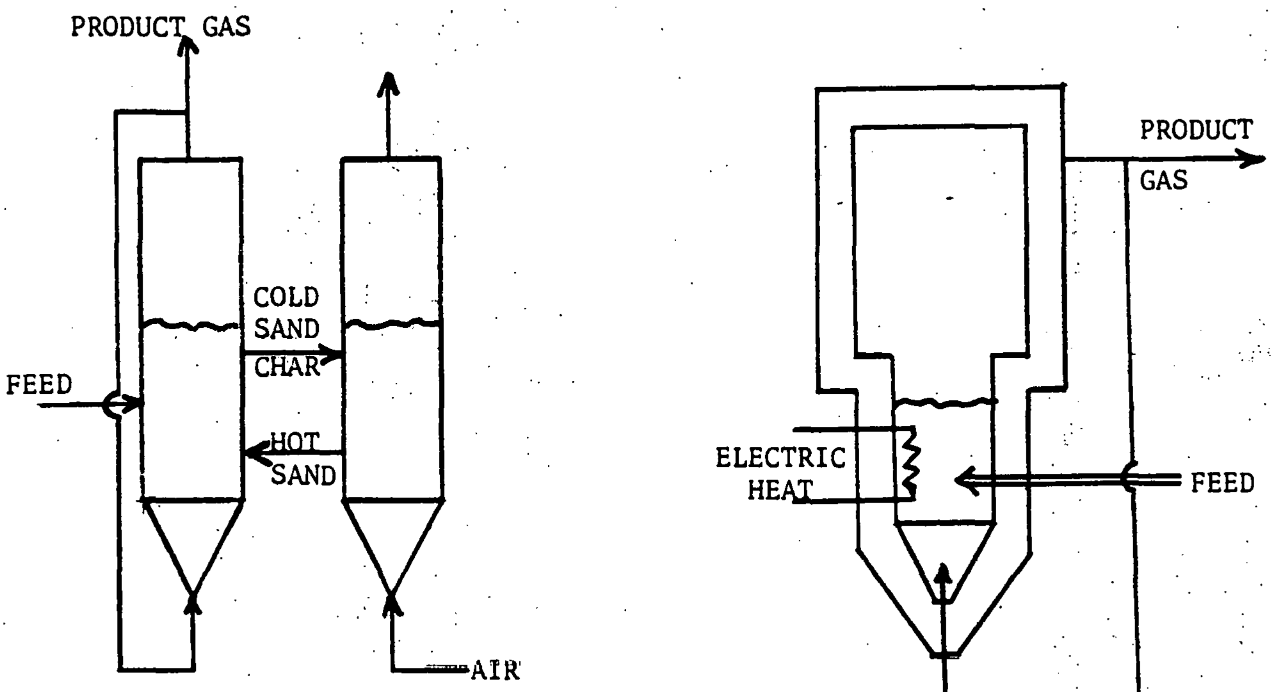
Two fluidized beds which can produce 300 Btu/ft^3 gas not diluted with N_2 without need for oxygen plant. Operates on most any cellulosic feed.

Status (research, pilot scale, commercial, etc.)

Research - Pilot facility

General Information (description, photo, sketch, etc.)

Sketch of commercial system is shown below. Test facility adds heat electrically instead of circulating sand as shown.



COMMERCIAL FACILITY TEST FACILITY

Plans for Future

Demonstrate with sand circulation.

Name R. C. Bailie Date Jan. 24, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization
Forest Fuels, Inc.

Address
7 Main St., Keene, N. H. 03431

Personnel
Administrative Staff
3 Engineers, Mechanics

Phone
(603) 357-3319

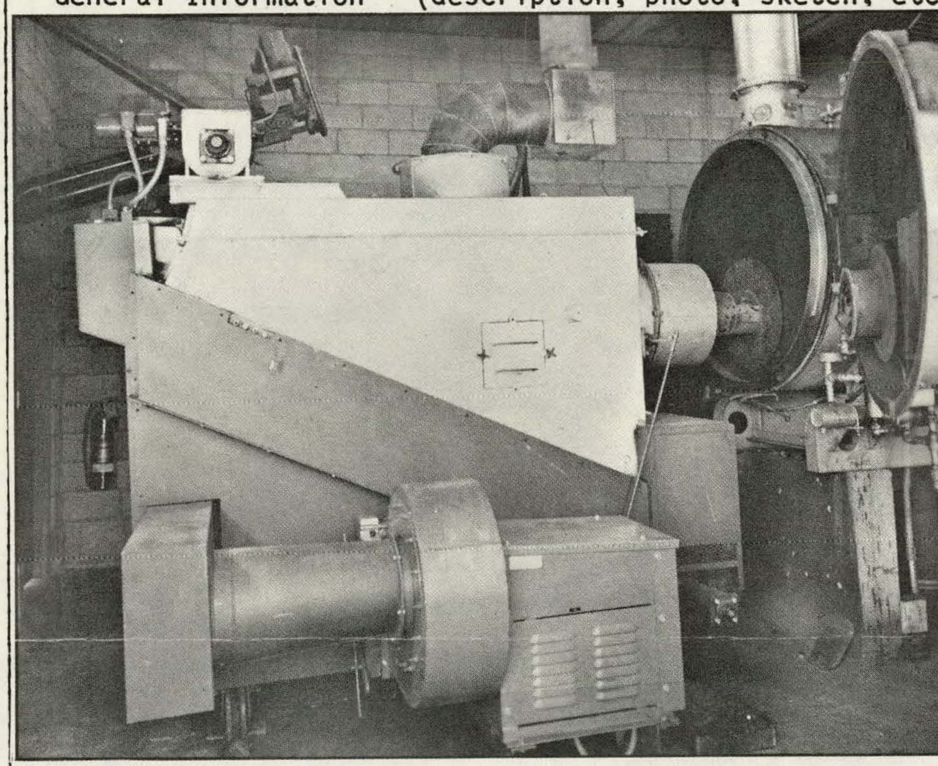
Type of Gasifier (up/down draft, size, fuel, application, etc.

