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Appendix A: Feasibility Study of Methane 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
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INVESTIGATIONS ON CATALYZED STEAM GASIFICATION OF BIOMASS

APPENDIX A: FEASIBILITY STUDY OF METHANE PRODUCTION VIA CATALYTIC GASIFICATION OF 2000 TONS OF WOOD PER DAY

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WOOD TO METHANE STUDY

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I. EXECUTIVE SUMMARY

A study has been made of the economic feasibility of producing substitute natural gas (SNG) 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 SNG. Plant production is 21.6 MM scfd of SNG with a HHV of 956 Btu per scf. All process and support facilities necessary to convert wood to SNG are included in this study. The plant location is Newport, Oregon.

The capital cost for the plant is $95,115,000 - September, 1980 basis. Gas production costs which allow for return on capital have been calculated for various wood prices for both utility and private investor financing. For utility financing, the gas production costs are respectively $5.09, $5.56, $6.50, and $8.34 per MM Btu for wood costs of $5, $10, $20, and $40 per dry ton delivered to the plant at a moisture content of 49.50 wt%. For private investor financing, the corresponding product costs are $6.62, $7.11, $8.10, and $10.06 per MM Btu. The cost calculated by the utility financing method includes a return on equity of 15% and an interest rate of 10% on the debt. The private investor financing method, which is 100% equity financing, incorporates a discounted cash flow (DCF) return on equity of 12%.

The thermal efficiency without taking an energy credit for by-product char is 58.3%.

II. INTRODUCTION AND SUMMARY

A. Introduction

The purpose of this study is to determine the feasibility of producing substitute natural gas (SNG) by catalytic gasification of wood and forest residue with steam. The plant is designed to process 2,000 dry tons per day of feedstock. All necessary process and support facilities needed to convert chipped forest residue to SNG 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 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 SNG from wood as obtained in this study indicate that this is an economically feasible alternate when compared with future natural gas prices. 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. This price is for wood delivered to the plant with a moisture content of 49.5 wt%. For utility financing, the production costs are $5.09, $5.56, $6.50, and $8.34

per MM Btu 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 \$6.62, \$7.11, \$8.10, and \$10.06 per MM Btu. Both financial calculation methods included a return on equity--a rate of 15% for the utility method and a DCF rate of 12% for the private investor method. The capital cost of the plant is \$95,115,000 - September, 1980 basis.

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, as defined by the following equation, is 58.3%. When the heating value of the excess char is included in the output, the thermal efficiency is 62.6%.

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

The plant production is 6.81×10^{12} Btu per year. The yield of product gas is 10,790 scf per ton of dry wood feed.

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. Substitute Natural Gas

HHV	900 Btu/scf
CO	0.1 mol%
H_2S	0.25 gr/100 scf
Total S	10 gr/100 scf
Inerts	5%
CO_2	3%

Water 7 lb/million scf

Specific gravity - 0.59-0.62 (recommended)

Hydrocarbon dewpoint -40°C @ 100 psig

No poisonous compounds or gum formers.

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%)

	Residue	Alder	Fir	Weighted Average
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	8.68	0.98	1.18	5.64
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/ft^3 (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 - 550°C

2. Reactor Yields

a. Steam/wood (MAF), lb/lb - 0.33 (includes H_2O in wood)

b. Gas production = 1.09 lb/lb MAF wood

Component	Mol%
H_2O	38.0
H_2	11.2
CH_4	23.6
CO_2	19.5
CO	7.7
Total	100.0

c. Char production - 0.24 lb/lb MAF wood
Char heat of combustion - 13,500 Btu/lb

d. H_{rxn} = +224 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:

Size, Microns	Weight %
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 95%.

3. Catalyst Regeneration and Reduction

The catalyst is regenerated by passing steam at 600°C over the catalyst for 20 hours. The total steam requirement is 20 lb/lb of catalyst. The catalyst is reduced by product gas from the gasifier. The consumption of hydrogen to reduce the catalyst is 6.4×10^{-4} lb-mol/lb of catalyst.

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 - 50 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 750 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 for start-up only 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. <u>Wood Drying</u>

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 absorbtion 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 ±15% difference.

3. Methanation

The catalytic hydrogenation of carbon monoxide and carbon dioxide to methane is a common industrial process. Methanation catalysts are available from most catalyst vendors. However, most methanation applications have been a final stage of purification of synthesis gas to remove small amounts of carbon monoxide and carbon dioxide. The methanation of the products of gasification, with the large quantities of carbon oxides to hydrogenate and the attendant large heat release, requires some special considerations.

United Catalysts of Louisville were contacted to obtain their recommendations for a methanation system. They were selected based upon their research in the development of methanation catalysts to process the products of coal gasification.

4. 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.

5. Product Gas Drying

A liquid desiccant absorption system using ethylene glycol as the desiccant was selected over a solid desciccant. The use of a glycol system is standard industry practice whenever the glycol system will meet product specifications.

IV PROCESS AND OFFSITE DESCRIPTIONS

A. General

The process plant complex described in the following sections is capable of producing 21 million cubic feet per day (MMSCFD) of substitute natural gas from 2,000 tons per day of dry wood. The feedstock to the plant will consist primarily of forest residues of various species from logging operations within a 100 mile radius of Newport, Oregon. The wood is reacted with steam in the presence of a Ni catalyst in a fluid bed gasifier. The raw gas produced is methanated to produce a substitute natural gas. The following are the major process and offsite units of this plant. Further descriptions of each process step are presented in subsection C, "Detailed Unit Description."

Plant Areas

201 Wood Storage
202 Wood Drying
203 Gasification
204 Compression
205 Shift Conversion
206 Primary Methanation
207 Acid Gas Removal
208 Final Methanation and Product Gas Drying
209 Catalyst Regeneration
210 Wastewater Treating
211 Raw Water Treating and Cooling Water
212 Boilers and Boiler Feedwater System
213 Miscellaneous Utility Systems

B. Summary

Chipped forest residue which has been delivered to the plant by truck is stored in open piles. The chips are reclaimed automatically and dried to 10% moisture content in rotary drum dryers. From drying the chips are transferred to fluid bed gasifiers and partially gasified with steam in the presence of a Ni catalyst. In the reacting bed are tubes through which flow hot combustion gases which supply heat to the reactants. Products of gasification are a raw gas containing methane, carbon dioxide, hydrogen, carbon monoxide, and steam and a char residue. The char is used as fuel to supply heat to the gasifier, to dry the wood, and to generate steam in a boiler.

The gas is compressed and then shifted to adjust the ratio of hydrogen, carbon monoxide, and carbon dioxide. The gas is then reacted in the primary methanator to reduce substantially the concentration of hydrogen and carbon monoxide. The gas is cooled and a portion is recycled to the inlet of the methanator to be combined with gas from the shift area. The remainder of the gas goes to a Benfield system for carbon dioxide removal. After removal of the carbon dioxide, the gases flow to the final methanator in which the carbon monoxide content is reduced to less than 0.1%. The product gas is then compressed to 1015 psia, dried in an ethylene glycol system, and delivered to battery limits.

Cooling tower water is used for process cooling. Steam is generated from waste heat sources and by combustion of char. Excess char will be stored for shipment from the plant. Raw water is available at plant battery limits and requires clarification before use in the cooling tower and demineralization before use as boiler feedwater. All wastewater streams will be treated before discharge, the treatment to consist of neutralization followed by biological treatment.

C. Detailed Unit Descriptions

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

1. Wood Storage - Unit 201

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.

2. Wood Drying - Unit 202

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.

3. Gasification - Unit 203

This area contains wood gasification, associated gas clean-up, and char/catalyst separation.

Wood chips from drying are delivered to the wood surge bins of the gasifiers. Each gasifier is equipped with its bin. Wood is taken from the surge bins by screw conveyors and delivered to the lock hoppers of the gasifiers. Each gasifier is equipped with three feed lock-hoppers due to the relatively low bulk density of wood chips and the resulting high volumetric feed requirements. The lock hoppers feed the wood into the gasifier which is operating at a pressure of 150 psia. 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.

In the gasifier the wood chips are gasified with steam to produce a gas containing methane, carbon dioxide, hydrogen, carbon monoxide, and water. Gasification is not complete and there is a char residue by-product. The gasifier operates at conditions of 150 psia and 550°C. The steam-carbon reaction is highly endothermic, while the methanation reaction is exothermic. The net gasification reactions are endothermic, requiring a heat input to maintain the gasification. The heat is supplied by hot combustion gases (up to 1000°C) flowing through a bank of tubes immersed in the reaction bed. Char is the fuel for the gasifier heater. After leaving the gasifier, the combustion gases pass through a series of heat exchangers to recover heat. The gases are used to superheat steam to the gasifier operating temperature, to generate 600 psig steam, and to preheat the combustion air to the char burner.

The raw gas from the gasifier passes through a series of exchangers which recover heat by generating 600 psig steam superheated to 750°F. These exchangers are a series of coils in a refractory lined shell through which the raw gas flows. These exchangers are, in the order that the raw gas sees them, the steam superheater, the boiler, and the boiler feedwater preheater. The gas is cooled to 350°F in these exchangers. The gas contains particulate in the form of entrained char and catalyst. The gas is then cleaned by a cyclone followed by a bag filter containing a high temperature glass fabric. Under normal conditions the gas then flows to the compression area for further processing. During the reducing cycle of the catalyst regeneration system, a small portion (about 10%) of the gas flows to the catalyst regeneration for reduction and regeneration of the catalyst. The gas is returned and combined with the remainder of the raw gas before compression.

A mixture of char and catalyst from several sources is collected in a lock hopper system which reduces the pressure from 150 psia to atmospheric. These sources are the overflow from the gasifier bed, the particulate which settles from the gas stream in the waste heat exchangers, and the particulate collected in the cyclones and bag filters. The material discharged from the lock hoppers is conveyed to a screen for removal of fine material below 100 mesh. It is assumed that the fines contain very little catalyst material. The fines report directly to the char surge hopper while the larger size material drops into a high intensity, induced magnetic roll separator. Here the catalyst is recovered and drops into a surge hopper with the char dropping into the char surge hopper with the char fines. From the surge hopper the char is conveyed pneumatically to the storage bins for the gasifier heaters or to the char distribution system for the plant fuel needs. The catalyst is conveyed pneumatically with inert gas (carbon dioxide) to the storage bins of the catalyst regeneration system.

All streams containing catalyst will be enclosed and blanketed with carbon dioxide to prevent contact from air. Contact with air or some other oxidizing medium would destroy the catalyst. The carbon dioxide for blanketing will be available from the acid gas removal area where carbon dioxide is removed from the process gas stream.

4. Compression - Unit 204

The clean raw gas streams from the bag filters in the gasification area are combined and compressed to 350 psia in a single stage centrifugal compressor. The gas is cooled with cooling water to 120°F before entering the compressor to give an acceptable temperature on the discharge of the compressor. The discharge temperature is 330°F. The compressed gas flows to the shift section while water condensed from the gas in the cooling operation goes to the wastewater treatment area.

The drive for the compressor is a steam turbine using 600 psig steam superheated to 750°F and exhausted to condensing service.

5. Shift Conversion - Unit 205

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

$$CO + H_2O \qquad CO_2 + H_2$$

The raw gas from compression flows first to the saturator in the shift conversion area. Here the gas is heated and saturated with water vapor by contacting the gas with a hot recirculating water stream in the saturator vessel, a packed-bed column. The water is heated by the process gas stream or downstream side of the shift reactor. The temperature of the saturated water gas is controlled at a level, expected to be about 350°F, which will maintain the water vapor content at the optimum ratio for the shift reaction. Make-up water to the saturator consists of demineralized water and condensate recovered from the process gas in the heat exchange system downstream of the shift reactor. A blowdown water stream is sent to the wastewater treating area.

From the saturator the shift reactor feed gas is heated from 350°F to 700°F by exchange with the shifted gas from the high temperature shift reactor, which has a single bed of shift catalyst. For start-up, a start-up shift gas heater using natural gas is supplied. The gas leaving the shift reactor contains a carbon monoxide content of about 3.0% and has a temperature of about 810°F. The gas is then cooled in a series of exchangers.

The gas leaving the shift reactor is first cooled by preheating the shift feed gas. Additional heat is then recovered by heating the recirculating water, reheating the gas to the methanator, and preheating demineralized water to be used as boiler feedwater and saturator make-up water. The gas is then cooled with cooling water to 200°F to reduce the water vapor content of the gas to the methanator. The gas is then reheated to 275°F and flows to the primary methanation section. Condensate which results from the cooling of the gas is recycled to the saturator water loop.

6. Primary Methanation - Unit 206

In the methanation section hydrogen, carbon dioxide, and carbon monoxide are converted to methane according to the following reactions:

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$
$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

These sections are highly exothermic, and the equilibrium constants decrease rapidly with temperature. Therefore, the process design must take into account means to accommodate the high heat releases and prevent excessive temperatures in the reactor. Fortunately, in this plant the methane content of the gas leaving the gasifier is quite high (more than 35%), compared to the gas from coal gasification processes. This greatly reduces the amount of methanation required, and the methane and the carbon dioxide in the gas temper the heat rise.

Due to the high initial methane content, United Catalysts has recommended the following. The gas from the shift section is combined with a recycle stream from the methanator and heated to a feed temperature to the methanator of 550°F by the hot gases leaving the methanator. By recycling a portion of the gas and by methanating before carbon dioxide removal, the reactants are sufficiently diluted to give an acceptable maximum temperature of 830°F in the reactor, which is well below the normal maximum operating temperature of 900°F for these catalysts. The gases from the methanator are cooled, first to 575°F by preheating the feed gas to the methanator and then to 300°F by heating a portion of the saturator circulating water stream. A portion of the gas is recycled to the feeds of the methanator by means of a centrifugal blower while the remainder flows to the acid gas removal section.

7. Acid Gas Removal - Unit 207

The acid gas removal system selected is the Benfield system, which uses a recirculating aqueous solution of potassium carbonate to absorb carbon dioxide from the gas stream. The Benfield system was selected on the basis of a study of acid removal systems by Davy McKee engineers. The conclusion was that Benfield is generally the most economical system of acid gas removal at these partial pressures of carbon dioxide if selective absorption of carbon dioxide and sulfur containing acid gases is not required. The absence of sulfur in the wood eliminates the need for selective removal.

Gas from the primary methanation section is cooled by supplying heat to the reboiler of the regenerator of the CO_2-rich carbonate solution. The gas then flows to the absorber, a packed column containing two beds of steel slotted ring packing. Carbon dioxide is absorbed by a circulating aqueous solution of potassium carbonate to a concentration level of about 1.6% of the dry gas. The process gas then flows to the final methanation section for additional methanation.

The CO_2-rich solution flows frcm the absorber to the regenerator, a packed column which also contains two-inch steel slotted-ring packing. From the absorber to the regenerator the pressure is reduced from 340 psia to 18.7 psia across a power recovery turbine. This reduction in pressure facilitates the stripping of carbon dioxide from the rich solution. The heat required for stripping the carbon dioxide and regenerating the solution is supplied by cooling the feed gas to the system and by low pressure steam. The overhead stream from the regenerator contains the carbon dioxide which has been stripped from the rich solution. A portion of the overhead is condensed and refluxed to the regenerator column. The lean solution from the regenerator bottoms is returned to the absorber.

The carbon dioxide rich overhead stream from the regenerator is available for use as an inert gas for blanketing and conveying of the catalyst and utility uses in the gasifier area such as pressurizing lock hoppers and cleaning bags in the bag filter.

