



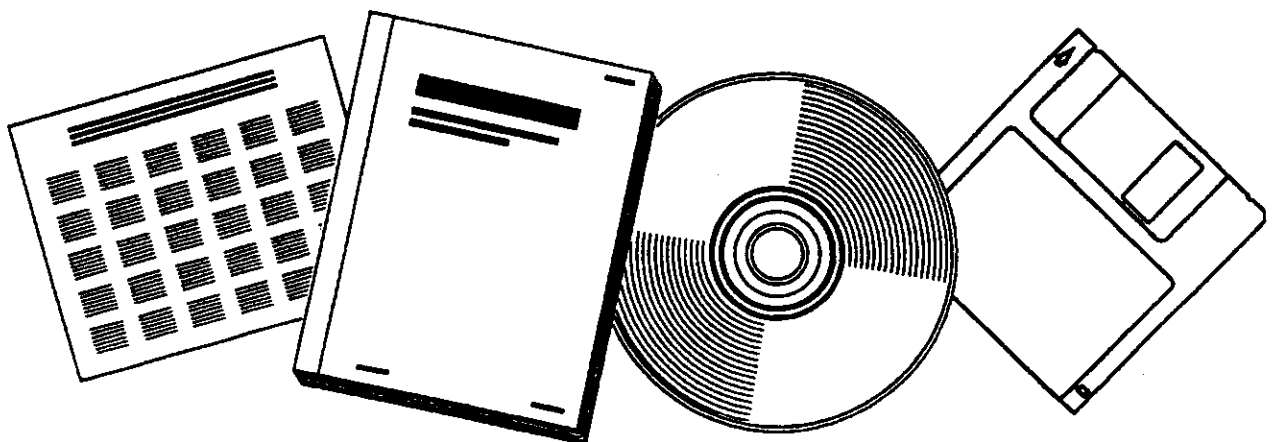
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CONVERSION OF CELLULOSIC WASTES TO LIQUID HYDROCARBON FUELS: VOL. 1, PROJECT OVERVIEW: FINAL REPORT

ARIZONA STATE UNIV., TEMPE. COLL. OF
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CONVERSION OF CELLULOSIC WASTES
TO LIQUID HYDROCARBON FUELS
VOL 1: PROJECT OVERVIEW

Submitted

by

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ABSTRACT

A thermochemical conversion process to convert various biomass materials to diesel type fuels has been under development at Arizona State University (ASU) since 1975. An indirect liquefaction approach is used, i.e., gasification to synthesis gas followed by liquefaction of the synthesis gas. The primary virtue of an indirect liquefaction approach for cellulosic type feedstocks is that oxygen contained in the materials is easily separated. Thus the hydrocarbon liquid product is free of oxygenated compounds and can therefore be tailored to match transportation fuel products currently derived from petroleum. Approximately 100 biomass materials were studied as received from private industry, government laboratories and other university laboratories. The feedstock candidates included industrial wastes, agricultural and forest residues and crops that would be deliberately grown for energy conversion purposes. The product of the process is a liquid hydrocarbon transportation grade fuel similar to diesel. This can be upgraded to high octane gasoline via catalytic reforming if desired. The products should be compatible with existing engine designs and fuel distribution and marketing systems. The major virtue of the process is that a renewable, often low valued material is used as the feedstock to produce a quality product.

This final report consists of six volumes. This first volume contains an overview of the project from inception. Volumes 2-6 report on tasks completed and/or in progress in the reporting period from June 1, 1984 through May 31, 1985 that were at least partly funded by the Department of Energy. The volume titles are as follows:

Volume 1: Project Overview

**Volume 2: Kinetic Study of the Modified Fisher-Tropsch Synthesis over
an Alumina-Supported Cobalt Oxide Catalyst**

**Volume 3: Supervisory Control System Development for an Indirect
Liquefaction Process**

**Volume 4: Slurry Phase Synthesis of Liquid Hydrocarbon Fuels from
Biomass Pyrolysis Gas Using Iron Catalysts**

**Volume 5: Microwave Heating of Fluidized Bed Reactors--Pyrolysis and
Calcination Applications**

**Volume 6: The Modelling and Design of a Staged Indirect Liquefaction
Reactor**

The individual report volumes are intended to be self standing.

