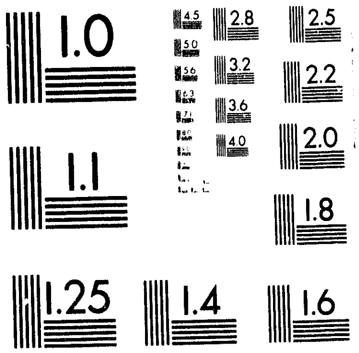
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INFORMAL REPORT

HYNOL - AN ECONOMIC PROCESS FOR METHANOL PRODUCTION FROM BIOMASS AND NATURAL GAS WITH REDUCED CO_2 EMISSION

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Yuanji Dong* and Meyer Steinberg**

ABSTRACT

The Hynol process is proposed to meet the demand for an economical process for methanol production with reduced CO_2 emission. This new process consists of three reaction steps: (a)hydrogasification of biomass, (b)steam reforming of the produced gas with additional natural gas feedstock, and (c)methanol synthesis of the hydrogen and carbon monoxide produced during the previous two steps. The H_2-rich gas remaining after methanol synthesis is recycled to gasify the biomass in an energy neutral reactor so that there is no need for an expensive oxygen plant as required by commercial steam gasifiers. Recycling gas allows the methanol synthesis reactor to perform at a relatively lower pressure than conventional while the plant still maintains high methanol yield. Energy recovery designed into the process minimizes heat loss and increases the process thermal efficiency.

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If the Hynol methanol is used as an alternative and more efficient automotive fuel, an overall 41% reduction in CO_2 emission can be achieved compared to the use of conventional gasoline fuel. A preliminary economic estimate shows that the total capital investment for a Hynol plant is 40% lower than that for a conventional biomass gasification plant. The methanol production cost is $0.43/gal for a 1085 millon gal/yr Hynol plant which is competitive with current U.S. methanol and equivalent gasoline prices. Process flowsheet and simulation data using biomass and natural gas as cofeedstocks are presented. The Hynol process can convert any condensed carbonaceous material, especially municipal solid waste (MSW), to produce methanol.

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INTRODUCTION

Methanol is an industrially important chemical feedstock used mainly in the manufacture of formaldehyde. It is also used in the manufacture of dimethyl terephthalate, often called "DMT". More recently, methanol has been considered as an alternative fuel that would reduce greenhouse gas emissions as well as improve the national economy by reducing oil imports. Compared to natural gas, methanol as a liquid fuel has the advantage of greater compatibility with the existing auto refueling infrastructure and would avoid the powerful greenhouse effect of CH_4 emissions from natural gas fueled vehicles. It also has no undesirable emissions and contributes no nitrogen oxides (NO_x) to exhaust gases. Methanol burns not only cleaner but also at lower temperature than most fuels derived from petroleum, making the design of methanol combustion units simpler.[1,2]

As of 1989, the world methanol industry produced at the rate of approximately 20 million tons of methanol per year. Any significant displacement of gasoline or diesel fuel by methanol would imply a much larger world methanol industry. For example, if methanol displaced gasoline use by 1 MMBD, approximately 2 MMBD of methanol would be required, or an addition to worldwide production that is 5 times larger than the existing industry.[3] However, the biggest impediment to the use of methanol at present is its relatively high price. Accordingly, the development of a new process which uses an abundant resource to more economically produce methanol with minimum pollution is in demand.

About 75% of domestic and 70% of worldwide methanol is produced from natural gas[4]. In the modern natural-gas-based methanol process, natural gas (principally methane) is desulfurized (usually to <0.25 ppm H_2S), mixed with steam and preheated to 425-550°C. The mixture is fed to a reformer where it passes through an arrangement of externally fired tubes containing a nickel-impregnated ceramic catalyst. The typical exit conditions of the reformer is 840-880°C and 7-17 atm. The overall reaction is highly endothermic and requires significant amounts of fuel. Reformer waste heat recovered from flue gas and product gas is principally used to generate 40-100 atm steam for meeting driver requirements and distillation loads. The synthesis gas generated by steam reforming of natural gas contains more hydrogen than necessary for the methanol reaction. Methanol synthesis requires a feed gas, $H_2/(2\ CO + 3\ CO_2)$ ratio near 1.05 whereas steam reforming of natural gas yields a ratio of about 1.4 without CO_2 addition. For low pressure catalysts, the excess hydrogen improves the catalyst effectiveness. Thus, converter costs are reduced and the necessity of shifting and removing excess hydrogen from the synthesis feed gas, as commonly practiced with high pressure technology, is avoided. Excess hydrogen is vented during synthesis and used as fuel in the reforming step. Low pressure methanol plants can be designed for CO_2 addition, taking advantage of the excess hydrogen to reduce natural-gas usage per unit of methanol as long as the CO_2 is inexpensive.

