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DIESEL FUEL FROM BIOMASS

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ABSTRACT

A project to convert various biomass materials to diesel type transportation fuel compatible with current engine designs and the existing distribution system is described. A continuous thermochemical indirect liquefaction approach is used. The system consists of a circulating solid fluidized bed gasification system to produce a synthesis gas containing olefins, hydrogen and carbon monoxide followed by a catalytic liquefaction step to convert the synthesis gas to liquid hydrocarbon fuel.

The major emphasis on the project at the present time is to maximize product yield. A level of 60 gals of diesel type fuel per ton of feedstock (dry, ash free basis) is expected. Numerous materials have been processed through the conversion system without any significant change in product quality (essentially C_7-C_{17} paraffinic hydrocarbons with cetane indicies of 50+). Other tasks in progress include factor studies, process simplification, process control and scale-up to a 10 ton/day Engineering Test Facility.

DIESEL FUEL FROM BIOMASS

INTRODUCTION

Current forecasts indicate an increasing demand for diesel fuel in future years with a corresponding percentage decline in high octane gasoline (1,2). One potential feedstock for producing diesel fuel is biomass. These may consist of agricultural, forest, industrial and urban wastes or crops deliberately grown for energy conversion purposes. The contribution of these feedstocks would be contingent upon the quantity of material available in a collection area and the delivered feedstock cost to a processing facility. Marketing conditions appear to be robust, i.e., collection areas for biomass materials normally are heavily dependent upon diesel fuel for such applications as farm machinery, trucks, industrial equipment, etc. Also biomass collection areas are often rural and are subject to a low priority with regard to fuel allocations in times of scarcity. Thus self sufficiency is a very real incentive in many locations. It also should be noted that many developing nations are rich in biomass materials but short on domestic supplies of fossil feedstocks for the production of liquid hydrocarbon fuels. Thus, with the development of commercial biomass conversion processes, the opportunity will become available for these countries to decrease their dependence upon foreign sources of liquid fuel.

Biomass vs Coal

The only commercial scale conversion facility in the world to convert non-petroleum feedstocks to liquid hydrocarbon fuels is the SASOL facility in South Africa (3). There, coal is gasified to a synthesis gas containing hydrogen and carbon monoxide. After purification, the gas is converted to a paraffinic mixture in a second stage reactor utilizing an iron catalyst. Following some refining steps, a transportation grade fuel is produced. The fundamental characterization differences that exist between a coal feedstock and biomass are summarized in Table 1. As indicated, biomass contains a higher hydrogen/carbon and oxygen/carbon ratio but lower sulfur and ash content. The heating value for biomass is lower (due to the oxygen content) but the volatile matter is greater. Thus, except for the oxygen content, biomass exhibits more attractive characteristics than coal for producing a liquid hydrocarbon fuel (less hydrogen source addition, less sulfur and ash removal, milder operating conditions). Coal, of course, has the advantage of densification thus leading to a more favorable economy of scale. Biomass, of course, is renewable and thus will be the only available feedstock with the eventual depletion of the fossil sources.

Table 1. COAL AND BIOMASS COMPOSITION (WEIGHT %)

	Coal	Biomass
C	70 - 80	35 - 55
H	4 - 6	4 - 6
O	5 - 20	25 - 50
N	0.5 - 2	<0.5
S	1 - 5	<0.5
ash	5 - 30	0 - 10
Heating values (Btu/lb) (dry basis)	9500 - 15000	6500 - 9500
Volatile matter, wt. %	30 - 50	60 - 90

Processing Options

Several options are under study to convert various biomass materials to liquid hydrocarbon transportation fuels equivalent to that derived from petroleum. Possible routes are indicated in Figure 1. A major virtue of these approaches (as compared with biological conversion to ethanol) is compatibility with the present fuel distribution system and engine designs.

