18 A

PNL-3695 App B

UC-11

Investigations on Catalyzed Steam Gasification of Biomass

Appendix B:
Feasibility Study of Methanol Production via
Catalytic Gasification of 2000 Tons of Wood
Per Day

January 1981

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

PNL-3695 App B

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$_____ * Microfilm \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.25
276-300	\$11.00

3 3679 00059 6819

INVESTIGATIONS ON CATALYZED
STEAM GASIFICATION OF BIOMASS

APPENDIX B:
FEASIBILITY STUDY OF METHANOL
PRODUCTION VIA CATALYTIC GASIFICATION
OF 2000 TONS OF WOOD PER DAY

L. K. Mudge
S. L. Weber
D. H. Mitchell
L. J. Sealock, Jr.
R. J. Robertus
Pacific Northwest Laboratory

and
Davy McKee Engineers and Constructors

January 1981

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

WOOD TO METHANOL STUDY

TABLE OF CONTENTS

I	EXECUTIVE SUMMARY
II	INTRODUCTION AND SUMMARY
III	DESIGN BASIS
IV	PROCESS AND OFFSITES DESCRIPTION
V	HEAT AND MATERIAL BALANCE
VI	SUMMARY OF PROCESS MATERIALS AND UTILITIES
VII	OVERALL BLOCK FLOW DIAGRAM AND MATERIAL BALANCE
VIII	PLANT LAYOUT AND DESCRIPTION
IX	CAPITAL COST ESTIMATE AND SCALING FACTOR DISCUSSION
X	OPERATING COST ESTIMATE

Major contributors to this report from Davy McKee were T. J. Kendron,
O. A. Kuby, M. McClintock, and J. H. Rooker.

I EXECUTIVE SUMMARY

A study has been made of the economic feasibility of producing fuel grade methanol from wood via catalytic gasification with steam. The plant design in this study was developed from information on gasifier operation supplied by the Pacific Northwest Laboratory (PNL), operated by Battelle. PNL obtained this information from laboratory and process development unit testing.

The plant is designed to process 2,000 tons per day of dry wood to methanol. Plant production is 997 tons per day of methanol with a HHV of 9784 Btu per pound. All process and support facilities necessary to convert wood to methanol are included in this study. The plant location is Newport, Oregon.

The capital cost for the plant is \$120,830,000 - September, 1980 basis. Methanol production costs which allow for return on capital have been calculated for various wood prices for both utility and private investor financing. These wood costs include delivery to the plant. For utility financing, the methanol production costs are respectively \$.45, \$.48, \$.55, and \$.69 per gallon for wood costs of \$5, \$10, \$20, and \$40 per dry ton. For private investor financing, the corresponding product costs are \$.59, \$.62, \$.69, and \$.83 per gallon for the corresponding wood costs. Both calculation methods include a return on equity capital in the costs.

The thermal efficiency of the plant is 52.9%.

II INTRODUCTION AND SUMMARY

A. Introduction

The purpose of this study is to determine the feasibility of producing methanol by catalytic gasification of wood and forest residue with steam. The plant is designed to process 2,000 tons per day of dry feedstock. All necessary process and support facilities needed to convert chipped forest residue to methanol are included in this study. The plant location is Newport, Oregon.

Wood has several characteristics which make it attractive as a feedstock material. It is a domestic renewable resource; it contains very little ash or sulfur; and it is quite reactive. However, it has been little used in the past for several reasons. The first has been the availability of cheap liquid and gaseous fossil fuels which are easier to utilize. The second is that wood resources are more widely dispersed and require significant costs for collection of a quantity large enough for economic industrial processing. Additional costs are also incurred to process the wood to a readily usable fuel. Of course, fossil fuels are no longer cheap. To improve the economics of wood processing, Pacific Northwest Laboratory (PNL), operated by Battelle, has conducted research into the gasification of wood with steam in the presence of catalysts. This improves yields from the wood, and gasification with only steam reduces capital costs by elimination of the oxygen plant. The work of PNL in the laboratory and in a process development unit forms the basis of this study.

This report contains both the technical and economic results of this study. The technical information includes: (1) the design basis, (2) a description of the process, (3) an overall

plant material and energy balance, (4) a summary of utilities and raw materials, (5) a plant description, (6) block flow diagram, (7) layouts and arrangements, and (8) an equipment list. The economic information includes: (1) a capital cost estimate, with costs supplied by plant area, and (2) operating cost estimates using both utility and private investor financing.

B. Basis of Design

The information in this study was developed from data of catalytic wood gasification which was supplied by Battelle PNL. These data included reactor operating conditions such as temperature, pressure, char and gas yields, and size and throughput; catalyst regeneration requirements; and feedstock conditions. From this information an overall processing scheme and material balance was developed. Individual areas were then designed. Information on processing areas downstream of gasification was developed from Davy McKee's experience in these areas. However, for wood storage and drying, information obtained from vendors of wood storage and drying systems and users of these systems such as pulp and paper mills was incorporated into the design.

C. Summary

The production costs for methanol from wood as obtained in this study indicate that this is an economically feasible alternate when compared with current methanol prices, which are about \$0.75 per gallon. The production costs were calculated for a base case with a wood price of \$20 per dry ton, with costs also calculated for prices of \$5, \$10, and \$40 per dry ton. For utility financing, the production costs are \$.45, \$.48, \$.55, and \$.69 per gallon for wood prices of \$5,

\$10, \$20, and \$40 per dry ton, respectively. For private investor financing and the same wood prices, the corresponding production costs are \$.59, \$.62, \$.69, and \$.83 per gallon.

Some aspects of this plant must be further defined and demonstrated before the economic feasibility can be definitely determined. A major area is the wood supply to the plant. This is one of the most significant cost factors, and one in which there are large uncertainties. A demonstration is needed of the catalyst gasification of wood with steam in a commercial-size unit and also of the subsequent catalyst recovery and regeneration.

The thermal efficiency of the plant, is defined as

$$\text{Efficiency, \%} = 100 \times \frac{\text{Methanol, HHV}}{\text{Wood, HHV} + \text{Electricity} + \text{Diesel Fuel}}$$

The thermal efficiency is 52.9%.

III DESIGN BASIS

A. Plant

1. Capacity - The plant shall have the capacity to process 2,000 tons per day of dry wood.
2. Location - Newport, Oregon
3. Operating factor - 330 days/year

B. Site Data (Weather data taken from Reedsport, Oregon)

1. Altitude - 100 feet
2. Wind load - 75 mph
3. Maximum/minimum ambient design temperature - 81°F/25°F
4. Design wet bulb temperature - 61°F

C. Product Specification

1. Fuel Grade Methanol

Methanol content (wt. %)	99.3 (min.)
Distillation (vol. %)	To distill out not less than 95% between 64°C and 66°C
Free acid (consumption of alkali, .01N NaOH ml/50 ml)	2 (max.)
Residue on evaporation (wt. %)	.002 (max.)

Indoform producing substances (calculated as wt. % acetone)	0.1 (max.)
Specific gravity (15°C/4°C)	0.798 (max.)

D. Raw Material and Imported Utility Specifications

1. Feedstock - The wood feed is from local sources and is 60% forest residue, 20% fir twigs, and 20% alder. The individual and combined analyses are given below.

a. Ultimate Analysis (wt%)

	<u>Residue</u>	<u>Alder</u>	<u>Fir</u>	<u>Weighted Average</u>
Moisture (as received)	53.90	50.81	35.00	49.50
C	46.39	45.34	47.98	46.50
H	5.94	5.90	5.96	5.87
N	0.00	0.00	0.00	0.00
O	39.09	47.78	44.88	41.99
Ash	<u>8.68</u>	<u>0.98</u>	<u>1.18</u>	<u>5.64</u>
Total	100.00	100.00	100.00	100.00
Btu/dry lb	8,720	8,610	8,780	8,762

- b. The material arrives at the plant site as chips of a size suitable for feed to the gasifier. The wood storage requirement is for five months storage of the "as received" storage and a two weeks storage after screening. A laydown area which can store twenty days capacity of unchipped forest residue is included.

c. The bulk density of the wood chips is 11 lb/ft³
(moisture free basis).

2. Electricity - available at 4160V, 3 ph

3. Water - water available at battery limits.

E. Gasifier Operation

1. Reactor Operating Condition

a. P - 10 atm

b. T - 750°C

2. Reactor Yields

a. Steam/wood (MAF), lb/lb - 0.75 (includes H₂O in wood)

b. Gas production = 1.60 lb/lb MAF wood

<u>Component</u>	<u>Mol%</u>
H ₂ O	28.7
H ₂	36.6
CH ₄	4.0
CO ₂	12.4
CO	<u>18.3</u>
Total	100.0

c. Char production - 0.15 lb/lb MAF wood
Char heat of combustion - 14,000 Btu/lb

d. $\Delta H_{rxn} = +1048 \text{ Btu/lb MAF wood}$

3. Reactor Size

Three gasifiers with an inside diameter of 15 feet are required. The depth of the fluid bed is 10 feet.

F. Char-Catalyst Recovery

1. Char-Catalyst Collection

Char and catalyst are collected from the gas by the gas cleaning system and combined with the overflow from the gasifier. The ratio of char to catalyst by weight is 50:1. Half the material is in the raw gas from the gasifier and half comes from the overflow from the gasifier. The entrained particulate has the following size distribution:

<u>Size, Microns</u>	<u>Weight %</u>
149	10
-149 +105	5
-105 +74	5
-74 +53	5
-53 +10	55
-10	20

2. Char-Catalyst Separation

Fines in the char-catalyst mixture consist primarily of char. Very little catalyst will be lost when in the fines when they are removed by screening. The char and catalyst can then be separated by a magnetic roll separator. Catalyst recovery is 90%.

G. Utility Systems

1. Steam

Steam is produced and consumed within the plant battery limits at the following levels:

- High pressure - 600 psig, 750°F
- Low pressure - 150 psig and saturated

2. Steam Condensate

All steam condensate except small tracings are collected and used in the production of boiler feedwater in a deaerator operating at 20 psia and 228°F.

3. Boiler Feedwater

Boiler feedwater, deaerated and inhibited steam condensate and demineralized water, is produced and consumed within the plant battery limits at 150 psig and 228°F.

4. Cooling Water

Cooling water suitable for use in shell and tube heat exchangers is supplied from a cooling tower at the following conditions:

- Supply: 75°F and 50 psig
- Return: 100°F maximum and 30 psig minimum

5. Potable Water

Potable water is available at 50 psig and ambient temperature.

6. Firewater

Firewater is available at 140 psig from the raw water settling basin.

7. Instrument Air

Oil free instrument air is available at the following conditions:

Pressure	100 psig
Temperature	100°F
Water Dew Point	-20°F

8. Carbon Dioxide

Carbon dioxide is available from the acid gas removal unit at the following conditions:

Pressure	275 psia
Temperature	100°F
Purity	99.5%
Water Dew Point	-40°F

9. Natural Gas

Natural gas is available at 50 psig for start-up and is supplied at the plant battery limits.

H. Process Selection

The design philosophy of the plant is that commercially available process units are used in all areas other than gasification and that standard design practice is used in development of the design of the gasifier. The following paragraphs discuss some of the factors involved in the process selection in certain areas. Of course, in preparing a feasibility study of this type, definitive studies to optimize the process completely are outside the scope of this study.

1. Wood Storage

Reclaiming of forest residue from the logging sites is still under development. There are three methods which are being used: chipping, shearing (or chopping), and baling. The economy of each operation depends on local conditions which may vary for each logging site. Significant local variations include:

- a. Accessibility of a site with regards to road conditions
- b. Site situation and its topography
- c. Quantity of the residue, which may vary between 15% to 45% of the total harvest.

The wood chips were considered as the main material being delivered to the gasification plant site, with provision for occasional deliveries of sheared or baled residue.

The stockpiling facilities consist of two wood chip piles with a capacity of 25 days by use of the stacker which

can be extended to 125 days or even more by bulldozers, a 20-days capacity pile of sheared or baled residue, and finally two piles of screened wood chips with 14-days total capacity. The capacity of storage will be governed by availability of forest residue and can be projected from the schedule of logging operations within the area. The above capacity of wood storage will ensure continuous chip supply to the plant and will cover any contingencies, such as interrupted deliveries due to weather conditions or deliveries during the plant turnaround.

Several vendors of stacking and reclaiming systems were contacted to obtain quotations and information on wood handling practices. Several logging sites and pulp mills in the Eugene, Oregon, area were visited, and several other pulp mills in this area were contacted by telephone. Some general findings from this search included:

- a. Totally automatic stacking and reclaim systems are capital-intensive.
- b. Storage capacities for pulp mills in the coastal region of Oregon are quite high (2-4 1/2 months) due to the extended rainy season.
- c. Most large wood processors use a system which is a combination of automatic stacking and partially automatic or manual reclaiming with front-end loaders or bulldozers.

In recognition of these factors the system selected has a small live storage area served by a belt conveyor tripper/stacker and chain reclaimers and a large dead storage area in which bulldozers are used for stacking and reclaiming.

2. Wood Drying

The three following types of rotary dryers were considered for wood chip drying:

- a. Single pass, circular cross section unit
- b. Triple pass, circular cross-section unit
- c. Single pass, annular cross section unit

Preliminary studies favored selection of the single pass, annular cross section rotary dryer. The other two types of dryers in comparison appear to have certain negative aspects, such as:

- a. Single Pass, Circular Cross Section Unit
 - i. Due to the large diameter, the flow of wood particles through the dryer will not result in uniform retention time.
 - ii. The dispersion of wood particles will be uneven, resulting in less efficient heat absorption from the drying gases.
- b. Triple Pass Unit
 - i. Thermal gradients between individual passes imposes stresses on the dryer material due to the differential thermal expansion.

- ii. The wood is passed through the dryer by drying gases and the wood particles within the annular portions of the dryer may not be uniformly dispersed.

A thorough investigation which is not within the scope of this study, will be necessary to establish definitively advantages and disadvantages of individual types of dryers.