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PROJECT OVERVIEW

This volume will provide an overview of the project from the starting date of June 1, 1976 through the termination date of December 30, 1985. The general steps to be addressed for the project were as follows:

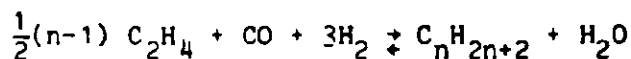
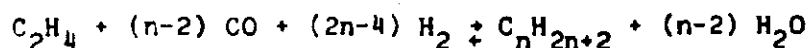
- 1) product quality
- 2) product yields
- 3) operational reliability
- 4) environmental compatibility
- 5) throughput
- 6) simplicity/automation
- 7) scaleup
- 8) economics

Product Quality. It was decided at project inception that the desired product would be a high quality, transportation grade liquid hydrocarbon fuel equivalent to that derived from petroleum. Thus, as opposed to the flurry of alcohol fuel development projects popular at the time, engine modification and alterations in the fuel distribution system would not be required.

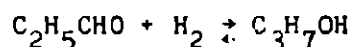
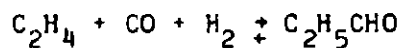
A fundamental consideration in choosing a conversion path for converting cellulosic type materials to liquid hydrocarbon fuels is the elemental compositions of the feedstock and product. Typical values are as follows (wt%):

	<u>Feedstock</u>	<u>Product</u>
C	47	85
H	6	15
O	47	0

Thus oxygen has to be eliminated and the H/C ratio has to be enhanced. An indirect liquefaction route was chosen to achieve this goal. The first step was to consist of decomposing the feedstock to the basic reactive compounds of hydrogen, carbon monoxide and ethylene. In addition, carbon dioxide and methane were to be expected. To achieve efficient heat transfer and thus promote the formation of olefins, a fluidized bed system was selected for the decomposition step (pyrolysis, gasification). To avoid the probable gas separation of combustion products, a circulating bed mode was chosen (separate fluidized bed combustor (regenerator) and pyrolyzer (gasifier)). The generated gases were passed through a cyclone (to remove any particulates) and scrubber (to cool the gas and remove any condensable liquids) before being compressed into a catalytic liquefaction reactor. Here, the carbon monoxide, hydrogen and ethylene were to be converted to a paraffinic hydrocarbon fuel by the following general stoichiometry,

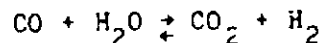


In addition, a secondary reaction to produce normal propanol was expected,



A fluidized bed system was initially selected for the catalytic liquefaction step to control the temperature in the presence of the significant exothermic heat of reaction. A slurry phase mode was later tested with the primary objective of relieving the complexity of operating fluidized bed systems in series.

The net result was that an oxygen free product ($C_n H_{2n+2}$) could be produced with product distribution dependent upon catalyst choice and system operating conditions. The H/C ratio could be manipulated by addition of steam to the gasification step thus promoting the water-gas shift reaction,