8. Final Methanation and Product Gas Drying - Unit 208

Gas from the acid gas removal section is given its final treatment and cleaning in this section. The first step is the final methanation which produces additional methane but primarily serves to reduce the carbon monoxide concentration to meet product specifications. The final methanator is a pressure vessel containing a single bed of methanation catalyst similar to the primary methanator. The feed gas is preheated to a temperature of 550°F by exchange with the final methanator discharge gas, which has a temperature of 710°F. The gas is cooled with cooling water before compression and cooling to 1015 psia and 100°F with a two-stage centrifugal compressor. This removes water to a low level, but a final drying step is needed to meet the product specification of less than 7 pounds per million scf.

The drying system used is an ethylene glycol system, the most commonly used system for gas dehydration. Glycol dehydration is generally the most economical means of drying natural gas, compared to drying by use of a solid desiccant or by refrigeration. The glycol system contains a glycol-gas contactor, a glycol regenerator, heat exchangers and a glycol circulation pump. In the contactor the product gas is contacted with a water-lean glycol solution which absorbs water. The glycol is regenerated by heating at atmospheric pressure to drive off the water.

The product gas which has been cleaned, compressed, and dried flows to the battery limits of the plant for tie-in to the natural gas pipeline system. The product has a high heating value of 956 Btu/scf.

9. Catalyst Regeneration - Unit 209

This area accepts the spent catalyst recovered from the char by magnetic separation in the gasifier area. In this area the catalyst is stored and regenerated in a batch system using high temperature steam and a reducing gas which is clean raw gas from the gasifier.

Spent catalyst enters the regeneration area from the catalyst surge hopper following the magnetic separator in the gasification area. The expected flow rate of catalyst is 950 lb/hr. The catalyst is pneumatically conveyed with carbon dioxide throughout the process to avoid any contact with oxygen. A storage bin which has a capacity of four days receives the catalyst. Discharge from the bin to one of the regenerators occurs every one and a half days. The regeneration is a batch process which requires three days. Each regenerator is sized to handle 50% of the process flow. The use of two regenerators on different time cycles allows the reduction of the maximum instantaneous requirement for steam and reducing gas without over complicating the system.

The regenerators are refractory lined cylindrical vessels with a bottom discharge with bottom inlets for all gases. Each regenerator operates on a three-day cycle for regeneration of the catalyst. Charging the regenerator takes one hour. The catalyst is then heated with inert gas to 370°F and then with steam to a temperature of 1110°F. Steam from the regenerator flows to the gasifiers for use as process feed. The catalyst is heated first with the inert gas to prevent steam from condensing when introduced. Regeneration takes twenty hours to complete with a maximum temperature rise of 50°F per hour. The catalyst is cooled to 850°F before reduction using inert gas for cooling. Reduction takes place for eighteen hours using clean raw gas from the gasifier as the reducing agent. The off-gas from regeneration is returned to the process and combined with the remainder of the gas from the gasifier before compression. The gas required for regeneration is about 10% of the total flow from the gasifiers.

Storage for the regenerated catalyst of four days is provided. From this storage the catalyst is conveyed pneumatically to the catalyst feed lock hopper systems in the gasifier.

10. Wastewater Treating - Unit 210

This area includes a biological treatment system for the plant water effluent and a boiler ash system to collect and store ash from burning the char in the boiler, the dryers, and the gasifier heaters.

The liquid waste streams from the plant are treated in a neutralizing basin followed by conventional biological treatment in a three-stage system of aerated lagoons with clarifiers. Clarified and treated effluent is discharged from the plant battery limits, while the underflow of biological sludge from the clarifiers is sent to lagoons for concentration. The waste streams to be treated include blowdown from the cooling towers, condensate from compression, blowdown from the saturator, condensate from the acid gas removal unit, blowdown from the boilers, and overflow from the boiler ash wash system.

A boiler ash wash system is supplied which includes a settling basin and circulation pumps. The pumps circulate water to collect ash at the boiler, the dryer, and the gasifier heaters. Excess water during periods of high rainfall overflows into the neutralizing basin for treatment.

11. Raw Water Treating and Cooling Water System - Unit 211

Raw water enters from battery limits to a settling basin where some of the larger solid particles settle out. The water is then pretreated with chemicals and fed to a clarifier at a rate of about 400 gpm. Here the solids content of the raw water is significantly reduced; solids are removed as clarifier underflow which goes to wastewater treating, while clarified water flows to the cooling tower basin and to the boiler feed water clearwell.

From the clearwell water is pumped through sand filters and through a demineralization package which produces water suitable for use in high pressure steam boilers and turbines. Demineralized water is stored in a lined tank, from which a low head pump supplies make-up boiler feed water to the deaerator and a high pressure pump furnishes demineralized water to process users. Potable water is obtained by taking a slip stream from the boiler feed water clear well pump, passing it through activated carbon beds, chlorinating it, and storing it in an atmospheric tank. From the tank it is pumped to distribution headers.

Two firewater pumps of 1250 gpm each take suction from the raw water settling basin. One pump is electric motor driven; the other, diesel engine driven. A diesel fuel storage tank with 24-hour capacity for the pump plus fifteen days capacity for the bulldozers of the wood preparation area is provided. Two jockey pumps, of 50 gpm each, also take suction from the settling basin and maintain a pressure of approximately 150 psig in the firewater header at all times. The firewater system serves as a source of plant utility water.

The entire plant cooling load is handled by cooling towers with a total recirculation capacity of 12,000 gpm, cooling this water from 100°F to 75°F. This represents a 14°F approach to the design wet-bulb temperature of 61°F at the site. Three vertical circulation pumps are provided. One of these electric pumps is for standby use. Approximately 350 gpm of clarified make-up water is fed to the cooling tower basin and a blowdown stream of about 140 gpm is sent to wastewater treating. An automated chemical injection package adds chemicals to control pH, scale, corrosion and algae. A non-chromate type of corrosion inhibitor is used in order to avoid the necessity for difficult and expensive treatment which would otherwise be required to recover chromate from the blowdown stream. A small slipstream from the discharge of the circulating pumps is filtered and returned to the cooling tower basin.

12. Boiler and Boiler Feedwater System - Unit 112

This area includes boiler feed water preparation, condensate handling, steam generation in a combination char/gas fired boiler, a gas fired superheater, and char storage and distribution facilities.

Boiler feed water consists of returned condensate plus demineralized make-up water, both of which are deaerated to eliminate oxygen. Condensate from process heat exchangers is collected in condensate drums and pumped to the deaerator; demineralized make-up water is preheated by exchange with shift reactor effluent gas before going to the deaerator. Chemicals are injected into the boiler feed water to control scale and corrosion. A high pressure pump supplies boiler feed water to the boiler and to the high pressure waste heat boiler of the gasifiers.

The fired boiler package generates 600 psig superheated steam and consists of an air preheater, economizer, boiler and firewater box, superheater, dust removal equipment, char feeders, induced draft and forced draft fans, ash removal system, stack, burners for simultaneously firing char and gaseous fuels, and a burner control system. Char is pneumatically conveyed from the char storage to a cone-bottom bunker. From the bunker it flows by gravity through the feeders and then is blown into the boiler burners. Ash is removed as a water slurry to the wastewater treating area.

The main plant fuel is the char residue from the gasifier. The char storage and distribution system provides for storage and distribution of char to in-plant users and to shipping for transport from the plant.

The char is collected from the char surge bins on the discharge of the char-catalyst separation system and conveyed pneumatically to either the storage for the gasifier heaters or to the primary storage. The gasifier heater storage bins have a capacity of sixteen hours, which should be sufficient capacity for start-up. The primary storage is sized to handle a capacity of five days of excess char to shipping and two days requirement for the dryers and the boiler. The char is conveyed pneumatically to storage bins of all users.

13. Miscellaneous Utilities - Unit 213

Instrument Air System

An instrument air package of 800 scfm capacity is provided. The package consists of two compressors of 800 scfm capacity each discharging at 125 psig and each with inter-coolers, after-coolers, and a surge/separator drum. A common electrically regenerated dryer with prefilter and afterfilter feeds two air receivers.

Carbon Dioxide System

The carbon dioxide compression and drying system supplies dried CO_2 for uses such as blanketing and conveying of the catalyst, pressurizing of lock hoppers, and backflow cleaning of the bag filters. The system has a capacity of up to 2,000 scfm and includes compression, drying, and a surge receiver.

Flare

A 36-inch diameter flare stack is provided to handle flow from all three gasifiers. The required height is 75 feet.

Miscellaneous Storage

A diesel fuel storage tank with a capacity of 6,000 gallons is provided.

A carbonate storage tank with a capacity of 9,000 gallons is provided. This tank is large enough to hold the contents of the Benfield system should draining be required for maintenance.

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, which include the output streams identified as "Losses from Steam System" and "Mechanical and Other Losses," are 5.5%.

TABLE I. HEAT AND MATERIAL BALANCE SUMMARY

REFERENCE: H_2O(liq.) @ 60°F

INPUT STREAM	TEMPERATURE °F	Lb/Hr.	Btu/Lb.	10^6 Btu/Hr.
1. Raw Wood	60	330,561	4425	1462.7
2. Dryer Combustion Air	60	976,558	13.6	13.3
3. Boiler Combustion Air	60	107,993	13.6	1.5
4. Gasifier Htr.Comb.Air	60	221,166	13.6	3.0
5. Water	60	349,418	-	-
6. Lime Solution	60	26,860	-	-
7. Gasifier Catalyst	60	48	-	-
8. Electricity	(4,100 Kw @ 3,413 $\frac{\text{Btu}}{\text{Kw-Hr.}}$)			14.0
9. Diesel Fuel	(13.75 gal/hr @ 140,000 Btu/gal)			1.9
TOTAL		2,012,604		1496.4
OUTPUT STREAM				
1. Vent Gas from Dryer	180	1,137,658	181.2	206.2
2. Boiler Flue Gases	300	120,210	81.5	9.8
3. Gasifier Htr. Flue Gases	300	225,236	76.4	17.2
4. Product SNG	100	38,824	22,189.2	861.5
5. Hot CO_2 Vent	202	107,501	505.9	54.4
6. Cool CO_2 Vent	122	14,027	63.4	0.9
7. Ash to Pond	200	8,042	35.0	0.3
8. Excess Char	300	7,091	10,881.3	77.2
9. Product Gas Drying Vent	220	34	1,138.8	0.04
10. Losses from Steam System	212	7,699	1,127.4	8.7
11. Cooling Tower Losses	100	173,000	1,077.1	186.3
12. Treated Water	60	168,486	-	-
13. Sludge	60	4,796	-	-
14. Mechanical and Other Losses		-		73.9
TOTAL		2,012,604		1496.4

VI. SUMMARY OF PROCESS MATERIALS AND UTILITIES

In the following sections are given the expected raw materials and utilities consumption and production for the plant complex.

A. Summary of Raw Materials and Utilities Imported

1. Wood

Quantity, dry tons per day	2000
Moisture content, wt. %	49.5

2. Raw Water

Flow, gpm	700

3. Gasifier Catalyst

Usage, lb/hr.	48

4. Electricity

Normal operating draw, kw	4100

5. Diesel Fuel

Average usage, gallons/day	330

B. Products and Byproducts Exported

1. Product Substitute Natural Gas

Production, scfh	899,520
HHV, Btu/scf	956

2. Wood Char

Quantity, tons/day	85
Composition: wt.% combustibles	80.2
wt. % ash	19.8

3. Wood Ash to Pond

Quantity, tons/day	96.5

4. Treated Wastewater

Flow, gpm	340

5. Sludge from Wastewater Treating

Quantity, tons/day	72

C. Summary of Catalyst and Chemicals

1. Catalysts

	INITIAL CHARGE, ft.3	MINIMUM LIFE, YEARS
Shift Conversion	1500	1
Primary Methanation	620	1
Secondary Methanation	400	1

2. Process Chemicals

	Lbs/Day
K_2CO_3 for Acid Gas Removal	192
V_2O_5 for Acid Gas Removal	4
DEA for Acid Gas Removal	15
Lime for Wastewater Treating	64,460

Boiler Chemicals

Scale Inhibitor	15
Oxygens Scavenger	1
Corrosion Inhibitor	7.5

Cooling Tower

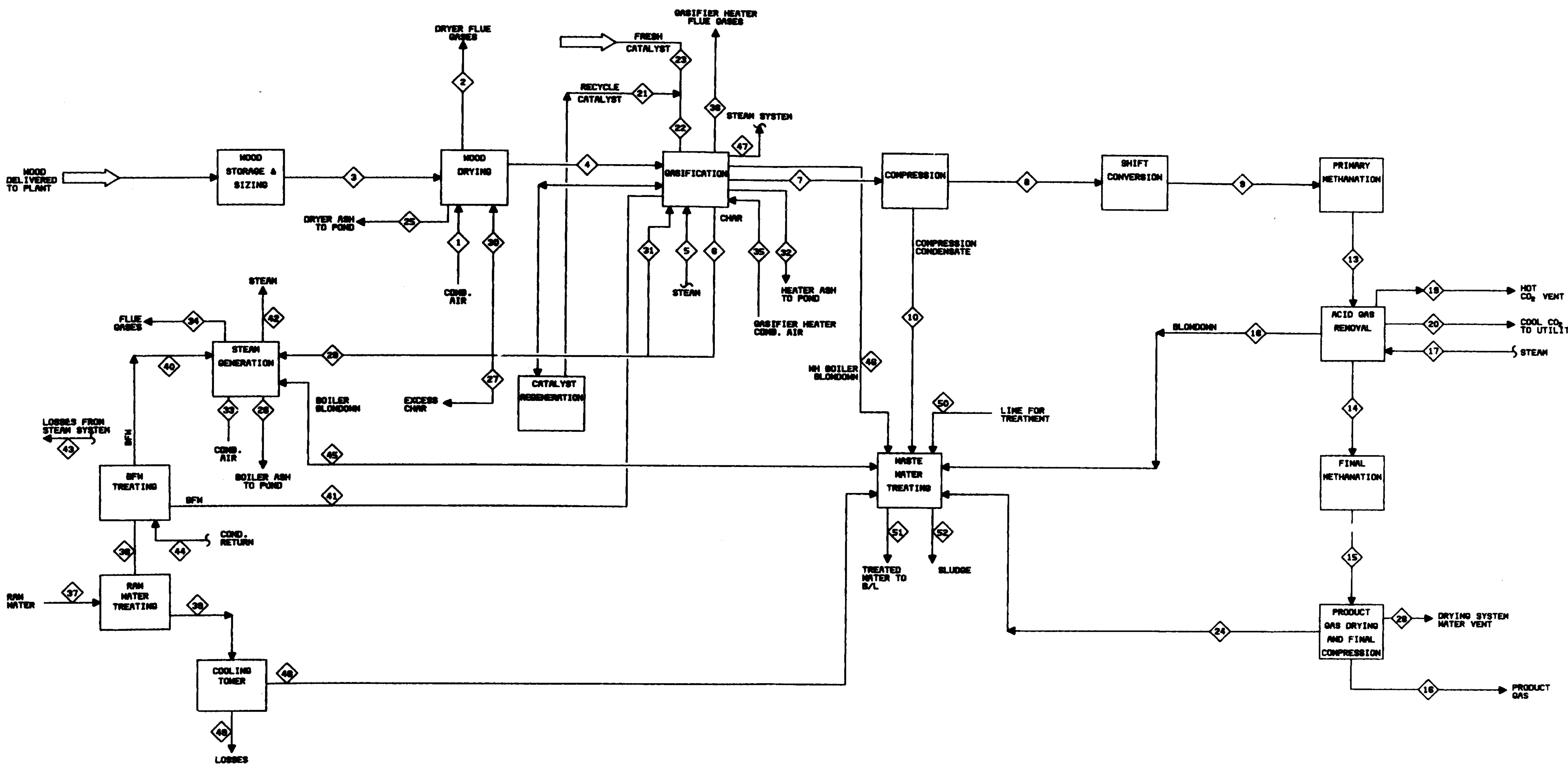
H_2SO_4 for pH Control	128
Corrosion Control	40
Dispersant	16
Algae Control	5
Chlorine	72

D. Summary of Operating Labor

Areas	Personnel Required
Wood Storage and Drying	15
Gasification, Cleanup, Shift, Methanation, Compression, Acid Gas Removal, Gas Drying	18
Offsites including Boilers, Char Distribution, Cooling Tower, Wastewater Treatment, Catalyst Regeneration	18
TOTAL	51

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-0001, and accompanying material balance sheets which list the composition, flow, and conditions of each stream are shown in this section.