The selected dryer is the Rader-Thompson type as manufactured by Rader Companies, Inc. The investment cost of this dryer is approximately the average of the other two types with $\pm 15\%$ difference.

3. Acid Gas Removal

Davy McKee engineers have performed a study of the use of acid gas removal systems in the purification of synthesis gas. The results of this study were used in the selection of the Benfield process for acid gas removal. The requirement in this study is only for the removal of carbon dioxide, due to the absence of sulfur in the wood. For the inlet carbon dioxide concentration and partial pressure and the required carbon dioxide removal, the Benfield process is the preferred system.

IV PROCESS AND OFF-SITES DESCRIPTION

A. Summary

The process plant complex detailed in the following description is capable of producing 997 tons per day of fuel grade methanol. These flows are based on a dry wood feed to the plant of 2000 tons per day. The wood feed is a mixture of forest residue, twigs, and alder, and is gasified with steam to produce a synthesis gas suitable for methanol production by means of the ICI low pressure methanol process. Following is a list of the major process and offsite units of the plant:

Process Areas -

- 101 - Wood Storage and Sizing
- 102 - Wood Drying
- 103 - Gasification
- 104 - Shift Conversion
- 105 - Acid Gas Removal
- 106 - Compression
- 107 - Methanol Synthesis and Distillation
- 108 - Purge Gas Reforming
- 109 - Waste Water Treating
- 110 - Raw Water Treating and Cooling Water
- 111 - Boilers and BFW System
- 112 - Miscellaneous Utility Systems
- 113 - Storage and Loading - Product and Utilities

The mixture of forest residue is delivered by truck to the plant site. The wood is then stored. Withdrawal from storage is done by bulldozers and chain reclaimers. Belt conveyors then deliver wood to drying and subsequently to the gasifier. The catalytic reaction of wood and steam in the gasifier

produces a gas consisting mainly of hydrogen, carbon monoxide, carbon dioxide and water vapor along with various hydrocarbons and nitrogen. This gas is cooled primarily by the generation of steam before it passes through a baghouse to remove any entrained particulates. The gas is then heated to a temperature suitable for reaction in a high temperature shift reactor, which adjusts the hydrogen to carbon monoxide ratio to the proper level for methanol synthesis. Prior to the synthesis stage, the gas must go through a Benfield CO₂ removal system and a compression step. When the gas has been processed in the synthesis unit crude liquid methanol product is made and sent to the distillation unit for purification and then to product storage.

A purge gas rich in combustibles is a by-product of the methanol synthesis. This gas is combined with steam and reacts in a steam reforming furnace to produce a second gas rich in hydrogen, carbon monoxide, and carbon dioxide. This effluent gas is combined with the synthesis gas prior to CO₂ removal.

The remaining light ends, flash gases, and light oils from the distillation process are combined and used as a fuel supplement to the package boiler.

A portion of the wood delivered to the plant is used both as fuel for the package boiler and as fuel to supply heat for the gasifier.

The char generated in the gasifier is removed, separated from any accompanying catalyst, and used as fuel in both the wood dryers and the package boiler. Catalyst is recovered from the char by magnetic separation and returned to the gasifier.

All wastewater streams will be treated before discharging. The treatment will consist of neutralization followed by biological treatment.

B. Detailed Unit Descriptions

Detailed descriptions of the various units within the plant are presented in the following sections.

Wood Storage - Area 101

At the plant site the main bulk of the forest residue is received already chipped. The chips are delivered by truck trailers. Trucks entering and leaving the unloading area are weighed on one of the two truck scales. Six (6) unloading stations are installed to permit a maximum unloading rate of 1,200 tph, which represents 48 trucks per hour. The capacity to handle this number of trucks per hour ensures continuous unloading when considering that they are making deliveries from several logging sites and that they may arrive in groups. Each truck unloading station consists of a hydraulic truck dumper, a truck dump hopper, and a chain feeder.

Each chain feeder transports the chips onto a tripper/stacker belt conveyor or onto a reclaiming belt conveyor. The tripper/stacker conveyor delivers the chips to one of the two (2) primary storage piles via a double wing stacker. Each primary pile is limited to approximately 40 ft high, as some bark and fines are supplied along with the 1/2" chips. The stacker builds 25 days capacity storage and any enlargement of the storage will be done by two (2) bulldozers spreading the piles. The reclaiming conveyor allows chips to bypass the primary storage and be delivered directly to the primary screening station and from there to the secondary storage. This provision is made to allow the use of only two bulldozers and also to take care of peak deliveries.

Each of the two (2) primary storage piles is 2,800 ft long and 80 ft wide for 25 days capacity, with possible enlargement to 240 ft width and 125 days capacity.

The reclaiming of chips from the primary storage is carried out by 14 chain reclaimers (8 ft. wide), seven for each pile. Each reclaimer has a capacity of 700 tph which represents the total required reclaiming rate based on 8 hrs/day, 5 days/week. The bulldozers are used to push chips towards reclaimers when needed. Two reclaiming belt conveyors, one for each pile, collect chips from the respective chain reclaimers and deliver them to the primary screening station.

The primary screening station consists of equipment for rock and tramp iron removal and for rechipping of oversize chips.

Screened chips transported by a tripper/stacker conveyor to the secondary storage pile. Stacking and reclaiming of the chips are identical to the method used for primary storage. Two (2) piles, each 1,800 ft long and 80 ft wide form 14 days storage. Also a provision is made to bypass secondary storage by using one of the two reclaiming belt conveyors.

Wood Drying - Area 102

The chips from the secondary storage are screened to remove any incidental oversize trash and conveyed by chain conveyors to the surge bins for the dryers. Two conveying strands and two secondary screens are used to ensure uninterrupted chip supply.

Six (6) rotary drum dryers complete with a burner, ash removal cyclone, exhaust dust cyclone, ducting, and all necessary appurtenances are installed to reduce the moisture content of green chips from 50 wt% of total feed to 10%. The by-product char from the gasifier is used to fuel the burners for the dryers. Five (5) dryers normally operate while the sixth dryer will be on standby.

Dried chips are conveyed from the dryers to a surge bin of one hour capacity. The chip inventory of this bin allows a start-up of the standby dryer. The chips from this bin are conveyed to three gasifier lock hopper systems. Again two strands of conveyors are used from the dryers to the gasifiers.

The lock hopper system for each gasifier consists of a surge bin and of three (3) sets of upper and lower lock hoppers, equally spaced @ 120°. The chips are fed to the upper lock hopper by a double screw feeder at a preset rate. When the upper lock hopper is filled to a given level the screw feeder stops and a gas valve at this hopper inlet shuts. Then the upper lock hopper, after being pressurized, is inactive until the chips content of the lower lock hopper reaches a low level. A low level indicator initiates opening of another gas valve installed at the inlet of the lower lock hopper, which permits the chips to be discharged from the upper lock hopper. After the preset time the gas valve closes and the upper lock hopper can be depressurized to accept another batch of chips from the surge bin. The chips are fed from the lower lock hopper into the gasifier continuously by a screw feeder at an adjustable feed rate. The operating cycle is above 10 minutes. Each chip feed connection to

the gasifier has a shutoff valve to allow isolation of one set of lock hoppers should the necessity arise. All gas valves and shutoff valves are operated hydraulically from a one power cabinet common to all three gasifiers. The power cabinet contains pumps, oil reservoir, pressure relief valves, accumulators and all necessary selector valves to ensure a continuous supply of hydraulic power and to allow for an emergency shutdown.

Wood Gasification and Clean-Up - Area 103

Wood chips from the gasifier feed bins are continuously fed by screw conveyors to the three fluidized bed gasifiers. High pressure steam is fed into each bed to gasify the wood as well as fluidize the beds. Contained within each bed is the catalyst required for the reaction, a 3/8" diameter spherical ball of nickel catalyst on a silica alumina structure. The gasifiers operate at a temperature of 1380°F and a pressure of 150 psia. At these conditions most hydrocarbons will be cracked to give a crude synthesis gas consisting primarily of hydrogen and carbon oxides with only a small amount of methane.

About 285 tons per day (dry basis) of the wood supplied to the gasification area is burned in a heater to supply the necessary heat input to the gasifier. This is accomplished by first allowing the hot combustion gases (approximately 1800°F) to circulate through tube bundles located in each gasifier bed. These gases upon exiting the tube bundles are then used to preheat the fluidizing steam and combustion air.

The crude synthesis gas leaves the gasifier at the bed temperature of 1380°F. Before any particulate matter can be removed from this stream, the gas must be cooled to a reasonable temperature. This is accomplished mainly by generating 600 psig superheated steam in a waste heat boiler. The gas exits the waste heat boiler at a temperature of 350°F and is subsequently passed through a cyclone and bag filter arrangement to remove any entrained char or catalyst material. At this point the gas is clean enough for continued processing, but must first be heated to a temperature suitable for the subsequent CO shift reaction. This is done using an additional tube bundle located in the waste heat boiler section, where the gas can be heated to 550°F and then sent to the CO shift area.

Provisions for the continual removal of char from the gasifier beds are required and this is achieved by an overflow line from bed level on each gasifier. Because catalyst will be mixed not only with this char but with the char leaving the cyclones and the bag filter, it is necessary to include a char/catalyst separation system. Char and catalyst from all these sources flow by gravity to a char/catalyst lock hopper where the pressure is let down to atmospheric. From this point the mixture is fed to a magnetic separator which allocates each component to its respective hopper. From this point, catalyst is pneumatically conveyed back to the gasifier feed system and re-enters the gasifier through a separate lock hopper system. Char from the separation system is used both as boiler fuel and dryer fuel. The entire char/catalyst system operates under a protective CO₂ atmosphere.

Shift Conversion - Area 104

The purpose of the shift conversion step is to adjust the ratio of carbon monoxide to hydrogen according to the exothermic reaction:

This shift is accomplished catalytically by a one-stage conversion reactor.

To adjust this ratio in the raw synthesis gas it is necessary to react only a portion of the gas in the reactor. The remaining portion is combined with the reforming furnace effluent and this mixture is sent to a second waste heat boiler to generate 150 psig steam. The effluent from this waste heat boiler is then combined with the effluent from the shift reactor and sent to the demineralized water heater which heats all the boiler feed water for the plant to 200°F.

Final cooling of the synthesis gas prior to acid gas removal is achieved by using cooling water and brings the gas temperature down to 200°F.

Acid Gas Removal - Area 105

The purpose of the acid gas removal unit is to remove any unwanted CO₂ in the synthesis gas prior to the methanol synthesis stage. The Benfield process has been chosen for removal of acid gas.

Gas from the shift conversion area first enters the absorber column where it is contacted with a recirculated

aqueous potassium carbonate solution. The absorber is a column packed with 1 1/2 inch steel slotted rings. In the absorber a sufficient amount of CO_2 is removed to give the proper concentration in the make-up synthesis gas. From here the gas goes to the compression stage prior to methanol synthesis.

From the bottom of the absorber column, the aqueous K_2CO_3 solution, rich in absorbed CO_2 , is sent to the regenerator, a second packed column which uses steam to strip the CO_2 from the solution. The packing in the regenerator is 2 inch steel slotted rings. Heat to the regenerator is supplied by two different means. First low pressure steam is used to supply heat to a conventional thermosyphon reboiler. Second, the lean K_2CO_3 solution from the bottom of the regenerator flows to a four-stage flash tank where the pressure is lowered from 20 psia to 14.7 psia. Steam is flashed from the solution and returned to the regenerator by means of an ejector utilizing low pressure steam. The lean solution from the flash tank is pumped to the top of the absorber.

The overhead from the regenerator, consisting of CO_2 and steam at 201°F , is cooled to 120°F in a water cooled exchanger. A portion of the water condensed is returned to the top of the regenerator while the remainder flows to the waste water treatment system. The saturated acid gas is then sent to a compressor and used as inert gas within the plant.

Gas Compression - Area 106

A pressure of 1000 psig is required for the synthesis gas entering the methanol loop. This pressure is achieved

using a multi-stage centrifugal booster compressor. A water cooled heat exchanger precedes the compressor to cool the synthesis gas from 176°F to 100°F. Following the compressor are a chloride guard bed and a sulfur guard bed to prevent these elements, if any, from entering any subsequent processing stages. The final stage in this area is another water cooled exchanger to bring the synthesis gas temperature down to 100°F prior to entering the methanol loop.

Methanol Synthesis and Distillation Area 107

The methanol synthesis loop make-up gas enters the synthesis loop at the suction of the circulator. The circulator is a motor driven centrifugal compressor. The mixture of recycled gas and fresh make-up synthesis gas is preheated to the warm shot temperature in the cold shell loop interchanger; a portion is further heated to the reaction temperature in the warm shell loop interchanger and fed to the top of the converter. The remaining gas (warm shot) serves as quench gas for temperature control in the methanol converter.

The methanol converter is a pressure vessel of single wall design constructed of low alloy steel, which holds a single continuous bed of catalyst. Temperature control is affected by injecting warm shot gas at appropriate levels directly into the catalyst bed using specially developed distributors. These distributors provide excellent gas mixing while allowing free flow of catalyst between them, thus allowing rapid catalyst charging and discharging. Catalyst charge-out times of less than 36 hours from hot shutdown to start of catalyst reduction are consistently achieved. On stream availability for

Davy McKee designed methanol plants has proven to be over 97%.

The main feed gas and the quench mix in the catalyst bed where the reaction to methanol takes place as the gases pass downward through the methanol converter. The reactions to produce methanol are between hydrogen and carbon monoxide or carbon dioxide and are represented by the following chemical equations:

Thus, water is produced in addition to methanol when CO_2 is involved in the reaction. Since both reactions are reversible, methanol and water vapor in the exit gas should be condensed and separated as thoroughly as possible from the recycle loop gas to maximize the methanol production.

The converter exit gas is first cooled in the warm shell loop interchanger and the distillation column reboiler operating in parallel. The converter exit gas is then recombined and is further cooled in the cold shell loop interchanger, where the heat is recovered from the exit gas to preheat the converter inlet gas. Final cooling and crude methanol condensation is achieved in the methanol condenser.