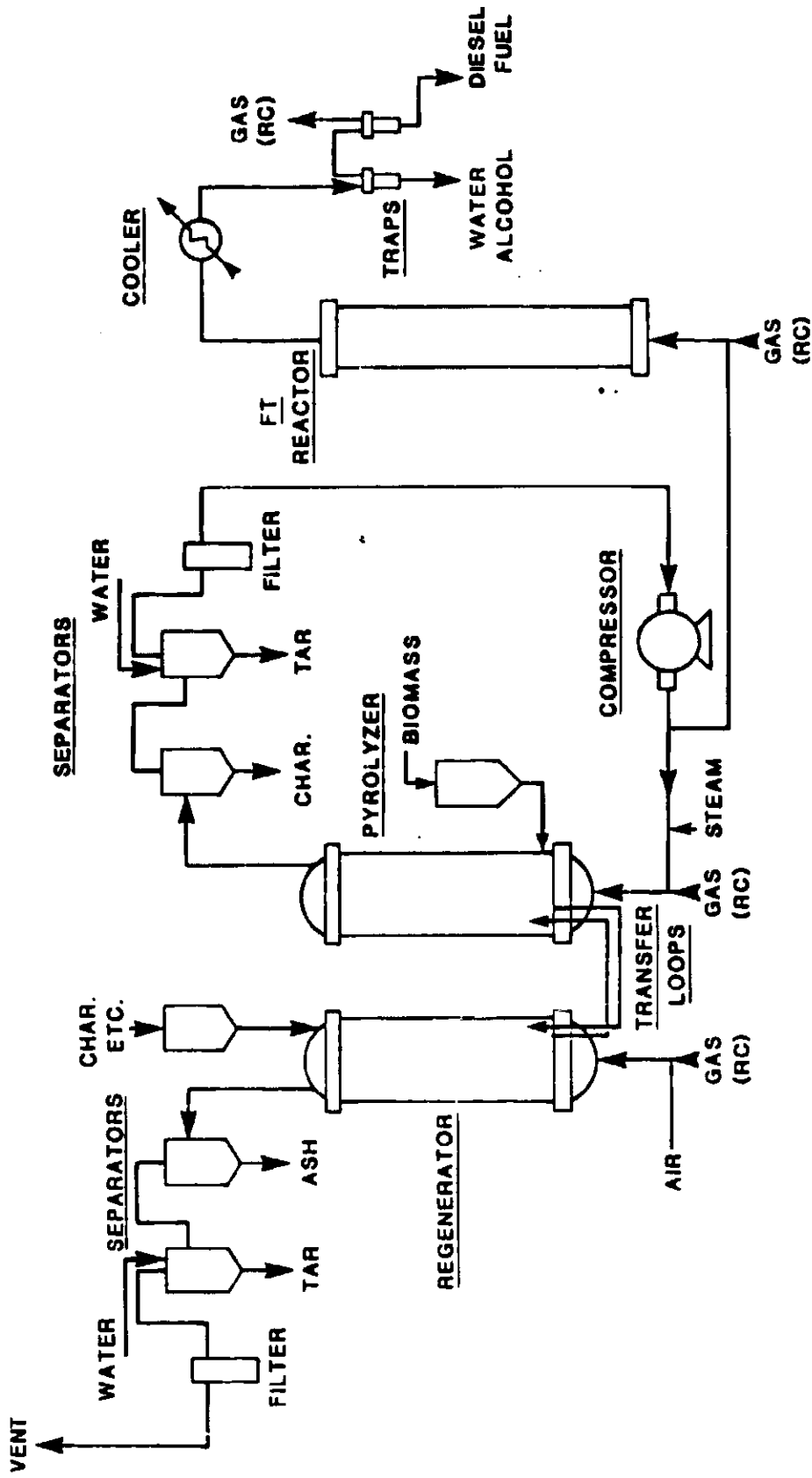


The early stages of the project also explored the concept of producing a high octane gasoline product. This was achieved by passing the paraffinic fuel product through a fixed bed catalytic reformer using a commercially available catalyst. Here, the desired reactions to regulate molecular weight and introduce structural complexity were introduced. Octane rating could be manipulated over a broad range with little difficulty.

A schematic of the integrated conversion system (without the reforming step) is shown in Figure 1. This basic processing configuration remained essentially intact throughout the project, although numerous improvements were implemented for the various steps. An indication of the product quality attainable for this system (without product refining) is given in Table 1, as compared with commercial materials.

Product Yields. Calculated elemental balances for the conversion system indicated a maximum product yield (e.g. No. 2 diesel) of about 100 gals. per ton of feedstock (dry, ash free basis). Numerous factor studies were performed over the course of the project to approach this limit. Much of this experimentation was performed in separate, smaller scale equipment (see Table 2). A general list of factors is contained in Table 3. Details of these studies have been reported (1-6,10-52). The status at the termination of the project is summarized in Tables 4 and 5. As indicated, a yield of approximately 50 gals. of diesel fuel type product appears possible. Single

CONVERSION SYSTEM SCHEMATIC



LIQUID FUELS SYNTHESIS

GASIFICATION

Figure 1. Indirect Liquefaction System Schematic (RC = recycle)

Table 1. Product Characteristics

	JP-4 (ASTM D1655)	JP-5 (ASTM D1655)	Kerosene (ASTM D3699)	Diesel No. 2 (ASTM D975)	A1 Jet Fuel (ASTM D1655)	ASD Product	ASTM Test Method
Gravity, deg API @ 60°F	57 max. 45 min.	51 max. 37 min.			51 max. 39 min.	60	D-287
Specific Gravity @ 60°F	.751 min. .802 max.	.775 min. .840 max.			.775 min. .830 max.	.739	D-287
Distillation temperature, deg F							D-86
10 percent evaporated	...	400 max.	401 max.		400 max.	230	
20 percent evaporated	290 max.	258	
50 percent evaporated	370 max.	450 max.			450 max.	338	
90 percent evaporated	470 max.	503	
Final boiling point, deg F	550 max.	572 max.	572 max.		572 max.	594	
Viscosity at 100 °F, ca			1.0 min. 1.9 max. (100°F)	1.9 min. 4.1 max.		0.96	D-445
Sulfur percent by weight	0.3 max.	0.3 max.	0.3 max. (No. 2-E)	0.5 max. 0.3 max.		0.05	D-129
Cloud point, deg F						12	D-97
Pour point, deg F						-43	D-97
Flash point, deg F			100 min.	125 min.		<75	D-92
Celene Number				40 min.		61.5	D-975