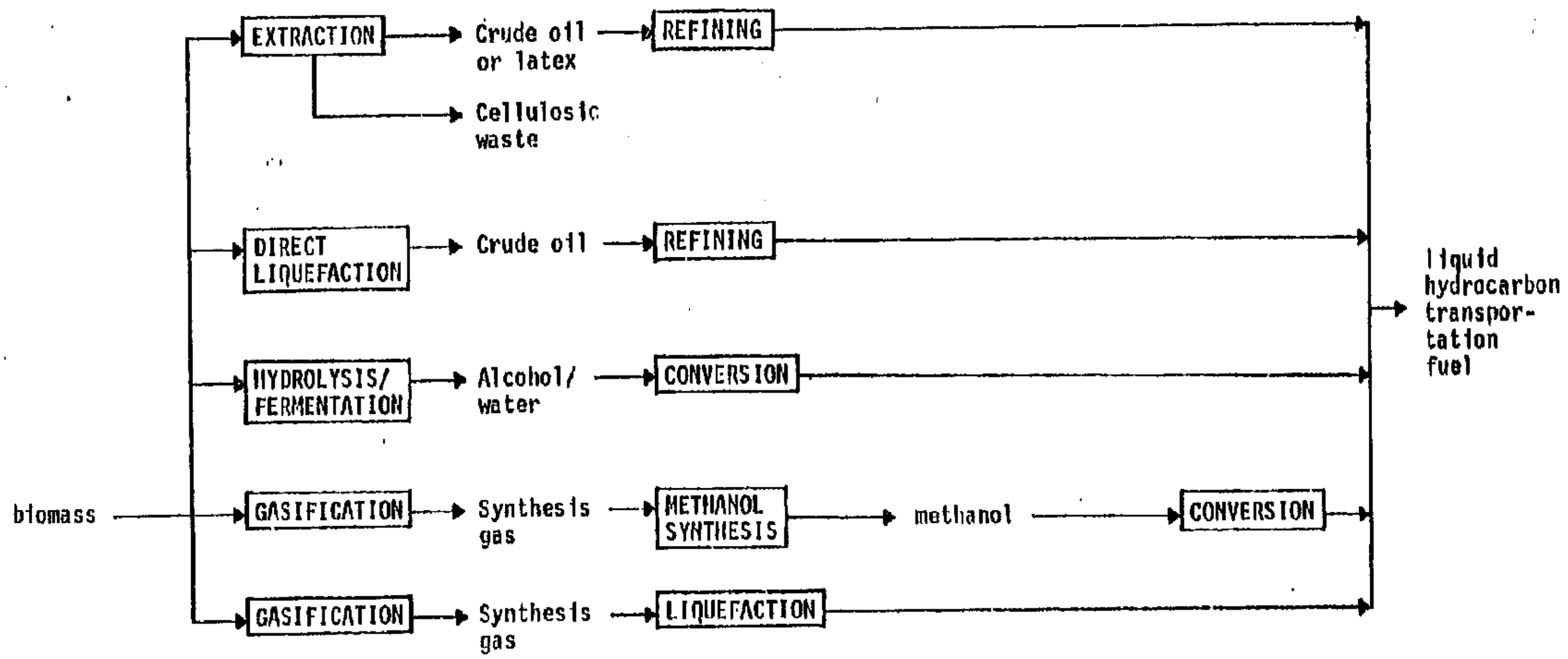
The first approach shown in Figure 1 consists of extraction of crude oil or latex from appropriate species (e.g., oil seed crops, euphorbia plants, etc.) followed by some degree of refining to achieve the proper compound types and molecular weight range. Of particular concern is the removal of oxygenated compounds present in the crude material which may result in a high viscosity, acidic product. The present status of seed oils for diesel fuel use has been recently described (4). Preliminary work on refining of extracted materials has also been reported (5). In general, the degree of refining necessary to produce a high quality marketable fuel from these materials has not yet been established. Also, as indicated in Figure 1, a large portion of the plant will remain as a cellulosic waste after the oil or latex is extracted. The processing economics will be directly affected by the utilization of these portions of the plant.

Direct liquefaction has been studied as a possible route to produce liquid hydrocarbon transportation fuel. These approaches consist of a pyrolysis or incomplete combustion step to maximize liquid production followed by some degree of refining to eliminate the oxygenated compounds and achieve the desired commercial fuel properties. Some investigators have attempted to minimize the oxygenated compounds via the use of reducing agents (e.g., hydrogen, carbon monoxide) in the pyrolysis/incomplete combustion step (6) while others have left this task for a sequence of refining steps (7,8). In both cases, demonstration of a process to produce a quality product has not yet emerged.

A study has been reported to convert the unseparated alcohol-water mixture from a hydrolysis-fermentation step to a high octane gasoline via a catalytic (zeolite) second stage (9). The incentives are to produce a liquid hydrocarbon fuel and avoid the energy intensive distillation step to separate the ethanol-water mixture. This work currently is at the microreactor scale. Inherent constraints are the long processing times associated with the fermentation step and demonstration of the hydrolysis step on a commercial scale in order to utilize low cost (cellulosic) feedstocks.

Mobil Oil has developed a catalytic (zeolite) process to convert methanol to high octane gasoline (10).