The crude methanol product is recovered from the loop gas in the crude methanol separator, a knock-out drum type unit with a stainless steel mist eliminating section of high separation efficiency.

The inert components in the synthesis loop are controlled by adjusting a purge from the synthesis loop between the methanol separator and the point of make-up gas addition. This gas is sent to the purge gas reforming area. The crude methanol is let down to 75 psig in the letdown vessel and some of the gases physically absorbed at the 700 psig loop pressure flash off.

Flash gas from the letdown vessel, mostly dissolved gases, is fed to the bottom of the flash gas scrubber where cooled water from the refining column bottoms is used to recover most of the methanol contained in the flash gas. The scrubber underflow becomes part of the crude feed to make up an optimum feed composition. The remaining flash gas is fed as a fuel to the package boiler.

Crude methanol from the letdown vessel passes to the crude methanol storage tank or to the refining area under its own pressure.

One of the major advantages of the ICI low pressure methanol process is the excellent selectivity of the converter catalyst. Because of this selectivity, the ICI crude methanol is of the highest purity produced today. Typical levels of total organic impurities in the crude methanol at the end of catalyst life are less than 2,000 ppm and at the beginning of life less than 1,000 ppm.

Crude methanol, either from the synthesis area or from the crude storage tank, is pumped to the single distillation column via feed preheaters. A premixed aqueous solution of 1% sodium hydroxide is metered into the crude feed at a rate sufficient to neutralize any organic acid

in the crude, in order to suppress corrosion. The crude is preheated first by the condensing vapor of the refining column overheads in the feed/ overheads exchanger. It is further heated to the bubble point by heat exchange with the column bottoms stream in the feed/bottoms exchanger. The column overheads are cooled first in the feed/overheads exchanger and then in the primary condenser. The secondary reflux obtained from the secondary condenser is joined back to the top of the column as total reflux.

The light ends in the crude methanol, such as dimethylether and remaining dissolved gases are removed as net overheads. This overhead purge is compressed to fuel gas pressure in the light ends compressor and sent to the package boiler as a fuel.

Heat to the columns is supplied by a thermosyphon reboiler utilizing heat from the methanol converter exit gas. Bottoms water partially preheats the feed and then is cooled in the bottoms cooler. A portion of the bottoms water is recycled to the flash scrubber with the balance to be exported to waste treatment facilities.

Fuel grade methanol is removed a few trays from the top as a sidestream drawoff. The product is cooled in the product cooler before being exported to storage.

Fusel oil is a sidestream taken towards the bottom of the column. This stream contains methanol and water and all higher alcohols such as ethanol, propanol and iso-butanol. The fusel oil is cooled in the fusel oil cooler before being exported as a liquid fuel for use in the package boiler.

Purge Gas Reforming - Area 108

The purge gas reforming furnace reacts a portion of the purge gas stream with steam to produce a hydrogen rich gas. This gas is combined with the gasifier effluent to enrich the synthesis gas. The remaining portion of the purge gas is burned to provide the heat duty in the reforming furnace.

The reforming furnace consists of a furnace cell containing a total of 40 tubes packed with nickel catalyst required for the steam reforming reaction. A portion of the available purge gas is burned and flows through the convection section of the furnace external to these tubes. The remaining purge gas is mixed with high pressure steam, preheated, and passed through the tubes. The presence of heat and catalyst causes the reforming reaction to occur. The product gas exits at 1,600°F and flows through a heat exchanger to preheat the feed mixture. From here the gas is sent to the shift conversion area where it will be used to generate low pressure steam and then combine with the syn gas from the CO shift reactor.

Wastewater Treating - Area 109

All liquid wastewater streams for the plant are treated in a neutralizing basin and a subsequent three stage biological treatment system before being allowed to overflow to drainage. These streams include shift condensate, acid gas condensate, compression condensate, wastewater from distillation, boiler and cooling tower blowdowns, and backwash and underflow from raw water treatment.

Neutralized water overflows from the basin to a conventional biological treatment system. This system consists of three stages of aerated lagoons with clarifiers. The treated water overflows from the treatment system and is discharged from the plant. The underflow of biological sludge from the clarifier goes to lagoons for settling of the sludge. There are three sludge lagoons each to be operated on the following cycle: loaded for one year, drying for eighteen months, cleaned and allowed to rest for six months.

Raw Water Treating - Area 110

Raw water is delivered from outside the battery limits to the raw water storage tank. Cooling tower make-up water is pumped from this tank to the cooling tower, which supplies the cooling water for the plant. The cooling tower has a circulation rate of 25,000 gpm, cooling this water from 110°F to 75°F. The cooling tower is equipped with a slipstream filter for solids removal and a chemical injection package which includes a biocide control, acid for pH control, and a non-chromate corrosion inhibitor. Blowdown from the cooling tower will be sent to the waste water treatment section.

To supply higher quality water for such users as the boilers, a portion of the water will be filtered and then softened in a sodium zeolite water softening system. The softened water will go to a storage tank from which it will be pumped to the boilers and other users.

A potable water supply is also maintained for the plant. Raw water is pumped to two activated carbon filters to remove any impurities and then on to the the potable water storage tank.

Boiler and Boiler Feedwater Systems Area 111

This area includes boiler feedwater preparation, condensate handling, steam generation in a wood, gas, and char fired boiler, and fuel handling facilities.

Boiler feedwater consists of returned condensate plus softened make-up water, both of which are deaerated to eliminate oxygen. Usable condensate is collected from various sources and sent directly to the deaerator; softened make-up water is preheated by exchanger with the synthesis gas leaving the shift conversion area and then sent to the deaerator. Chemicals are injected into the boiler feed water to control scale and corrosion. A low head pump furnishes the feedwater for low pressure steam generation in the shift unit waste heat boiler. A high pressure pump supplies boiler feedwater to the high pressure waste heat boilers in the gasifier area as well as the package boiler.

The package boiler generates 600 psig steam superheated to 750°F. It is fired mainly by the combustion of char but requires additional burners for wood and fuel gases to generate all the necessary high pressure steam. The rest of the package includes an air preheater, economizer, boiler and firebox, induced draft fan, stack, and a burner control system.

Fuel gas for the boiler is a mixture of the various gases taken from the methanol synthesis and distillation area, including light ends, flash gases, and fusel oil. Gases from these sources are collected in a fuel gas drum and used mainly in the boiler, although a small portion is used as pilots on the two flares included in the plant.

Miscellaneous Utility System - Area 112

Instrument Air System

An instrument air package of 300 scfm capacity is provided. The package consists of two compressors of 300 scfm capacity, each discharging at 125 psig and each with inter- and after- coolers, and a surge/separator drum. A common electrically regenerated dryer with prefilter and afterfilter feeds two air receivers.

Inert Gas System

A 2000 scfm compressor is provided to compress the CO₂ vent stream produced by the acid gas removal unit. This gas is used for instruments, pneumatic conveying, gas blanketing and for purging. A surge drum is also provided for the compressed CO₂.

Flare System

Two flares are included in this plant. The gasifier start-up flare is sized to handle the total amount of gas produced from the three gasifiers during start-up. The methanol flash flare is included to handle flash gases from the methanol pressure letdown step. Both flares are piloted by the gas mixture from the distillation unit.

V OVERALL HEAT AND MATERIAL BALANCE SUMMARY

An overall heat and material summary has been made for the streams entering or leaving the battery limits of the plant. The reference point for calculating the enthalpies of the streams is a temperature of 60°F and the normal state of the constituents of the stream at 60°F. Unaccounted losses from the plant are 12.3% of the energy input to the plant.

TABLE I. HEAT AND MATERIAL BALANCE SUMMARYREFERENCE: $\text{H}_2\text{O}(\text{liq.}) @ 60^\circ\text{F}$

<u>INPUT STREAM</u>	<u>TEMPERATURE °F</u>	<u>Lb/Hr.</u>	<u>Btu/Lb.</u>	<u>10^6 Btu/Hr.</u>
1. Raw Wood	60	330,561	4425	1462.7
2. Dryer Air	60	976,558	13.6	13.3
3. Boiler Air	60	277,160	13.6	3.8
4. Gasifier Heater Air	60	643,419	13.6	8.8
5. Reformer Air	60	124,001	13.6	1.7
6. Water	60	554,487	-	-
7. Lime Solution	60	35,025	-	-
8. Electricity	(22,239 Kw @ 3,413 $\frac{\text{Btu}}{\text{Kw-Hr.}}$)			75.9
9. Diesel Fuel	(13.75 gal/hr @ 140,000 Btu/gal)			1.9
TOTAL		2,941,211		1568.1
<u>OUTPUT STREAM</u>				
1. Dryer Vent	180	1,135,900	181.2	206.9
2. CO_2 Vent	120	62,970	12.3	.8
3. Methanol	105	83,087	9811.4	815.2
4. Sludge	60	8,287	-	-
5. Treated Waste Water	60	297,342	-	-
6. Cooling Tower Losses	100	255,403	1077.1	275.1
7. Boiler Vent	250	291,458	91.2	26.8
8. Heater Vent	150	668,542	49.6	32.8
9. Reformer Vent	300	128,823	130.4	16.8
10. Ash to Pond	60	9,399	-	-
11. Mechanical & Other Losses		-	-	193.7
TOTAL		2,941,211		1568.1

VI SUMMARY OF PROCESS MATERIALS AND UTILITIES

A. Raw Material and Utilities Imported

1.	Wood	
	Quantity, tons per day wet	3,967
2.	Raw Water	
	Flow, gpm	1,108
3.	Electricity	
	Normal operating usage, kw	22,239

B. Products and Utilities Exported

1.	Fuel Grade Methanol	
	Production, tons per day	997
2.	Treated Wastewater	
	Flow, gpm	594
3.	Wood Ash	
	Quantity, tons per day	113
4.	Sludge from Wastewater Treating	
	Quantity, tons per day	99

C. Catalysts and Chemicals

1.	<u>Catalyst Initial Charge</u>	<u>Requirements</u>	<u>Life</u>
	Gasifier Charge	*	
	Shift Converter Charge	150 ft ³	3-5 yrs.
	Chloride Guard Bed Charge	3330 ft ³	2-5 yrs.
	Sulfur Guard Bed Charge	2500 ft ³	2-5 yrs.
	Methanol Catalyst	Confidential	2-5 yrs.
	Reformer Charge	140 ft ³	2-5 yrs.

*.167 tons/gasifier - day
 13.9 lb/hr of catalyst is continually fed to each gasifier as a
 make-up stream.

2.	<u>Process Chemicals</u>	<u>lb/day</u>
	K ₂ CO ₃ for Acid Gas Removal	911
	V ₂ O ₅ for Acid Gas Removal	17
	DEA for Acid Gas Removal	68
	Caustic for Methanol Distillation	166
	Lime for Wastewater Treating	84,072
3.	<u>Boiler Chemicals</u>	
	Scale Inhibitor	63
	Oxygen Scavenger	4.2
	Corrosion Inhibitor	31.4
4.	<u>Cooling Tower</u>	
	H ₂ SO ₄ for pH control	240
	Corrosion control	75
	Dispersant	30
	Algae control	9
	Chlorine	135
D.	<u>Summary of Operating Labor</u>	
	<u>Area</u>	<u>Total Operating Personnel Required</u>
	Wood storage and drying	15
	Gasification, cleanup, shift, acid gas removal, compression, methanol synthesis and distillation, and purge gas reforming	22
	Offsites including boilers, char distribution, cooling tower, wastewater treatment, and raw water treatment	<u>18</u>
	TOTAL	55

VII OVERALL BLOCK FLOW DIAGRAM AND MATERIAL BALANCE

A material balance has been made which gives feed and discharge streams for each major processing and utility area for the plant. An overall block flow diagram, drawing number 5471-F-0101, and accompanying material balance sheets which list the composition, flow, and conditions of each stream are shown in this section.

Davy McKee
ENGINEERS AND CONSTRUCTORS

5471-F-0101

MOD TO METHANOL GASIFICATION BLOCK FLOW DIAGRAM

NO.	DESCRIPTION	DATE	BY	CHK.	APPROVED	DATE	BY	CHK.	APPROVED	DATE	BY	CHK.	APPROVED
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													

NOV 77

100

SHO 101A 10

VII-3

[illegible]

[illegible]

STREAM NUMBER		15		16		17		18		19		20		21	
DESCRIPTION		SHIFT BOILER BLowDOWN		CONDENSATE FROM SHIFT		L.P. STEAM FROM SHIFT		GAS TO ACID GAS REMOVAL		L.P. STEAM TO AGR		CD ₂ VENT		ACID GAS CONDENSATE	
PHASE															
COMPONENT		MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR
CARBON		12.011													
HYDROGEN		2.016						6,557.0	13,219			3.3	7		
OXYGEN		32.000													
NITROGEN		28.014						70.8	1,983						
SULFUR		32.060													
ASH		--													
WATER		18.018	47.5	855	4,783.6	86,182	2373.7	42,765	1,293.0	3475.7	62,618	173.2	3120	1948.1	35097
CARBON MONOXIDE		28.011							2,499.5			.9	25		
CARBON DIOXIDE		44.011							1,934.1			1359.1	59815		
METHANE		16.043							511.3			.2	3		
PROPANE		44.097													
HYDROGEN SULFIDE		34.078													
CARBONYL SULFIDE		60.071													
METHANOL		32.043													
DIMETHYL ETHER		46.068													
HIGHER ALCOHOLS		74.120													
PROPYLENE		42.081													
TARS/OILS		233.870*													
SOLUBLE ORGANICS		80.000*													
SULFUR DIOXIDE		64.066													
LIME		56.006													
AMMONIA		17.031													
TOTAL		47.5	855	4,783.6	86,182	2373.7	42,765	12865.7	201,835	3475.7	62,618	1536.7	62,970	1948.1	35,097
TOTAL DRY, MOL/HR								11572.7				1363.5			
H ₂ , MM BTU/HR			0.26		12.1		49.9				73.1		0.8		2.1
AVERAGE MOL WT															
VOL. FLOW RATE - SCFM/MSCFD/USGPM															
PRESSURE - PSIA		165		115		165					165	30		15	
TEMPERATURE - °F		366		200		366					366	120		120	
DENSITY - LB/FT ³															
* ASSUMED															