Spectrographic Analysis
(Soap, AA Method), ppm

Al	<1
Fe	0.1
Cu	1.2
Mn	<1
Cr	<1
Ag	<1
Pb	1
Si	1

Table 2. Experimental Systems

<u>System</u>	<u>Description</u>
<u>Large Scale Integrated Unit:</u>	10" pyrolyzer-regenerator circulating solid heating system with 6" liquefaction reactor. SIHI compressor. Gas recycle from liquefaction to gasification.
<u>Small Scale Integrated Unit:</u>	3" pyrolyzer staged with 6" liquefaction reactor. Electrically heated. Intermediate scrubber stage. Nash compressor for recycle.
<u>Microreactor System:</u>	microscale fixed and fluidized bed reactors with fluidized bath heater.
<u>Slurry Phase Fischer-Tropsch Reaction System:</u>	5" x 35" reactor with off gas and circulating circulating catalyst slurry system.
<u>Liquefaction Catalyst Testing Unit:</u>	2" fluidized bed reactors with common synthesis gas feed system. Six units in parallel. Additional reactor with recycle capability with compressor.
<u>Process Control Equipment:</u>	electronic controllers, recorders, data reduction equipment, etc. to monitor and control the various conversion systems.
<u>Simulator Equipment:</u>	plastic model units -- cross riser transfer loop, injector transfer loop, internal recycle transfer loop, etc.
<u>Feedstock Preparation:</u>	cutting, hammer and ball mills, pulverizer, chipper, screeners.
<u>Feedstock Analysis:</u>	heating values, extraction analyses, ash content, etc.
<u>Catalyst Preparation:</u>	hot plate mixers, calcining furnace, drying equipment, etc.
<u>Analytical Support:</u>	gas chromatographs, (5), gel permeation chromatograph.
<u>Catalyst Characterization:</u>	surface area, porosity, surface and bulk composition, etc.

Continuous Extractor:

4" diameter x 7" screw extractor with continuous solids feeding and withdrawal and solvent delivery system.

Microwave Heated Fluidized Bed:

915 MHZ, 0-30KW microwave source coupled to fluidized bed system with related control equipment.

Table 3. 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 configuration
 5. Conversion temperature
 6. Conversion pressure
 7. Conversion residence time
 8. Feedgas composition
 9. Recycle effects
-

Table 4: 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 5. LIQUEFACTION SYSTEM PRESENT STATUS

Factors: 1. Catalyst

- a. Co/Al₂O₃
- 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 H₂, 30 CO, 15 paraffins, 10 CO₂
- 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).

pass high octane gasoline yields would be less (~20 vol. % yield loss through the reformer) but some of this could be recovered via off gas recycling.

A large list of feedstocks were investigated over the course of the project. (Table 6). These were supplied by private industry, government laboratories (various nations), municipalities, other universities, etc. Feedstock characteristics for these materials are summarized in Table 7. A range of synthesis gas compositions possible for these materials (at various operating conditions) is given in Table 8. The adjustments are not independent. Thus, for example, the $H_2/CO/CO_2$ trends were normally dictated by water-gas shift reaction effects.

The most promising areas for product yield improvement are:

1. Improvement of synthesis gas yields, (particularly with respect to olefin content). The use of an appropriate catalyst in the fluidized bed would appear to be the best approach. Note that the conversion system is already configured to continuously regenerate a fluidized catalyst.

2. Improvements in the liquefaction catalyst, particularly with regard to selectivity away from noncondensable gases (methane, ethane, etc.).

Operational Reliability. The system, as configured in Figure 1, would be potentially sensitive to problems in the following primary areas: (1) solids feedings, (2) hot solids transfer, (3) tar condensation, and (4) catalyst activity maintenance. Problems were encountered and addressed in all of these areas over the course of the project, particularly in the early stages. All the solid handling steps were contained in the gasification system. Solids feeding problems were minimized when sufficient funds were available to purchase a reliable system. The system was operated to minimize tar formation and transfer lines were maintained above condensation