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NO.	DESCRIPTION	BY	CH.	APPROVED	DATE

Davy McKee
ENGINEERS AND CONSTRUCTORS

TITLE: WOOD TO METHANE BLOCK FLOW DIAGRAM

5471-F-0001 — REVISION 1

Davy McKee MATERIAL BALANCE SHEET

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANE CLIENT BATTELLE PNL Sheet 1 of 8

STREAM NUMBER		1		2		3		4		5		6		7	
DESCRIPTION		AIR TO DRYERS		VENT GAS FROM DRYERS		WET WOOD TO DRYERS		DRIED WOOD TO GASIFIERS		STEAM TO GASIFICATION		CHAR FROM GASIFICATION		RAW GAS FROM GASIFIERS	
PHASE		GAS		GAS		SOLID		SOLID		GAS					
COMPONENT	MOL WT	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	DRY MOL%
CARBON	12.011					6,452.4	77,500	6,452.4	77,500			2,431.5	29,205		
HYDROGEN	2.016					4,852.7	9,783	4,852.7	9,783			103.1	208	886.5	18.00
OXYGEN	32.000	7018.8	224,600	6,080.1	194,563	2,187.0	69,984	2,187.0	69,984			275.3	8,810		
NITROGEN	28.014	26,394.9	739,427	26,394.9	739,427	18.8	527	18.8	527					18.8	0.38
SULFUR	32.060														
CHLORIDE	--														
ASH	--						9,400		9,400				9,400		
WATER	18.016	695.5	12,531	8779.3	158,168	9,0679	163,367	1,027.9	18,518	1,852.8	33,380			3,007.8	
CARBON MONOXIDE	28.011													609.5	12.37
CARBON DIOXIDE	44.011			1033.8	45,500									1,543.4	31.33
METHANE	16.043													1,868.0	37.92
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
CATALYST													48		
TOTAL		34,109.2	976,558	42,288.1	1,137,658	18,204.8	330,561	14,538.8	185,712	1,852.8	33,380	2,809.9	47,671	7,934.0	100.00
TOTAL GAS FLOW, MOL/HR.	(DRY)	33,433.7		33,508.8		9,136.9		13,510.9						4,926.2	
WATER (V)/DRY GAS	(VOL/VOL)	0.021		0.262		0.498		0.076						0.611	
TOTAL (WET) FLOW, LB/HR			976,558		1,137,658		330,561		185,712		33,380		47,671		171,469
PRESSURE - PSIA		ATM		ATM		ATM		ATM		615		ATM		150	
TEMPERATURE - °F		60		180		60		60		750		300		350	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS															
H*, MM BTU/HR		13.3		206.2		1462.7		1462.7		45.1		518.7		978.6	

*REF.: H_2O (Liq.) @ 60°F

DavyMcKee MATERIAL BALANCE SHEET

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANE CLIENT BATTELLE PNL Sheet 2 of 8

STREAM NUMBER		8		9		10		11		12		13		14	
DESCRIPTION		GAS TO SHIFT CONVERSION		GAS TO PRIMARY METHANATOR		COMPRESSION CONDENSATE		BLOWDOWN FROM SHIFT CONVERSION		MAKE-UP WATER TO SHIFT CONVERSION		GAS TO ACID GAS REMOVAL		GAS FROM ACID GAS REMOVAL	
PHASE		GAS		GAS		LIQUID		LIQUID		LIQUID		GAS		GAS	
COMPONENT	MOL WT	LB-MOL/HR	DRY MOL%	LB-MOL/HR	DRY MOL%	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	DRY MOL%	LB-MOL/HR	DRY MOL%
CARBON	12.011														
HYDROGEN	2.016	886.5	18.00	1334.8	24.84							213.8	5.03	213.8	8.51
OXYGEN	32.000														
NITROGEN	28.014	18.8	0.38	18.8	0.35							18.8	0.44	18.8	0.75
SULFUR	32.060														
CHLORIDE	--														
ASH	--														
WATER	18.016	67.6		197.0		2940.2	52,971	471.8	8,500	1049.5	18,908	711.4		85.0	
CARBON MONOXIDE	28.011	609.5	12.37	161.2	3.00							69.0	1.62	69.0	2.75
CARBON DIOXIDE	44.011	1543.4	31.33	1991.7	37.06							1780.6	41.86	39.7	1.58
METHANE	16.043	1868.0	37.92	1868.0	34.75							2171.3	51.05	2171.3	86.41
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
TOTAL		4993.8	100.00	5571.5	100.00	2940.2	52,971	471.8	8,500	1049.5	18,908	4964.9	100.00	2597.6	100.00
TOTAL GAS FLOW, MOL/HR.	(DRY)	4926.2		5374.5								4253.5		2512.6	
WATER (V)/DRY GAS	(VOL/VOL)	0.014		0.037								0.167		0.034	
TOTAL (WET) FLOW, LB/HR			118,498		128,906		52,971		8,500		18,908		127,168		39,264
PRESSURE-PSIA		350		340		ATM		350		350		335		328	
TEMPERATURE - °F		330		275		120		300		100		300		220	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS		481		441								537		909	
H, MM BTU/HR		914.5		915.8		3.2		2.0		0.8		893.6		872.8	

Davy McKee **MATERIAL BALANCE SHEET**

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANE CLIENT BATTELLE PNL Sheet 3 of 8

STREAM NUMBER		15		16		17		18		19		20		21	
DESCRIPTION		GAS FROM FINAL METHANATION		PRODUCT GAS		LP STEAM TO ACID GAS REMOVAL		CONDENSATE FROM ACID GAS REMOVAL		HOT CO_2 VENT		COOLED CO_2 TO COMPRESSION		RECYCLED CATALYST	
PHASE		GAS		GAS		GAS		LIQUID		GAS		GAS			
COMPONENT	MOL WT	LB-MOL/HR	DRY MOL%	LB-MOL/HR	DRY MOL%	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR		LB/HR
CARBON	12.011														
HYDROGEN	2.016	74.3	3.13	74.3	3.13										
OXYGEN	32.000														
NITROGEN	28.014	18.8	0.79	18.8	0.79										
SULFUR	32.060														
CHLORIDE	--														
ASH	--														
WATER	18.016	172.9		0.3		2300.9	41,453	317.4	5,718	2571.0	46,319	38.9	701		
CARBON MONOXIDE	28.011	2.1	0.09	2.1	0.09										
CARBON DIOXIDE	44.011	55.0	2.32	55.0	2.32			48.0	2,110	1390.1	61,182	302.8	13,326		
METHANE	16.043	2222.9	93.67	2222.9	93.67										
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
CATALYST															903
TOTAL		2546.0	100.00	2373.4	100.00	2300.9	41,453	365.4	7,828	3961.1	107,501	341.7	14,027		903
TOTAL GAS FLOW, MOL/HR.	(DRY)	2373.1		2373.1						1390.1		302.8			
WATER (V)/DRY GAS	(VOL/VOL)	0.073		0.0001						1.850		0.128			
TOTAL (WET) FLOW, LB/HR			41,933		38,824		41,453		7,828		107,501		14,027		903
PRESSURE--PSIA		323		1015		65		330		18		15			
TEMPERATURE -- °F		380		100		298		248		202		122		100	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS		956		956											
H, MM BTU/HR		874.3		861.5		47.7		1.2		54.4		0.9		0.009	

Davy McKee **MATERIAL BALANCE SHEET**

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANE CLIENT BATTELLE PNL

STREAM NUMBER		22		23		24		25		26		27		28	
DESCRIPTION		TOTAL CATALYST FEED TO GASIFIER		FRESH CATALYST MAKE-UP		CONDENSATE FROM FINAL COMPRESSION		DRYER ASH TO POND		BOILER ASH TO POND		EXCESS CHAR		DRYING SYSTEM VENT	
PHASE		SOLID		SOLID		LIQUID		SOLID		SOLID					
COMPONENT	MOL WT		LB/HR		LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR
CARBON	12.011											361.7	4344		
HYDROGEN	2.016											15.3	31		
OXYGEN	32.000											41.0	1310		
NITROGEN	28.014														
SULFUR	32.060														
CHLORIDE	--														
ASH	--								3997		3004		1398		
WATER	18.016					170.7	3075							1.9	34
CARBON MONOXIDE	28.011														
CARBON DIOXIDE	44.011														
METHANE	16.043														
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
CATALYST			951		48				20		15		8		
TOTAL			951		48	170.7	3075		4017		3019	418.0	7,091	1.9	34
TOTAL GAS FLOW, MOL/HR.	(DRY)														
WATER (V)/DRY GAS	(VOL/VOL)														
TOTAL (WET) FLOW, LB/HR			951		48		3075		4017		3019				34
PRESSURE-PSIA		150		ATM		ATM		ATM		ATM		ATM		ATM	
TEMPERATURE – °F		100		60		100		200		200		300		220	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS															
H, MM BTU/HR		0.01		0		0.12		0.14		0.11		77.2		0.04	

Davy McKee **MATERIAL BALANCE SHEET**

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANE CLIENT BATTELLE PNL Sheet 5 of 8

STREAM NUMBER		29		30		31		32		33		34		35	
DESCRIPTION		CHAR TO BOILER		CHAR TO DRYERS		CHAR TO GASIFIER HEATER		ASH FROM GASIFIER HEATER		COMBUSTION AIR TO BOILER		BOILER FLUE GASES		COMBUSTION AIR TO GASIFIER HEATER	
PHASE		SOLID		SOLID		SOLID		SOLID		GAS		GAS		GAS	
COMPONENT	MOL WT	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR		
CARBON	12.011	777.1	9334	1033.8	12,417	258.9	3110								
HYDROGEN	2.016	33.0	67	43.8	88	11.0	22								
OXYGEN	32.000	88.0	2816	117.0	3,746	29.3	938			776.2	24,838	70.6	2,259	1589.6	50,867
NITROGEN	28.014									2918.9	81,770	2918.9	81,770	5977.8	167,462
SULFUR	32.060														
CHLORIDE	--														
ASH	--		3004		3,997		1001		1001						
WATER	18.016									76.9	1,385	109.9	1,980	157.5	2837
CARBON MONOXIDE	28.011														
CARBON DIOXIDE	44.011											777.1	34,201		
METHANE	16.043														
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
CATALYST			15		20		5		5						
TOTAL		898.1	15,236	1194.6	20,268	299.2	5,076		1,006	3772.0	107,993	3876.5	120,210	7724.9	221,166
TOTAL GAS FLOW, MOL/HR.	(DRY)									3695.1		3766.6		7567.4	
WATER (V)/DRY GAS	(VOL/VOL)									0.021		0.029		0.021	
TOTAL (WET) FLOW, LB/HR			15,236		20,268		5,076		1,006		107,993		120,210		221,166
PRESSURE-PSIA		ATM		ATM		ATM		ATM		ATM		ATM		ATM	
TEMPERATURE - °F		300		300		300		200		60		300		60	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS															
H, MM BTU/HR		165.8		220.5		55.2		0.04		1.5		9.8		3.0	

DavyMcKee **MATERIAL BALANCE SHEET**

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

STREAM NUMBER		36		37		38		39		40		41		42	
DESCRIPTION		GASIFIER HEATER FLUE GASES		RAW WATER TO TO PLANT		RAW WATER TO BFW TREATING		RAW WATER TO COOLING TOWER		BFW TO BOILER		BFW TO WH BOILER		STEAM FROM BOILER	
PHASE		GAS		LIQUID		LIQUID		LIQUID		LIQUID		LIQUID		LIQUID	
COMPONENT	MOL WT	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR
CARBON	12.011														
HYDROGEN	2.016														
OXYGEN	32.000	1354.5	43,344												
NITROGEN	28.014	5977.8	167,462												
SULFUR	32.060														
CHLORIDE	--														
ASH	--														
WATER	18.016	168.5	3,036		349,418	5823.6	104,918	13,571.3	244,500	6583.9	118,616	4023.5	72,488	6454.8	116,290
CARBON MONOXIDE	28.011														
CARBON DIOXIDE	44.011	258.9	11,304												
METHANE	16.043														
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
TOTAL		7759.7	225,236	19,394.9	349,418	5823.6	104,918	13,571.3	244,500	6583.9	118,616	4023.5	72,488	6454.8	116,290
TOTAL GAS FLOW, MOL/HR.	(DRY)	7591.2													
WATER (V)/DRY GAS	(VOL/VOL)	0.022													
TOTAL (WET) FLOW, LB/HR			225,236		349,418		104,918		244,500		118,616		72,488		
PRESSURE PSIA		ATM		ATM		ATM		ATM		700		700		615	
TEMPERATURE - °F		300		60		60		60		220		220		750	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS															
H, MM BTU/HR		17.2		0		0		0		19.0		11.6		157.1	

Davy McKee MATERIAL BALANCE SHEET

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

STREAM NUMBER		43		44		45		46		47		48		49	
DESCRIPTION		LOSSES FROM STEAM SYSTEM		CONDENSATE RETURN		BOILER BLOWDOWN		WH BOILER BLOWDOWN		STEAM FROM WH BOILER		COOLING TOWER BLOWDOWN		COOLING TOWER LOSSES	
PHASE		GAS		LIQUID		LIQUID		LIQUID		VAPOR		LIQUID		VAPOR	
COMPONENT	MOL WT	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	B-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR
CARBON	12.011														
HYDROGEN	2.016														
OXYGEN	32.000														
NITROGEN	28.014														
SULFUR	32.060														
CHLORIDE	--														
ASH	--														
WATER	18.016	427.3	7,699	5803.4	104,554	129.1	2,326	78.9	1,421	3944.7	71,067	3968.7	71,500	9602.6	173,000
CARBON MONOXIDE	28.011														
CARBON DIOXIDE	44.011														
METHANE	16.043														
HYDROGEN SULFIDE	34.076														
CARBONYL SULFIDE	60.071														
TOTAL		427.3	7,699	5803.4	104,554	129.1	2,326	78.9	1,421	3944.7	71,067	3968.7	71,500	9602.6	173,000
TOTAL GAS FLOW, MOL/HR.	(DRY)														
WATER (V)/DRY GAS	(VOL/VOL)														
TOTAL (WET) FLOW, LB/HR			7,699		104,554		2,326		1,421		71,067		71,500		
PRESSURE-PSIA		15		15		615		615		615		ATM		ATM	
TEMPERATURE - °F		212		212		490		490		750		100		100	
VOL. FLOW RATE - SCFH (DRY)															
HHV BTU/LB															
HHV BTU/SCF DRY GAS															
H, MM BTU/HR		8.7		15.9		1.0		0.61		96.0		2.9		186.3	