Up Draft Close-Coupled 1.5MM BTU/hr. - 30MM BTU/hr. Wood chips, pellets, etc. Retrofit Package and other Boilers - Direct Fire

Status (research, pilot scale, commercial, etc.)

Pilot - Pre-commercial in some applications; selective commercial in others.

General Information (description, photo, sketch, etc.)



Wood fuel (whole tree chips, planer shavings, pellets, hog fuel, bark, sawdust) is fed to the travelling grate in the primary burner. The fuel is heated in an oxygen-deficient chamber, producing a hot combustible gas containing nitrogen, carbon monoxide, hydrogen, vaporized resins and other volatiles. This gas is fed directly to the mixing nozzle where secondary air is added to complete combustion.

Plans for Future

Complete pilot work. Complete work on market readiness of a range of sizes and applications and fuels.

Name [illegible signature]
President

Date 1/18/79

BIOMASS AIR GASIFIER DIRECTORY

Organization	Foster Wheeler Energy Corp.	Address	110 South Orange Avenue Livingston, New Jersey 07039
Personnel		Phone	
Roger J. Broeker		201-533-2667	

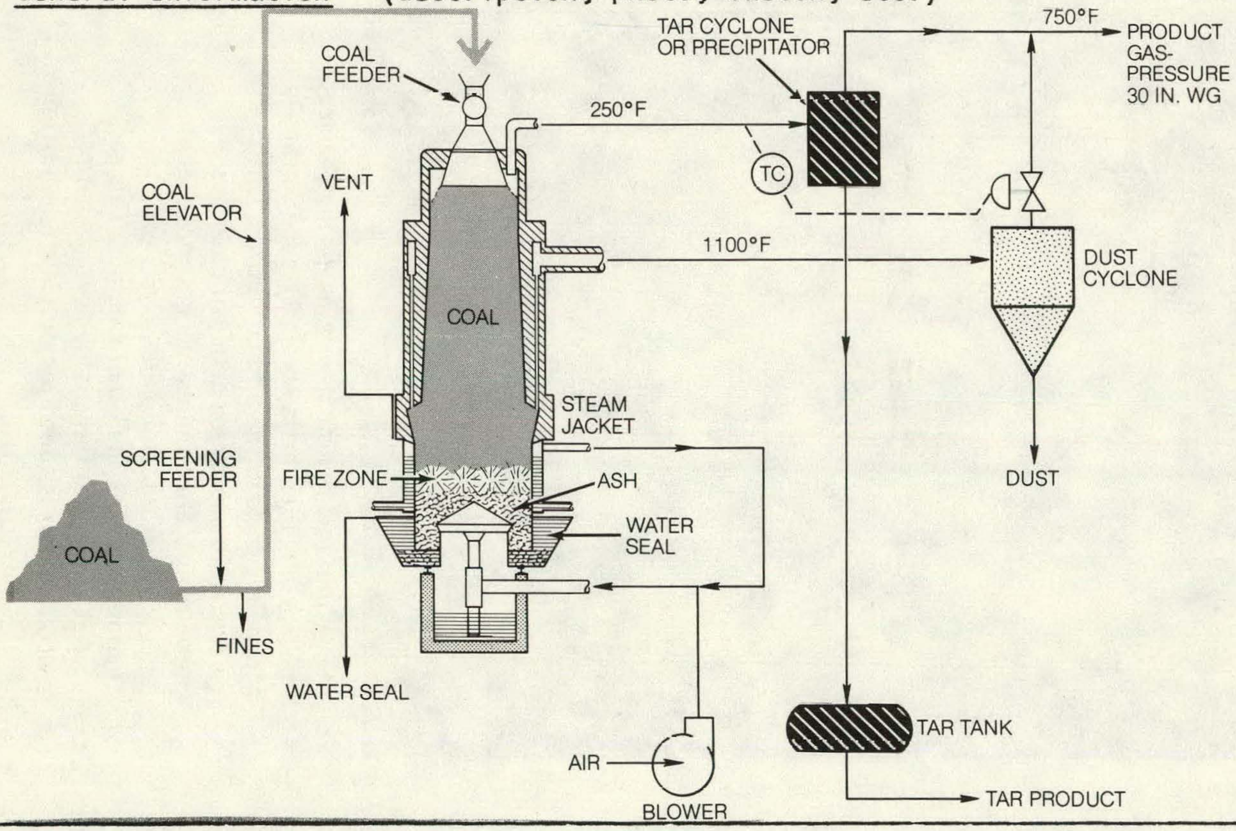
Type of Gasifier (up/down draft, size, fuel, application, etc.

updraft

Status (research, pilot scale, commercial, etc.)

Gasifier is commercial on coal. Have bench scale gasifier and 2-ft diameter test gasifier available for test work on wood.