Figure 1. LIQUID HYDROCARBON TRANSPORTATION FUEL FROM BIOMASS OPTIONS



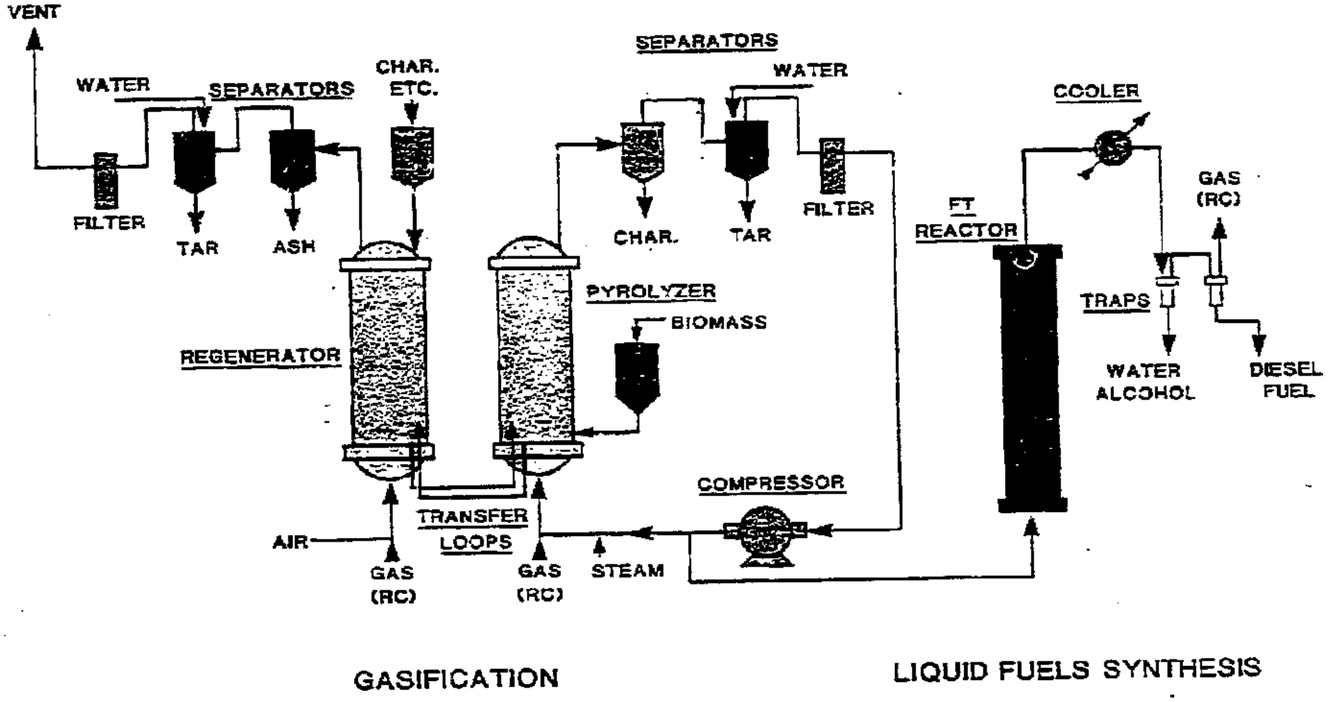
The potential synthesis gas sources promoted for producing the methanol have included coal, natural gas and biomass. A modification of this process to convert synthesis gas containing hydrogen and carbon monoxide directly to high octane fuel using a blended zeolite-iron catalyst system has also been reported at the laboratory scale (11). In general, the methanol-to-gasoline process appears to be at an advanced stage of development. An integrated system using a biomass feedstock has not been demonstrated.

The process under development at Arizona State University (ASU) is the final option shown in Figure 1. Here, biomass is gasified to a synthesis gas containing the reactive components hydrogen, carbon monoxide and olefins in the presence of paraffins, carbon dioxide and water. The unseparated gas stream is passed through a second stage catalytic reactor from which a paraffinic liquid hydrocarbon fuel is condensed. Compared to the alternative options indicated in Figure 1, this approach offers the potential of producing a diesel type transportation fuel from various biomass materials with fewer processing steps and at relatively attractive operating conditions. The present status and future plans of the ASU project is described in this paper.

EXPERIMENTAL SYSTEMS

A schematic of the ASU indirect liquefaction system is shown in Figure 2. The existing system is laboratory scale with a capacity of approximately 25 lbs/hr of feedstock. Target product yields are in the 50-100 gals. of diesel type fuel per ton of feedstock (dry, ash free). Continuous processing is employed. While the unit is of small scale, the processing steps and procedures are commercially realistic. Thus designed experiments can be sometimes tedious to accomplish but the resulting data should be highly reliable for scale up purposes. The gasification system is comprised of two fluidized beds with connecting circulating solid transfer loops. One fluidized bed is used as a feedstock pyrolyzer while the second bed (regenerator) operates in a combustion mode to heat the circulating solids media. Both inert solids (sand) and catalytic materials are under investigation. The fluidized bed approach allows for efficient heat transfer, continuous solids recirculation and elimination of a combustion zone in the pyrolyzer (and thus avoid gas clean up steps). Cellulosic (biomass) feedstocks are continuously fed to the pyrolyzer and flashed to a synthesis gas consisting of paraffins, olefins, carbon monoxide, hydrogen and carbon dioxide. The gas passes through a cyclone-scrubber system to a compressor. From the compressor, the gas can be distributed to the pyrolyzer and/or liquefaction reactor. Additional gas candidates for fluidizing the pyrolyzer are steam and off gas from the downstream reactors. Studies to date

Figure 2. CONVERSION SYSTEM SCHEMATIC



indicate that the use of recycle pyrolyzer gas is not desirable for fluidizing the pyrolyzer due to the increased effective residence time with respect to the reactive gas components. The regenerator is fluidized by air and recycle gas from the pyrolyzer and/or downstream reactors. The off gas from the regenerator is passed through a cyclone-scrubber system before being vented.

The liquefaction system consists of a catalytic reactor to produce paraffinic liquid fuel. Both fluidized and slurry phase systems are under study. These reactor types allow for effective temperature control in the presence of the significant exothermic heat of reaction that is evolved and also offer the possibility of continuous regeneration via external circulation if necessary. The fluidized bed is a simpler system than the slurry phase type. The slurry phase system however offers the potential advantages of better temperature control, longer catalyst life, residence time flexibility and improved gas-solid contacting. In both reactor types, the reactive components in the synthesis gas (olefins, carbon monoxide, hydrogen) are converted to a primary paraffinic hydrocarbon phase and a secondary alcohol-water phase. The off gas from this reactor accumulates an appreciable amount of normal paraffins plus carbon dioxide and exhibits an enhanced heating value as compared to the synthesis gas (due to hydrogen and carbon monoxide depletion).

Work also has been performed on the system to produce a high octane gasoline via catalytic reforming of the paraffinic liquid phase in a conventional fixed bed system using commercial catalysts. To achieve a commercial octane range, a liquid yield loss of about 20% occurs in the reforming step. The off gas is of high heating value (~2300 Btu/SCF) due to the presence of C_1-C_4 normal paraffins and thus some of the yield loss could be recovered via recycling of this gas in the overall process.