Davy McKee MATERIAL BALANCE SHEET

PROJECT NUMBER NC-5471 PROJECT NAME WOOD TO METHANE CLIENT BATTELLE PNL

STREAM NUMBER		50		51		52	
DESCRIPTION		LIME SOLUTION		TREATED WATER TO B/L		SLUDGE	
PHASE		LIQUID		LIQUID		SOLID	
COMPONENT	MOL WT	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR	LB-MOL/HR	LB/HR
CARBON	12.011						
HYDROGEN	2.016						
OXYGEN	32.000						
NITROGEN	28.014						
SULFUR	32.060						
CHLORIDE	--						
ASH	--						
WATER	18.016	1341.8	24,174	9352.0	168,486	66.6	1199
CARBON MONOXIDE	28.011						
CARBON DIOXIDE	44.011						
METHANE	18.043						
HYDROGEN SULFIDE	34.076						
CARBONYL SULFIDE	60.071						
LIME - CaO	56.006	48.0	2,686				
SLUDGE (as $CaCO_3$)	100.017					48.0	4,796
TOTAL		1389.8	26,860	9352.0	168,486	114.6	5995
TOTAL GAS FLOW, MOL/HR.	(DRY)						
WATER (V)/DRY GAS	(VOL/VOL)						
TOTAL (WET) FLOW, LB/HR			26,860		168,486		5995
PRESSURE - PSIA		ATM		ATM		ATM	
TEMPERATURE - °F		60		60		60	
VOL. FLOW RATE - SCFH (DRY)							
HHV BTU/LB							
HHV BTU/SCF DRY GAS							
H, MM BTU/HR		0		0		0	

VIII. PLANT LAYOUT AND DESCRIPTION

A. OVERALL PLANT LAYOUT

B. GASIFICATION AREA ARRANGEMENT

C. GASIFICATION AREA FLOWSHEET

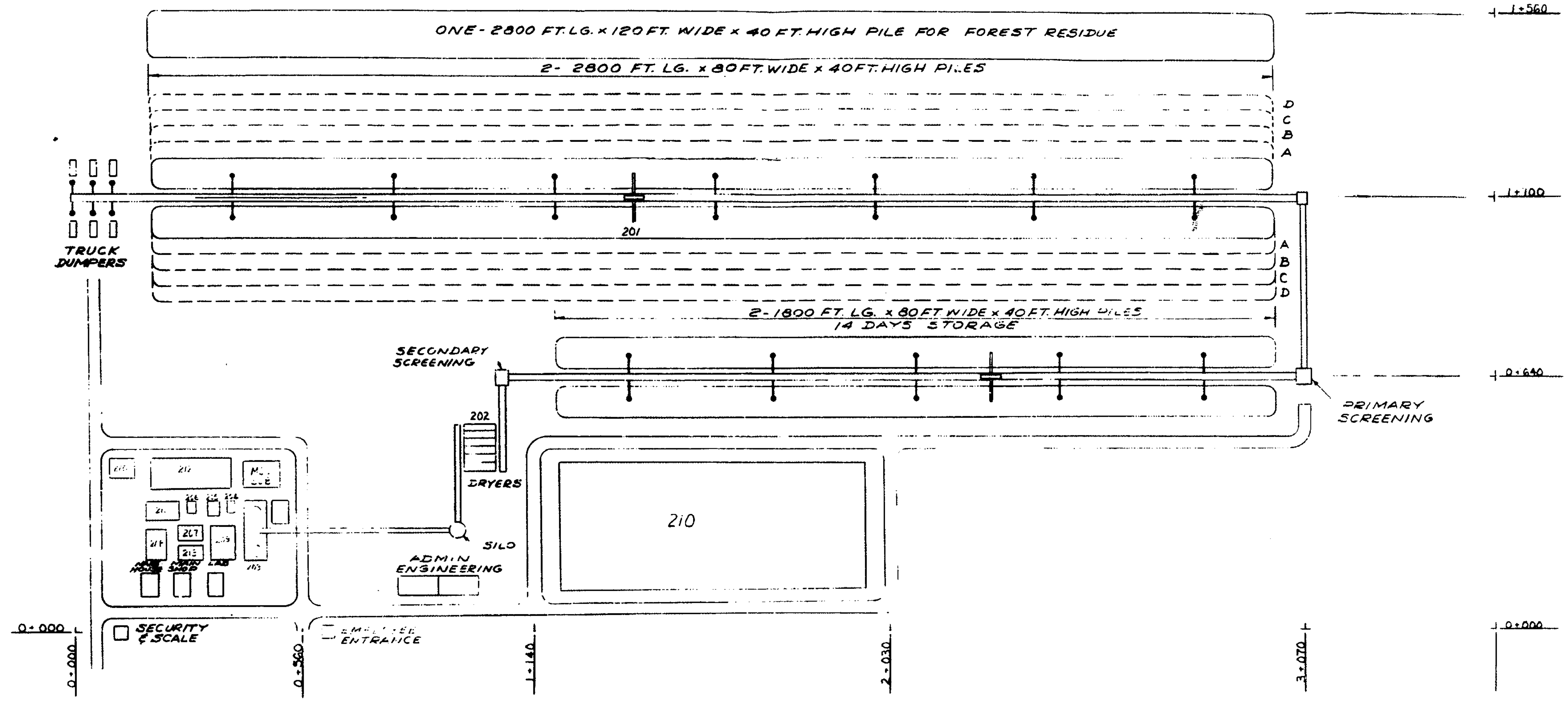
D. GASIFICATION VESSEL DRAWING

E. SINGLE-LINE EQUIPMENT LIST

F. DETAILED EQUIPMENT LIST

A. Overall Plant Layout

An proposed layout has been made for the plant. As may be seen from the attached drawing, number 5471-A-0021, 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.



NOTE:
A,B,C,D DENOTES 25 DAY STORAGE CAPACITY WITH BOTH SIDES

201	WOOD STORAGE	207	ACID GAS REMOVAL
202	WOOD DRYING	208	FINAL METHANATION DRYING
203	GASIFICATION	209	CATALYST REGENERATION
204	COMPRESSION	210	WASTE WATER TREATING
205	SHIFT CONVERSION	211	RAW WATER TREATING & COOLING WATER
206	PRIMARY METHANATION	212	BOILERS & BOILER FEED WATER SYSTEM
		213	MISCELLANEOUS UTILITIES

Davy McKee
ENGINEERS AND CONSTRUCTORS

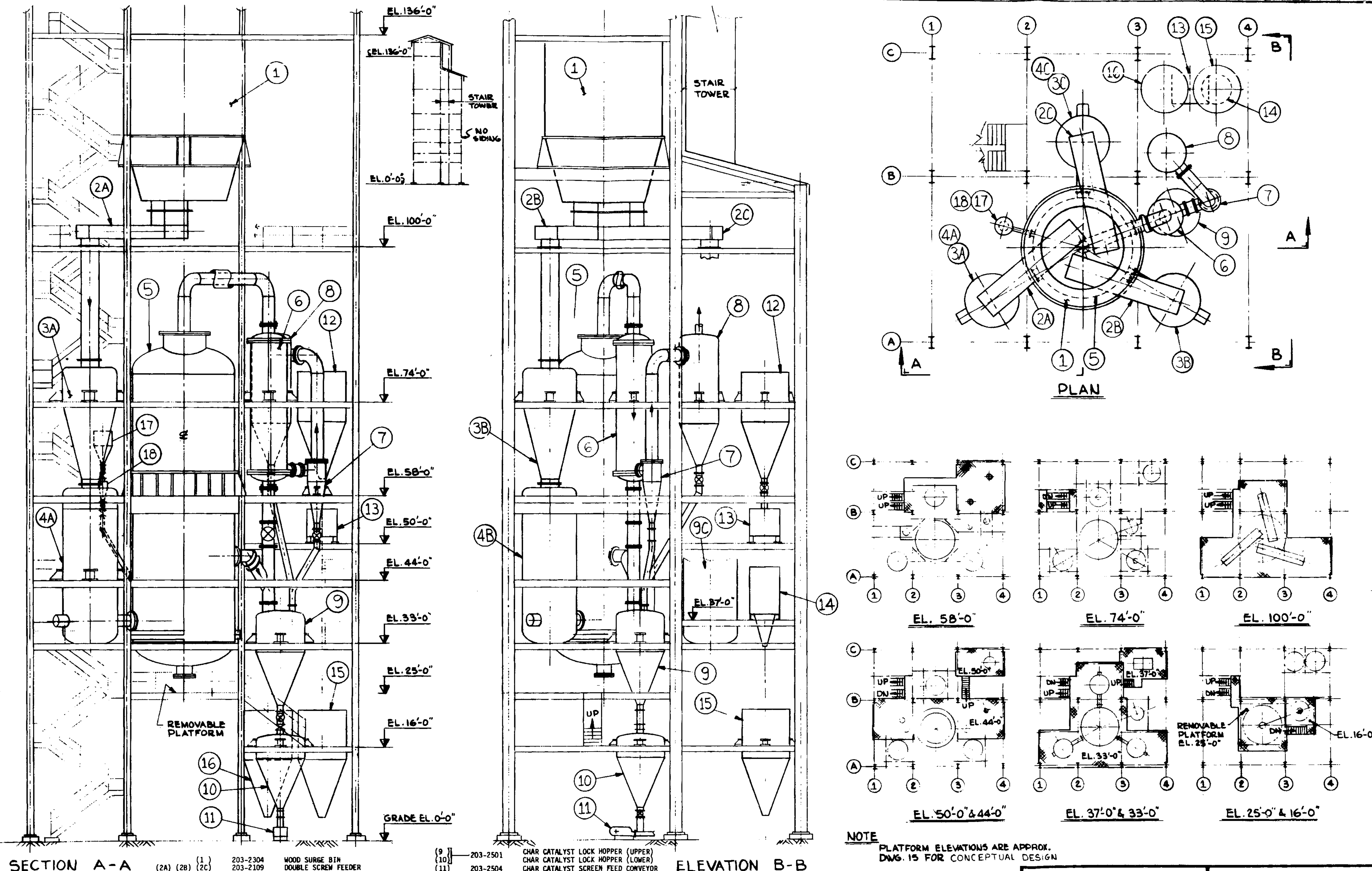
TITLE: OVERALL PLOT PLAN WOOD TO METHANE PLANT

SCALE: 1" = 10'

5471-A-0021

B. Gasification Area Arrangement

Plans and elevations of major equipment in the gasifier area are shown on the arrangement drawing, number 5471-A-0201.



	(1)	203-2304	WOOD SURGE BIN
(2A) (2B)	(2C)	203-2109	DOUBLE SCREW FEEDER
(3A) (3B)	(3C)	203-2502	WOOD FEED LOCK HOPPER (UPPER)
(4A) (4B)	(4C)	203-2502	WOOD FEED LOCK HOPPER (LOWER)
	(5)	203-2201	GASIFIER
	(6)	203-1603	GASIFIER WASTE HEAT BOILER
	(7)	203-1701	CYCLONE
	(8)	203-1702	RAW GAS BAG FILTER
	(9)	203-2501	CHAR CATALYST LOCK HOPPER (UPPER)
	(10)	203-2501	CHAR CATALYST LOCK HOPPER (LOWER)
	(11)	203-2504	CHAR CATALYST SCREEN FEED CONVEYOR
	(12)	203-2306	CHAR CATALYST SURGE BIN
	(13)	203-1401	CHAR CATALYST SCREEN
	(14)	203-1402	MAGNETIC SEPARATORS
	(15)	203-2301	CHAR SURGE HOPPER
	(16)	203-2302	CATALYST HOPPER
	(17)	203-2503	CATALYST FEED LOCK HOPPER (UPPER)
	(18)	203-2503	CATALYST FEED LOCK HOPPER (LOWER)

NOTE
PLATFORM ELEVATIONS ARE APPROX.
DWG. 15 FOR CONCEPTUAL DESIGN

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ENGINEERS AND CONSTRUCTORS

TITLE: WOOD TO METHANE
ONE GASIFIER SECTION
PLANS AND ELEVATIONS

SCALE 1" = 20' & 1/8" = 1'-0"

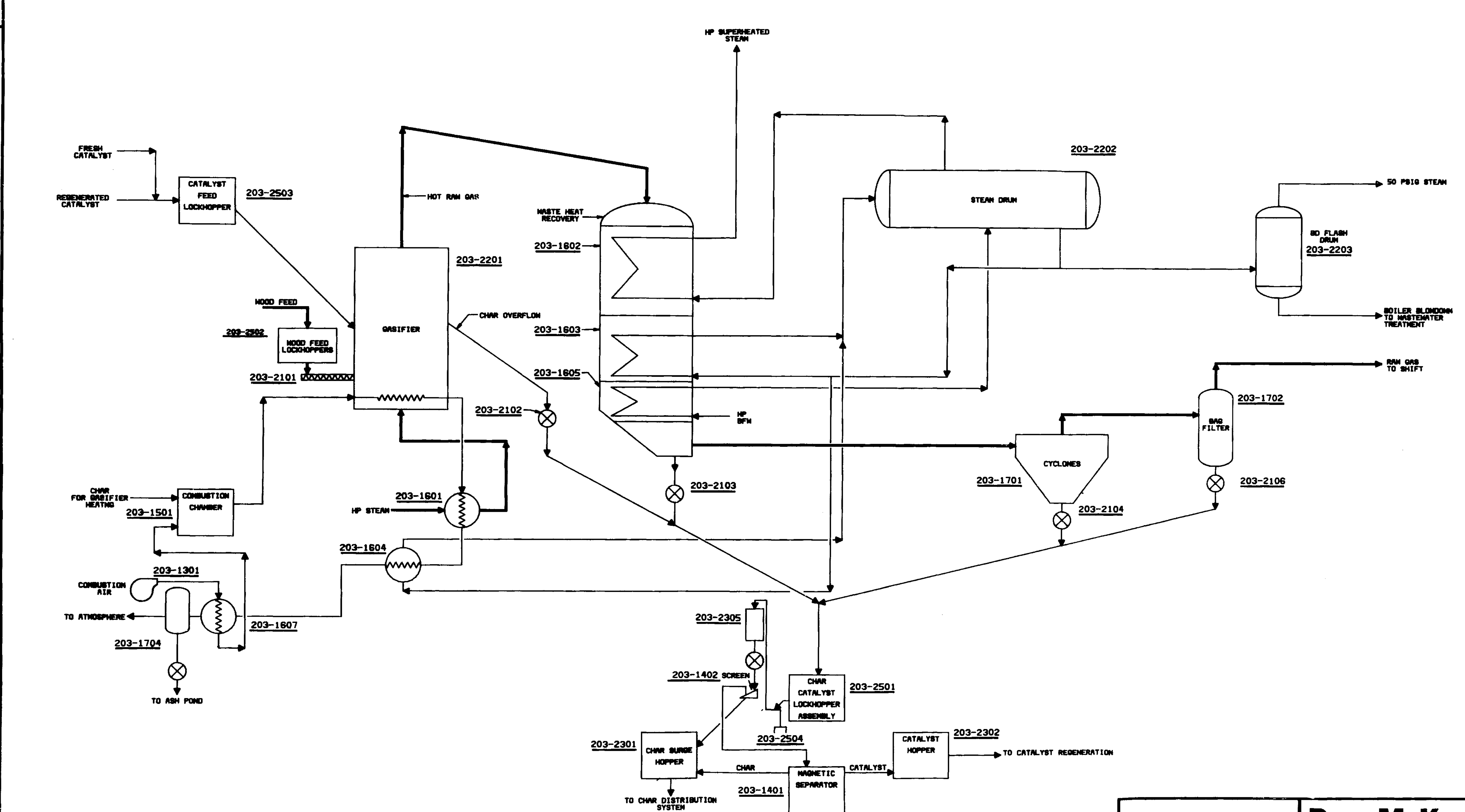
DESIGNED BY: GLM, 9-4-80

5471-A-0201

REVISION: P.