General Information (description, photo, sketch, etc.)



Plans for Future

Name R. J. Broeker Date 1/12/79

BIOMASS AIR GASIFIER DIRECTORY

Organization
The Fuel Conversion Project
"Biomass"

Address
Biomass Corporation, 951 Live Oak Blvd., Yuba City, Ca. 95991

Personnel
Theodore H. Crane, President
Robert O. Williams, Vice President Engineering

Phone
(916) 674-7230

Type of Gasifier (up/down draft, size, fuel, application, etc.

Downdraft, fuel from prune pit size to 2x2x2 "hay-cubes" 5000 Btu per pound and up heating value, biomass or coal.

Status (research, pilot scale, commercial, etc.)

Commercial system. 1 to 15 million Btu per unit. Manifold units to 70 million Btu.

General Information (description, photo, sketch, etc.)

The BIOMASS GASIFIER is a down draft, co-current flow, fixed bed reactor for conversion of solid carbonaceous fuel to low-Btu fuel gas. The fuel gas may be directly substituted for natural gas or fuel oil in existing or new boilers with only a change in the burner. Available standard low Btu gas burners are standard commercial products in sizes up to 100 million Btu.

The Biomass gasifier discharges no tar, oils or liquors which could require expensive or hazardous disposal by the operator. The char residue contains carbon and inorganic matter suitable for blending with conventionally produced charcoal for briquettes or as a low sulfur metallurgical carbon source. The residue is inert and may be land filled if there is no other use for it.

A large internal fuel hopper and a system of sealed external hoppers, augers and knife gate valves allow continuous operation with full automation of the fuel cycle and no possibility of gas leaks at any time.

The design analysis of the various sized Biomass gasifiers includes a detailed thermal stress study. The suspended design of the gasifier shall allow full expansion of the gasifier eliminating stress build-up, a subsequent shell cracking. Details of system designs, system sizing and economic analysis of the benefits of gasifier ownership available upon application.

Plans for Future

Detailed studies of the use of the biomass gasifier as a fuel source for internal combustion engines. These studies will include complete mass and energy balances and the wear factor upon the engines.

Name THEODORE H. CRANE Date January 16, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Georgia Institute of Technology
Engineering Experiment Station

Address

Room 1512-A C&S Building
33 N Avenue - Atlanta, Ga. 30332

Personnel

Jerry L. Birchfield
Tomas F. McGowan

Phone

(404) 894-3448

Type of Gasifier (up/down draft, size, fuel, application, etc.

Up draft, 1/2 million Btu/hr, textile drying

Status (research, pilot scale, commercial, etc.)

Research, under design and construction

General Information (description, photo, sketch, etc.)

Up draft gasifier operating under forced draft. Product gas will be burned in a closecoupled arrangement. Hot combusted gases will be mixed with air for textile drying and curing tests.

Plans for Future

Experiments with pellets, dry and wet chip wood fuels.

Name Thomas F. McGowan **Date** 2-22-79

BIOMASS AIR GASIFIER DIRECTORY

Organization

Halcyon Associates, Inc.

Address

Maple Street, East Andover, N.H. 03231

Personnel

William G. Finnie, President

Phone

(603) - 735 - 5356

Type of Gasifier (up/down draft, size, fuel, application, etc.

Up draft - 6 MMBTUH through 50 MMBTUH - Green or dry wood waste or biomass fuel - For direct heating, boiler firing & direct power generation.

Status (research, pilot scale, commercial, etc.)

Commercial - 4 units sold, others being negotiated.

General Information (description, photo, sketch, etc.)

The Halcyon Gasifier produces cool clean gas using green or dry hogged size fuel or biomass. Calorific value is around 150 BTU per cubic foot. When burned, particulates are less than .02 pounds per million BTU with low Nox, well within E.P.A. requirements, without any cleaning of flue gases.

The gasifier operates below ash fusion temperatures and the grates are automatically self-cleaning. Ash removal is automatic.

Series of controls on the gasifier allows for automatic operation with little supervision.

A burner of up to 100 MMBTUH capacity, which can be adapted to fit most existing oil or natural gas fired boilers, can be supplied. The burner is capable of firing oil and/or natural gas as well as producer gas.

Output of the gasifier and burner(s) is controlled by regulating the gas flow actuated by boiler steam pressure or dryer/furnace temperature. Full modulation and flame failure safety features to meet insurance company requirements are included.

On power generation or direct drives, the gas is further cleaned to remove sub-micron size particles, and directly fuels internal combustion or compression ignition engines. This further cleaning may be used also when gas is burned where extremely low particulates are required.

Maintenance and power requirements are low.

Plans for Future

To engineer, manufacture, and apply units for commercial and industrial requirements.

Name William G. Finnie

Date January 18, 1979

Organization IMBERT AIR GASIFIER

Address Steinweg Nr. 11,
5760 Arnsberg 2, Germany

Personnel Walter Zerbin

Phone (0 19 31) 35 49
Telex 84 222 ins d

Type of Gasifier (up/down draft, size, fuel, application, etc.

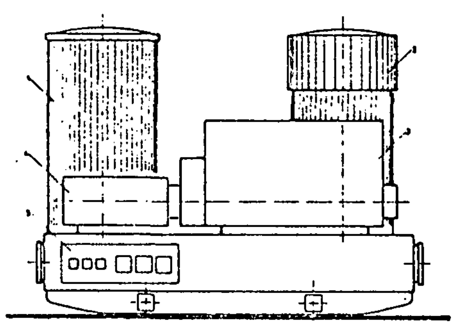
Downdraft air gasifier for diesel power generation

Status (research, pilot scale, commercial, etc.)