Photographs of the laboratory scale indirect liquefaction system and associated control room are shown in Figures 3 and 4. Typical operating conditions for the processing steps are as follows:

	Pyrolyzer	Fluid Bed/Slurry Phase Liquefaction Reactor	Reformer
Temperature, °C	600-800	250-300	490
Pressure psig	0-1	140	400
Residence Time, sec	2	18	11

A large array of additional experimental equipment exists in the ASU laboratory to support the project.

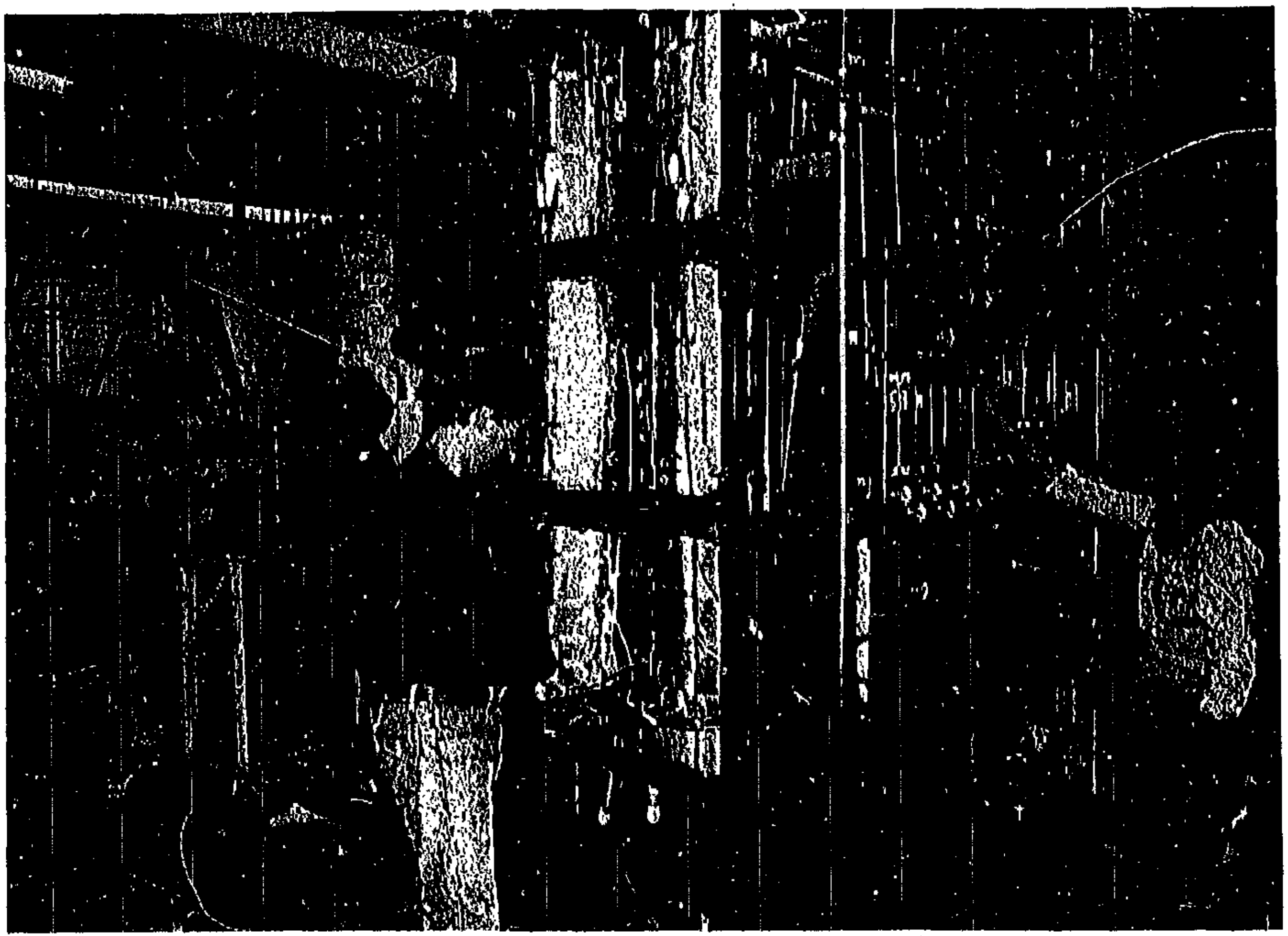


Figure 3. LARGE SCALE INDIRECT LIQUEFACTION CONVERSION SYSTEM

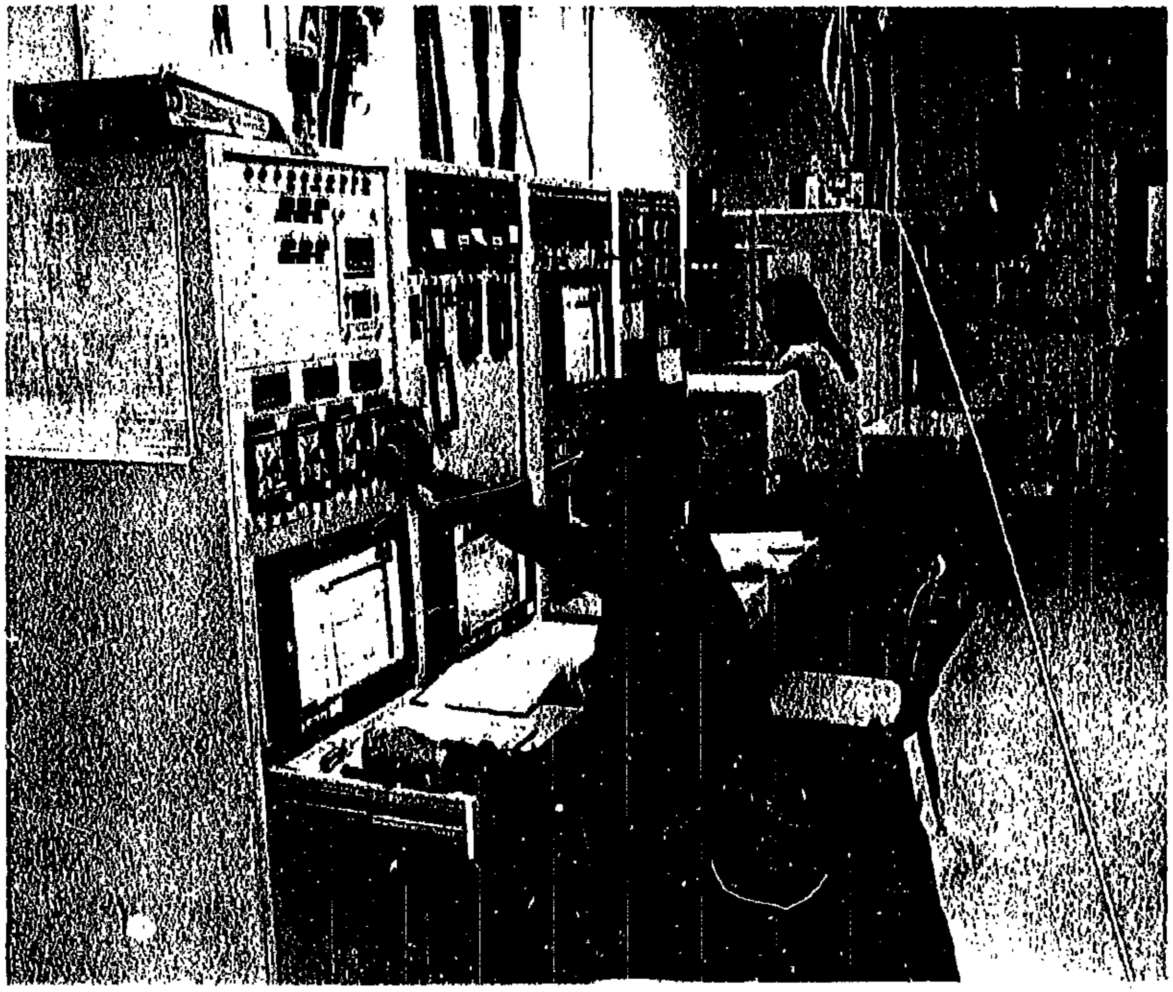


Figure 4. CONTROL ROOM

Included are systems for catalyst preparation, characterization and testing; simulators (cold model) for reactor design studies; feedstock preparation and analysis equipment, and analytical instrumentation. These equipment items have been described elsewhere (13).

PROCESS CHEMISTRY

The basic objective of the project is to maximize product yields of quality, oxygen free liquid hydrocarbon fuel suitable for transportation use in existing engines. The oxygen in the biomass is converted to carbon monoxide, carbon dioxide and water in the gasification step. In the liquefaction step, the carbon monoxide is converted to paraffinic hydrocarbons, water, and normal propanol via the following possible reactions:

$$C_2H_4+(n-2)CO+(2n-4)H_2 \rightleftarrows C_nH_{2n+2}+(n-2)H_2O$$

$$1/2(n-1)C_2H_4+CO+3H_2 \rightleftarrows C_nH_{2n+2}+H_2O$$

$$C_2H_4+CO+H_2 \rightleftarrows C_2H_5CHO$$

$$C_2H_5CHO+H_2 \rightleftarrows C_3H_7OH$$

With proper manipulation of the above reactions, the oxygen in the biomass will end up in water, carbon dioxide and normal propanol. Carbon dioxide and water will be vented from the gasification system regenerator and an immiscible alcohol-water phase will be separated from an oxygen free paraffinic hydrocarbon phase. Past and present efforts on the project have been aimed at optimizing the implementation of this scheme via feedstock assessment, factor studies and operational reliability/control improvements.

FEEDSTOCK ASSESSMENT

A listing of feedstocks under study in the laboratory appears in Table 2. These materials may be grouped into the categories of industrial, urban, agricultural and forest wastes and crops deliberately grown for energy conversion purposes. Also included are some non-biomass materials (e.g., coal, synthetic polymers). The materials are received from private industry, municipalities, government laboratories (U.S. and foreign) and other university laboratories. A range of characterization data for the biomass feedstocks listed is given in Table 3. Performance date is detailed elsewhere (14). In general, all the feedstocks will produce a quality product. Yields will be dependent on the synthesis gas composition potential of the feedstocks. Some variations have been observed. Thus, for example, cork materials produce a high olefin content while Euphorbia lathyris gives a high H_2/CO ratio. A fairly wide variation in ash