Davy McKee

MATERIAL BALANCE SHEET

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANOL CLIENT BATELLE PUL

Sheet 4 of 8

STREAM NUMBER	DESCRIPTION	22		23		24		25		26		27		28	
		GAS TO COMPRESSION		COMPRESSION CONDENSATE		MAKE-UP SYN GAS		PRODUCT METHANOL		COLUMN BOTTOMS TO WASTE TREATING		FLASH GAS TO FUEL		LIGHT ENGS TO FUEL	
PHASE	COMPONENT	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR
CARBON	12011														
	2016	6553.7	13,212			6553.7	13,212					23.3	47	.6	1
	32000														
	28014	70.8	1,983			70.8	1,983					.5	14		
	32060														
	ASH														
	18010	662.6	11,937	653.0	11,764	9.6	173	10.3	185	386.3	6960	.3	6	2.1	37
	28011	2498.6	69,988			2498.6	69,988					16.7	469	7.6	214
	44011	575.0	25,306			575.0	25,306					27.5	1210	39.4	1732
	18043	511.1	8,200			511.1	8,200					42.9	688	4.2	67
HYDROGEN SULFIDE	44087														
	34076														
	60071														
	32043							2585.0	82832	.1	3	7.3	235	26.6	853
	48068											.3	15	2.8	130
	74120							.9	70	.8	57			.2	13
	42081														
	233870*														
	80000*														
	64068														
SULFUR DIOXIDE	58008														
	17031														
TOTAL		10871.8	130626	653.0	11764	10218.8	118662	2596.2	83087	387.2	7020	118.8	2684	83.5	3047
	TOTAL DRY, MOL/HR	10209.2				10209.2		2585.9		.9		118.5		81.4	
	1327.5			0.7		1309.4		815.2		1.0		23.9		12.6	
	AVERAGE MOL WT														
	VOL. FLOW RATE - SCF/MMSCFD/USGPM														
	PRESSURE - PSIA	113		100		1015		50		85		50		50	
	TEMPERATURE - °F	176		120		100		105		120		105		105	
	DENSITY - LB/FT³														
	*ASSUMED														

Davy McKee

MATERIAL BALANCE SHEET

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANOL CLIENT BATTELLE PNL Sheet 6 of 8

STREAM NUMBER		36		37		38		39		40		41		42	
DESCRIPTION		VENT GASES FROM BOILER		H. P. STEAM FROM BOILER		RAW WATER TO TREATING		WASTE WATER		RAW WATER TO COOLING TOWER		COOLING TOWER BLOWDOWN		COOLING TOWER LOSSES	
PHASE															
COMPONENT	MOL WT	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR
CARBON	12.011														
HYDROGEN	2.016														
OXYGEN	32.000	1355.4	43374												
NITROGEN	28.014	7492.7	209900												
SULFUR	32.060														
ASH	—														
WATER	18.016	677.9	12213	4780.8	86130	10400.2	187,370	819.5	14,764	20377.3	367,117	6200.8	111,714	14176.5	255,403
CARBON MONOXIDE	28.011														
CARBON DIOXIDE	44.011	590.1	25971												
METHANE	16.043														
PROPANE	44.097														
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
METHANOL	32.043														
DIMETHYL ETHER	48.068														
HIGHER ALCOHOLS	74.120														
PROPYLENE	42.081														
TARS/OILS	233.870*														
SOLUBLE ORGANICS	80.000*														
SULFUR DIOXIDE	64.066														
LIME	56.006														
AMMONIA	17.031														
TOTAL		10116.1	291458	4780.8	86130	10400.2	187,370	819.5	14,764	20377.3	367,117	6200.8	111,714	14176.5	255,403
TOTAL DRY, MOL/HR		9438.2													
H ₂ , MM BTU/HR		26.8		114.8		0		0		0		1.7		275.1	
AVERAGE MOL WT															
VOL. FLOW RATE - SCFM/MSCFD/USGPM															
PRESSURE - PSIA		ATM		615		ATM		ATM		ATM		ATM		ATM	
TEMPERATURE - °F		250		750		60		60		60		75		100	
DENSITY - LB/FT ³															
* ASSUMED															

Davy McKee

MATERIAL BALANCE SHEET

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANOL CLIENT BATTELLE PNL Sheet 7 of 8

STREAM NUMBER	43		44		45		46		47		48		49	
	LIME SOLUTION TO WASTE WATER		SLUDGE		TREATED WASTE WATER		CONDENSATE FROM AGR		AIR TO BOILER		AIR TO REFORMER		COMBUSTION VENT GAS	
PHASE														
COMPONENT	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR	MOL/HR	LB/HR
CARBON	12.011													
HYDROGEN	2.018													
OXYGEN	32.000								1991.5	63728	890.8	28506	570.4	18252
NITROGEN	28.014								7492.0	209881	3351.3	93883	3366.8	94318
SULFUR	32.060													
ASH	---													
WATER	18.016	1749.7	31522	113.0	2036	16504.3	297,342	1984.9	35,760	197.1	3551	89.5	1612	474.4
CARBON MONOXIDE	28.011													
CARBON DIOXIDE	44.011													
METHANE	16.043													
PROPANE	44.097													
HYDROGEN SULFIDE	34.078													
CARBONYL SULFIDE	60.071													
METHANOL	32.043													
DIMETHYL ETHER	48.068													
HIGHER ALCOHOLS	74.120													
PROPYLENE	42.081													
TARS/OILS	233.870*													
SOLUBLE ORGANICS	80.000*													
SULFUR DIOXIDE	64.066													
LIME	56.006	62.5	3503											
AMMONIA	17.031													
				62.5	6251									
				175.5	8287									
TOTAL	1812.2	35025		62.5	8287	16504.3	297,342	1984.9	35,760	9680.6	277160	4331.6	124001	4586.7
TOTAL DRY, MOL/HR	62.5			62.5						9483.5		4242.1		128823
H, MW BTU/HR	0			0		0		10.9		3.8		1.7		4096.8
AVERAGE MOL WT														16.8
VOL. FLOW RATE - SCFM/MSCFD/USGPM														
PRESSURE - PSIA	ATM			ATM		ATM		165		ATM		ATM		ATM
TEMPERATURE - °F	60			60		60		366		60		60		300
DENSITY - LB/FT ³														
*ASSUMED														

VIII PLANT LAYOUT AND DESCRIPTION

- A. OVERALL PLANT LAYOUT
- B. GASIFICATION AREA ARRANGEMENT
- C. GASIFICATION AREA FLOWSHEET
- D. GASIFICATION VESSEL DRAWING
- E. SINGLE-LINE EQUIPMENT LIST
- F. DETAILED EQUIPMENT LIST

A. Overall Plant Layout

A proposed layout has been made for the plant. As may be seen from the attached drawing, number 5471-A-0011, the major space requirement is that for the storage area. It should be noted that this is a conceptual plan and that modifications would be needed to adapt the plan to a particular plot. However, the total area required of about 110 acres would be the same.

B. Gasification Area Arrangement

Plans and elevations of major equipment in the gasifier area are shown on the arrangement drawing, number 5471-A-0101.

Davy McKee
ENGINEERS AND CONSTRUCTORS
1000 15th St., N.W.
WASHINGTON, D.C. 20004

WOOD TO METHANOL
DESIGNER SECTION
PLANS AND ELEVATION
NO. 5471-A-0101

VIII-7

NO.	DESCRIPTION	BY	CHK.	DATE	REVISION	DATE
1	WOOD SHREDDER	103-2004				
2	WOOD SHREDDER	103-2004				
3	WOOD SHREDDER	103-2004				
4	WOOD SHREDDER	103-2004				
5	WOOD SHREDDER	103-2004				
6	WOOD SHREDDER	103-2004				
7	WOOD SHREDDER	103-2004				
8	WOOD SHREDDER	103-2004				
9	WOOD SHREDDER	103-2004				
10	WOOD SHREDDER	103-2004				
11	WOOD SHREDDER	103-2004				
12	WOOD SHREDDER	103-2004				
13	WOOD SHREDDER	103-2004				
14	WOOD SHREDDER	103-2004				
15	WOOD SHREDDER	103-2004				
16	WOOD SHREDDER	103-2004				
17	WOOD SHREDDER	103-2004				
18	WOOD SHREDDER	103-2004				
19	WOOD SHREDDER	103-2004				
20	WOOD SHREDDER	103-2004				
21	WOOD SHREDDER	103-2004				
22	WOOD SHREDDER	103-2004				
23	WOOD SHREDDER	103-2004				
24	WOOD SHREDDER	103-2004				
25	WOOD SHREDDER	103-2004				
26	WOOD SHREDDER	103-2004				
27	WOOD SHREDDER	103-2004				
28	WOOD SHREDDER	103-2004				
29	WOOD SHREDDER	103-2004				
30	WOOD SHREDDER	103-2004				
31	WOOD SHREDDER	103-2004				
32	WOOD SHREDDER	103-2004				
33	WOOD SHREDDER	103-2004				
34	WOOD SHREDDER	103-2004				
35	WOOD SHREDDER	103-2004				
36	WOOD SHREDDER	103-2004				
37	WOOD SHREDDER	103-2004				
38	WOOD SHREDDER	103-2004				
39	WOOD SHREDDER	103-2004				
40	WOOD SHREDDER	103-2004				
41	WOOD SHREDDER	103-2004				
42	WOOD SHREDDER	103-2004				
43	WOOD SHREDDER	103-2004				
44	WOOD SHREDDER	103-2004				
45	WOOD SHREDDER	103-2004				
46	WOOD SHREDDER	103-2004				
47	WOOD SHREDDER	103-2004				
48	WOOD SHREDDER	103-2004				
49	WOOD SHREDDER	103-2004				
50	WOOD SHREDDER	103-2004				
51	WOOD SHREDDER	103-2004				
52	WOOD SHREDDER	103-2004				
53	WOOD SHREDDER	103-2004				
54	WOOD SHREDDER	103-2004				
55	WOOD SHREDDER	103-2004				
56	WOOD SHREDDER	103-2004				
57	WOOD SHREDDER	103-2004				
58	WOOD SHREDDER	103-2004				
59	WOOD SHREDDER	103-2004				
60	WOOD SHREDDER	103-2004				
61	WOOD SHREDDER	103-2004				
62	WOOD SHREDDER	103-2004				
63	WOOD SHREDDER	103-2004				
64	WOOD SHREDDER	103-2004				
65	WOOD SHREDDER	103-2004				
66	WOOD SHREDDER	103-2004				
67	WOOD SHREDDER	103-2004				
68	WOOD SHREDDER	103-2004				
69	WOOD SHREDDER	103-2004				
70	WOOD SHREDDER	103-2004				
71	WOOD SHREDDER	103-2004				
72	WOOD SHREDDER	103-2004				
73	WOOD SHREDDER	103-2004				
74	WOOD SHREDDER	103-2004				
75	WOOD SHREDDER	103-2004				
76	WOOD SHREDDER	103-2004				
77	WOOD SHREDDER	103-2004				
78	WOOD SHREDDER	103-2004				
79	WOOD SHREDDER	103-2004				
80	WOOD SHREDDER	103-2004				
81	WOOD SHREDDER	103-2004				
82	WOOD SHREDDER	103-2004				
83	WOOD SHREDDER	103-2004				
84	WOOD SHREDDER	103-2004				
85	WOOD SHREDDER	103-2004				
86	WOOD SHREDDER	103-2004				
87	WOOD SHREDDER	103-2004				
88	WOOD SHREDDER	103-2004				
89	WOOD SHREDDER	103-2004				
90	WOOD SHREDDER	103-2004				
91	WOOD SHREDDER	103-2004				
92	WOOD SHREDDER	103-2004				
93	WOOD SHREDDER	103-2004				
94	WOOD SHREDDER	103-2004				
95	WOOD SHREDDER	103-2004				
96	WOOD SHREDDER	103-2004				
97	WOOD SHREDDER	103-2004				
98	WOOD SHREDDER	103-2004				
99	WOOD SHREDDER	103-2004				
100	WOOD SHREDDER	103-2004				

C. Gasification Area Flowsheet

A flow schematic for the gasification area is shown on drawing number 5477-F-0102 which follows.

D. Gasification Vessel Drawing

A detailed drawing of the gasifier equipment item number 103-2201, follows this page. This drawing is typical for each of the three gasifiers and is numbered 5471-V-0101.

10 9 8 7 6 5 4 3 2 1

MARK	NO	REQ.	SIZE	RATING	SERVICE	REMARKS
A-3	3	24"	14"		WOOD FEED	4" REFRACTORY LINED
B-10	5	14"			HOT GAS FEED	
C	1	16"			HOT GAS DISCHARGE	
D	1	16"			STEAM FEED W/ 1" INCH	
E	1	750"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
F	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
G	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
H	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
I	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
J	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
K	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
L	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
M	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
N	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
O	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
P	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
Q	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
R	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
S	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
T	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
U	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
V	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
W	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
X	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
Y	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED
Z	1	24"			CASE 725 GAS OUTLET	9" REFRACTORY LINED

- NOTES:
- DESIGN: 140 PSIG @ 300°F
 - MATERIAL: CARBON STEEL
 - SHELL & HEAD MAT'L: A-516-70
 - SHALL BE REFRACTORY LINED WITH 8" INSULATING CASTABLE AND 4" REFRACTORY BRICK.
 - INTERIORS INCLUDE CYCLONE, HEAT EXCHANGER, STEAM FEED, AERATION GAS AND ALL THERE SUPPORTS, MOUNTED TO BE 40-335 OR INCLINED BOOM.

END VIEW

DETAIL X-X (EXCHANGER MANIFOLD)
31 RINGS W/ 30 TUBES EACH ROW

Davy McKee
ENGINEERS AND CONSTRUCTORS

WOOD GASIFIER - METHANOL
TAG: 103-2201

5471-V-0101

SCALE

8 VIII-15

10

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

E. Single Line Equipment List

A single line equipment list for all areas of the plant, by area, is given on the following pages.