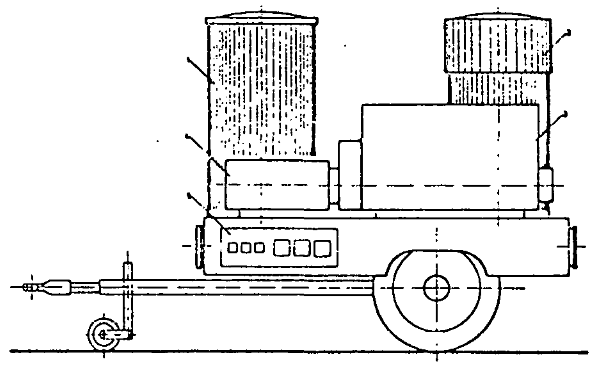
500,000 built and used over last 40 years

General Information (description, photo, sketch, etc.)

10 to 10,000 kw gasifier power plants. complete.

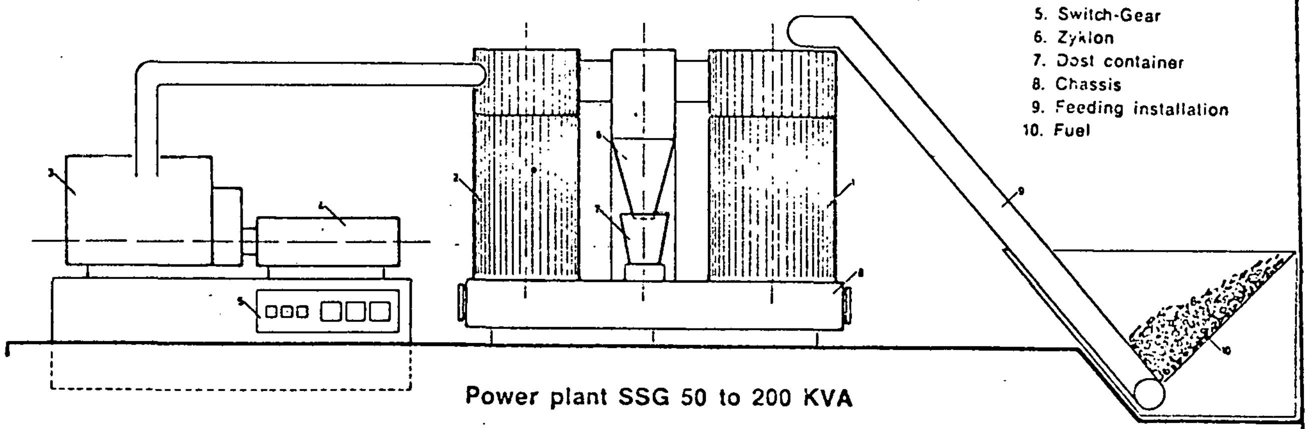


Power plant TSG 10 to 60 KVA



Power plant FSG 10 to 60 KVA

1. Gas producer
2. Gas-Cooling and cleaning plant
3. Motor
4. Elektric-Generator
5. Switch-Gear
6. Zyklon
7. Dost container
8. Chassis
9. Feeding installation
10. Fuel



Power plant SSG 50 to 200 KVA

Name (TBR) Date 3/27/79

BIOMASS AIR GASIFIER DIRECTORY

Organization

Lamb-Cargate Industries Ltd.

Address

1135 Queens Avenue
New Westminster, B.C.

Personnel

F.H. Lamb, President

Phone

604/521-8821

Type of Gasifier (up/down draft, size, fuel, application, etc.

Up-draft, 25 x 10^6 Net BTU, Green Hog Fuel.

Status (research, pilot scale, commercial, etc.)

Commercial

General Information (description, photo, sketch, etc.)

The Lamb Wet-Cell Burner is a double chamber system. The fuel is fed in up through the bottom of the grates. The lower chamber gasifies the green hog fuel and the gases are burned in the second chamber with a close control of excess air. There are two 25 x 10^6 BTU/hour units in commercial services. One in British Columbia directly fires two lumber kilns and one in New Zealand fires a pulp flash dryer at a new TMP mill.

Plans for Future Going up to 150 x 10^6 BTU/hour and firing lime kilns, waste heat boilers, veneer dryers, rotary dryers, etc.

Name F.H. Lamb

Date 1979 February 21

BIOMASS AIR GASIFIER DIRECTORY

Organization

Lamb-Cargate Industries Ltd.

Address

1135 Queens Avenue
NewWestminster, B.C.

Personnel

F.H. Lamb, President

Phone

604/521-8821

Type of Gasifier (up/down draft, size, fuel, application, etc.

Up-Draft, 4 x 10^6 B.T.U./hour, clean hog fuel

Status (research, pilot scale, commercial, etc.)

Pilot Scale

General Information (description, photo, sketch, etc.)

Semi-fluid bed reactor, complete with fuel metering and continuous ash discharge. Fuel metering adjacent to the grate.

Equipped with gas cleaning station consisting of:

a) cyclone
b) wet centrifugal scrubber
c) gas dryers.

Hudson Bay, Saskatchewan, installation includes gas engine generation.