The synthesis gas for methanol production can also be obtained from other raw materials including petroleum residues (<15% of methanol capacity for 1980), Naphtha (<5% of methanol capacity for 1980) and coal (<2% of methanol capacity for 1980)[4]. The process steps to produce methanol from naphtha are nearly identical to those for reforming of natural gas except that naphtha requires vaporization prior to the desulfurization step. The process for partial oxidation of petroleum residues or the process for gasification of coal requires a large quantity of oxygen. A Shell gasifier process for methanol production from coal was described by Larson and Katofsky.[5] Coal dried to 5% moisture is fed through a lock hopper into an entrained-bed gasifier which operates at 20-25 atm and 1300-1400°C. The steam and oxygen feed ratio is 0.032 (kg/kg dry feed) and 0.88 (kg/kg dry feed), respectively. The high temperatures produce a product gas with essentially an equilibrium composition - large amounts of CO (64.3%) and H_2 (31.8%), little CO (1.7%) and no hydrocarbons. The exit gas is cooled down to 100-

200°C and quenched to remove particulate and other contaminants. Sulfur is then removed to prevent poisoning of downstream catalysts. The clean gas passes through a shift reactor to adjust the hydrogen-carbon monoxide ratio to the level needed for effective methanol production. After removing CO_2 and H_2O, the exit gas from the shift reactor is then compressed to 100 atm and introduced to the methanol synthesis unit.

In this report, the Hynol process, a new process for economical production of methanol with reduced CO_2 emission, is introduced. The process uses biomass or other condensed carbonaceous materials together with natural gas as cofeedstocks to produce more methanol and less CO_2 than the above conventional processes. The Hynol process only involves the design and operation of reactor units which are commercially operable or have been demonstrated in large scale equipment. As discussed later, the Hynol process has a number of advantages over the conventional processes for methanol production.

PROCESS DESCRIPTION

The Hynol process mainly consists of three reaction steps: (a)hydrogasification of condensed carbonaceous materials, (b)steam reforming of the process gas with the natural gas feedstock, and (c)methanol synthesis. The characteristic features of the process are (1)energy neutral in the gasifier by recycling the H_2-rich gas to the hydrogasifier so that no oxygen or external heat source is needed to maintain the required hydrogasification temperature; (2)the methane-rich gas produced by hydrogasification is subject to steam reforming with methane feedstock to produce H_2 and CO for methanol production; (3)a totally integrated cyclical processing.

Figure 1 shows a flowsheet of the Hynol process with biomass as feedstock. The operating pressure of the system is 30 atm. The process simulation results are also presented in the figure. The typical biomass composition, shown in Table 1, was used in the simulation calculation. The process simulation was made based on the assumption that the exit gas from the reactor of each step approaches to equilibrium. As illustrated in the flowsheet, biomass is fed into a fluidized-bed hydrogasifier (HGR) and reacted with recycled H_2-rich process gas (H_2 concentration is 73.9 mol.%) at 30 atm and 800°C. Some steam at a rate of 0.2 kg per kg of biomass is simultaneously fed into the HGR. This high pressure steam can be used for a Venturi-type nozzle to feed biomass into the pressurized HGR. The independent reactions taking place in the HGR can be expressed as:

$$C + 2H_2 \rightarrow CH_4 \qquad \text{(i)}$$

$$C + H_2O \rightarrow CO + H_2 \qquad \text{(ii)}$$

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad \text{(iii)}$$

If the feedstock contains high sulfur, limestone is used to reduce the concentration of H_2S in the exit gas of the HGR. Thus, another reaction takes place as follows

$$CaCO_3 + H_2S \rightarrow CaS + CO_2 + H_2O \qquad (iv)$$

The equilibrium constants for the above reactions were calculated from the standard free energy of formation data using the method provided by Baron et al.[6] The process gas produced in the HGR, according to the calculation, has 9.86 mol.% CO and 24.64 mol.% CH_4. Nitrogen which comes from the feedstock forms inert N_2 in the process gas and is taken into account in the calculation of equilibrium gas composition. The conversion of the carbon in biomass feedstock in the HGR is 82.3%. The unconverted carbon is withdrawn from the reactor with ash in the form of char. The char can be either used as fuel or sequestered. The reactions (ii) and (iii) are endothermic and require additional energy input to the gasifier. This is the reason why the conventional gasification processes need oxygen or air to supply combustion heat by burning part of carbon in the feedstock within the gasifier. In the Hynol process, the hydrogasification reaction (i) between the carbon in feedstocks and the hydrogen in the recycled process gas is exothermic and provides sufficient heat for the reactions (ii) and (iii). The HGR, thus, can be energy neutral without the need for an internal or external heat supply. The process gas from the HGR of the Hynol process usually needs to be cleaned up before entering the SPR to remove particulate and impurities which may contaminate catalysts in the subsequent reaction steps. Conventional dry gas clean-up methods can be used for this purpose. Accordingly, the HGR exit gas is first cooled down by a heat exchanger to a temperature that the clean-up requires. The recovered heat is used to reheat the clean gas entering the SPR so that a minimum heat loss by gas clean-up can be achieved. The process gas is then introduced to the steam reformer (or alternatively called the steam pyrolysis reactor, SPR) where it together with additional methane are reacted with steam which is directly fed into the SPR to form CO and H_2. The steam reforming can be described by two independent reactions:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \qquad \text{(v)}$$