WOOD STORAGE - AREA 101

<u>EQUIPMENT NUMBER</u>	<u>NUMBER REQUIRED</u>	<u>DESCRIPTION</u>
101-1001	2	Rechippers
101-1401	1	Tramp Iron Separator
101-1402	4	Primary Screens
101-1403	2	Secondary Screens
101-1801	2	Weigh Scale
101-1901	6	Truck Dumpers
101-2101	6	Dumpers to Storage
101-2102	2	Storage Stacker Conveyors
101-2103	14	Chip Reclaimers
101-2104	2	Reclaim Conveyors
101-2105	1	Collecting Conveyor
101-2106	1	Primary Screening Feed Conveyor
101-2107	1	Oversize Conveyor
101-2108	1	Trash Conveyor
101-2109	1	Primary Screen Delivery Conveyor
101-2110	1	Secondary Stacker
101-2111	10	Secondary Storage Reclaimers
101-2112	2	Secondary Storage Reclaim Conveyor
101-2113	1	Fines Conveyor
101-2301	6	Truck Dump Hoppers
101-3901	4	Bulldozer

WOOD DRYING - AREA 102

<u>EQUIPMENT NUMBER</u>	<u>NUMBER REQUIRED</u>	<u>DESCRIPTION</u>
102-1601	5 + 1	Wood Dryers
102-1801	1	Dried Chip Feeder
102-2101	2	Dryer Distribution Conveyors
102-2102	2	Dried Wood Collecting Conveyors
102-2103	1	Dried Wood to Storage Conveyor
102-2104	1	Storage to Gasifier Conveyor
102-2105	1	Gasifier Distribution Diverter
102-2106	1	Gasifier Distribution Conveyors

GASIFICATION - AREA 103

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-1301	3	Combustion Air Blower
103-1401	3	Char/Catalyst Screen
103-1402	3	Magnetic Separator
103-1501	3	Gasifier Heater
103-1601	3	HP Steam Superheater
103-1602	3	CO Shift Feed Preheater
103-1603	3	Gasifier Waste Heat Boiler
103-1604	3	Gasifier BFW Preheater
103-1605	3	HP Steam Preheater
103-1606	3	Combustion Air Preheater
103-1701	3	Cyclone
103-1702	3	Raw Gas Bag Filter
103-1703	3	Ventilation Bag Filter
103-1704	3	Combustion Gas Bag Filter
103-2101	9	Double Screw Feeder
103-2102	9	Gasifier Feed Screw
103-2103	3	Waste Heat Boiler Discharge Feeder
103-2104	3	Cyclone Discharge Feeder
103-2105	3	Bag Filter Discharge Feeder
103-2106	3	Screw Conveyor to Heater Feed Bin
103-2107	3	Screw Feeder to Heater
103-2108	3	Char Overflow Feeder
103-2109	3	Combustion Gas Bag Filter Discharge Feeder
103-2110	3	Ventilation Bag Filter Discharge Feeder
103-2201	3	Gasifier
103-2202	1	Steam Drum
103-2203	1	Blowdown Flash Drum

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-2203	1	Blowdown Flash Drum
103-2302	3	Heater Feed Bin
103-2303	3	Char Surge Hopper
103-2305	3	Catalyst Hopper
103-2501	9	Wood Feed Lock Hopper
103-2502	3	Char/Catalyst Lock Hopper
103-2503	3	Catalyst Feed Lock Hopper

SHIFT CONVERSION - AREA 104

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
104-1601	1	Reformer Effluent Waste Heat Boiler
104-1602	1	Demineralized Water Heater
104-1603	1	Trim Gas Cooler
104-2201	1	Synthesis Gas K-O Drum #1
104-2202	1	Synthesis Gas K-O Drum #2
104-2204	1	High Temperature Shift Reactor
104-2204	1	Steam Drum

ACID GAS REMOVAL - AREA 105

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
105-1101	1	Condensate Solution Pump
105-1102	1	Reflux Pump
105-1301	4	Steam Ejectors
105-1601	1	Acid Gas Cooler
105-1602	1	Lean Solution Cooler
105-1603	1	Reboiler
105-2201	1	Absorber
105-2202	1	Regenerator
105-2203	1	Condensate Separator
105-2204	1	Flash Tank

GAS COMPRESSION - AREA 106

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
106-1301	1	4-Stage Booster Compressor
106-1601	1	Precompressor Gas Cooler
106-1602	1	First Stage BC Intercooler
106-1603	1	Second Stage BC Intercooler
106-1604	1	Third Stage BC Intercooler
106-1605	1	Post Compressor Gas Cooler
106-2201	1	Precompressor K-0 Drum
106-2202	1	Post Compressor K-0 Drum
106-2203	1	Chloride Guard Bed
106-2204	1	Sulfur Guard Bed

METHANOL SYNTHESIS AND DISTILLATION - AREA 107

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
107-1101A,B	1 + 1	Crude Methanol Pump
107-1102A,B	1 + 1	Bottoms Pump
107-1103A,B	1 + 1	Reflux Pump
107-1104A,B	1 + 1	Steam Condensate Pump
107-1301	1	Circulator
107-1401A,B	1 + 1	HP Methanol Filter
107-1402A,B	1 + 1	LP Methanol Filter
107-1601	1	Cold Shell Loop Interchanger
107-1602	1	Warm Shell Loop Interchanger
107-1603	1	Loop Start-up Heater
107-1604	1	Loop Saturator Water Heater
107-1605	1	Crude Methanol Condenser
107-1606	1	Feed/Overheads Exchanger
107-1607	1	Primary Condenser
107-1608	1	Secondary Condenser
107-1609	1	Feed/Bottoms Exchanger
107-1610	1	Bottoms Cooler
107-1611	1	Reboiler
107-1612	1	Methanol Cooler
107-1613	1	Fusel Oil Cooler
107-2201	1	Methanol Converter
107-2202	1	Methanol Separator
107-2203	1	Letdown Vessel
107-2204	1	Distillation Column
107-2205	1	Reflux Drum
107-2206	1	Steam Condensate Drum
107-2301	1	Crude Methanol Storage Tank
107-2501	1	Caustic Dosing Set

PURGE GAS REFORMING - AREA 108

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
108-1501	1	Reforming Furnace
108-1601	1	Feed Effluent Gas Exchanger

WASTEWATER TREATING - AREA 109

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
109-1101	1 + 1	Neutralizing Basin Circulation Pump
109-1102	1 + 1	Lime Solution Pump
109-1103	1 + 1	Sludge Pump
109-1201	2	Lime Solution Tank Agitator
109-1301	1	Lime Conveying Blower
109-1701	1	Lime Storage Hopper Bag Filter
109-2101	1	Lime Rotary Feeder
109-2301	1	Neutralizing Basin
109-2302	3	Sludge Lagoons
109-2303	1	Lime Storage Hopper
109-2304	2	Lime Solution Tank
109-2501	1	Biological Treating Package

RAW WATER TREATING AND COOLING WATER - AREA 110

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
110-1101	1 + 1	LP Softened Water Pump
110-1102	2 + 1	Cooling Tower Circulation Pump
110-1103	1 + 1	Raw Water Feed Pump
110-1104	1 + 1	Potable Water Pump
110-1401	3	Sand Filter
110-1402	2	Cooling Tower Sidestream Filter
110-1403	2	Activated Carbon Filters
110-1601	1	Cooling Tower
110-2301	1	Softened Water Storage Tank
110-2302	1	Raw Water Storage Tank
110-2303	1	Potable Water Storage Tank
110-2501	1	Water Softening Package
110-2502	1	Cooling Tower Chemical Injection Package

BOILER AND BOILER FEED WATER SYSTEM - AREA 111

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
111-1101	1 + 1	LP Boiler Feed Water Pump
111-1102	1 + 1	HP Boiler Feed Water Pump
111-2201	1	HP Boiler Blowdown Flash Drum
111-2202	1	Deaerator
111-2203	1	Fuel Gas Drum
111-2501	1	Package Boiler

MISCELLANEOUS UTILITY SYSTEM - AREA 112

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
112-1301	1	CO ₂ Compressor
112-1501	1	Methanol Flash Flare
112-1502	1	Gasifier Start-up Flare
112-2201	1	CO ₂ Receiver
112-2501	1	Instrument Air Package

STORAGE AND LOADING - PRODUCT & UTILITIES - AREA 113

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
113-1101	5	Methanol Loading Pumps
113-1102	1	Carbonate Charging Pump
113-2301	5	Methanol Product Storage Tank
113-2302	1	Diesel Fuel Storage Tank
113-2303	1	Carbonate Storage Tank

F. Detailed Equipment List

A four line equipment list by plant area is given for the area of wood receiving and storage, wood drying and gasification with the following legend applying.

T - Type
C - Capacity
S - Size
M - Material
D - Driver
A - Area
Des P/T - Design Pressure/Temperature

Wood Storage and Sizing - Area 101

<u>Equipment Number</u>	<u>Number Required</u>	<u>Description</u>
101-1001	2	<u>Rechippers</u> T - Drum chipper C - 40 tons/hr
101-1401	1	<u>Tramp Iron Separator</u> T - Magnetic
101-1402	4	<u>Primary Screens</u> T - Vibrating S - 8' x 20'
101-1403	2	<u>Secondary Screens</u> T - Vibrating S - 8' x 20"

101-1801	2	<u>Weigh Scale</u> T - Truck C - 50 tons
101-1901	6	<u>Truck Dumpers</u> T - Hydraulic C - 50 Tons
101-2101	6	<u>Dumper Feeders to Storage</u> T - Chain S - 30' ctrs. x 8' lift C - 24,000 ft ³ /hr M - CS Drive - 40 hp
101-2102	2	<u>Storage Stacker Conveyors</u> T - Belt w/tripper S - 60" w x 3,060' w/125' stacker boom C - 24,000 ft ³ /hr M - CS D - 75 hp, 30 hp, 7 1/2 hp
101-2103	14	<u>Chip Reclaimers</u> T - Chain S - 8' w. x 60' ctrs. x 10' lift C - 70,000 ft ³ /hr M - CS D - 40 hp
101-2104	2	<u>Reclaim Conveyors</u> T - Belt S - 60" w. x 3,220' C - 70,000 ft ³ /hr M - CS D - 100 hp

101-2105	1	<u>Collecting Conveyor</u> T - Belt S - 60" w x 600' C - 70,000 ft ³ /hr M - CS D - 75 hp
101-2106	1	<u>Primary Screening Feed Conveyor</u> T - Belt S - 72" w x 60' C - 70,000 ft ³ /hr M - CS D - 15 hp
101-2107	1	<u>Oversize Conveyor</u> T - Belt C - 8,000 ft ³ /hr
101-2108	1	<u>Trash Conveyor</u> T - Belt
101-2109	1	<u>Primary Screen Delivery Conveyor</u> T - Belt S - 60" w x 400' ctrs. x 20' lift C - 70,000 ft ³ /hr M - CS D - 50 hp
101-2110	1	<u>Secondary Storage Stacker</u> T - Belt S - 60" w x 1,000' w/125' boom C - 70,000 ft ³ /hr M - CS D - 40 hp, 30 hp, 2-7 1/2 hp

101-2111	10	<u>Secondary Storage Reclaimers</u> T - Chain S - 8' x 60' crtrs. x 10' lift C - 17,000 ft ³ /hr M - CS D - 30 hp
101-2112	2	<u>Secondary Storage Reclaim Conveyor</u> T - Belt S - 42" w x 2,000' C - 17,000 ft ³ /hr M - CS D - 75 hp
101-2113	1	<u>Fines Conveyor</u> T - Belt
101-2301	6	<u>Truck Dump Hoppers</u> T - Open w/grate bottom S - 14' x 14' plan M - CS
101-3901	4	<u>Bulldozer</u> T - Caterpillar D8G

Wood Drying - Area 102

102-1601	6	<u>Wood Dryers</u> T - Rotary Drum S - 16' ϕ x 30' C - 800 ton/day of wood from 50% to 10% H ₂ O M - CS
102-1801	1	<u>Dried Chip Feeder</u> T - Rotary table S - 17' ϕ C - 23,000 ft ³ /hr M - CS D - 30 hp
102-2101	2	<u>Dryer Distribution Conveyors</u> T - Chain S - 48" w x 150' C - 18,000 ft ³ /hr M - CS D - 50 hp
102-2102	2	<u>Dried Wood Collecting Conveyors</u> T - Belt S - 42" w x 100' C - 17,000 ft ³ /hr M - CS D - 15 hp

102-2103	1	<u>Dried Wood to Storage Conveyor</u> T - Belt S - 60" x 100' C - 1,200 ton/hr of chips D - 30 hp
102-2104	1	<u>Storage to Gasifier Conveyor</u> T - Belt S - 42" w x 1,000' x 125' lift C - 23,000 ft ³ /hr M - CS D - 100 hp
102-2105	1	<u>Gasifier Distribution Diverter</u> T - Three-way, pneumatically operated
102-2106	1	<u>Gasifier Distribution Conveyors</u> T - Belt S - 42" w x 80' C - 23,000 ft ³ /hr M - CS D - 15 hp

Gasification - Area 103

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-1301	3	<u>Combustion Air Blower</u> T - Centrifugal C - 46,500 scfm @ 60°F & 20" W.G. P M - CS D - 325 hp electric motor
103-1401	3	<u>Char/Catalyst Screen</u> T - Vibrating screen C - 5 t/hr M - CS - 100 mesh screen
103-1402	3	<u>Magnetic Separator</u> T - Induced magnetic roll separator C - 5 t/hr of char/catalyst S - 30" wide roll
103-1501	3	<u>Gasifier Heater</u> T - Forced draft combustion chamber C - 70 MM Btu/hr heat release w/wood combustion
103-1601	3	<u>HP Steam Superheater</u> T - Shell and tube - shell refractory lined C - 4.50 MM Btu/hr S - 130 ft ² M - Shell and tubes - CS Des P/T - Shell - 160 psig/1520°F Tubes - 660 psig/825°F
103-1602	3	<u>CO Shift Feed Preheater</u> T - Shell and tube - shell refractory lined C - 6.78 MM Btu/hr S - 190 ft ² M - Shell and tubes - C.S. Des P/T - Shell - 160 psig/1520°F Tubes - 160 psig/400°F
103-1603	3	<u>Gasifier Waste Heat Boiler</u> T - Water tube - shell refractory lined C - 18.70 MM Btu/hr S - 1520 ft ² M - Shell and tubes - CS Des P/T - Shell - 160 psig/1520°F Tubes - 660 psig/540°F