Plans for Future

Package generation unit for small isolated communities, dry kilns, dryers, etc.

Name F.H. Lamb

Date 1979 February 21

BIOMASS AIR GASIFIER DIRECTORY

Organization
University of Missouri, Rolla
School of Engineering

Address
V. J. Flanigan
ME Dept., UMR Rolla, MO 65401

Personnel
V. J. Flanigan N.E. Welch
Y. O. Murtag J. Halligan

Phone
314-341-4661

Type of Gasifier - (up/down draft, size, fuel, application, etc.

Fluidized Bed

Status (research, pilot scale, commercial, etc.)

research, pilot scale

General Information (description, photo, sketch, etc.)

Research project to study biomass gasification in a reactor originally designed by Coors Corporation for municipal waste.

Plans for Future

Name V. J. Flanigan Date 3/2/79

Organization MOTEURS DUVANT
Represented by:
INDUSTRIAL DEVELOPMENT & PROCUREMENT

Address ONE OLD COUNTRY ROAD
CARLE PLACE, N.Y. 11514

Personnel

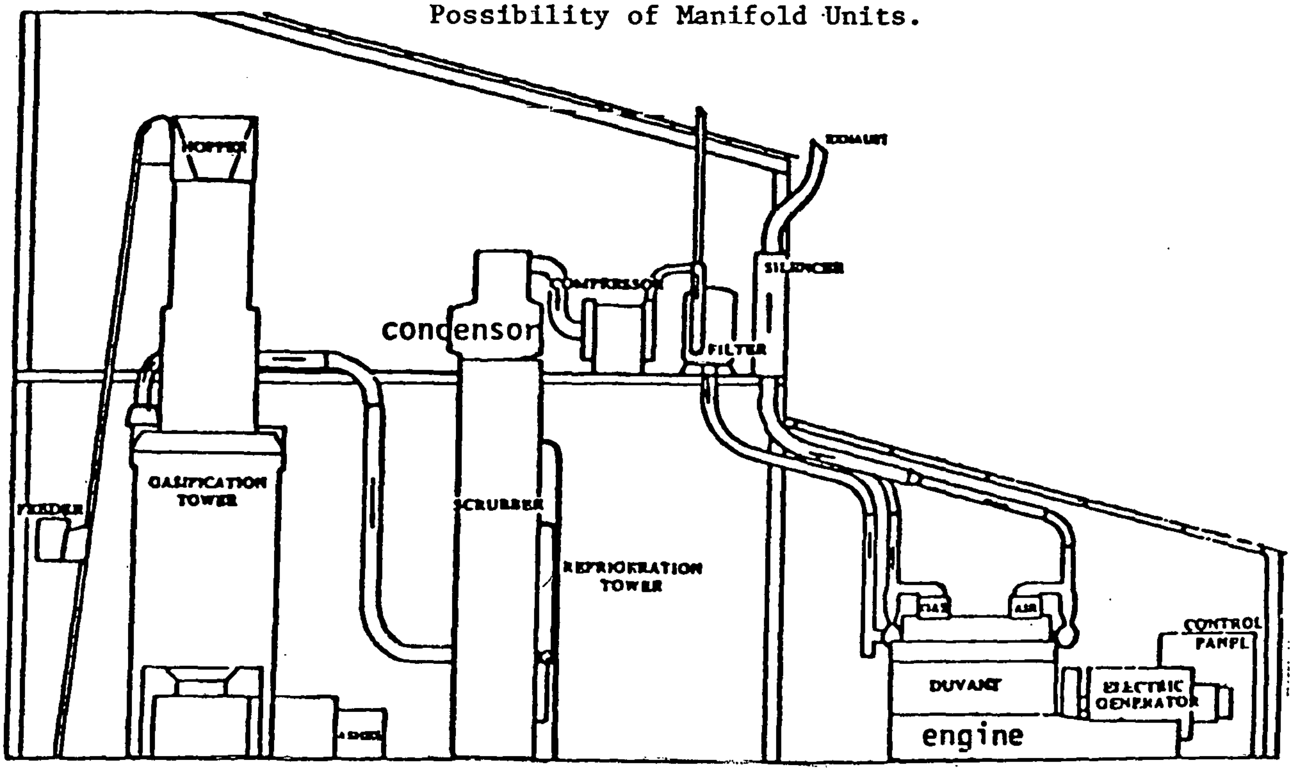
Jules A. LUSSIER, Vice-President

Phone 516-248-0880

Type of Gasifier (up/down draft, size, fuel, application, etc.
Down draft - 1 to 8 million BTU per unit. Fuel: Wood waste, chips,bark, corn cobs, rice husks, cotton gin residues, coffee shells, coconut shells and husks, sun flower seed residues, paper mill sludge, other miscellaneous organic waste.

Status (research, pilot scale, commercial, etc.) Commercial
Several Duvant Dual Fuel Engine systems have been delivered and installed in Europe, Africa, South Pacific, Asia, Central America.

General Information (description, photo, sketch, etc.)
Complete energy systems consisting of a low BTU gas production unit, a filtering and cooling unit and a dual fuel engine - generator set. Range 100 to 750 KW. Possibility of Manifold Units.



Plans for Future

Promote and develop sales in North America.

Name Philippe Santini **Date** March 27, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

PIONEER HI-BRED INTERNATIONAL, INC.