Table 6 Feedstock List

1) Euphorbia lathyris	35) Tall goldenrod	69) Shruboak
Euphorbia lathyris	Solidago altissima	Abus trilobata
2) Cassia bignoniifolia	36) Sassafras	70) Yerba-santa
Euphorbia antiarypallitia	Sassafras albidum	Eriodictyon angustifolia
3) Raw guayule	37) Coral berry	71) Fourwing saltbush
Parthenium argentatum	Symphoricarpos orbiculatus	Atriplex canescens
4) Guayule resin	38) Wild bergamot	72) Netleaf hackberry
Parthenium argentatum	Monarda fistulosa	Celtis reticulata
5) Guayule bagasse	39) Russian thistle	73) Catalpa biondina
Parthenium argentatum	Salsola kali	Mimosa biuncifera
6) Guayule bark	40) Water hyacinth	74) Sewage sludge
Parthenium argentatum	Hyacinthus spp.	
7) Grassweed	41) Common milkweed	75) Corn stover
Sarcobatus vermiculatus	Asclepias syriaca	
8) Jojoba seed	42) Swamp milkweed	76) Coal
Simmondsia chinensis	Asclepias incarnata	
9) Almond hulls	43) Peat	77) Polyethylene
Terminalia catappa	Sphagnum spp.	
10) Almond shells	44) Portuguese oak cork	78) Polypropylene
Terminalia catappa	Quercus suber	
11) Almond prunings	45) Silver maple	79) Lignin
Terminalia catappa	Acer saccharinum	
12) Sugarcane bagasse	46) Yellowleaf silkthistle	80) Saw dust
Saccharum officinarum	Garrya flavescens	
13) Wheat straw	47) Sweet sorghum	81) Paper chips
Triticum aestivum	Sorghum saccharatum	
14) Crosscut bums	48) Pale Indian plantain	82) Hog fuel
Larrea tridentata	Fernia stipuleifolia	
15) Fir bark	49) Tall bellflower	83) Mesquite
Pseudotsuga densata	Campanula americana	Prosopis torreyana
16) Incense cypress	50) Cherry oleagnus	84) Calotropis
Cupressus arizonica	Oleagnus multiflora	Calotropis procera
17) Pringle sarranite	51) Grass leaved goldenrod	85) Rice hulls
Aristida purpurascens	Solidago graminifolia	
18) Wright silkthistle	52) Common elder	86) Whorled milkweed
Garrya wrightii	Sambucus canadensis	Asclepias verticillata
19) Pointleaf sarranite	53) Parake wildrye	87) Stiff leaved goldenrod
Aristida purpurascens	Elymus canadensis	Solidago rigida
20) Shrub live oak	54) Field thistle	88) Ironweed
Quercus turbinella	Cirsium discolor	Ternstroemia missouriensis
21) Hairy mountain mahogany	55) Saw thistle	89) Toothed spurge
Cercocarpus breviflorus	Conium maculatum	Euphorbia dentata
22) Utah juniper	56) Compass plant	90) Weeping willow
Juniperus osteosperma	Silphium laciniatum	Salix pyralis
23) Myron pine	57) Managrove roots	91) Carpenter's square
Pinus edulis	Palmetto	Complanata marilandica
24) Velvet mesquite	58) Cut leaf tassel	92) Aspen
Prosopis juliflora var. velutina	Cyperus laciniatus	Populus
25) ECD Fuel 22 (municipal	59) Blue tassel	93) Locust
preprocessed refuse)	Cyperus sylvaticus	Robinia
26) Saw pulp	60) American germander	94) Laminated lumbered
	Teucrium canadense	guayule
27) Pulp residue	61) Woody milkweed	95) Flax shive
	Asclepias spp.	
28) Tanning waste	62) Round-leaf milkweed	96) Whole cotton
Thus copallina	Asclepias spp.	Simmondsia chinensis
29) Smooth waste	63) Cotton seed coat	97) Tertiary sludge
Thus glabra	Gossypium thurberi	
30) Red sarranite honey-suckle	64) Delinted cotton seed	98) Pecan shells
Lonicera tatarica	Gossypium thurberi	
31) Giant regrass	65) Cotton seed lint	
Imbricaria trifida	Gossypium thurberi	
32) Foxweed	66) Cotton seed meal	
Thytolacca americana	Gossypium thurberi	
33) Tall boneset	67) Cotton seed hulls	
Eupatorium altissimum	Gossypium thurberi	
34) Peain seed	68) Cotton gin trash	

Abbreviations: var. = variety
spp. = species

Table 7. 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

Table 8. Synthesis Gas Composition (mole %)

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

temperatures up to the inlet of the scrubber. Clinker formation problems were essentially eliminated with proper choice of fluidized solid and proper fluidization control. At the termination of the contract, the integrated system was essentially an unattended operation with the exception of loading of the feed hopper and dumping of the product tank. Continuous run lengths were never scheduled, however, for more than a five day period. Long term effects (erosion, tar buildup, catalyst activity etc.) remain for future work.

Environmental Compatibility. The areas to consider in the process with regard to compliance with environmental regulations are as follows:

- (1) particulates (from feedstock preparation and storage, ash removal).
- (2) air emissions (from regenerator vent and liquid product storage),
- (3) liquid effluents (from scrubber water processing), and
- (4) noise control.