TABLE 2. FEEDSTOCK LIST

(THE SCIENTIFIC NAME IS LOCATED UNDER THE COMMON NAME WHERE APPROPRIATE)

1) Euphorbia lathyris
Euphorbia lathyris

2) Candelilla bagasse
Euphorbia antisyphilitica

3) Raw guayule
Parthenium argentatum

4) Guayule resins
Parthenium argentatum

5) Guayule bagasse
Parthenium argentatum

6) Guayule cork
Parthenium argentatum

7) Greasewood
Sarcobatus vermiculatus

8) Jojoba meal
Simmondsia chinensis

9) Almond hulls
Terminalia catappa

10) Almond shells
Terminalia catappa

11) Almond prunings
Terminalia catappa

12) Sugarcane bagasse
Saccharum officinarum

13) Wheat straw
Triticum aestivum

14) Creosote bush
Larrea tridentata

15) Fir bark
Pseudotsuga menziesii

16) Arizona cypress
Cupressus arizonica

17) Pringle manzanita
Arctostaphylos Pringlei

18) Wright silktassel
Garrya Wrightii

19) Pointleaf manzanita
Arctostaphylos pungens

20) Shrub live oak
Quercus turbinella

21) Hairy mountain mahogany
Cercocarpus breviflorus

22) Utah juniper
Juniperus osteosperma

23) Pinyon pine
Pinus edulis

24) Velvet mesquite
Prosopis juliflora var. velutina

25) ECO FUEL II (municipal preprocessed refuse)

26) Raw kelp

27) Kelp residue

28) Smiling sumac
Rhus copallina

29) Smooth sumac
Rhus glabra

30) Red tatarian honeysuckle
Lonicera tatarica

31) Giant ragweed
Ambrosia trifida

32) Pokeweed
Phytolacca americana

33) Tall boneset
Eupatorium altissimum

34) Rosin weed
Silphium integrifolium

35) Tall goldenrod
Solidago altissima

36) Sassafras
Sassafras albidum

37) Coral berry
Symphoricarpos orbiculatus

38) Wild bergamot
Monarda fistulosa

39) Russian thistle
Salsola Kali

40) Water hyacinth
Hyacinthus spp.

41) Common milkweed
Asclepias syriaca

42) Swamp milkweed
Asclepias incarnata

43) Peat
Sphagnum spp.

44) Portuguese oak cork
Quercus suber

45) Silver maple
Acer saccharinum

46) Yellowleaf silktassel
Garrya flavescens

47) Sweet sorghum
Sorghum saccharatum

48) Pale indian plantain
Cacalia atriplicifolia

49) Tall bellflower
Campanula americana

50) Cherry elaeagnus
Elaeagnus multiflora

51) Grass leaved goldenrod
Solidago graminifolia

52) Common elder
Sambucus canadensis

53) Canada wildrye
Elymus canadensis

54) Field thistle
Cirsium discolor

55) Sow thistle
Sonchus oleraceus

56) Compass plant
Silphium laciniatum

57) Canaigre roots
Rumex hymenosepalus

58) Cut leaf teasel
Dipsacus laciniatus

59) Blue teasel
Dipsacus sylvestris

60) American germander
Teucrium canadense

61) woody milkweed
Asclepias spp.

62) Rotund-leaf milkweed
Asclepias spp.

63) Cotton seed meat
Gossypium Thurberi

64) Cotton seed
Gossypium Thurberi

65) Cotton seed lint
Gossypium Thurberi

66) Cotton seed meal
Gossypium Thurberi

67) Cotton seed hulls
Gossypium Thurberi

68) Cotton gin trash
Gossypium Thurberi

69) Skunkbush
Rhus trilobata

70) Yerba-santa
Eriodictyon angustifolia

71) Fourwing saltbush
Atriplex canescens

72) Netleaf hackberry
Celtis reticulata

73) Catclaw mimosa
Mimosa biuncifera

74) Sewage sludge

75) Corn starch

76) Coal

77) Polyethylene

78) Polypropylene

79) Lignin

80) Saw dust

81) Paper chips

82) Hog fuel

83) Mesquite
Prosopis torreyana

84) Calotropis
Calotropis procera

85) Rice hulls

86) Black greasewood
Sarcobatus vermiculatus

Abbreviations:

ver. = variety

spp. = species

Table 3. FEEDSTOCK CHARACTERISTICS
(dry basis)

	Ranges
Heating value, Btu/lb	7,400 - 12,700
Ash, wt%	0.1 - 35.9
Protein, wt%	0.1 - 25.3
Polyphenol, wt%	0.1 - 20.2
Oil, wt%	0.03 - 9.20
Hydrocarbons, wt%	0 - 10.4
Suberin, wt%	0.5 - 26.6
Lignin, wt%	7.8 - 28.8
Cellulose, wt%	17.7 - 46.7
Lipids, wt%	5.1 - 14.9
Elemental analysis, wt%:	
C	37.7 - 60.9
H	4.7 - 8.8
O	28.9 - 54.4
N	0.3 - 1.7
S	<0.01

content and composition has also been observed. This has ramifications with regard to necessary ash handling facilities, possible catalytic effects and disposal options.