Address

5700 MERLE HAY ROAD, JOHNSTON, IA. 50131

Personnel

Walter Stohlgren

Phone

1-515-245-3721

Type of Gasifier (up/down draft, size, fuel, application, etc.

Down Draft 9×10^6 Btu/Hr. Corn Cobs. Seed Dryer.

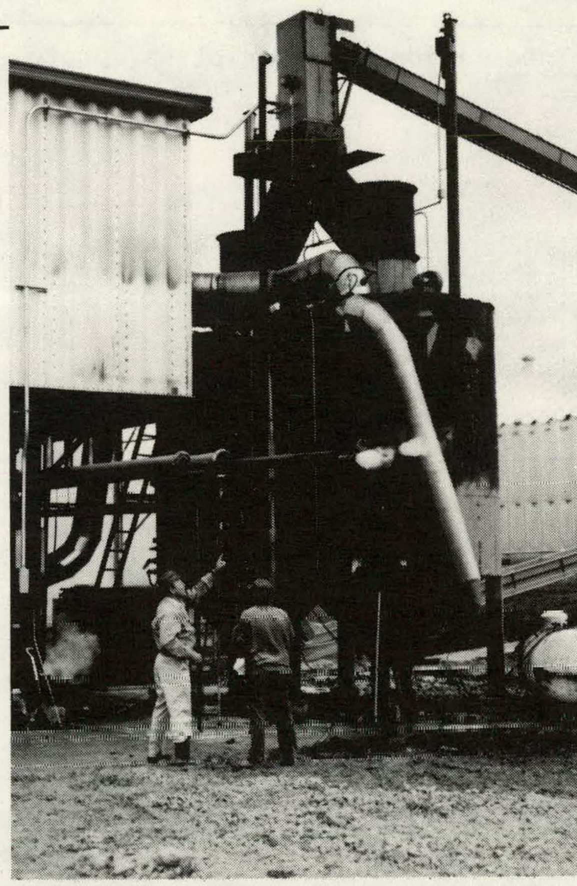
Status (research, pilot scale, commercial, etc.)

Research, Commercial

General Information (description,

Testing close coupled burner.

Looks good for eliminating the tar problem.



Plans for Future

Redesign grate to eliminate the ash caking problem.

Name [signature] Date February 6, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization
Pulp and Paper Research Institute of Canada

Address 570 St. John's Blvd., Pointe Claire, Quebec, Canada H9R 3J9

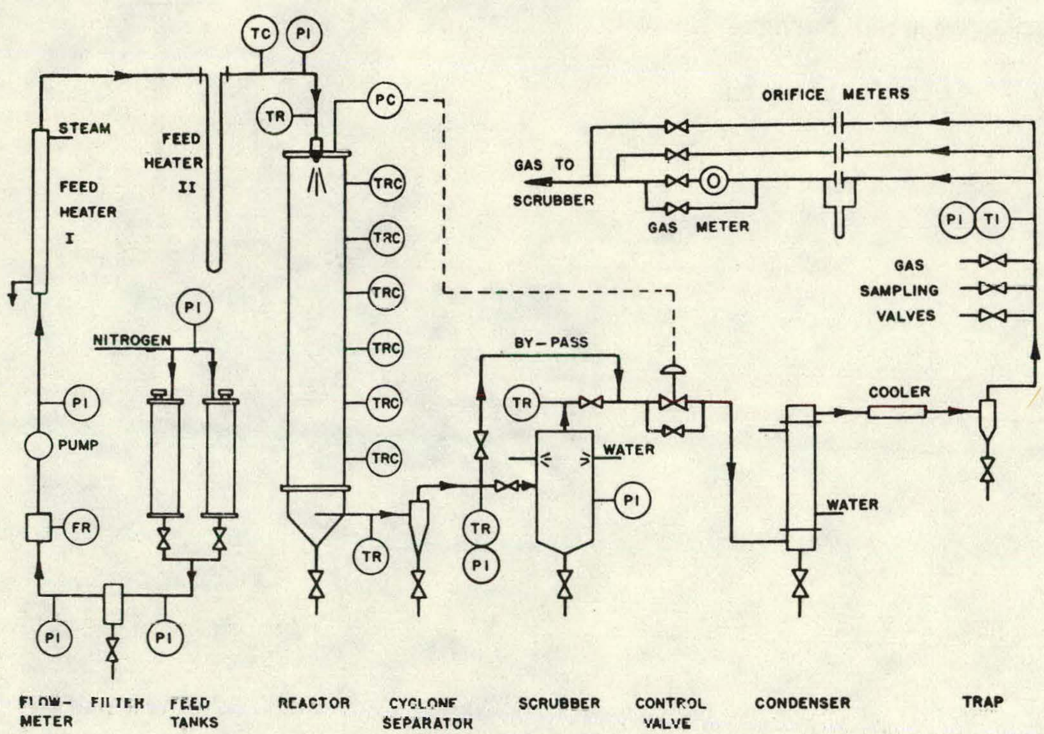
Personnel
S. Prahacs and M.K. Azarniouch

Phone (514) 697-4110

Type of Gasifier (up/down draft, size, fuel, application, etc.)
Down draft reactor, 316 SS, 12 in. diameter, 15 ft. high, suitable for spent pulping liquors and lignocellulosic material, pressure - 45 psig/atmospheric, temperature - 1450°F/1650°F.

Status (research, pilot scale, commercial, etc.)
Pilot scale (presently not operated).