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad \text{(vi)}$$

The equilibrium constants for these reaction used in the process simulation were obtained by using the correlations presented by Ridler and Twigg(7). The reactions are performed at 30 atm and 1000°C. A catalyst packed tubular externally fired furnace reactor similar to a conventional natural gas reformer furnace reactor is used for the SPR. Steam feed ratio is 1.2 kg per kg of biomass. Methane feed into the SPR is at a rate of 0.5 kg per kg of biomass. The H_2 and CO concentration in the exit gas of the SPR are increased to 62.8% and 19.0%, respectively. This process gas is then passed through a gas heat exchanger where it is cooled down to 728°C. The recovered heat is used to heat the recycled gas from 50°C up to 917°C. The process gas at 728°C then generates high pressure steam (50 atm) in a boiler for the use in both the HGR and the SPR. And the process gas is cooled to about 260°C for the MSR feed. The steam produced in this way is about 1.62 times biomass feed rate in weight, which makes steam self-sufficient within the system. The cooled process gas then enters the methanol synthesis reactor (MSR) to produce methanol. The reactions taking place in the MSR are:

$$CO + 2H_2 \rightarrow CH_3OH \qquad \text{(vii)}$$

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O \qquad \text{(viii)}$$

The equilibrium constant for Reaction (vii) was calculated by using the correlation provided by Lywood[8]. The methanol synthesis is performed at 30 atm and 260°C. The MSR can be a conventional methanol synthesis reactor using a copper based low pressure catalyst. The MSR reactions are highly exothermic. The released process heat can be extracted from the MSR and used to dry the biomass feedstock. Methanol is separated from water in a condenser and fractionated to produce concentrated methanol. In order to increase the conversion of CO in the MSR, the uncondensed gas from the condenser is partially returned to the MSR. The ratio of this internal loop is set to be 4 mol per mol of input process gas from the SPR in a manner similar to that used commercially. This results in an 85.5% conversion of CO to methanol in the MSR. Unlike those conventional processes where CO conversion in the MSR is a most critical parameter which affects the efficiency losses of the process, the Hynol process reprocesses the unconverted material by recycling the gas to the HGR and thus prevents losses of process gas constituents including the energy recovery. For this reason, the Hynol process obtains a high thermal efficiency, even though the CO conversion in the MSR may be lower than conventional. The condenser operates at 50°C. The gas exiting the MSR system is introduced to the gas heat exchanger mentioned previously, after purging a small amount of gas (3.7% of the recycled gas). The purge gas eliminates the accumulation of inert nitrogen in the system and keeps the nitrogen concentration in the system below 3.6 mol.%. The carbon efficiency, defined as the total moles of carbon in the methanol product divided by the mole sum of biomass and methane used for both feed and fuel, is 67.9%. The thermal efficiency, defined as the total higher heating value (HHV) of methanol product divided by the sum of the higher heating values of biomass and both feed and fuel methane, is 69.0%. The CO_2 emission is 107 lb CO_2/MMBTU of methanol HHV energy and is 41% lower than obtained by the conventional steam reforming of methane process (180 lb CO_2/MMBTU).

The steam reforming and methanol synthesis have been in commercial use for decades. A great deal of design data are available for these two types of reactors and, therefore, almost no further development work for this part of the Hynol process is needed. Hydrogasification has been demonstrated on a quite large scale for coal[7] but some specific design data is needed when biomass is used as feedstock. Further design studies for gas clean-up may also be needed. Thus, the development work for the Hynol process depends mainly on the integration of the above three reactor units.

Hynol can also process any other condensed carbonaceous materials such as coal, municipal solid waste (MSW), agricultural waste, residual oil and other similar types of carbonaceous materials. The pressures for the three steps can vary, for example, the HGR and MSR operate at 50 atm while the SPR operates at 30 atm or even lower. In this case, a gas expander can be used to recover the energy from the pressure reduction for process gas compression. When a high sulfur content feedstock is used for the HGR, the reactor temperature should be around 900°C to insure sulfur removal by limestone.