At the laboratory scale, none of the above were studied in depth other than to achieve a safe working environment for operating personnel. Thus, the scrubber systems were considered to be well oversized to achieve sufficient dilution before disposal, the laboratory was continuously vented during runs with an exhaust system, appropriate masks were worn when handling feedstocks, etc. Compatibility with environmental regulations is not considered to be a major hurdle, however. Pyrolysis type technology lends itself to minimal air emissions control problems. The major stream of concern is the scrubber effluent. On a commercial scale, separation of organic condensibles from the water stream would probably be implemented with disposal of the organics in the gasification regenerator and recycle of the water to the process distribution system. Scrubber effluent samples were retained for all documented runs performed in the laboratory. Analysis

were performed on selected samples (5,6). The project was terminated before any detailed correlation of feedstock type and processing conditions vs. effluent composition could be developed.

Throughput. The continuous, integrated laboratory system was considered to be commercially realistic with regard to processing steps, operating modes and procedures. However, the configuration at the end of the contract period was limited with regard to throughput (defined as quantity of feedstock processed/volume of equipment) by the regenerator size and/or efficiency. Thus, as feedstock flow rates were increased, eventually it would be impossible to maintain desired pyrolysis temperatures. Equipment height in the laboratory was limited by the laboratory roof. Recognizing that a taller regenerator would be required to optimize throughput, a major renovation was funded in the laboratory to accommodate the planned throughput study. Unfortunately, although the renovation was completed, so was the project budget. Thus, this aspect remains for future study.

Simplicity/Automation. It is recognized that the process technology is analogous to that utilized in a typical chemical plant or refinery. As limited by delivered feedstock costs, any facility processing cellulosic wastes will be relatively small, however, thus limiting the advantages of economy of scale with respect to operating labor requirements. Thus, process simplicity and/or reliable, vendor supported automation is considered an absolute necessity for commercial implementation of the technology. This was addressed throughout the project. A thorough discussion regarding automation of the process can be found elsewhere (10, 19, 28, 38). A major effort to simplify the process via a staged conversion

system design was also performed (11), but not implemented by the project termination date.

Scaleup. A detailed design of a nominal 10 ton/day pilot plant was performed based on data supplied by the project laboratory. This study has been reported separately (9).

Economics. Several economic studies were performed externally on the process (7-9). Cost figures for the 10 ton/day design were based on vendor quotations. Using the pilot plant numbers as a base, an economic model using a chemical plant simulator package was under development at the end of the contract period. The intent of the model is to accurately project process costs at various scales based on individual units rather than overall scale factors. The model will also enable one to tailor the design to specific site and feedstock requirements.

BIBLIOGRAPHY

1. Kuester, J. L., Conversion of Cellulosic and Waste Polymer Material to Gasoline, DOE Interim Report No. COO-2982-38, Contract No. EY-76-S-02-2982 (March 1979).
2. Kuester, J. L., Conversion of Cellulosic Wastes to Liquid Fuels, DOE Interim Report No. COO-2982-57, Contract No. EY-76-S-02-2982 (September 1980).
3. Kuester, J. L., Conversion of Cellulosic Wastes to Liquid Fuels, DOE Interim Report No. COO-2982-74, Contract No. EY-76-S-02-2982 (September 1981).
4. Kuester, J. L., Conversion of Cellulosic Wastes to Liquid Hydrocarbon Fuels, DOE Interim Report No. COO-2982-83, Contract No. DE-AC02-76CS40202 (August 1982).
5. Kuester, J. L. Conversion of Cellulosic Wastes to Liquid Hydrocarbon Fuels, DOE Interim Report No. 200-7982-107, Contract No. DE-AC02-76CS40202 (September 1984).
6. Kuester, J. L., DOE Progress Reports, COO-2982-1 to 119 (1976 to 1985), Contract No. EY-76-S-02-2982, DE-AC02-76CS40202.
7. Mittelhauser Corp., "Preliminary Economic Assessment of Two Facilities Using the Arizona State University Flash Pyrolysis Method for Conversion of Cellulosic and Waste Polymer Materials to a Light Heating Oil Product" prepared for Argonne National Laboratory, Argonne, IL (February 19, 1981).
8. Second Year Project Analysis of the Arizona State University Process to Convert Cellulosic Wastes into Light Fuel Oil, Draft Final Report, prepared by Energetics, Inc. for Argonne National Laboratory under Subcontract No. 31-109-38-5869 (March 10, 1981).
9. 10 Ton/Day Cellulosic Waste to Liquid Hydrocarbon Fuels Experimental Test Facility (4 Volumes), Subcontract 959304-1 from ASU to Ultrasystems, Inc., (March, 1985).
10. Vol. 3 (this report).
11. Vol. 6 (this report).
12. Kuester, J. L., "Catalytic Conversion of Biomass Derived Synthesis Gas to Diesel Fuel in a Slurry Reactor," presentation at the American Chemical Society Symposium on Syngas Conversion Catalysis, Anaheim (September, 1986).
13. Kuester, J. L., "Diesel Fuel from Cellulosic Materials," presentation at the American Chemical Society Symposium on Alternative Sources for Diesel Fuels, New York (April, 1986).