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-1604	3	<u>Gasifier BFW Heater</u> T - Water tube - shell refractory lined C - 7.37 MM Btu/hr S - 215 ft ² M - Shell and tubes - CS Des P/T - Shell - 160 psig/1520°F Tubes - 675 psig/540°F
103-1605	3	<u>HP Steam Preheater</u> T - Shell and tube C - 49.45 MM Btu/hr S - 1,330 ft ² M - Shell - CS; Tubes - 310 SS Des P/T - Shell - 15 psig/1760°F Tubes - 675 psig/1600°F
103-1606	3	<u>Combustion Air Preheater</u> T - Shell and tube C - 36.40 MM Btu/hr S - 1155 ft ² M - Shell and tubes - CS Des P/T - Shell - 15 psig/770°F Tubes - 15 psig/880°F
103-1701	3	<u>Cyclone</u> T - Centrifugal C - 4500 acfm @ 150 psia, 350°F S - 4' Ø M - CS Des P/T - 160 psig/650°F
103-1702	3	<u>Raw Gas Bag Filter</u> T - Bag filter C - 4500 acfm @ 150 psia/350°F M - CS - glass bags Des P/T - 160 psig/400°F
103-1703	3	<u>Ventilation Bag Filter</u> T - Bag filter C - 1500 acfm M - CS - glass bags Des P/T - atmospheric/400°F
103-1704	3	<u>Combustion Gas Bag Filter</u> T - Bag filter C - 85,000 acfm @ 150°F and 15 psig M - CS - glass bags Des P/T - 40 psig/200°F

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-2101	9	<u>Double Screw Feeder</u> T - Screw conveyor C - 11,100 ft ³ /hr S - 18" Ø x 20' M - CS D - 5 hp
103-2102	9	<u>Gasifier Feed Screw</u> T - Screw conveyor C - 2,200 ft ³ /hr S - 14" Ø x 14' M - Heat resistant alloy D - 5 hp variable Des P/T - 175 psi/1500°F
103-2103	3	<u>Waste Heat Boiler Discharge Feeder</u> T - Rotary C - 2.5 t/hr M - C.S. D - 3 hp electric motor, direct
103-2104	3	<u>Cyclone Discharge Feeder</u> T - Rotary C - 2.5 t/hr M - CS D - 3 hp electric motor, direct
103-2105	3	<u>Bag Filter Discharge Feeder</u> T - Rotary C - 2.5 t/hr M - CS D - 3 hp electric motor direct
103-2106	3	<u>Screw Conveyor to Heater Feed Bin</u> T - Screw C - 4.5 t/hr M - CS D - 5 hp electric motor, direct
103-2107	3	<u>Screw Feeder to Heater</u> T - Screw C - 4.5 t/hr M - CS D - 5 hp electric motor, direct
103-2108	3	<u>Char Overflow Feeder</u> T - Rotary C - 2.5 t/hr M - CS D - 3 hp electric motor, direct

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-2109	3	<u>Combustion Gas Bag Filter Discharge Feeder</u> T - Rotary C - 100 lb/hr M - CS D - 1 hp
103-2110	3	<u>Ventilation Bag Filter Discharge Feeder</u> T - Rotary C - 1,000 lb/hr M - CS D - 1 hp
103-2201	3	<u>Gasifier</u> T - Fluid bed, vertical, refractory lined S - 15' ID (17' OD) x 50' T/T M - CS Des P/T - 160 psig/1500°F
103-2202	1	<u>Steam Drum</u> T - Horizontal C - 77,000 lb/hr S - 5' Ø x 10' T/T M - CS Des P/T - 660 psig/825°F
103-2203	1	<u>Blowdown Flash Drum</u> T - Vertical S - 2'-6" Ø x 5' T/T M - CS Des P/T - 75 psig/350°F
103-2301	3	<u>Wood Surge Bins</u> T - Cylindrical w/conical bottom C - 6000 ft ³ S - 20' Ø x 17' - Cone 14' Ø x 11' M - CS Des P/T - atmospheric/125°F
103-2302	3	<u>Heater Feed Bin</u> T - Rectangular w/screw conveying line bottom S - 5' x 10' x 15' T/T M - CS Des P/T - atmospheric/125°F
103-2303	3	<u>Char Surge Hopper</u> T - Cylindrical bin w/60° conical bottom S - 5' Ø x 8'-6" T/T M - CS Des P/T - atmospheric/1400°F

<u>Item No.</u>	<u>Number Required</u>	<u>Description</u>
103-2305	3	<u>Catalyst Hopper</u> T - Cylindrical bin w/60° conical bottom S - 2' Ø x 3'-6" T/T M - CS Des P/T - 15 psig/400°F
103-2501	9	<u>Wood Feed Lock Hopper</u> T - Double chamber lock hopper assembly to include: - upper lock hopper - lower lock hopper - surge hopper - gas valves (2/system) - rotary feeder C - 2000 ft ³ /hr from atmosphere to 150 psia
103-2502	3	<u>Char/Catalyst Lock Hopper</u> T - Double chamber lock hopper assembly C - 1000 ft ³ /hr of char and catalyst from 150 psia to atmosphere
103-2503	3	<u>Catalyst Feed Lock Hopper</u> T - Double chamber lock hopper assembly C - 10 ft ³ /hr of catalyst from atmosphere to 150 psia

IX CAPITAL COST ESTIMATE AND SCALING FACTORS DISCUSSION

This section includes the Capital Cost Estimate for the Wood-to-Methanol plant. Total plant costs are indicated as well as costs by plant area. The capital cost is \$120,830,000--September 1980 basis--for the plant to process 2,000 tons per day of dry wood. The detailed estimate summary is included on the following pages.

A study was made of the plant areas to obtain capital cost scaling factors down to 300 tons per day of wood. An exponential factor of 0.6 is normally used for chemical processing plants. That is, if the cost of a given plant is known at one capacity and the cost is desired at some capacity X times as great, the known cost multiplied by $X^{0.6}$ will provide the cost of the second plant capacity. However, it appears that a factor of 0.9 would be more appropriate for the areas of wood storage and drying. These areas represent 29.9% of the plant cost at a processing rate of 2,000 tons per day of dry wood.

Using the 0.9 factor for wood storage and drying and 0.6 for the remainder of the plant, a plant to process 1,000 tons per day would cost \$75,240,000; for 500 tons per day, \$47,240,000; for 300 tons per day, \$33,680,000. The overall plant factor is about 0.68. Of course, this method of obtaining costs cannot replace a detailed estimate for accuracy and must be considered a broad approximation. Even so, this method is of use provided its limitations are kept in mind.

EXECUTIVE SUMMARY

WOOD TO METHANOL

	<u>COST</u>	<u>% OF T.I.C.</u>
Equipment	\$ 35,390M	26.7
Direct Purchase Material	10,840	8.2
Subcontract: Material	650	0.5
Labor (403 M-MHRS)	11,600	8.8
Direct Hire Labor (665 M-MHRS)	<u>8,530</u>	<u>6.5</u>
S/T Direct Costs	\$ 67,010M	50.7
Field Indirects	14,150	10.7
Pro-Services	15,920	12.0
Other	1,750	1.3
METHANOL PLANT (By Lakeland-T.I.C.)	<u>22,000</u>	<u>16.7</u>
9/12/80 T.I.C.	\$120,830M	91.4
ESCALATION	<u>11,370</u>	<u>8.6</u>
Escalated T.I.C.	\$132,200M	100.0

EXCLUSIONS:

- . Property
- . Start-up Costs
- . Plant Roadways
- . Demolition of Underground Obstructions
- . Premium Time
- . Operating and Maintenance Costs
- . Contingency

CLIENT: Battelle Pacific Northwest Laboratories

LOCATION: Newport, Oregon

PROJECT: 2,000 TPD of Wood to Methanol

TYPE OF ESTIMATE: Class VI ($\pm 25\%$) Total Installed Cost Estimate

DOCUMENTS: The following documents prepared for this project were used to prepare the estimate:

- . Revision 0 of the Project Description of feasibility Studies for: Wood to Methanol and Wood to Methane dated June 1980
- . Four line equipment list developed by Process Engineering
- . Davy McKee interoffice communication - Estimate of the Methanol Plant from A. J. Frost of the Lakeland Office to T. Kendron of the Cleveland Office, dated September 2, 1980
- . Preliminary drawing of the Wood Gasifier (Tag #103-2201)
- . Preliminary layout drawing of the Wood Sizing, Storage, and Drying areas

SCOPE OF WORK: Davy McKee is to determine the economic feasibility of producing methanol by catalytic gasification of wood. The Estimating Department is to evaluate the cost of Engineering, Procurement, and Construction for the plant based on the following areas:

- 101 - Wood Storage and Sizing
- 102 - Wood Drying
- 103 - Gasification
- 104 - Shift Conversion
- 105 - Acid Gas Removal
- 106 - Compression
- 107 - Methanol Synthesis and Distillation
- 108 - Purge Gas Reforming
- 109 - Waste Water Treating
- 110 - Raw Water Treating and Cooling Water
- 111 - Boilers and Boiler Feedwater System
- 112 - Miscellaneous Utility System
- 113 - Storage and Loading - Product and Utilities

NC-5471
9/12/80

SCHEDULE:

The following schedule was assumed based on historical information:

Engineering:	Start	10/01/80
	Completion	4/01/82
	Duration	18 Months
Procurement:	Start	4/01/81
	Completion	10/01/82
	Duration	18 Months
Construction:	Start	4/01/81
	Completion	4/01/83
	Duration	24 Months
TOTAL PROJECT DURATION		30 Months

ESTIMATE APPROACH:

The following paragraphs outline the techniques used for the entire project exclusive of the Methanol Plant (Area 107) which was estimated by Davy Powergas Inc., Lakeland at a Total Installed Cost of \$22,000M which equates to 16.7% of the TIC.

MAJOR EQUIPMENT (\$12,298M Direct, 9.3% of TIC)
(\$23,095M S/C Equip. Mat'l Portion
17.4% of TIC)

Each equipment item defined on the four line equipment list developed by Davy McKee's Process Department was priced in one of four ways:

- . Single Source budget quotations solicited specifically for this project.
- . Vendor quotations for similar equipment (similarity determined by 4-line equipment list) on recent estimates.
- . In-house historical cost information correlating cost to equipment characteristics (e.g., pricing exchangers on a dollar per square foot of exchanging area basis).
- . Factoring to other recent estimates using the six-tenths method.

NC-5471
9/12/80

ESTIMATE APPROACH:
(continued)

MAJOR EQUIPMENT (continued)

An allowance for freight, where applicable, was made and is included in the equipment price. The following is a breakdown of equipment pricing:

	\$-M	%
Vendor Budget Quotes	\$19,669M	55.6%
In-house Pricing	8,821	24.9
Factored	6,903	19.5
	<u>\$35,393M</u>	<u>100.0%</u>

DIRECT PURCHASE MATERIALS (\$10,841M, 8.2% of TIC)

All materials including Piping, Civil, Structural Steel, Electrical, Instrumentation, Insulation, Painting, Fireproofing, and Miscellaneous except those in Areas 101, 102, 105, and 107 were factored to equipment. The material to equipment factors used were developed by area based on recent gasification plant estimates. Materials except Civil for Areas 101 and 102 were included with the vendor quote. The Civil work was estimated utilizing preliminary site layouts for these areas. Areas 105 and 107 were quoted on a Total Installed Cost basis therefore included all materials.

The material purchase strategy (i.e., direct purchase vs. subcontractor purchase) was formulated in accordance with recent gasification estimates. The items that were assumed to be direct purchase are as follows:

- . Piping
- . Civil
- . Structural Steel
- . Major Electrical Equipment
- . Instruments

SUBCONTRACTS (Material \$648M, 0.5% of TIC)
(Labor \$11,595M, 8.8% of TIC)
(Excludes S/C Equip. Mat'l. Portion)

The following material costs, established as described above, were assumed to be subcontractor purchases:

- . Electrical Bulk Materials
- . Insulation
- . Painting
- . Fireproofing

NC-5471
9/12/80

ESTIMATE APPROACH:
(continued)

SUBCONTRACTS (continued)

Subcontract labor man-hours for materials were factored to S/C material dollars on a man-hour per material dollar basis. These man-hours were then priced using an "all-in" subcontract labor rate. This rate which includes craft wages and fringe benefits, and the subcontractor's indirect costs, overhead and profit was established using Davy McKee in-house information. The mark-up for indirects, overhead and profit was calculated to be 110% of wages, resulting in a total S/C rate of \$26.96/MHR.

Subcontract labor costs for equipment installation were separated from a total fabrication and erection cost using historical material/labor splits. Subcontract man-hours for equipment installation were calculated by dividing the labor dollars by the "all-in" labor rate.

DIRECT HIRE LABOR (\$8,530M, 6.5% of TIC)

Equipment erection and installation direct hire man-hours were developed using Davy McKee base 1.0 man-hours.

Direct hire man-hours for material installation were factored from material dollars on a man-hour per material dollar basis. These factors were developed for each plant area based on recent gasification estimates.

Miscellaneous direct hire labor man-hours were included for the following items at 7% of all other direct hire labor man-hours:

- . Clean-up
- . Show-up
- . Subcontractor Assistance
- . Scaffolding (other than piping)
- . Equipment Protection
- . Welder Qualification (other than piping)

The direct hire man-hours were priced using one composite wage rate for Eugene, Oregon. This rate of \$12.84/MHR was calculated using in-house craft mix and wage rate data.