Biomass feedstocks will vary considerably in moisture content, depending primarily on the nature of the feedstock, location and the season. Thus industrial and urban wastes are typically quite wet whereas forest residues in certain locations and seasons can be quite dry. The process chemistry is not significantly affected by the moisture content, i.e., steam is used for gasification and water is sprayed into the gasification scrubber and removed. Thus the prime considerations are the feeder design and energy balance penalties. In general, dry materials and those in slurry form are easier to feed than wet cakes. Pre drying versus accepting a gasification system energy balance penalty will be dependent on site conditions. Thus, for example, "solar drying" may be tractable in some areas but not in others, etc.

FACTOR STUDIES

Numerous factor studies have been performed in the laboratory. Details are available elsewhere (12,13,15, 16,). A listing of factors is given in Table 4. Present status of selected factors and corresponding system responses are given in Tables 5 and 6. Synthesis gas compositions experienced in the laboratory for a wide range of feedstocks and operating conditions are listed in Table 7 with typical product characteristics (as compared with commercial fuel oils) shown in Table 8.

Factor studies in the gasification system indicate that low pressure and residence time, ~1500°F and a combination of steam (hydrogen source) and liquefaction reactor off gas (paraffin source for cracking to olefins and hydrogen) for fluidization are favorable. The fluidized solid candidates are still under investigation to satisfy the criteria of operational reliability and selectivity (catalysts). For the liquefaction system, an impregnated cobalt catalyst is the current champion with conversion conditions of 500°F, 140 psig, 15-30 seconds single pass residence time with 3/1 recycle (weight basis). The H_2/CO mole ratio in the synthesis gas can be manipulated over a broad range for a given feedstock (say 0.5-8.) but the olefin composition is heavily feedstock dependent. Typical synthesis gas compositions considered achievable for virtually any biomass feedstock are indicated in Table 7.

The product quality, without any post reactor refining, is most similar to JP-4 jet fuel due to the presence of materials in the C_7-C_{10} range. A simple distillation will produce a product in the No. 2 diesel

Table 4. FACTOR STUDIES

Gasification:

1. Reactor system configuration
2. Feedstock characterization
3. Heat transfer media/catalyst
4. Fluidization gas composition
5. Residence time
6. Temperature
7. Pressure
8. Recycle effects

Liquefaction:

1. Catalyst composition
2. Catalyst preparation method
3. Catalyst calcination, reduction, pretreatment
4. Reactor system configuraiton
5. Conversion temperature
6. Conversion pressure
7. Conversion residence time
8. Feedgas composition
9. Recycle effects

Table 5. GASIFICATION SYSTEM PRESENT STATUS

Factors:

a. sand, dolomite, catalyst heat transfer media
b. steam + liquefaction reactor off gas fluidizing gas
c. ~ 1 psig pressure
d. ~ 1500°F temperature
e. 1-5 secs. residence time
f. no pyrolysis gas recycle

Responses:

a. 85% feedstock conversion to gas
b. gas composition, mole %:
   15 olefins
   30 hydrogen
   30 carbon monoxide
   15 paraffins
   10 carbon dioxide

Table 6. LIQUEFACTION SYSTEM PRESENT STATUS

Factors:

1. Catalyst
   - a. Co/Al_2O_3
   - b. Impregnation (incipient wetness)
   - c. No wash
   - d. Calcination at 400°F, 4 hours
   - e. Hydrogen reduction (1 atm, 750°F, 3 hours)
   - f. No pretreatment
2. Conversion
   - a. Fluidized bed, slurry reactors
   - b. Temperature = 500°F
   - c. Pressure = 140 psig
   - d. Feed gas composition (mole %) = 15 olefins, 30 H_2, 30 CO, 15 paraffins, 10 CO_2
   - e. Residence time (single pass) = 15-30 secs.
   - f. Recycle = 3/1

Responses:

1. Product quality = No. 2 diesel fuel
2. Product yields = 40-50 gals. per ton of biomass feedstock (dry ash free).

Table 7. SYNTHESIS GAS COMPOSITION
(mole %)

	Range	Typical
Hydrogen	10 - 53	30
Carbon Monoxide	6 - 60	30
Olefins	5 - 39	15
Paraffins	6 - 33	15
Carbon Dioxide	4 - 26	10

Table 8. **PROPERTIES OF FISCHER-TROPSCH PRODUCT AND COMMERCIAL FUEL OILS**

		Commercial Fuel Oils			Fischer-Tropsch Product	
		No. 2 Diesel	Kerosene	JP-4	Almond Pruning Feedstock	Guayule Bagasse
Specific gravity		.8360	.8108	.7586	.7902	.7950
Gravity, API^0		37.8	43	55	47.6	46.5
Boiling point range, ^oF						
evaporated at	10%	369	336	147	235	238
	50%	458	410	302	352	414
	90%	563	479	438	471	535
Calculated cetane index		45.9	47.8	48.3	45.3	55.7
Heating value, Btu/lb		19383	21676	22440	19354	21043

fuel range. Further "tuning" of process conditions is expected to establish the flexibility to manipulate the product quality without the necessity of a separation step.

OPERATIONAL RELIABILITY/PROCESS CONTROL

The major operational reliability sensitive areas for the process are as follows:

Gasification system:	solids feeding, hot solids transfer, clinker formation, tar removal.
Liquefaction system:	catalyst activity.

Solids feeding is not considered a major problem, i.e., a feeder and/or feedstock can be tailored to perform. Hot solids transfer and clinker problems can occur, usually as a result of other control problems in the system. The system is operated to minimize tar formation and to isolate the removal of such material in the gasification scrubbers. Of prime concern in the liquefaction system is long term catalyst activity stability. This is difficult to study under current laboratory operating constraints, i.e., a series of relatively short runs (18-40 hours) are performed on a weekly basis. Continuous regeneration to remove carbon (say oxidation followed by reduction) may be complex.