C. Gasification Area Flowsheet

A flow schematic for the gasification area is shown on drawing number 5477-F-0202 which follows.



IGS AC0821

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ENGINEERS AND CONSTRUCTORS

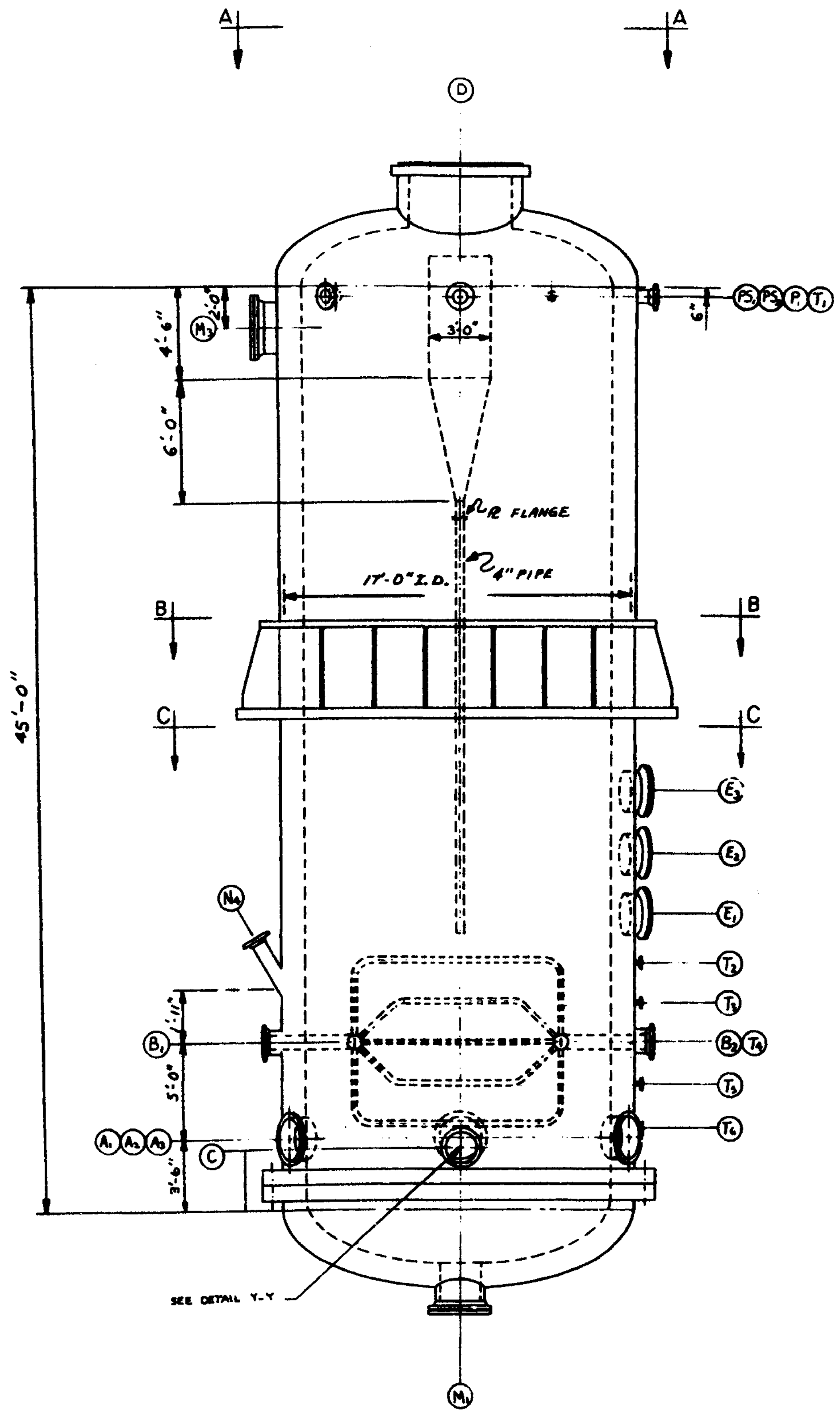
WOOD TO METHANE GASIFICATION AND GAS CLEANUP AREAS

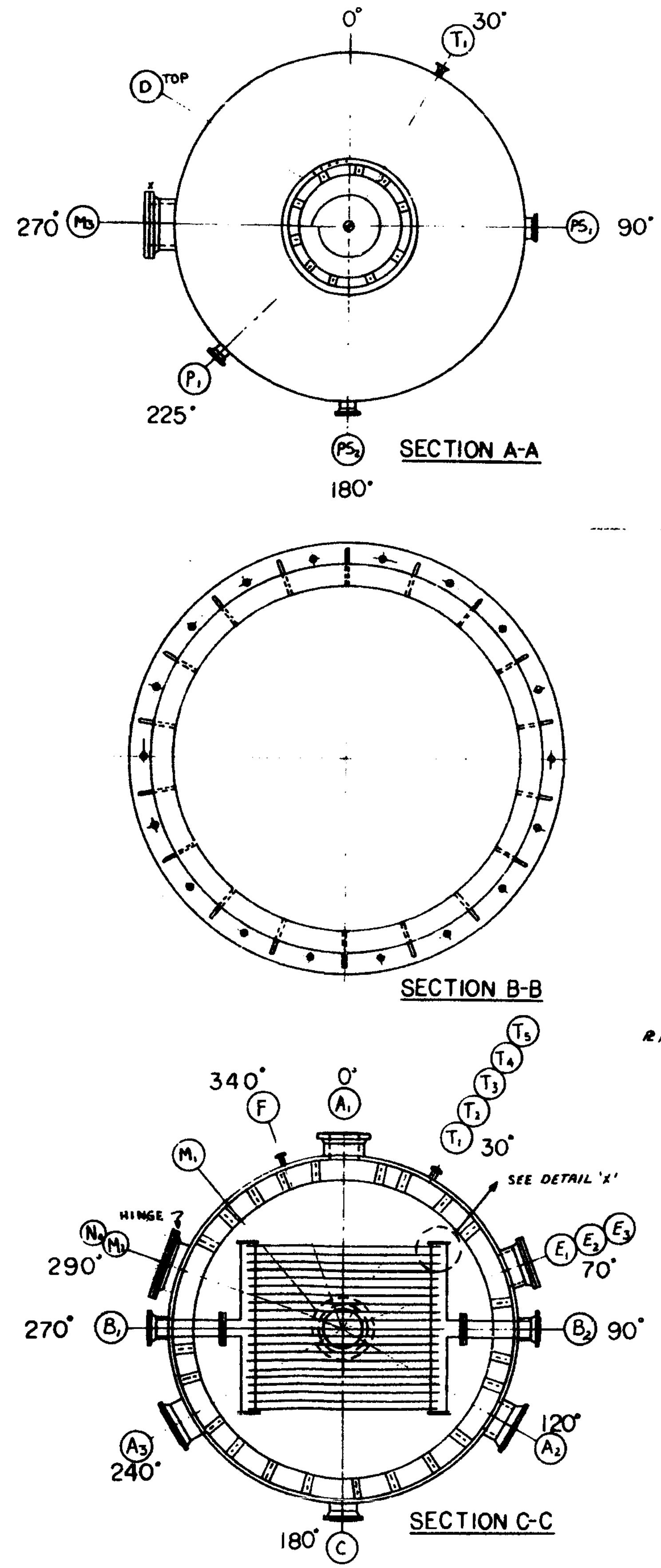
5471-F-0202

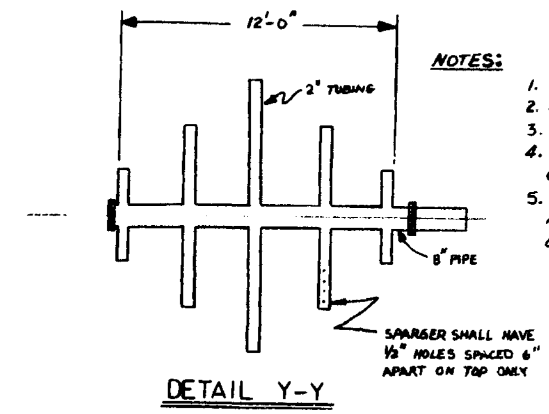
REVISION 1

D. Gasification Vessel Drawing

A detailed drawing of the gasifier equipment item number 203-2201, follows this page. This drawing is typical for each of the three gasifiers and is numbered 5471-V-0201.





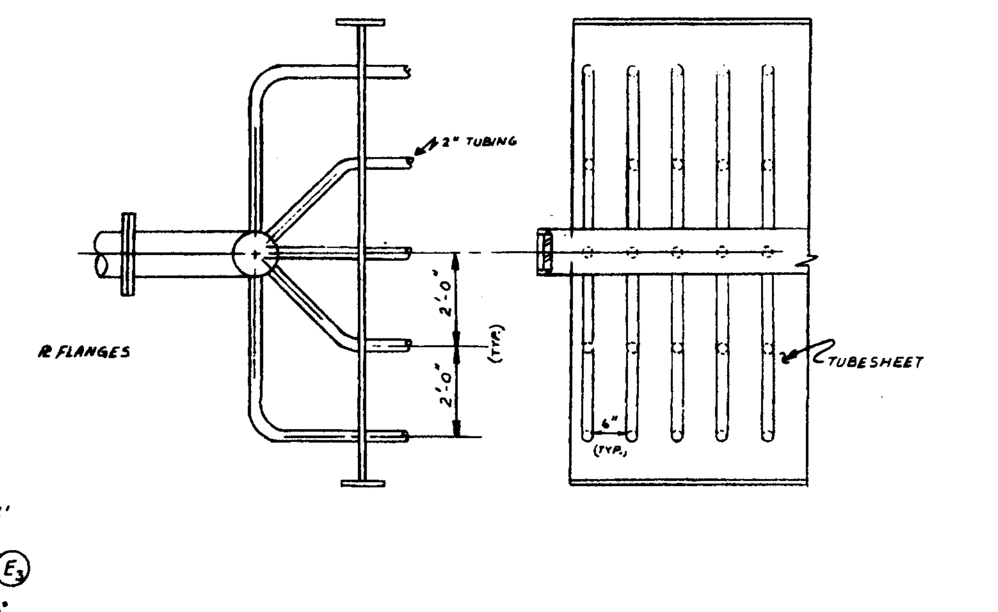


DETAIL Y-Y

MARK	Nº REQ.	SIZE	RATING	SERVICE	REMARKS
A1-3	3	24"	150#	WOOD FEED	4" REFRACTORY LINING
B1	1	14"		HOT GAS FEED	
B2	1	14"		HOT GAS DISCHARGE	
C	1	16"		STEAM FEED w/ INTERNAL PIPE	
D	1	6'-0"	CLASS 175	GAS OUTLET	9" REFRACTORY LINING
E1	1	24"	150#	CHAR OVERFLOW	4" REFRACTORY LINING
E2-3	2	24"		FUTURE w/BLIND	
F	1	1"		AERATION GAS	w/ INTERNAL PIPE
M1-3	3	30"		MANWAY w/BLIND	4" REFRACTORY LINING
P1	2	8"		PRESSURE GAGE	
PS1	1	8"		RELIEF VALVE	
PS2	1	8"		RUPTURE DISK	
T1-6	6	1½"		THERMOWELLS	
N4	1	8"		CATALYST FEED	

NOTES:

1. DESIGN: 160 PSIG @ 500° F
2. RADIOGRAPHY: PARTIAL
3. SHELL & HEAD MAT'L: A-516-70
4. SHELL & HEADS TO BE REFRACTORY LINED WITH 8" INSULATING CASTABLE AND 4½" REFRACTORY BRICK
5. INTERNALS INCLUDE CYCLONE, HEAT EXCHANGER, STEAM FEED, AERATION GAS AND ALL SUPPORTS, MAT'L TO BE RA-333 OR INCOLOY 800H.



SIDE VIEW END VIEW

DETAIL X-X (EXCHANGER MANIFOLD)

21 ROWS w/ 5 TUBES EACH ROW

Davy McKee
ENGINEERS AND CONSTRUCTORS

TITLE: WOOD GASIFIER - METHANE
TAG: 203-2201

5471-V-0201

Revision: 0

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

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
201-1001	2	Rechippers
201-1401	1	Tramp Iron Separator
201-1402	4	Primary Screens
201-1403	2	Secondary Screens
201-1801	2	Weigh Scale
201-1901	6	Truck Dumpers
201-2101	6	Dumpers to Storage
201-2102	2	Storage Stacker Conveyors
201-2103	14	Chip Reclaimers
201-2104	2	Reclaim Conveyors
201-2105	1	Collecting Conveyor
201-2106	1	Primary Screening Feed Conveyor
201-2107	1	Oversize Conveyor
201-2108	1	Trash Conveyor
201-2109	1	Primary Screen Delivery Conveyor
201-2110	1	Secondary Stacker
201-2111	10	Secondary Storage Reclaimers
201-2112	2	Secondary Storage Reclaim Conveyor
201-2113	1	Fines Conveyor
201-2301	6	Truck Dump Hoppers
201-3901	4	Bulldozer

WOOD DRYING

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
202-1601	5 + 1	Wood Dryers
202-1801	1	Dried Chip Feeder
202-2101	2	Dryer Distribution Conveyors
202-2102	2	Dried Wood Collecting Conveyors
202-2103	1	Dried Wood to Storage Conveyor
202-2104	1	Storage to Gasifier Conveyor
202-2105	1	Gasifier Distribution Diverter
202-2106	1	Gasifier Distribution Conveyors

GASIFICATION

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
203-1102	3	Ash Slurry Pump
203-1301	3 + 3	Combustion Air Blower
203-1401	3	Char-Catalyst Screen
203-1402	3	Magnetic Separator
203-1501	3	Gasifier Heater
203-1601	3	HT Steam Superheater
203-1602	3	Steam Superheater
203-1603	3	Gasifier WH Boiler
203-1604	3	Gasifier Heater WH Boiler
203-1605	3	BFW Heater
203-1607	3	Combustion Air Preheater
203-1701	3	Cyclone
203-1702	3	Raw Gas Bag Filter
203-1703	3	Ventilation Bag Filter
203-1704	3	Heater Dust Collector
203-2101	9	Gasifier Feed Screw
203-2102	3	Char Overflow Feeder
203-2103	3	Waste Heat Boiler Discharge Feeder
203-2104	3	Cyclone Discharge Feeder
203-2106	3	Bag Filter Discharge Feeder
203-2109	9	Double Screw Feeders

203-2201	3	Gasifier
203-2202	1	Steam Drum
203-2203	1	BD Flash Drum
203-2301	3	Char Surge Hopper
203-2302	3	Catalyst Hopper
203-2303	3	Char Storage Bin
203-2304	3	Wood Surge Bin
203-2305	3	Ash Slurry Tank
203-2306	3	Char-Catalyst Surge Bin
203-2501	3	Char-Catalyst Lock Hopper Assembly
203-2502	9	Wood Feed Lock Hopper Assembly
203-2503	3	Catalyst Feed Lock Hopper Assembly
203-2504	3	Char-Catalyst Screen Feed Conveyor
203-2505	3	Spent Catalyst to Storage Conveyor