14. Kuester, J. L., "Diesel Fuel from Renewable Resources," presentation to the IEEE Power Engineering Society, Phoenix, AZ (January, 1986).
15. Kuester, J. L., "Process of Producing Liquid Hydrocarbon Fuels from Biomass," U.S. Patent Disclosure 784269 (filed October 4, 1985).
16. Kuester, J. L., "Conversion of Guayule Residue to Diesel Fuel," 4th International Conference on Guayule Research and Development, Tucson (October, 1985) (published in Proceedings).
17. Kuester, J. L., "Diesel Fuel from Biomass Residues," Southwest Industrial Biomass Conference, Phoenix (September, 1985) (published in Proceedings).
18. Kuester, J. L., "Conversion of Biomass to Liquid Hydrocarbon Fuels," presentation to the Association of Energy Engineers, Phoenix, AZ (May, 1985).
19. Prasad, B., L. Bellamy and J. Kuester, "Integrating a Microcomputer for On-Line Monitoring of an Existing Biomass Conversion Indirect Liquefaction Process," First National Conference on Microcomputer Applications for Conservation and Renewable Energy, Tucson (February, 1985) (published in Proceedings).
20. Kuester, J. L., "Diesel Fuel from Biomass via Indirect Liquefaction," in BioEnergy 84, Vol. 3: Biomass Conversion, Elsevier Applied Science Publishers, ISBN-0-85334-348-9 (1985).
21. Kuester, J. L., "Liquid Hydrocarbon Fuel Potential of Agricultural Materials," in Fundamentals of Thermochemical Biomass Conversion, Elsevier Applied Science Publishers, Ltd., ISBN 0-85334-306-3, pp. 875-895 (1985).
22. Kuester, J. L., "Diesel Fuel via Indirect Liquefaction," Chapter 24 in Energy Applications of Biomass, M. Lowenstein, ed., Elsevier Applied Science Publishers, Ltd., ISBN 0-85334-409-4 (1985).
23. Kuester, J. L., "Conversion of Synthesis Gas Containing Olefins to Diesel Fuel," Seminar, EXXON Research and Engineering Co., Corporate Research and Science Laboratories, Clinton Township, NJ (October, 1984).
24. Kuester, J. L., "Gasification of MSW in Fluidized and Entrained Bed Reaction Systems," in Energy from Municipal Waste Research: A Technical Review of Thermochemical Systems, ANL/CNSV-TM-144, Argonne National Laboratory (September, 1984).
25. Kuester, J. L., "Diesel Fuel from Biomass," in Energy from Biomass and Wastes VIII, Institute of Gas Technology ISBN-X-910091-50-1 (September, 1984).
26. Kuester, J. L., "Liquid Fuels from Wastes," presented at the U.S. D.O.E./United Kingdom DE Waste Combustion Symposium, Argonne National Laboratory (July, 1984) (published in Proceedings).