General Information (description, photo, sketch, etc.)



Plans for Future
To carry out gasification tests on lignocellulosic material.

Name S. Prahacs **Date** January 15, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization | **Address**

Agricultural Engineering Department, Purdue University, W. Lafayette, IN 47907

Personnel | **Phone**

Robert M. Peart, Michael Ladisch (317) 749-2971

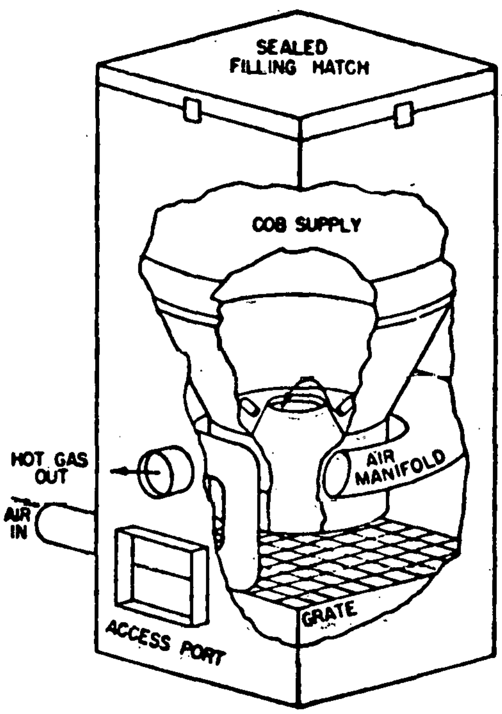
Type of Gasifier (up/down draft, size, fuel, application, etc.

Downdraft, corn cobs, for direct firing of corn dryer.

Status (research, pilot scale, commercial, etc.)

Research, crude operational model only

General Information (description, photo, sketch, etc.)



This batch unit holds about 300 pounds of cobs, is about 8 feet tall, 31.5 inches square, mild steel except for stainless steel support cone. Air flow 25 scfm, heat output estimated approximately 250,000 Btu/hr (50 pounds of cobs/hr). We have gasified cobs of from 15-25% moisture, wet basis.

Plans for Future

1) Build continuous flow unit for more accurate measurement of input/output.
2) Test turn-down ratios, cob moisture, air flow, insulation.
3) Build bench test unit for more accurate tests on composition as affected by operating variables.

Name Robert M. Peart Date January 16, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization

Saskatchewan Power Corporation

Address

2025 Victoria Ave., Regina, Sask., Canada S4P-0S1

Personnel

Dr. A. Verma

Phone

306-527-7611

Type of Gasifier (up/down draft, size, fuel, application, etc.

Fluidized bed gasifier, 4 mmBtu/hr.

Status (research, pilot scale, commercial, etc.)

Demonstration scale

General Information (description, photo, sketch, etc.)

The gasifier is a scale up of the B.C. Research unit with major modifications and addition of a cleanup train. The gasifier is located at Hudson Bay in Saskatchewan at the Saskatchewan Forest Products' plywood plant.

The gas will be tested in a burner as well as a modified diesel engine for power generation. The plant is presently undergoing startup runs.

(A slide is attached)

Plans for Future

To operate at a northern location in Saskatchewan. A scaleup may also take place if the project is successful.

Name [signature] Date 1979, February 28th

BIOMASS AIR GASIFIER DIRECTORY

Organization
Department of Chemical Engineering
Texas Tech University

Address
Lubbock, Texas 79409

Personnel
Steven R. Beck
Uzi Mann

Phone
(806) 742-3553

Type of Gasifier (up/down draft, size, fuel, application, etc.

Fluidized Bed, 50 lb/hr, any biomass for conversion to medium-GTU gas

Status (research, pilot scale, commercial, etc.)

Pilot scale testing has been in progress for 2 years.

General Information (description, photo, sketch, etc.)

A counter current pyrolysis reactor for cattle wastes has been invented which allows volatile organic compounds to escape from the heating zone very rapidly. This results in a different product mix than has been observed in other pyrolysis research, containing unusually high concentrations of ethylene. Fuel values of gases plus the sparing of petroleum needs by ethylene, if economically feasible, would supplement petroleum supplies. The work includes studies in an existing 1/2 ton/day test reactor to determine the influence of temperature, residence time, pressure, and feedstock materials on the yield and quality of the products of reaction. The scope of work includes economic assessments of the process, utilizing animal manures and other biomass materials as feedstocks. Studies include the effects of reactor geometry and solid/gas contact in cold models. Relationships for the design of a staged reactor will be developed. This work may benefit programs on coal hydrogasification and coal gasification.

Plans for Future

Evaluate other feedstocks. Develop kinetic model of reactor.

Name Steven R. Beck Date 1/15/79

BIOMASS AIR GASIFIER DIRECTORY

Organization
Texas Tech University

Address
Dept. of Chemical Engineering
Lubbock, TX 79409

Personnel
Harry W. Parker

Phone
(806) 742-3553

Type of Gasifier (up/down draft, size, fuel, application, etc.

Prototype is up-draft batch, but subject to change. Objective is to utilize gin trash for fueling internal combustion engines on irrigation wells.

Status (research, pilot scale, commercial, etc.)

pilot scale

General Information (description, photo, sketch, etc.)

The present gasifier is a simple up-draft batch gasifier 20 inches in diameter. This gasifier will have to have significant modifications to succeed in gasifying gin trash for operation of irrigation wells. Another type of gasifier may be selected.