COMPRESSION

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
204-1301	1	Booster Compressor
204-1602	1	Booster Compressor Bypass Cooler
204-2201	1	Booster Compressor Feed K.O. Drum

SATURATION AND SHIFT CONVERSION

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
205-1101	1 + 1	Saturator Circulating Pump
205-1102	1 + 1	Process Gas Condensate Pump
205-1501	1	Start-up Shift Gas Heater
205-1601	1	Gas-Gas Exchanger
205-1602	1	Saturator Water/Gas Exchanger
205-1603	1	Methanator Feed Gas Reheater
205-1604	1	Deminieralized Water Heater
205-1605	1	Trim Gas Cooler
205-1606	1	Process Gas Condensate Cooler
205-2201	1	Saturator
205-2202	1	Process Gas K.O. Drum No. 1
205-2203	1	Process Gas K.O. Drum No. 2
205-2204	1	Process Gas K.O. Drum No. 3
205-2205	1	High Temperature Shift Reactor

ACID GAS REMOVAL

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
207-2501	1	Benfield Acid Gas Removal System Includes the following major equipment: Absorber Regenerator Flash Tank Feed Gas Separator Acid Gas Separator Solution Pump Reflux Pump K_2CO_3 Reboiler Acid Gas Condenser

PRIMARY METHANATION

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
206-1301	1	Circulator
206-1601	1	Methanator Feed Gas Heater
206-1602	1	Saturator Water/Methanator Gas Exchanger
206-2201	1	Primary Methanation Reactor

FINAL METHANATION AND DRYING

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
208-1301	1	Product Gas Compressor
208-1601	1	Final Methanator Preheater
208-1602	1	Product Gas Cooler
208-1603	1	Interstage Cooler
208-1604	1	Compressor Discharge Cooler
208-2201	1	Final Methanator
208-2202	1	Pdt. Gas Condensate K.O. Drum
208-2203	1	Compressor Intercooler K.O. Drum
208-2204	1	Compressor Discharge K.O. Drum
208-2501	1	Product Gas Drying Package

CATALYST REGENERATION

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
209-1301	2	Inert Gas Compressor
209-1601	1	Compressor Suction Inert Gas Cooler
209-1602	1	Compressor Discharge Inert Gas Cooler
209-1603	1	Inert Gas Heater
209-1604	1	Inert Gas Exhaust Cooler
209-1701	1	Inert Gas Vent Baghouse
209-2201	1	Regenerator #1
209-2202	1	Regenerator #2
209-2203	1	Compressor Suction Knock-out Drum
209-2204	1	Aftercooler Knock-out Drum
209-2301	1	Spent Catalyst Storage
209-2302	1	Regenerated Catalyst Storage
209-2501	1	Spent Catalyst Conveyor
209-2502	1	Stored Catalyst Conveyor (to Regenerator)
209-2503	1	Regenerator Catalyst Conveyor (to Storage)

WASTEWATER TREATMENT

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
210-1101	1 + 1	Neutralizing Basin Circulation Pump
210-1102	1 + 1	Boiler Ash Wash Pump
210-1103	1 + 1	Lime Solution Pump
210-1104	1 + 1	Boiler Ash Sludge Pump
210-1105	1 + 1	Biological Sludge Pump
210-1201	2	Lime Solution Tank Agitator
210-1301	1	Lime Conveying Blower
210-1701	1	Lime Storage Hopper Bag Filter
210-2101	1	Lime Rotary Feeder
210-2301	1	Neutralizing Basin
210-2302	3	Sludge Lagoons
210-2303	1	Boiler Ash Slurry Settling Basin
210-2304	1	Lime Storage Hopper
210-2305	2	Lime Solution Tank
210-2501	1	Biological Treating Package

RAW WATER TREATING AND COOLING WATER

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
211-1101	1 + 1	Firewater Pump
211-1102	1 + 1	Firewater Jockey Pump
211-1103	1 + 1	Raw Water Feed Pump
211-1104	1 + 1	Sand Filter Pressure Pump
211-1105	1 + 1	HP Demin. Water Pump
211-1106	1 + 1	Potable Water Pump
211-1107	2 + 1	Cooling Tower Circulation Pumps
211-1108	1 + 1	Demin. Water Pump
211-1401	2	Sand Filter
211-1402	1	Cooling Tower Sidestream Filter
211-1403	2	Activated Carbon Filter
211-1404	1	Raw Water Clarifier
211-1601	1	Cooling Tower
211-2301	1	Demin. Water Storage Tank
211-2302	1	Potable Water Storage Tank
211-2303	1	Raw Water Settling Basin
211-2304	1	BFW Clearwell
211-2501	1	Water Treatment Chemical Feed Package
211-2502	1	Demin. Water Package
211-2503	1	Cooling Tower Chemical Injection Package

BOILER AND BOILER FEEDWATER SYSTEM

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
212-1101	2 + 1	BFW Pump
212-1701	1	Boiler Char Collector
212-2201	1	Boiler Blowdown Flash Drum
212-2202	1	Deaerator
212-2301	1	Char Bunker
212-2302	1	Ash Slurry Tank
212-2303	1	Char Storage Bins
212-2304	1	Dryer Char Storage Bins
212-2501	1	Char/Gas Fired Boiler
212-2502	1	BFW Chemical Injection Package
212-2503	1	Char Conveying to Storage
212-2504	1	Char Conveying to Boiler
212-2505	1	Char Loadout Conveying
212-2506	1	Char Conveying to Dryer

MISCELLANEOUS UTILITIES

EQUIPMENT NUMBER	NUMBER REQUIRED	DESCRIPTION
213-1101	1	Carbonate Charging Pump
213-1301	1	CO_2 Compressor
213-1501	1	Flare Stack
213-1601	1	CO_2 Aftercooler
213-2201	1	CO_2 Surge Drum
213-2202	1	CO_2 Aftercooler K.O. Drum
213-2301	1	Diesel Fuel Tank
213-2302	1	Carbonate Storage Tank
213-2501	1	Instrument Air Package
213-2502	1	CO_2 Drying System

F. Detailed Equipment List

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

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

1. Wood Storage

Equipment Number	Number Required	Description
201-1001	2	Rechippers T - Drum chipper C - 40 tons/hr
201-1401	1	Tramp Iron Separator T - Magnetic
201-1402	4	Primary Screens T - Vibrating S - 8' x 20"
201-1403	2	Secondary Screens T - Vibrating S - 8' x 20'

201-1801	2	Weigh Scale T - Truck C - 50 tons
201-1901	6	Truck Dumpers T - Hydraulic C - 50 Tons
201-2101	6	Dumper Feeders to Storage T - Chain S - 30' ctrs. x 8' lift C - 24,000 ft^3/hr M - CS Drive - 40 hp
201-2102	2	Storage Stacker Conveyors 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
201-2103	14	Chip Reclaimers T - Chain S - 8' w. x 60' ctrs. x 10' lift C - 70,000 ft^3/hr M - CS D - 40 hp

201-2104	2	<u>Reclaim Conveyors</u> T - Belt S - 60" w. x 3,220' C - 70,000 ft^3/hr M - CS D - 100 hp
201-2105	1	<u>Collecting Conveyor</u> T - Belt S - 60" w x 600' C - 70,000 ft^3/hr M - CS D - 75 hp
201-2106	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
201-2107	1	<u>Oversize Conveyor</u> T - Belt C - 8,000 ft^3/hr
201-2108	1	<u>Trash Conveyor</u> T - Belt
201-2109	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

201-2110	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
201-2111	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
201-2112	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
201-2113	1	<u>Fines Conveyor</u> T - Belt
201-2301	6	<u>Truck Dump Hoppers</u> T - Open w/grate bottom S - 14' x 14' plan M - CS
201-3901	4	<u>Bulldozer</u> T - Caterpillar D8G

2. Wood Drying

202-1601	6	Wood Dryers T - Rotary Drum S - 16' ø x 30' C - 800 ton/day of wood from 50% to 10% H_2O M - CS
202-1801	1	Dried Chip Feeder T - Rotary table S - 17' ø C - 23,000 ft^3/hr M - CS D - 30 hp
202-2101	2	Dryer Distribution Conveyors T - Chain S - 48" w x 150' C - 18,000 ft^3/hr M - CS D - 50 hp
202-2102	2	Dried Wood Collecting Conveyors T - Belt S - 42" w x 100' C - 17,000 ft^3/hr M - CS D - 15 hp
202-2103	1	Dried Wood to Storage Conveyor T - Belt S - 60" x 100' C - 1,200 ton/hr of chips D - 30 hp

202-2104	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
202-2105	1	<u>Gasifier Distribution Diverter</u> T - Three-way, pneumatically operated
202-2106	1	<u>Gasifier Distribution Conveyors</u> T - Belt S - 42" w x 80' C - 23,000 ft^3/hr M - CS D - 15 hp

3. Gasification

203-1102	3	Ash Slurry Pump T - Vertical centrifugal C - 25 gpm @ 50 psi P M - 304 SS D - 3 hp electric motor
203-1301	3 + 3	Combustion Air Blower T - Centrifugal C - 18,000 acfm @ 60°F & 5 psi ΔP M - CS D - 500 hp
203-1401	3	Char-Catalyst Screen T - Vibrating screen S - 5' Ø M - CS w/304SS mesh
203-1402	3	Magnetic Separator T - Induced magnetic roll separator C - 5 ton/hr of char catalyst S - 30" wide roll
203-1501	3	Gasifier Heater T - Forced draft combustion chamber C - 30 MM Btu/hr heat release w/char combustion
203-1601	3	HT Steam Superheater T - Shell & tube A - 610 ft^2 (2 MM Btu/hr) M - Shell - CS, refractory-lined; Tubes, 310 SS Des P/T - Shell - 15 psia/650°F Tubes - 675 psig/1100°F

203-1602	3	<u>Steam Superheater</u> T - Shell & tube A - 200 ft^2 (3.1 MM Btu/hr) M - Shell - CS, refractory-lined; Tubes - CS Des P/T - Shell - 160 psig/650°F Tubes - 675 psig/825°F
203-1603	3	<u>Gasifier WH Boiler</u> T - Shell & Tube A - 760 ft^2 (8.8 MM Btu/hr) M - Shell - CS refractory-lined; Tubes - CS Des P/T - Shell - 180 psig/650°F Tubes - 675 psig/550°F
203-1604	3	<u>Gasifier Heater WH Boiler</u> T - Shell & tube A - 500 ft^2 (9.7 MM Btu/hr) M - Shell - CS, refractory-lined; Tubes - CS Des P/T - Shell - 15 psig/650°F Tubes - 675 psig/550°F
203-1605	3	<u>BFW Heater</u> T - Shell & tube A - 980 ft^2 (6.9 MM Btu/hr) M - CS Des P/T - Shell - 160 psig/650°F Tubes - 675 psig/550°F

203-1607	3	<u>Combustion Air Preheater</u> T - Shell tube A - 8,600 ft^2 M - Shell - CS, refractory-lined; Tubes - CS Des P/T - Tubes - 15 psig/550°F Shell - 15 psig/650°F
203-1701	3	<u>Cyclone</u> T - Centrifugal C - 2,600 acfm @ 150 psia, 350°F S - 3' ø M - CS Des P/T - 160 psig/650°F
203-1702	3	<u>Raw Gas Bag Filter</u> T - Bag filter C - 2,600 acfm @ 150 psia, 350°F M - CS Des P/T - 160 psig/400°F
203-1703	3	<u>Ventilation Bag Filter</u> T - Bag filter C - 1,500 acfm M - CS w/Nomex bags Des P/T - Atm./350°F
203-1704	3	<u>Heater Dust Collector</u> T - Bag filter C - 25,000 acfm M - CS w/Nomex bags Des P/T - Atm./350°F

203-2101	9	<u>Gasifier Feed Screw</u> T - Screw conveyor
203-2102		<u>Char Overflow Feeder</u> T - Rotary valve C - 5 t/hr M - CS D - 2 hp electric motor
203-2103		<u>Waste Heat Boiler Discharge Feeder</u> T - Rotary valve C - 5 t/hr M - CS D - 2 hp electric motor
203-2104	3	<u>Cyclone Discharge Feeder</u> T - Rotary valve C - 5 t/hr M - CS D - 2 hp electric motor
203-2106	3	<u>Bag Filter Discharge Feeder</u> T - Rotary valve C - 5 t/hr M - CS D - 2 hp electric motor
203-2109	9	<u>Double Screw Feeder</u> T - Screw Conveyors
203-2201	3	<u>Gasifier</u> T - Cylindrical vessel S - 15' ID (17' OD) x 45' T/T M - CS, refractory lined Des P/T - 175 psia/650°F

203-2202	1	<u>Steam Drum</u> T - Horizontal S - 5' 5" x 11' T-T M - CS Des P/T - 675 psig/550°F
203-2203	1	<u>BD Flash Drum</u> T - Vertical S - 8" ø x 3' T-T M - CS Des P/T - 75 psig/350°F
203-2301	3	<u>Char Surge Hopper</u> T - Cylindrical bin w/60° conical bottom S - 8" ø x 18' total M - CS Des P/T - Atm/400°F
203-2302	3	<u>Catalyst Hopper</u> T - Cylindrical bin w/60° conical bottom S - 2' ø x 6' straight sides M - CS Des P/T - 15 psig/400°F
203-2303	3	<u>Char Storage Bin</u> T - Cylindrical bin w/60° conical bottom S - 20' ø x 40' straight sides M - CS Des P/T - Atm/400°F

203-2304	3	<u>Wood Surge Bin</u> T - Cylindrical bin w/conical bottom S - 20' Ø x 17' straight sides M - CS Des P/T - Atm/150°F
203-2305	3	<u>Ash Slurry Tank</u> T - Open top S - 3' Ø x 3' M - CS Des P/T - Atm/200°F
203-2306	3	<u>Char-Catalyst Surge Bin</u> T - Cylindrical bin w/conical bottom S - 8' Ø x 18' OAH M - CS Des P/T - Atm/400°F
203-2501	3	<u>Char-Catalyst Lock Hopper Assembly</u> T - Double chamber lock hopper assembly C - 1500 ft^3/hr of char-catalyst from 150 psia to atm
203-2502	9	<u>Wood Feed Lock Hopper Assembly</u> T - Double chamber lock hopper assembly C - 2000 ft^3/hr of wood from atm. to 150 psia

203-2503	3	<u>Catalyst Feed Lock Hopper Assembly</u> T - Double chamber lock hopper assembly C - 20 ft^3/hr of catalyst from atm. to 150 psia
203-2504	3	<u>Char-Catalyst Screen Feed Conveyor</u> T - Pneumatic C - 1600 ft^3/hr S - 20' x 100' lift
203-2505	3	<u>Spent Catalyst to Storage Conveyor</u> T - Pneumatic C - 6 ft^3/hr S - 60' x 30' lift

4. Catalyst Regeneration

209-1301	2	Inert Gas Compressor T - Centrifugal C - 23.25 scfm @ 20 psi Δ P M - CS w/304 SS inlet wheel D - 250 hp
209-1601	1	Compressor Suction Inert Gas Cooler T - Sheet & tube A - 2,900 ft^2 M - Shell - CS; Tubes - 304SS Des P/T - Shell - 75 psig/150°F Tubes - 50 psig/250°F
209-1602	1	Compressor Discharge Inert Gas Cooler T - Shell & tube A - 130 ft^2 M - Shell - CS; Tubes - 304SS Des P/T - Shell - 75 psig/150°F Tubes - 50 psig/400°F
209-1603	1	Inert Gas Heater T - Shell & tubes A - 10 ft^2 M - CS Des P/T - Shell - 50 psig/550°F Tubes - 650 psig/550°F
209-1604	1	Inert Exhaust Gas Cooler T - Shell & tube A - 20 ft^2 M - CS Des P/T - Shell - 50 psig/550°F Tubes - 75 psig/150°F