NC-5471
9/12/80

ESTIMATE APPROACH:
(continued)

FIELD INDIRECTS (\$14,150M, 10.7% of TIC)

The field indirects estimate includes construction supervision, field office labor, auxiliary labor, temporary construction, construction equipment, small tools, consumables, field office costs, and direct and indirect labor payroll burdens. Costs for these items except payroll burdens were developed on a percent to direct hire direct labor wages basis using historical data on completed projects.

Payroll burdens were calculated using in-house data on craft labor fringe benefits and existing governmental rates for payroll taxes and insurance.

PROFESSIONAL SERVICES (\$15,920M, 12.0% of TIC)

Professional Services include Engineering, Clerical, Engineering Services, Estimating, Cost Engineering, Schedule Control, Procurement, Home Office Construction, and Accounting. Home Office salaries were determined by factoring to total direct costs based on a recent similar sized project. Out-of-pocket costs (reproductions, computer utilization, telephone, etc.) were factored using a percentage of Home Office Salaries based on the same recent project. Fringe Benefits and Overhead were established at 118.9% of H.O. Salaries and Professional Services Fee was established at 7.5% of Professional Services. These terms are in accordance with government guidelines.

TERMS

Salaries	9% x Direct Cost
Fringe Benefits	} 118.9% x Salaries
Overhead	
Fee: Pro-Services	7.5% x Pro-Service Cost
Construction	2.0% x TIC (Cleveland Scope)

INSURANCE (\$1,600M, 1.2% of TIC)

Insurance coverages include general liability, automobile liability, installation all risk, and bare rental coverage. The cost of insurance was established at 1.5% of the Total Installed Cost (Cleveland Scope) based on recent gasification estimates.

TAXES

There are no applicable sales or use taxes in Oregon.

NC-5471
9/12/80

ESTIMATE APPROACH:
(continued)

ROYALTIES AND COMMISSIONS

A one-time, paid-up license fee of \$150M for the Benfield process is included. This fee was quoted by Benfield and is the only royalty or commission required.

ESCALATION (\$11,374M, 8.6% of TIC)

All escalation was developed using Davy McKee's Projected Escalation Technique (MPET). MPET's projected monthly escalation was utilized in conjunction with the assumed project schedule to develop escalation for commodities, labor, field indirects, and professional services. The following table summarizes the results of the analysis:

	BASE COST (\$-M)	PROJECTED ESC. (%)	TOTAL ESC. (\$-M)
Equipment	12,298	11.0	1,353
Direct Material	10,841	11.3	1,225
Subcontract (E,M, & L)	35,338	10.5	3,710
D/H Labor	8,530	9.3	793
S/T Directs	67,007	10.6	7,081
Field Indirects	12,107	10.1	1,223
Professional Services	15,260	5.7	870
TOTAL (excl. AREA 107- Methanol Plant)	94,374	9.7	9,174
AREA 107-Methanol Plant	22,000	10.0	2,200
TOTAL PROJECT	116,374	9.8	11,374

ESTIMATE ACCURACY:

Davy McKee Accuracy Calculation (MAC) program has been employed to analyze major estimate line item costs for potential cost variance. The calculations represent an analysis of thoroughness of technique used to establish quantities and reliability of the unit prices used in the estimate.

The analysis resulting from MAC indicates a Total Plant Accuracy of 23.8% (rounded = $\pm 25\%$). The MAC stated accuracy is determined by calculating the potential variance for each line item and summarizing as though all variances will occur as the highest possible over-run; therefore, giving the highest possible variance.

EXCLUSIONS:

- . Property
- . Start-up Costs
- . Plant Roadways
- . Demolition of Underground Obstructions
- . Premium Time
- . Operating and Maintenance Costs
- . Contingency

PROJECT SUMMARY SHEET

M-292

REV. 5/79

ESTIMATE NO. NC-5171

SCHEDULE: AWARD DATE 10/1/80
 MECH. COMPL: 4/1/83 30 MO.
 CONSTR. START: 4/1/81 24 MO.

CLIENT: BATELLE PACIFIC NORTHWEST LABORATORIES
 PLANT: 2000 TPD WOOD TO METHANOL
 LOCATION: NEWPORT, ORE. DATE: 9/12/80

ITEM	PROJECT SUMMARY SHEET (ALL AMOUNTS IN 1000'S)				MH DATA	CLEV	1KLD	TOTAL
1	EQUIPMENT					112298		
2	MATERIAL					10841		
3	SUBCONTRACT:	MAT'L 23743	LABOR 11595		403	35338	22000	
4	LABOR				665	8530		
5	PREMIUM TIME	S/C	D.L.					
6	ESCALATION:	EQUIP. 1353	MAT'L 1225	S/C 3710		7081	2200	
7	SUB TOTAL DIRECT COST				1068	74088	24200	98288
8	CONSTR. SUPERVISION:	W: 1305	O.C.	374	87	1629		
9	FIELD OFFICE LABOR				61	461		
10	AUXILIARY LABOR				56	725		
11	TEMPORARY CONSTRUCTION:	MAT'L	S/C	LABOR		1083		
12	CONSTRUCTION EQUIPMENT:	EQUIP.		LABOR		1766		
13	SMALL TOOLS	CONSUMABLES				793		
14	FIELD OFFICE COST					213		
15	PAYROLL BURDEN					5437		
16	ESCALATION					1223		
17	SUB TOTAL FIELD INDIRECT COST				204	13330	INCLUDED	13330
18	ESCALATION @ 5.7% x P.S.	W: 600	O.C. 7	1680		870		
19	ENGINEERING				550	7680		
20	PROCUREMENT	W: 930 x DC	O.C. 28% x SAL.					
21	H.O. CONSTRUCT. SUPPORT	W: 6100	O.C.					
22	COMPANY FRINGES ON P.S. COST @ 118.9% OF \$ 6100			INCL O/H		7130		
23	SUB TOTAL PROFESSIONAL SERVICES				550	15680	INCLUDED	15680
24	SUB TOTAL ESTIMATED COST	ITEMS 7, 17 & 22				103098		
25	CONTINGENCY: D.C.	F.I.C.	P.S.	O.C.				
26	ROYALTIES & COMMISSIONS					150		
27	TAXES							
28	INSURANCE @ 1.5% x TPC					1600		
29	SUB TOTAL OTHER COST					1750	INCLUDED	1750
30	OVERHEAD: % OF P.S.		% OF CONSTR. SUPERV.			INCLUDED		
31	FEE: PROFESSIONAL SERVICES @ 7.5% x P.S.					1110		1110
32	FEE: CONSTRUCTION @ 2.0% x TIC (CLEV. SCORE)					2042		2042
33	TOTAL PROJECT COST	CLASS VI (± 25%)				108000	24200	132200

APPROVED:

P. Smith

DIRECT COST SUMMARY SHEET

Davy McKee

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN 1000'S

PROJECT		PLANT AREA		PROJECT NO.		DATE									
2000 TPD WOOD TO METHANOL		ALL AREAS EXCLUDING AREA 107		NC-5471		9-12-80									
LOCATION		OWNER		BY											
NEWPORT, ORE		BATELLE PACIFIC NORTHWEST LABORATORIES		CJH											
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR			GRAND TOTAL \$	ITEM TO CAT	PERCENTAGES	ITEM TO TOTAL	
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	TOTAL \$	GRAND TOTAL	MAN HRS.					RATE
	EQUIPMENT			12298	23095	381.9	10294	33389	59.6		764	46451			
	PIPING			4978					219.7		2822	7800			
	CIVIL			1949					269.9		3464	5113			
	STRUCTURAL STEEL			1989					29.5		378	2367			
	ELECTRICAL			176	358	17.1	461	819				995			
	INSTRUMENTS			1470					55.8		717	2187			
	INSULATION				160	12.9	346	506				506			
	PAINTING				96	11.9	320	416				416			
	FIREPROOFING				34	6.5	174	208				208			
	MISCELLANEOUS			279					320		385	664			
	TOTAL			23139	23743	403.3	11595	35338	664.5		8530	67007			

DIRECT COST SUMMARY SHEET

Davy McKee

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN 1000'S

PROJECT		PLANT AREA		TOTAL PLANT - DIRECT COST SUMMARY				PROJECT NO.		DATE				
2000 TED WOOD TO METHANOL		OWNER		BATTLE PACIFIC NORTHWEST LABORATORIES				BY C.J.H.		9-12-80				
LOCATION		NEWPORT, ORE.												
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR			PERCENTAGES			
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	TOTAL \$	GRAND TOTAL	MAN HRS.	RATE	TOTAL \$	ITEM TO CAT	ITEM TO TOTAL
101	WOOD STORAGE & SIZING			1239	9598	156.4		4216	13814	206.5		2651	17,704	
102	WOOD DRYING				4730	77.6		2091	6821				6,821	
103	GASIFICATION			12,010	132.2	56.0		1509	2831	231.2		2968	17,881	
104	SHIFT CONVERSION			651	15	1.3		34	49	11.7		150	850	
105	ACID GAS REMOVAL				2914	60.3		1625	4539				4539	
106	COMPRESSION			4459	58	3.8		102	160	61.8		793	5412	
107	METHANOL SYNTHESIS & DISTILLATION				BY DAVY POWERGAS - LAKELAND									
108	FURGE GAS REFORMING			766	25	2.2		59	84	8.6		109	959	
109	WASTE WATER TREATING			642	1255	17.6		475	1730	28.1		361	2733	
110	RAW WATER TREAT & COOLING WATER			1072	587	10.9		293	880	28.4		364	2316	
111	BOILERS & BFW SYSTEM			1154	2275	30.8		830	3105	44.3		569	4828	
112	MISC. UTILITY SYSTEMS			891	29	1.1		38	67	34.7		447	1405	
113	STOR. & LOAD - FIBERGLASS UTILITIES			175	935	12.0		323	1258	9.2		118	1551	
	TOTAL			23139	23743	430.3		11595	35338	664.5		8530	67007	

Davy McKee

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN, 1000'S

IX-13

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN, 1000'S

IX-14

DM 1359A Rev. 10/79

2000 THD WOOD TO METHUEN
LOCATION
NEWPORT, ORE.

10.3 - WOOD GASIFICATION & CLEAN-UP

OWNER
BATTTELLE PACIFIC NORTHWEST LABORATORIES

BY CJH

DATE 9-12-80

IX-15

DIRECT COST SUMMARY SHEET

Davy McKee

DM 1359A Rev. 10/79

PROJECT		PLANT AREA		OWNER		PROJECT NO.		DATE						
2000 TPD WOOD TO METHANOL		104 - SHIFT CONVERSION		BATTELLE PACIFIC NORTHWEST LABORATORIES		NC-5471		11-12-80						
LOCATION		NEWPORT, ORE.				BY CJH								
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR			PERCENTAGES			
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	TOTAL \$	MAN HRS.	RATE	TOTAL \$	ITEM TO CAT	ITEM TO TOTAL	
	EQUIPMENT			410					0.7	12.84	9	419		
	PIPING			165					7.3		94	259		
	CIVIL			14					1.2		15	29		
	STRUCTURAL STEEL			15					0.4		5	20		
	ELECTRICAL			3		5	0.2	26.96				13		
	INSTRUMENTS			38					1.3		17	55		
	INSULATION					7	0.6					23		
	PAINTING					2	0.3					10		
	FIREPROOFING					1	0.2					6		
	MISCELLANEOUS @ (1%M + 7%L)			6					9.8		10	16		
	TOTAL			651	15	1.3			11.7		150	850		

DM 1359A Rev. 10/79

LOCATION
NEW PORT, ORE.

OWNER

BATTELLE PACIFIC NORTHWEST LABORATORIES

BY

NC-5471

BY CJH

DATE _____

9-12-80

ALL MANHOURS & DOLLARS IN, 1000'S

IX-17

DIRECT COST SUMMARY SHEET
Davy McKee
 DM 1359A Rev. 10/79

PROJECT		PLANT AREA		PROJECT NO.		DATE								
2000 TPD WOOD TO METHANOL		106 - COMPRESSION		NC-5471		9-12-80								
LOCATION		OWNER		BY										
NEWPORT, ORE.		BATTELLE PACIFIC NORTHWEST LABORATORIES		CJH										
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR			PERCENTAGES			
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	LABOR TOTAL \$	GRAND TOTAL \$	MAN HRS.	RATE	TOTAL \$	ITEM TO CAT	ITEM TO TOTAL
	EQUIPMENT			3102					11.9	12.84	153	3255		
	PIPING			838					27.7		356	1194		
	CIVIL			90					8.6		110	200		
	STRUCTURAL STEEL			62					1.1		14	76		
	ELECTRICAL			7		33	1.6	26.96	43	76		83		
	INSTRUMENTS			316							109	425		
	INSULATION					19	1.5		40	59		59		
	PAINTING					6	0.7		19	25		25		
	FIREPROOFING			-		-				-		-		
	MISCELLANEOUS @ (1% M + 7% L)			44							51	95		
	TOTAL			4459		58	3.8		102	160	793	5412		

DIRECT COST SUMMARY SHEET

Davy McKee

DM 1359A Rev. 10/79

PROJECT LOCATION		PLANT AREA		OWNER										PROJECT NO.		DATE	
2000 TPD WOOD TO METHANOL		108 - PURGE GAS REFORMING		BATTELLE PACIFIC NORTHWEST LABORATORIES										NC-5471		9-12-80	
NEWPORT, ORE.		MILESTONE		DIRECT P/O		SUBCONTRACT				DIRECT HIRE LABOR		PERCENTAGES					
CODE NO.	DESCRIPTION	QTY	UNIT	MATERIAL \$	MAN HRS.	RATE	TOTAL \$	GRAND TOTAL	MAN HRS.	RATE	TOTAL \$	GRAND TOTAL \$	ITEM TO CAT	ITEM TO TOTAL			
	EQUIPMENT			577					2.1	12.84	26	603					
	PIPING			63					2.8		36	99					
	CIVIL			16					1.8		23	39					
	STRUCTURAL STEEL			7					0.1		1	8					
	ELECTRICAL				12	0.6	26.96	16				28					
	INSTRUMENTS			33					1.2		15	48					
	INSULATION			1	0.1		3	4				4					
	PAINTING			12	1.5		40	52				52					
	FIREPROOFING			-				-				-					
	MISCELLANEOUS @ (1% M + 7% L)			70					0.6		8	78					
	TOTAL			766	25	2.2	59	84	8.6		109	959					

DIRECT COST SUMMARY SHEET

Davy McKee

DM 1359A Rev. 10/79

PROJECT
2000 THD WOOD TO METHANOL
LOCATION
NEWPORT, ORE.