Plans for Future

Determine feasibility of gasifying un-cubed gin trash for powering irrigation wells. If it is feasible a cost estimate will be made.

Name Harry W. Parker **Date** January 15, 1979

BIOMASS AIR GASIFIER DIRECTORY

Organization
The Vermont Wood Energy Corporation

Address
P.O. Box 280
Stowe, VT 05672

Personnel
J. Phillip Rich, President
Peter H. Bauer, Project Engineer
Cadwallader E. Brooks, Treasurer

Phone
802-253-7220

Type of Gasifier **(up/down draft, size, fuel, application, etc.)**
Close-coupled, down draft, semi-automatic (wood chips or pellets, manually loaded), thermostatic on/off operation, roughly 80,000 BTU/hr. output

Status **(research, pilot scale, commercial, etc.)**
One semi-automatic test model under development, about 2/3 of the way to successful operation.

General Information **(description, photo, sketch, etc.)**

The gasifier is intended for use with a home-size furnace, to convert a used or new furnace from oil flame to wood gas flame, or possibly as an adjunct installation with oil burner gun still in place.

The gasifier, about the size of a small suitcase, is surrounded by an insulating enclosure and has a chip hopper above it. Combustible gases are led through about 3 feet of pipe to the combustion chamber of a former oil burning furnace. The gasifier has been operating successfully using forced draft, and an induced draft system is under development.

When the thermostat signals for heat, the electrical/electronic control system begins a timed sequence of events, operating an electric fuel igniter, and then blowers, solenoid operated valves, tickler shaft motor, low fuel level detector motor, and the gas igniter electrodes. The controls shut off and turn on the system when signalled by the thermostat. Safe shutdown occurs upon electric supply failure or in case of various system failures or low fuel level.

Plans for Future Completion of development of semi-automatic test model... Development of automatic test model by replacing chip hopper with a surge bin, and adding a conveyor and storage bin for the fuel... Testing, prototype installations, modifications, marketing, production, and sales of one or both types of gasifiers

Name Peter H. Bauer **Date** January 12, 1979

SECTION 12.0

RETROFIT '79—Seattle, Washington
February 2, 1979

List of Attendees

A

Wieble M. Alley
Arkansas Power & Light Co.
P. O. Box 551
Little Rock, AR 72203
(501) 371-4325

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16935 S. Vermont Avenue
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North Central Forest Experiment
Station Forest Engineering Lab.
Houghton, MI 49931
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Edmonton, Alberta
CANADA T5J 1R9
(403) 429-4094

B

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(713) 782-3440

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(802) 253-7220

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226-7346

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CANADA M2N 5S8
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303 More Hall, FX-10
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Houston, TX 77074
(713) 981-8303

Vern Bowerman
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Winnipeg, Manitoba
CANADA R3C 3H8
(204) 944-2032

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Robert J. Brandon
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50 Water Street
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CANADA C1A 1A6
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Owen D. Brown
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Eugene, OR 97440
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William Bulpitt
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Atlanta, GA 30332
(404) 894-3448

John A. Burton
Wright Engineers LTD.
1444 Alberni Street
Vancouver, BC
CANADA V6G 2Z4
684-9371

C

John C. Calhoun, Jr.
Forest Fuels, Inc.
7 Main Street
Keene, NH 03431
(603) 357-3319

Donald G. Campbell
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11120 Roselle Street, Suite J
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(714) 452-8630

Ted Carpentier
Bio Solar R&D Corporation
1500 Valley River Drive
Eugene, OR 97401
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Keene, NH 03431
(603) 357-3319

Anil Chatterjee
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(415) 326-6200

Paul Claar
Thomas R. Miles Consultants
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Portland, OR 97225
(503) 292-2919

D

Humbert M. Dardani
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7 Main Street
Keene, NH 03431
(603) 357-3319

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SERI
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Golden, CO 80401
(303) 231-1479

Tom W. Dunbar
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Vancouver, BC
CANADA V7S 1W9
682-7841

Douglas W. Duncan
BC Research
3650 Westbrook Mall
Vancouver, BC
CANADA V6S 2L2
(604) 224-4331

John E. Dunwoody
Mittelhauser Corporation
5120 S. Belmont Street
Downers Grove, IL 60515
(312) 964-8164

E

Victor Engleman
Science Applications Inc.
P. O. Box 2351
La Jolla, CA 92038
(714) 454-3811

F

Robert Farley
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1536 Cole Blvd.
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(303) 231-1190

Allan Fernie
Westwood Polygas, Ltd.
1444 Alberni Street
Vancouver, BC
CANADA V6G 2Z4
(604) 684-9371

William G. Finnie
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The Halcyon, Maple Street
East Andover, NH 03231
(603) 735-5356

Ralph Fredrickson
Raphael Katzen Associates
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Cincinnati, OH 45208
(513) 871-7500

George Finnie
Halcyon Associates, Inc.
The Halcyon, Maple Street
East Andover, NH 03131
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G

Bob Gaar
Office of Energy Resources
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Atlanta, GA 30334
(404) 656-5176

John Goss
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Davis, CA 95616
(916) 752-1421

John Grantham
Forest Products Laboratory
1601 2nd Avenue
Seattle, WA 98101
(206) 442-7591

H. Kelton Grubbs
Mid-South Engineering
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Hot Springs, AR 71901
(501) 321-2276

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