209-1701	1	<u>Inert Gas Vent Baghouse</u> T - Bag filter C - 1500 acfm M - CS w/Nomex bags Des P/T - Atm/350°F
209-2201	1	<u>Regenerator No. 1</u> T - Cylindrical, conical bottom S - 7' ø x 17' straight sides M - CS, refractory lined Des P/T - 200 psia/1200°F
209-2202	1	<u>Regenerator No. 2</u> T - Cylindrical, conical bottom S - 7' ø 17' straight sides M - CS, refractory lined Des P/T - 200 psia/1200°F
209-2203	1	<u>Compressor Suction Knock-Out Drum</u> T - Vertical S - 3' ø x 6' T-T M - 304SS Des P/T - 20 psig/250°F
209-2204	1	<u>After Cooler Knock-out Drum</u> T - Vertical S - 2 1/2 ø x 5' T-T M - 304 SS Des P/T - 50 psig/400°F

209-2301	1	<u>Spent Catalyst Storage</u> T - Rectangular hopper w/double discharge S - 7' x 14 1/2' x 28' OAH M - CS Des P/T - Atm/150°F
209-2302	1	<u>Regenerated Catalyst Storage</u> T - Rectangular hopper w/double discharge S - 7' x 14 1/2' x 28' OAH M - CS Des P/T - Atm/150°F
209-2501	1	<u>Spent Catalyst to Regenerator Conveyor</u> T - Pneumatic C - 570 ft^3/hr
209-2502	1	<u>Spent Catalyst to Regenerator Conveyor</u> T - Pneumatic C - 570 ft^3/hr
209-2503	1	<u>Regenerated Catalyst to Gasifier Conveyor</u> T - Pneumatic C - 36 ft^3/hr

IX. CAPITAL COST ESTIMATE AND SCALING FACTORS DISCUSSION

This section includes the Capital Cost Estimate for the wood-to-methane plant. Total plant costs are indicated as well as costs by plant area. The capital cost is $95,115,000--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 100 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 38.5% 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 $58,220,000; for 500 tons per day, $35,980,000; for 100 tons per day, $12,170,000. The overall plant factor is about 0.70. 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.

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EXECUTIVE SUMMARY

WOOD TO METHANE

		COST	% OF T.I.C.
Equipment		$ 33,320M	32.3
Direct Purchase Material		10,690	10.3
Subcontract:	Material	590	0.6
	Labor (385 M-MHR)	10,370	10.0
Direct Hire Labor (685 M-MHR)		8,780	8.5
S/T Direct Costs		$ 63,750M	61.7
Field Indirects		14,490	14.0
Pro-Services		15,230	14.7
Other		1,645	1.6
9/12/80 T.I.C.		$ 95,115M	92.0
ESCALATION		8,185	8.0
Escalated T.I.C.		$103,300M	100.0

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

DM-2207

NC-5471
9/12/80

CLIENT: Battelle Pacific Northwest Laboratories

LOCATION: Newport, Oregon

PROJECT: 2,000 TPD of Wood to Methane

TYPE OF ESTIMATE: Class VI (±25%) Total Installed Cost

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

- Revision 0 of the Project Description of Feasibility Studies for: Wood to Methanol and Wood to Methane dated 6/80
- Four line equipment list developed by Process Engineering
- Preliminary drawing of the Wood Gasifier (Tag #203-2201)
- Preliminary layout drawing of the Wood Sizing, Storage, and Drying areas

SCOPE OF WORK: Davy McKee is to determine the economic feasibility of producing methane 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:

201 - Wood Storage and Sizing
202 - Wood Drying
203 - Gasification
204 - Compression
205 - Shift Conversion
206 - Primary Methanation
207 - Acid Gas Removal
208 - Final Methanation and Product Gas Drying
209 - Catalyst Regeneration
210 - Waste Water Treating
211 - Raw Water Treating and Cooling Water
212 - Boilers and Boiler Feedwater System
213 - Miscellaneous Utility System

SCHEDULE:

The following schedule was assumed based on historical information:

Engineering:	Start		10/01/80
	Completion		2/01/82
	Duration	16 Months	
Procurement:	Start		4/01/81
	Completion		8/01/82
	Duration	16 Months	
Construction:	Start		4/01/81
	Completion		2/01/83
	Duration	22 Months	
TOTAL PROJECT DURATION		28 Months	

ESTIMATE APPROACH:

The following paragraphs outlines the techniques used for the entire project.

MAJOR EQUIPMENT ($12,917M Direct, 12.5% of TIC)
($20,399M S/C Equip. Mat'l Portion 19.8% 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.

ESTIMATE APPROACH: (continued)

MAJOR EQUIPMENT (continued)

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

	$-M	%
Vendor Budget Quotes	$21,167M	63.5%
In-house Pricing	6,594	19.8
Factored	5,555	16.7
	$33,316M	100.0%

DIRECT PURCHASE ($10,686M, 10.3% of TIC)

All materials including Piping, Civil, Structural Steel, Electrical, Instrumentation, Insulation, Painting, Fireproofing, and Miscellaneous except those in Areas 201, 202, and 207 were factored to equipment. The material to equipment factors used were developed by area based on recent gasification plant estimates. Materials except for Civil for Area 201 and 202 were included with the vendor quote. The Civil work was estimated utilizing preliminary site layouts for these areas. Area 207 was quoted on a Total Installed Cost basis, therefore indicated all materials.

The material purchase strategy (i.e., direct purchase vs. subcontractor purchased) 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 $592M, 0.6% of TIC)
(Labor $10,368M, 10.0% 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

ESTIMATE APPROACH:
(continued)

SUBCONTRACTS (continued)

Subcontract labor man-hours for bulk materials were factored to S/C material dollars on a man-hour per 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.

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 ($8,786M, 8.5% 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 Qualifications (other than piping)

ESTIMATE APPROACH: (continued)

FIELD INDIRECTS ($14,490M, 14.0% 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 for payroll burdens were developed on a percent to direct hire direct labor basis using historical data on completed projects.

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

PROFESSIONAL SERVICES ($15,230M, 14.7% 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 & Overhead were established at 118.9% of H.O. Salaries; 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) Overhead)	118.9% x Salaries
Fee: Pro-Services	7.5% x Pro-Service Cost
Construction	2.0% x TIC

INSURANCE ($1,500M, 1.5% 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 based on recent gasification estimates.

TAXES

There are no applicable sales or use taxes in Oregon.

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ESTIMATE APPROACH: (continued)

ROYALTIES AND COMMISSIONS

A one-time, paid-up license fee of $145M for the Benfield process is included. This fee was quoted by Benfield and is the only royalty or commission required.

ESCALATION ($8,184M, 8.0% 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	12,917	10.4	1,343
Direct Materials	10,686	10.1	1,079
Subcontract (E, M, & L)	31,359	9.8	3,073
D/H Labor	8,786	8.7	764
S/T Directs	63,748	9.8	6,259
Field Indirects	12,472	9.5	1,185
Professional Services	14,600	5.1	740
TOTAL	90,820	9.0	8,184

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 the thoroughness of technique used to establish quantities and the reliability of the unit prices used in the estimate.

The analysis resulting from MAC indicates a Total Plant Accuracy of 24.6% (rounded = ±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 overrun; 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
McKee
M-292 Rev. 5/79
ESTIMATE NO. NC-5471

SCHEDULE: AWARD DATE 10/1/80
MECH. COMPL.: 2/1/83 28 MO.
CONSTR. START: 4/1/80 22 MO.

CLIENT: BATTELLE PACIFIC NORTHWEST LABORATORIES
PLANT: 2000 TPD WOOD TO METHANE
LOCATION: NEWPORT, ORE DATE: 9/12/80

ITEM	PROJECT SUMMARY SHEET (ALL AMOUNTS IN 1000'S)	MH DATA	
1	EQUIPMENT		12917
2	MATERIAL		10686
3	SUBCONTRACT: MAT'L. 20991 LABOR 10368	385	31359
4	LABOR	685	8786
5	PREMIUM TIME S/C ___ D.L. ___		
6	ESCALATION: EQUIP. 1343 ; MAT'L. 1079 ; S/C 3073 ; LABOR 764		6259
7	SUB TOTAL DIRECT COST	1070	70007
8	CONSTR. SUPERVISION: W: 1344 O.C. 334	90	1678
9	FIELD OFFICE LABOR	63	474
10	AUXILIARY LABOR	58	747
11	TEMPORARY CONSTRUCTION: MAT'L. ___ ; S/C ___ ; LABOR ___		1116
12	CONSTRUCTION EQUIPMENT: EQUIP. ___ LABOR ___		1819
13	SMALL TOOLS ___ CONSUMABLES ___		817
14	FIELD OFFICE COST		220
15	PAYROLL BURDEN		5601
16	ESCALATION		1185
17	SUB TOTAL FIELD INDIRECT COST	211	13657
	ESCALATION (@ 5.1% x P.S.)		740
18	ENGINEERING W: 5750 O.C. 1600	523	7350
19	PROCUREMENT W: @ 9% x D.C. O.C. @ 28% x SAL		
20	H.O. CONSTRUCT. SUPPORT W: ___ O.C. ___		
21	COMPANY FRINGES ON P.S. COST @ 118.9 % OF $ 5750 INCLUDED		6820
22	SUB TOTAL PROFESSIONAL SERVICES	523	14910
23	SUB TOTAL ESTIMATED COST ITEMS 7, 17 & 22		98574
24	CONTINGENCY: D.C. ___ F.I.C. ___ P.S. ___ O.C. ___		
25	ROYALTIES & COMMISSIONS		145
26	TAXES		
27	INSURANCE		1500
28	SUB TOTAL OTHER COST		1645
29	OVERHEAD: ___ % OF P.S. ; ___ % OF CONSTR. SUPERV.		INCLUDED
30	FEE: PROFESSIONAL SERVICES @ 7.5% x SAL		1060
31	FEE: CONSTRUCTION @ 2.0 % x TIC		2021
32	TOTAL PROJECT COST CLASS VI (±25%)		103300

APPROVED: [signature]

PAGE OF

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

ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT: 2000 TPD WOOD TO METHANE	PLANT AREA: ALL AREAS	PROJECT NO.: NC-5471	
LOCATION: NEWPORT, ORE.	OWNER: BATTELLE PACIFIC NORTHWEST LABORATORIES	BY: CJH	DATE: 9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			12917	20399	342.7		9239	29638	58.7		754	43309		
	PIPING			5450						249.4		3201	8651		
	CIVIL			1820						258.2		3315	5135		
	STRUCTURAL STEEL			1618						25.1		323	1941		
	ELECTRICAL			131	324	15.6		421	745				876		
	INSTRUMENTS			1446						61.9		793	2239		
	INSULATION				168	12.3		332	500				500		
	PAINTING				72	8.7		234	306				306		
	FIREPROOFING				28	5.3		142	170				170		
	MISCELLANEOUS			221						31.2		400	621		
	TOTAL			23603	20991	384.6		10368	31359	684.5		8786	63748		

DIRECT COST SUMMARY SHEET

Davy McKee

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	TOTAL PLANT - DIRECT COST SUMMARY	NC-5471	
LOCATION	OWNER	BY	DATE
NEWPORT, ORE	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
201	WOOD STORAGE & SIZING			1239	9598	156.4		4216	13,814	206.5		2651	17,704		
202	WOOD DRYING				4730	77.6		2091	6,821				6,821		
203	GASIFICATION			8606	460	30.1		812	1272	164.2		2108	11,986		
204	COMPRESSION			1610	22	1.5		40	62	19.8		254	1926		
205	SHIFT CONVERSION			2309	52	4.1		110	162	41.2		527	2998		
206	PRIMARY METHANATION			1749	26	1.9		51	77	28.5		366	2192		
207	ACID GAS REMOVAL				1322	30.5		821	2143				2143		
208	FINAL METHANATION & PRODUCT GAS DRYING			2198	114	3.6		98	212	43.2		554	2964		
209	CATALYST REGENERATION			1220	17	1.2		32	49	19.0		243	1512		
210	WASTE WATER TREATING			463	649	17.3		467	1116	17.3		222	1801		
211	RAW WATER & COOLING WATER			941	727	16.1		433	1160	29.7		382	2483		
212	BOILERS & BFW SYSTEM			2049	3222	42.3		1142	4364	68.2		877	7290		
213	MISC. UTILITY SYSTEMS			1219	52	2.0		55	107	46.9		602	1928		
	TOTAL			23603	20991	384.6		10368	31359	684.5		8786	63748		

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DIRECT COST SUMMARY SHEET
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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT: 3000 TPD WOOD TO METHANE
PLANT AREA: 201 - WOOD STORAGE & SIZING
PROJECT NO.: NC-5471
LOCATION: NEWPORT, ORE
OWNER: BATTELLE PACIFIC NORTHWEST LABORATORIES
BY: CJH
DATE: 9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT & BULKS (EXCL CIVIL)				9598	156.4		4216	13814				13814		
	CIVIL			1239						206.5	12.84	2651	3890		
	TOTAL			1239	9598	156.4		4216	13814	206.5	12.84	2651	17,704		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	202 - WOOD DRYING	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT & BULKS (EXCL. CIVIL)				4730	77.6		2091	6821				6821		
	CIVIL			INCLUDED IN AREA 201											
	TOTAL				4730	77.6		2091	6821				6821		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT: 2000 TPD WOOD TO METHANE	PLANT AREA: 203 - GASIFICATION	PROJECT NO.: NC-5471	
LOCATION: NEWPORT, ORE.	OWNER: BATTELLE PACIFIC NORTHWEST LABORATORIES	BY: CJH	DATE: 9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			5032	201	9.8	26.96	265	466	27.2	12.84	349	5847		
	PIPING			1502						67.6	↓	868	2370		
	CIVIL			230						20.0	↓	257	487		
	STRUCTURAL STEEL			1162						16.3	↓	209	1371		
	ELECTRICAL			87	138	6.5	26.96	175	313		↓		400		
	INSTRUMENTS			508			↓			22.4	↓	288	796		
	INSULATION				58	4.6	↓	124	182		↓		182		
	PAINTING				42	5.2	↓	140	182		↓		182		
	FIREPROOFING				21	4.0	↓	108	129		↓		129		
	MISCELLANEOUS @ (1% M + 7% L)			85			↓			10.7		137	222		
	TOTAL			8606	460	30.1		812	1272	164.2		2103	11986		

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ALL MANHOURS & DOLLARS IN 1000'S

PROJECT: 2000 TPD WOOD TO METHANE
PLANT AREA: 204- COMPRESSION
PROJECT NO.: NC-5471
LOCATION: NEWPORT, ORE.
OWNER: BATTELLE PACIFIC NORTHWEST LABORATORIES
BY: CJH
DATE: 9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			1120						1.8	12.84	23	1143		
	PIPING			302						10.0		128	430		
	CIVIL			33						3.2		41	74		
	STRUCTURAL STEEL			23						0.4		5	28		
	ELECTRICAL			2	13	0.6	26.96	16	29				31		
	INSTRUMENTS			114						3.1		40	154		
	INSULATION				7	0.6		16	23				23		
	PAINTING				2	0.3		8	10				10		
	FIREPROOFING				—				—				—		
	MISCELLANEOUS @ (1% M + 7% L)			16						1.3		17	33		
	TOTAL			1610	22	1.5		40	62	19.8		254	1926		