27. Kuester, J. L., "Diesel Fuel from Various Biomass Sources," Seminar, USDA Water Conservation Laboratory, Phoenix, AZ (May, 1984).
28. Kuester, J. L., "Instrumentation and Control of a Biomass Conversion Indirect Liquefaction Process," presented at the Pilot Plant Technologies, Equipment and Control Symposium, AIChE National Meeting, Anaheim (May, 1984).
29. Kuester, J. L., "Catalytic Conversion of Biomass Derived Synthesis Gas to Diesel Fuel in a Slurry Reactor," presented at the 4th Solar and Biomass Workshop, Atlanta, GA (April, 1984) (published in Proceedings).
30. Davis, E., J. L. Kuester and M. O. Bagby, "Biomass Conversion to Liquid Fuels: Potential of some Arizona Chaparral Brush and Tree Species," Nature, 307, pp. 726-728 (February 23, 1984).
31. Kuester, J. L., "Pyrolytic Conversion of Municipal Waste to Energy," in Energy from Municipal Waste: State-of-the-Art and Emerging Technologies, ANL/CNSV-TM-137, Argonne National Laboratory (February, 1984).
32. Kuester, J. L., "Pyrolytic Conversion," Chapter V in Thermal Conversion Systems for Municipal Solid Waste, Noyes Publications, ISBN-0-8155-1001-2, Park Ridge, NJ (1984).
33. Kuester, J. L., "Thermochemical Conversion of Biomass to Fuels and Chemical Feedstocks," Southwest Symposium on Thermosciences Lecture Series (Texas Tech, Texas A&M, University of Texas, LSU) (December, 1983).
34. Kuester, J. L., "Diesel Fuel from Biomass via Indirect Liquefaction, in Vegetable Oil as Diesel Fuel-Seminar III, ARM-IC-28, U. S. Department of Agriculture (October, 1983).
35. Kuester, J. L., Thermal Systems for Conversion of Municipal Solid Waste, Volume 5 - Pyrolytic Conversion: A Technology Status Report, ANL/CNSV-TM-120, Argonne National Laboratory (June, 1983).
36. Kuester, J. L. and L. Campbell, "Catalytic Conversion of Biomass Derived Synthesis Gas to Diesel Fuel in a Slurry Reactor," presented at the 3rd Solar and Biomass workshop, Atlanta, Georgia (April, 1983) (published in Proceedings).
37. Kuester, J. L., G. Heath and T. Wang, "Diesel Fuels from Biomass Derived Synthesis Gas," Catalytic Conversion of Pyrolysis Gases Symposium, AIChE Annual Meeting, Los Angeles (November 1982).
38. Kuester, J. L. and G. Heath, "Instrumentation of Indirect Liquefaction Processes," in Instrumentation in the Mining and Metallurgy Industries, Vol. 9, Instrument Society of America, ISBN-p0-87664-729-8 (May, 1982).
39. Kuester, J. L., "Catalytic Conversion of Biomass Derived Synthesis Gas to Diesel Fuel in a Slurry Reactor," presented at the 2nd Solar and

Biomass Workshop, Atlanta, GA (April, 1982) (published in Proceedings).

40. Kuester, J. L., "Biomass conversion to Liquid Hydrocarbon Fuels," Seminar, Westinghouse Research and Development Center, Pittsburg, PA (April, 1981).
41. Kuester, J. L., "Conversion of Wood Residues to Diesel Fuel," presented at the Fourth Annual Wood Energy and Contractor Review Meeting, U.S. D.O.E., Washington, D.C. (February, 1981).
42. Kuester, J. L., "Municipal Solid Waste Conversion Options," Seminar, Kyoto University, Kyoto, Japan (December, 1980.)
43. Kuester, J. L., Fluidized Bed Pyrolysis to Gases Containing Olefins," in Specialists' Workshop on Fast Pyrolysis of Biomass, Solar Energy Research Institute, SERI/CP-622-1096, Copper Mountain, CO (October, 1980).
44. Kuester, J. L., "Olefins from Cellulose Pyrolysis," presented at the American Chemical Society Symposium on Alternative Feedstocks for Petrochemicals, Las Vegas, NV (August 1980).
45. Kuester, J. L., "An Indirect Liquefaction Process for Producing Liquid Fuels from Biomass," presented at the American Institute of Chemical Engineers Session on Conversion of Biomass to Energy and High Value Products, Portland, Oregon (August 1980).
46. Kuester, J. L., "Liquid Hydrocarbon Fuels from Biomass," Chapter 8 in Biomass as a Nonfossil Fuel Source, D. L. Klass (ed.) ACS Symposium Series 144, ISBN-0-8412-0599, American Chemical Society, Washington, D.C. (1980).
47. Kuester, J. L., "Conversion of Cellulosic Wastes to Liquid Fuels," Chapter 15 in Design and Management for Resource Recovery: Vol. I, Energy from Waste, T. C. Frankiewicz (ed.), ISBN-0-250-40312-9, Ann Arbor Press, Ann Arbor, MI (1980).
48. Kuester, J. L., "Biomass Conversion to Liquid Hydrocarbon Fuels," Seminar, Weyerhaeuser Technology Center, Tacoma, WA (December, 1979).
49. "Kuester, J. L., "Conversion of Cellulosic and Waste Polymer Material to Gasoline," presented at the American Chemical Society Symposium on Thermal Conversion of Solid Wastes, Residues and Energy Crops, Washington, D.C. (September, 1979) (published in Preprints).
50. Kuester, J. L., "Thermochemical Conversion of Guayule," Seminar, Centro de Investigacion en Quimica Aplicada, Saltillo, Mexico (January, 1979).
51. Kuester, J. L., "Liquid Fuels from Biomass," presented at the AIAA/ASERC Conference on Solar Energy, Phoenix, AZ (November, 1978) (published in Proceedings).

52. Kuester, J. L., "Conversion of Waste Organic Materials to Gasoline,"
Proceedings of the Fourth National Conference on Energy and the
Environment, ISBN-0-917614-00-3, Cincinnati, OH (October, 1976).

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