A primary process control consideration is the distribution of liquefaction reactor off gas. Three destination candidates exist: liquefaction reactor inlet, pyrolysis reactor and gasification regenerator. The decision is based on composition. Thus, with a sufficient amount of unreacted olefins, carbon monoxide and hydrogen, recycle to the liquefaction reactor inlet is appropriate. With accumulation of noncondensable paraffins (C_2+), a return to pyrolysis for cracking is indicated. For removal of methane and CO_2, recycle to the regenerator is logical. The priority limits are currently under study in the laboratory.

Development of "user friendly", reliable automation devices for the process is considered a virtue, particularly for small scale, remote operations. Thus on-site highly skilled staff would not be necessary if a vendor service function is available in the event of component failure.

MASS/ENERGY BALANCES AND ECONOMIC STUDIES

Mass and energy balances for the process have been presented elsewhere (13). For the mass balances, some streams are directly measured, some are calculated and some are obtained by difference. The energy balance is largely a function of the mass balance. Thermal efficiencies (energy in product/(energy in feedstock + energy added to the system)) is estimated to be in the range of 50-55%. This is considered important primarily as an ingredient of economic studies. Detailed environmental analysis has received a secondary priority in favor of achieving attractive product yields and will be escalated as the project develops. In general, the primary stream of concern is the scrubber effluent with the eventual goal of separation of combustible materials and burning in the regenerator accompanied by recycle of water to the process. Any transfer of effluent to a municipal sewage treatment facility will have to satisfy flammability and toxicity constraints.

Economic studies of the process have been prepared externally (17,18). Example commercial scale projections are given in Table 9. These numbers indicate a realistic scale in the 300-1000 tons of feedstock per day range. Larger facilities (to achieve economy of scale) are limited by delivered feedstock cost. Smaller facilities (for isolated feedstock availability) are limited by process complexity.

CONTINUING RESEARCH

The laboratory scale research will address tasks to improve product yields, optimize system throughput, simplify the process and assess long term operation effects. In addition, alternative feedstock evaluation, alternative product potential and environmental compatibility will be addressed. Finally, the design of an Engineering Test Facility (10 tons/day) will be implemented.

Product Yield Improvement

The current product yields are in the range of 40-50 gallons of diesel type fuel per ton of feedstock (dry, ash free basis). The theoretical maximum possible yield is about 100 gallons/ton. Improvement in product yields has evolved over the length of the project. The most promising factors for further enhancement is improvement in catalyst performance (gasification and liquefaction) and optimization of liquefaction reactor off-gas recycle distribution (to liquefaction reactor, pyrolyzer and regenerator). The effect of these factors on product yields will be studied.

Throughput Optimization

The emphasis on the project to date has been to maximize yields of high quality product. Equipment has been sized for convenience and stability of operation and thus in many cases is not of optimal size, i.e., minimum capacity to achieve desired product yields and quality.

Table 9. COMMERCIALIZATION ECONOMICS

(1983 Dollars)

PLANT SIZE	CAPITAL	ANNUAL OPERATING COSTS	ANNUAL FEEDSTOCK COSTS	PRODUCT PRICE
500 TPD	27M	3M	2.4M	93¢/gal.
1000 TPD	41M	4M	4.8M	73¢/gal.

assumptions:
1. $15/ton delivered feedstock cost
2. yields = 80 gals./ton
3. operational reliability = 90%
4. 15% return on invested capital

At the present time the combustor (regenerator) in the gasification system is undersized compared to the pyrolyzer and the liquefaction reactor is undersized compared to the gasification system at present liquefaction reactor off gas recycle rates. Compatible equipment sizes and maximization of throughput will be addressed.

Process Simplificiation

External economic studies on the process indicate that the breakeven scale is approximately 300 tons/day of feedstock. With a reduction of this number, the number of potential commercial applications will grow as dictated primarily by delivered feedstock cost. Work will be continued on the project in this area with emphasis on reduced liquefaction system pressure (and thus reduced compression costs) and staged conversion system development without interstage gas compression. Liquefaction catalyst development will be the key factor.

Long Term Operation Assessment

The long term operational reliability and stability of the conversion system will be monitored. Of primary importance is accumulation of material (e.g., ash components) in the gasification system fluidized solid media, liquefaction catalyst activity/regeneration characteristics and liquefaction reactor slurry liquid stability. These potential problems will be addressed in the context of multiple short runs, i.e., the project is not budgeted for long term continuous operation.

Alternative Feedstocks and Products

Alternative feedstocks will be evaluated for the process as appropriate. Also a feasibility assessment of producing chemicals other than diesel fuel (e.g., aromatics, specialty chemicals) with the synthesis gas obtained from cellulosic waste will be continued.

Environmental Compatibility

Compatibility of the process with project emission standards will be monitored.

Engineering Test Facility (ETF) Design

A larger scale (10 tons/day) facility will be designed with the primary purpose of producing a sufficient amount of product for long term engine testing and to minimize the risk to a commercial scale. It is anticipated that this effort will be performed by an engineering firm subject to interactions with the ASU laboratory effort. It is expected that private industry will participate in the eventual construction and operation of this facility.

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