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ALL MANHOURS & DOLLARS IN 1000'S

PROJECT	2000 TPD WOOD TO METHANE
LOCATION	NEWPORT, ORE.
PLANT AREA	205 - SHIFT CONVERSION
OWNER	BATTELLE PACIFIC NORTHWEST LABORATORIES
PROJECT NO.	NC-5471
BY	CJH
DATE	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			1454						2.4	12.84	31	1485		
	PIPING			586						25.8		331	917		
	CIVIL			49						4.3		55	104		
	STRUCTURAL STEEL			52						1.3		17	69		
	ELECTRICAL			10	18	0.9	26.96	24	42				52		
	INSTRUMENTS			135						4.7		58	193		
	INSULATION				25	2.0		54	79				79		
	PAINTING				7	0.9		24	31				31		
	FIREPROOFING				2	0.3		8	10				10		
	MISCELLANEOUS @ (1% M + 7% L)			23						2.7		35	58		
	TOTAL			2309	52	4.1		110	162	41.2		527	2998		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	206 - PRIMARY METHANATION	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE.	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			1134						1.0	12.84	13	1147		
	PIPING			421						18.9		243	664		
	CIVIL			13						1.0		13	26		
	STRUCTURAL STEEL			56						1.0		13	69		
	ELECTRICAL			1	14	0.7	26.96	19	33				34		
	INSTRUMENTS			107						4.7		60	167		
	INSULATION				9	0.7		19	28				28		
	PAINTING				2	0.3		8	10				10		
	FIREPROOFING				1	0.2		5	6				6		
	MISCELLANEOUS @ (1% M + 7% L)			17						1.9		24	41		
	TOTAL			1749	26	1.9		51	77	28.5		366	2192		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD	207 - ACID GAS REMOVAL	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	TOTAL INSTALLED COST (QUOTED BY BENFIELD)				1322	30.5		821	2143				2143		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	203 - FINAL METHANATION & PRODUCT GAS DRYING	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE.	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			1396	80	1.0		27	107	1.9	12.84	24	1527		
	PIPING			550						24.8		318	868		
	CIVIL			16						1.3		17	33		
	STRUCTURAL STEEL			73						1.2		15	88		
	ELECTRICAL			2	17	0.8	26.96	22	39				41		
	INSTRUMENTS			139						11.2		144	283		
	INSULATION				12	1.0		27	39				39		
	PAINTING				3	0.4		11	14				14		
	FIREPROOFING				2	0.4		11	13				13		
	MISCELLANEOUS @ (1% M + 7% L)			22						2.8		36	58		
	TOTAL			2198	114	3.6		98	212	43.2		554	2964		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	209 - CATALYST REGENERATION	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE.	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			936						5.4	12.84	69	1005		
	PIPING			156						7.0	↓	90	246		
	CIVIL			31						2.9	↓	37	68		
	STRUCTURAL STEEL			33						0.6	↓	8	41		
	ELECTRICAL				8	0.4	26.96	11	19		↓		19		
	INSTRUMENTS			52			↓			1.9	↓	24	76		
	INSULATION				7	0.6	↓	16	23		↓		23		
	PAINTING				2	0.2	↓	5	7		↓		7		
	FIREPROOFING				—		↓		—		↓		—		
	MISCELLANEOUS @ (1% M + 7% L)			12						1.2		15	27		
	TOTAL			1220	17	1.2		32	49	19.0		243	1512		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	210 - WASTE WATER TREATING	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE.	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			161	630	15.8		426	1056	2.5	12.84	32	1249		
	PIPING			198						8.9		114	312		
	CIVIL			34						3.0		39	73		
	STRUCTURAL STEEL			21						0.6		8	29		
	ELECTRICAL			11	10	0.5	26.96	14	24				35		
	INSTRUMENTS			33						1.2		15	48		
	INSULATION				6	0.5		14	20				20		
	PAINTING				2	0.3		8	10				10		
	FIREPROOFING				1	0.2		5	6				6		
	MISCELLANEOUS @ (1%M + 7%L)			5						1.1		14	19		
	TOTAL			463	649	17.3		467	1116	17.3		222	1801		

DIRECT COST SUMMARY SHEET

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT: 2000 TPD WOOD TO METHANE

PLANT AREA: 211 - RAW WATER & COOLING WATER

PROJECT NO.: NC-5471

LOCATION: NEWPORT, ORE.

OWNER: BATTELLE PACIFIC NORTHWEST LABORATORIES

BY: CJH

DATE: 9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			390	676	12.6		339	1015	4.5	12.84	58	1463		
	PIPING			375						16.9		217	592		
	CIVIL			29						2.5		32	61		
	STRUCTURAL STEEL			34						0.9		12	46		
	ELECTRICAL			18	30	1.5	26.96	40	70				88		
	INSTRUMENTS			86						3.0		39	125		
	INSULATION				16	1.3		35	51				51		
	PAINTING				4	0.5		14	18				18		
	FIREPROOFING				1	0.2		5	6				6		
	MISCELLANEOUS @ (1% M + 7% L)			9						1.9		24	33		
	TOTAL			941	727	16.1		433	1160	29.7		382	2483		

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ALL MANHOURS & DOLLARS IN 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	212- BOILERS & BFW SYSTEM	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE.	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			862	3150	38.9	26.96	1050	4200	10.7	12.84	138	5200		
	PIPING			670						30.2	↓	388	1058		
	CIVIL			132						12.3		158	290		
	STRUCTURAL STEEL			140						2.4		31	171		
	ELECTRICAL				36	1.8	26.96	49	85				85		
	INSTRUMENTS			225			↓			8.1		104	329		
	INSULATION				28	1.0		27	55				55		
	PAINTING				8	0.6		16	24				24		
	FIREPROOFING				—				—				—		
	MISCELLANEOUS @ (1% M + 7% L)			20						4.5		58	78		
	TOTAL			2049	3222	42.3		1142	4364	68.2		877	7290		

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ALL MANHOURS & DOLLARS IN, 1000'S

PROJECT	PLANT AREA	PROJECT NO.	
2000 TPD WOOD TO METHANE	21[illegible] - MISCELLANEOUS UTILITY SYSTEM	NC-5471	
LOCATION	**OWNER**	**BY**	**DATE**
NEWPORT, ORE.	BATTELLE PACIFIC NORTHWEST LABORATORIES	CJH	9-12-80

CODE NO.	DESCRIPTION	MILESTONE QTY	MILESTONE UNIT	DIRECT P/O MATERIAL TOTAL $	SUBCONTRACT MATERIAL $	SUBCONTRACT LABOR MAN HRS.	SUBCONTRACT LABOR RATE	SUBCONTRACT LABOR TOTAL $	SUBCONTRACT GRAND TOTAL	DIRECT HIRE LABOR MAN HRS.	DIRECT HIRE LABOR RATE	DIRECT HIRE LABOR TOTAL $	GRAND TOTAL $	PERCENTAGES ITEM TO CAT	PERCENTAGES ITEM TO TOTAL
	EQUIPMENT			432	12	0.1		4	16	1.3	12.84	17	465		
	PIPING			690						39.3		504	1194		
	CIVIL			14						1.2		15	29		
	STRUCTURAL STEEL			24						0.4		5	29		
	ELECTRICAL				40	1.9	26.96	51	91				91		
	INSTRUMENTS			47						1.6		21	68		
	INSULATION				—				—				—		
	PAINTING				—				—				—		
	FIREPROOFING				—				—				—		
	MISCELLANEOUS @ (1%M + 7%L)			12						3.1		40	52		
	TOTAL			1219	52	2.0		55	107	46.9		602	1928		

X. Operating Cost Estimate

The production cost of SNG 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 $95,115,000--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 show in Table II. The total capital requirement for this plant is $115,191,000.

The annual direct operating costs have been calculated and are shown in Table III. These costs include raw materials, utilities, catalysts and chemicals, labor, administration and general overhead, supplies, and taxes and insurance, with a credit for by-product char. Total maintenance costs were calculated as percentage of plant investment as suggested by the guidelines. The annual costs are $29,990,000. 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/dry ton for wood, which is the value used for the base case shown in Table III, wood costs are almost 50% of the total direct costs and almost a third of the total production costs using utility financing. Thus, either lowering the wood cost or improving yields from the wood would 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 delivered to the plant, and the impact is illustrated in Figure 1.

In Tables IV and V the methods for calculating production costs are given 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 SNG production costs are $5.09, $5.56, $6.50, and $8.34 per MM Btu for wood prices of $5, $10, $20, and $40 per dry ton. For private investor financing, the SNG production costs are $6.62, $7.11, $8.10, and $10.06 per MM Btu for the corresponding wood costs.

TABLE II

TOTAL CAPITAL REQUIREMENT	$ 1,000
Total Plant Investment	$ 95,115
Allowance for funds During Construction (Total Plant Investment x 1.25 years x 0.09)	$ 10,698
Start-up Costs (20% of Total Annual Gross Operating Costs)	$ 6,084
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]	$ 3,294
Total Capital Requirement	$115,191

TABLE III

ANNUAL DIRECT OPERATING COSTS

Operating Factor: 330 days/years

COST COMPONENT	ANNUAL USE	COST $/UNIT	COST $1000/YR.
Raw Material			
Wood	660,000 dry tons	20/dry ton	13,200
Utilities			
Water	332,640 Mgal	0.50/Mgal	166
Electricity	3.25×10^7 kWh	0.03/kWh	974
Diesel Fuel	108,900 gal	1.00/gal	109
Catalysts and Chemicals			
Chemicals			510
Shift Catalysts	1500 ft^3	107/ft^3	160
Methanation Catalysts	1020 ft^3	435/ft^3	444
Gasifier Catalyst	380,160 lb	8.51/lb	3,235
Labor			
Process Operating	51 men @ 2080 hr.ea.	10.70/hr	1,135
Maintenance @	60% of total maintenance		2,527
Supervision @	20% of process operating and maintenance labor		732
Administration and General Overhead			
@	60% of total labor		2,636
Supplies			
Operating @	30% of process operating labor		340
Maintenance @	40% of total maintenance		1,685

Taxes and Insurance			
@	2.7% of total plant investment		2,568
Total Gross Operating Cost per Year			30,421
By-Product Credits			
Char	28,050 tons	$15.35/ton	(431)
Total Net Operating Cost per Year			29,990

TABLE IV

GAS COST - UTILITY FINANCING METHOD

BASIS:

20-year 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 Gas Production, 10^{12} Btu/year

d = Fraction debt

i = Interest on debt, %/year

r = Return on equity, %/year

p = Return on rate base, %/year

EQUATION FOR RETURN ON RATE BASE

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

GENERAL GAS COST EQUATION

Average Gas Cost, \$/MM Btu =

$$\frac{N + 0.05\,(C-W) + 0.005\,[p + 48/52\,(1-d)\,r]\,(C + W)}{G}$$

CALCULATION

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

Average gas cost, \$/MM Btu =

$$\frac{29.990+(0.05)(115.171-3.294)+(0.005)[11.25+(48/52)(1-0.75)(15)](115.171+3.294)}{6.811}$$

$$= \quad 6.50$$

TABLE V

GAS 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 \$/year

G = Annual gas production, 10^{12} Btu/year

GAS COST EQUATION AT 12% DCF RETURN

Gas cost, \$/10^6 Btu =

$$\frac{N + 0.247I + 0.1337S + 0.2305W}{G}$$

CALCULATION

Gas cost, \$/10^6 Btu =

$$= \frac{29.990 + (0.247)(95.095) + (0.1337)(6.084) + (0.2305)(3.748)}{6.811}$$

= 8.10

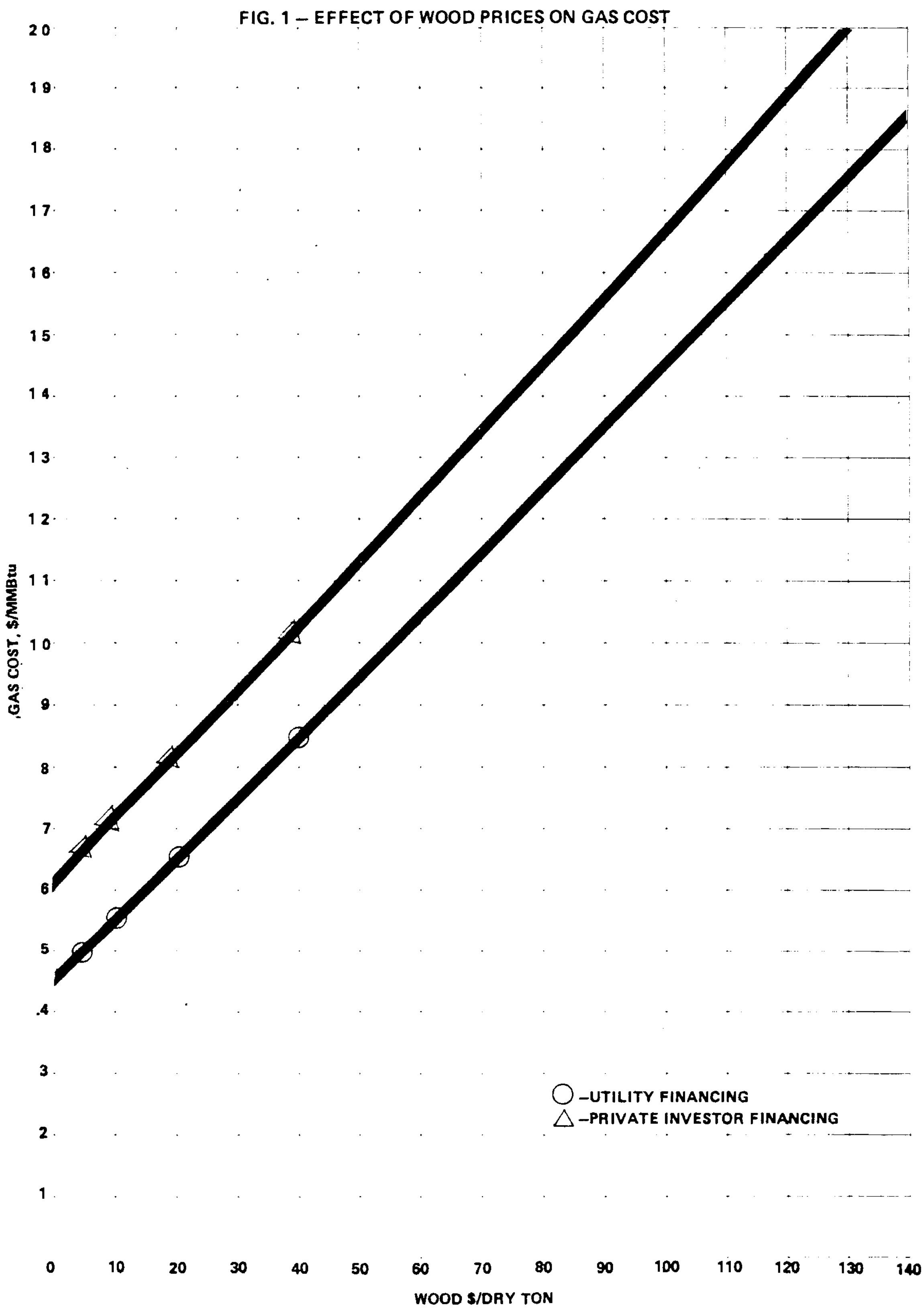

FIG. 1 – EFFECT OF WOOD PRICES ON GAS COST
GAS COST, $/MMBtu
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
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120
130
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