PLANT AREA

109 - WASTE WATER TREATING

OWNER
BATELLE PACIFIC NORTHWEST LABORATORIES

PROJECT NO.

NC-5471

BY

CJH

DATE

9-12-80

CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT				DIRECT HIRE LABOR			GRAND TOTAL \$	PERCENTAGE
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	LABOR TOTAL \$	GRAND TOTAL	MAN HRS.	RATE		
	EQUIPMENT			130		1222	15.2	26.96	411		1633		
	PIPING			338								1803	
	CIVIL			58								533	
	STRUCTURAL STEEL			35								122	
	ELECTRICAL			18		17	0.8	26.96	22		39	57	
	INSTRUMENTS			57								83	
	INSULATION					11	0.9		24		35	35	
	PAINTING					4	0.5		13		17	17	
	FIREPROOFING					1	0.2		5		6	6	
	MISCELLANEOUS @ (1% MT + 7% L)			6								29	
	TOTAL			647		1255	17.6		475		1730	2733	

DIRECT COST SUMMARY SHEET

Davy McKee

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT		PLANT AREA		PROJECT NO.		DATE									
2000 TPD WOOD TO METHANOL		110 - RAW WATER & COOLING WATER		NC-5471		9-12-80									
LOCATION		OWNER		BY											
NEWPORT, ORE.		BATELLE PACIFIC NORTHWEST LABORATORIES		CJH											
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR			PERCENTAGES				
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	TOTAL \$	MAN HRS.	RATE	TOTAL \$	ITEM TO CAT	ITEM TO TOTAL		
	EQUIPMENT			522	536	7.5	26.96	202	738	3.4	12.84	43	1303		
	PIPING			372						16.7		214	586		
	CIVIL			29						2.5		32	61		
	STRUCTURAL STEEL			34						0.9		12	46		
	ELECTRICAL			18	30	1.4	26.96	38	68				86		
	INSTRUMENTS			86						3.0		39	125		
	INSULATION				16	1.3		35	51				51		
	PAINTING				4	0.5		13	17				17		
	FIREPROOFING				1	0.2		5	6				6		
	MISCELLANEOUS @ (1% M + 7% L)			11						1.9		24	35		
	TOTAL			1072	587	10.9		293	880	28.4		364	2316		

DM 1359A Rev. 10/79

LOCATION
NEWPORT, ORE.

OWNER
BATTLE PACIFIC NORTHWEST LABORATORIES

DATE 11-12-80

ALL MANHOURS & DOLLARS IN 1000'S

[illegible]

DIRECT COST SUMMARY SHEET
Davy McKee

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT		PLANT AREA		PROJECT NO.		DATE									
2000 TPD WOOD TO METHANOL		112 - MISCELLANEOUS UTILITY SYSTEM		NC-5471		9-12-80									
LOCATION		OWNER		BY											
NEWPORT, ORE.		BATELLE PACIFIC NORTHWEST LABORATORIES		CJH											
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR			GRAND TOTAL \$	PERCENTAGES			
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	LABOR	MAN HRS.	RATE		TOTAL \$	ITEM TO CAT	ITEM TO TOTAL	
	EQUIPMENT			321						1.6	12.84	21	342		
	PIPING			499						28.4		365	864		
	CIVIL			10						0.9		12	22		
	STRUCTURAL STEEL			18						0.3		4	22		
	ELECTRICAL						29	1.4	26.96	38			67		
	INSTRUMENTS			34								1.2	49		
	INSULATION						-						-		
	PAINTING						-						-		
	FIRE PROOFING						-						-		
	MISCELLANEOUS @ (1% M + 7% L)			9								2.3	39		
	TOTAL			891			29	1.4		38		34.7	1405		

DIRECT COST SUMMARY SHEET
Davy McKee

DM 1359A Rev. 10/79

ALL MANHOURS & DOLLARS IN 1000'S

PROJECT		PLANT AREA		PROJECT NO.		DATE									
2000 TPD WOOD TO METHANOL		113 - PRODUCT STORAGE & LOADING		NC-5471		9-12-80									
LOCATION		OWNER		BY											
NEWPORT, ORE.		BATTELLE PACIFIC NORTHWEST LABORATORIES		CJH											
CODE NO.	DESCRIPTION	MILESTONE		DIRECT P/O MATERIAL TOTAL \$	SUBCONTRACT			DIRECT HIRE LABOR		GRAND TOTAL \$	PERCENTAGES				
		QTY	UNIT		MATERIAL \$	MAN HRS.	RATE	TOTAL \$	MAN HRS.		RATE	TOTAL \$	ITEM TO CAT	ITEM TO TOTAL	
	EQUIPMENT			45		928	11.5	26.96	310	1238	0.5	12.84	6	1289	
	PIPING			44							2.0		26	70	
	CIVIL			66							5.7		73	139	
	STRUCTURAL STEEL			7							0.1		1	8	
	ELECTRICAL			2		3	0.2	26.96	5	8				10	
	INSTRUMENTS			9							0.3		4	13	
	INSULATION					3	0.2		5	8				8	
	PAINTING					1	0.1		3	4				4	
	FIREPROOFING									-				-	
	MISCELLANEOUS@ (1% M + 7% L)			2							0.6		8	10	
	TOTAL			175		935	12.0		323	1258	9.2		118	1551	

X OPERATING COST ESTIMATE

The production cost of fuel-grade methanol from wood has been calculated based upon the capital costs and operating costs as generated by this study. The methods of calculating these costs are those presented in "Coal Gasification Commercial Concepts Gas Cost Guidelines", a paper prepared for the United States Energy Research and Development Administration and the American Gas Association by C.F. Braun & Co. (NTIS 8463). There are two potential methods of financing a plant of this type, (1) utility financing, and (2) private investor financing. Production costs have been calculated using both procedures.

The total plant investment has been estimated to be \$120,830,000 September, 1980 basis. To obtain the total capital requirement for the plant, additional costs must be added to the estimated plant investment. These costs are an allowance for funds during construction, start-up costs, and working capital. These costs and the basis for their calculation is shown in Table II. The total capital requirement for this plant is \$145,535,000.

The annual direct operating costs have been calculated and are shown in Table III. These costs include raw materials, utilities, catalyst and chemicals, labor, administration and general overhead, supplies, and taxes and insurance. Maintenance costs are calculated as a percentage of capital investment, as suggested by the cited guidelines. The annual costs are \$36,464,000. The most significant costs are wood, gasifier catalyst, labor, and taxes and insurance. Labor costs would not be very easy to reduce significantly, while taxes will depend upon local conditions and incentives. The major variable costs are wood and catalyst usage in the gasifier. At \$20/Day ton for wood, which is the value used for the base case shown in Table III, wood costs are about a third of the total direct costs and a fourth of the total production costs.

Thus, either lowering the wood cost or improving yields from the wood have more impact on costs than any other single variable. The production costs have also been calculated for wood costs of \$5, \$10, and \$40 per dry ton, and the impact is illustrated in Figure 1. These prices for wood include delivery to the plant.

In Tables IV and V are given the methods for calculating production costs based upon utility financing and private investor financing, respectively. The calculations for the base case of a wood cost of \$20/dry ton are shown. For utility financing, the methanol production costs are \$.45, \$.48, \$.55, and \$.69 per gallon for wood prices of \$5, \$10, \$20, and \$40 per dry ton. For private investor financing, the methanol production costs are \$.59, \$.62, \$.69 and \$.83 per gallon for the corresponding wood costs.

TABLE II. TOTAL CAPITAL REQUIREMENT

Total Plant Investment	120,830 M
Allowance for Funds During Construction (Total Plant Investment x 1.25 years x 0.09)	13,588 M
Start-Up Costs (20% of Total Annual Gross Operating Costs)	7,293 M
Working Capital (Sum of (1) Raw Material inventory of 14 days at full rate, (2) materials and supplies at 0.9% of total plant investment, and (3) net receivables at 1/24 annual gas and by-products revenue at calculated sales price)	<div>560 M (1)</div> <div>1,087 M (2)</div> <div>2,223 M (3)</div> <hr/>
Total Capital Requirement	145,571 M

TABLE III. ANNUAL DIRECT OPERATING COSTS

<u>COST COMPONENT</u>	<u>ANNUAL USE</u>	<u>\$/UNIT</u>	<u>\$1000/YR.</u>
<u>RAW MATERIAL</u>			
Wood	660,000 Dry Ton	20/Dry Ton	13,200
<u>UTILITIES</u>			
Water	526,522 M Gal.	0.50/M Gal.	263
Electricity	1.76×10^8 kwh	.03/kwh	5,280
Diesel Fuel	108,900 Gal.	1.00/Gal.	109
<u>CATALYSTS AND CHEMICALS</u>			
Gasifier Catalyst	330,660 lb.	8.51/lb.	2,814
Shift Catalyst	150 ft. ³	107/ft. ³	16
Chloride Guard Catalyst	3,300 ft. ³	151/ft. ³	50
Sulfur Guard Catalyst	2,500 ft. ³	75/ft. ³	188
Methanol Catalyst	Confidential	--	360
Reformer Catalyst	140 ft. ³	235/ft. ³	33
<u>LABOR</u>			
Process Operating	55 Men @2080 hr/ea.	10.70/hr.	1224
Maintenance	@ 60% of total maintenance		3160
Supervision	@ 20% of process operating and maintenance labor		877

ADMINISTRATIVE AND GENERAL OVERHEAD

@ 60% of Total Labor	3156
----------------------	------

SUPPLIES

Operating @ 30% of Process Operating Labor	367
--	-----

Maintenance @ 40% of Total Maintenance Cost	2106
---	------

TAXES AND INSURANCE

@ 2.77% of Total Plant Investment	<u>3261</u>
-----------------------------------	-------------

Total Gross* Operating Costs Per Year	36,464
---------------------------------------	--------

* No credits were taken for any by-products so that Total Net Operating Costs are the same as the Total Gross.

TABLE IV. METHANOL COST - UTILITY FINANCING METHOD

BASIS:

20-years project life

5%/year straight line depreciation on Total Capital Requirement excluding Working Capital

48% federal income tax rate

75/25 debt/equity ratio

10% interest on debt.

15% return on equity

DEFINITION OF TERMS:

C = Total Capital Requirement, 10^6 \$

W = Working Capital, 10^6 \$

N = Total Net Operating Cost, 10^6 \$/Year

G = Annual Fuel Production, 10^6 Gallon/yr.

d = Fraction Debt.

i = Interest on debt, %/year

r = Return on rate base, %/year

p = Return on rate base, %/year

EQUATION FOR RETURN ON RATE BASE

$$p = (d)i + (1-d)r$$

TABLE IV. METHANOL COST - UTILITY FINANCING METHOD (Cont'd)

Average Methanol Cost, \$/Gallon =

$$\frac{N + .05 (C-W) + .005 \left[P + \frac{48}{52} (1-d)r \right] (C + W)}{G}$$

CALCULATION

$$P = (0.75) (10) + (1 - 0.75) (15) = 11.25$$

$$G = 98.81 \cdot 10^6 \text{ Gallon/Hr.}$$

$$C = 145.45 \cdot 10^6 \text{ $/yr.}$$

$$W = 3.79 \cdot 10^6 \text{ $/yr.}$$

$$N = 36.46 \cdot 10^6 \text{ $/yr.}$$

Average Methanol Cost

$$= \frac{36.46 + (.05)(141.66) + (.005)(14.70)(149.24)}{98.81}$$

$$= \text{\$.55/gal.}$$

TABLE V. METHANOL COST - EQUITY FINANCING METHOD

BASIS:

20-year project life

16-year sum-of-the-years'-digits depreciation on Total Plant Investment

100% equity capital

12% DCF return rate

48% federal income tax rate

DEFINITION OF TERMS

I = Total Plant Investment, 10^6 \$

S = Start-up Costs, 10^6 \$

W = Working Capital, 10^6 \$

N = Total Net Operating Cost, 10^6 \$/yr.

G = Annual Methanol Production, 10^6 gallon/year

METHANOL COST EQUATION AT 12% DCF RETURN

Methanol Cost, \$/ 10^6 Btu =

$$\frac{N + 0.247I + 0.1337S + 0.2805W}{G}$$

N = 36.46 10^6 \$/yr.

G = 98.81 10^6 gal/yr.

I = 120.78 10^6 \$/yr.

S = 7.29 10^6 \$/yr.

W = 3.87 10^6 \$/yr.

Average Methanol Cost

$$= \frac{36.46 + (.247) (120.78) + (.1337) (7.29) + (.2305)(3.87)}{98.81}$$

$$= \$.69/\text{Gallon}$$

FIG. 1 — EFFECT OF WOOD PRICES ON METHANOL COST

DISTRIBUTION

No. of
Copies

No. of
Copies

OFFSITE

ONSITE

A. A. Churm
DOE Patent Division
9800 South Cass Avenue
Argonne, IL 60439

DOE Richland Operations Office

H. E. Ransom
D. R. Segna

B. J. Berger
DOE
Biomass Energy Systems Division
600 E. St. N.W.
Washington, DC 20545

26 Pacific Northwest Laboratory

C. M. Devary
D. H. Mitchell
L. K. Mudge (10)
R. E. Nightingale
R. J. Robertus
G. F. Schiefelbein (2)
L. J. Sealock, Jr.
P. C. Walkup
S. L. Weber
Publishing Coordination (2)
Technical Information (5)

Simon Friedrich (2)
DOE
Biomass Energy Systems Division
600 E. St. N. W.
Washington, DC 20545

27 DOE Technical Information Center