PROCESS ECONOMICS

A preliminary estimate of the capital investment of the Hynol biomass process can be made based on the capital costs estimated by the DOE for a biomass-to-methanol process.[10] In the DOE future-technology case, an IGT fluidized-bed steam-oxygen gasifier is used for the wood-to-methanol conversion. The IGT gasifier operates at 34 atm and 980°C, a condition similar to that for the hydrogasifier of the Hynol process. The gasifier product gas passes through a waste-heat boiler before entering a solids removal section consisting of cyclone and particulate removal units. The hot wet syngas is further heated before entering a methane steam reformer, where methane is converted to carbon monoxide and hydrogen over a nickel catalyst so that the usable components of methanol synthesis are maximized. The reformed gas is cooled, producing medium-pressure steam, and then goes to acid-gas removal of hydrogen sulfide and excess carbon dioxide. The purified syngas is then ready for methanol synthesis. Table 2 lists the capital costs of the equipment used for the IGT/DOE 101.5 MM Gal/yr methanol plant. Although this process differs from the Hynol process by the feature of its open system as well as the use of pure oxygen for biomass gasification, most of equipment used, such as fluidized bed gasifier, steam reformer and methanol synthesis reactor are similar to that for the Hynol process. As reported, for the 101.5 MM Gal/yr (38,494 kg/hr) IGT/DOE methanol plant, 2000 short tons per day or 75,598 kg/hr of wood is required. Thus, the ratio of the biomass feed to the methanol product can be calculated to be 1.964 kg/kg MeOH. While the gas produced from the IGT gasifier was reported to be 1.2 m^3/kg dry wood, the ratio of the gasifier exit gas to the methanol product is then obtained to be 0.1052 kmol/kg MeOH. For the Hynol process, the ratio of the biomass feed to the methanol product is 0.443 kg/kg MeOH and the ratio of the hydrogasifier exit gas to the methanol product is 0.074 kmol/kg MeOH. Since the cost of wood receiving and preparation as well as the hydrogasifier for the Hynol process are expected to be determined by the biomass capacity, the wood receiving & preparation cost can be calculated by using the 0.7 capacity scaling factor as:

$$\$15.9\ \text{MM} \times (0.443/1.964)^{0.7} = \$5.6\ \text{MM}$$

where $15.9 MM is the cost of wood receiving & preparation provided by the DOE for a 101.5 MM Gal/yr methanol plant. Similarly, the capital cost of the hydrogasifier for the same scale Hynol plant is estimated as:

$$\$27.3\ \text{MM} \times (0.443/1.964)^{0.7} = \$9.6\ \text{MM}$$

There is no oxygen plant for the Hynol process. Assuming the costs for solids and acid-gas removal depends upon the gas treat capacity, the cost of solids removal for the same scale Hynol plant can be obtained by using 0.7 scale factor as:

$$\$0.7\ \text{MM} \times (0.074/0.1052)^{0.7} = \$0.55\ \text{MM}$$

And the acid-gas removal cost would be

$$\$11.0\ \text{MM} \times (0.074/0.1052)^{0.7} = \$8.6\ \text{MM}$$

The capital cost of the steam reformer is assumed to be determined by the gas input to the reformer. For the Hynol process, the gas input to the reformer is the sum of the HGR process gas and the direct input fresh methane. The total amount of gas input per kg of methanol is 0.0896 kmol /kg MeOH. Therefore, the cost of the reformer for the Hynol process becomes:

$$\$29.7 \times (0.0896/0.1052)^{0.7} = \$26.5 \text{ MM}$$

Since the Hynol process involves intensive energy recovery from the hot gas by heat exchangers and steam generators, the gas cooling is assumed to cost $10.0 MM, more than five times the cost provided by the DOE for their discussed plant. The cost for the methanol synthesis reactor for the Hynol plant is assumed to remain the same as $22.5 MM. While the utilities cost is expected to be lower. A cost of $30.0 MM is chosen against the cost of $39.2 MM reported for the DOE plant. Accordingly, the total capital investment for a 101 MM Gal/yr methanol plant of the Hynol process would be $136 million 1987 dollars, showing a 60% reduction of the capital investment compared to the conventional biomass-to-methanol process. Using the chemical engineering inflation index, the total capital investment for the Hynol plant can be adjusted to the 1993 dollars by

$$\$136 \text{ MM} \times 359.1/323.8 = \$150.8 \text{ MM}$$

This is the capital cost for a 101.5 MM gal/yr Hynol methanol plant. The above results are summarized and compared with the IGT/DOE plant in Table 2.

The methanol production cost estimated as following is based on a plant capacity of 1.25×10^7 liters/day (1085 MM Gal/yr) methanol. The total capital investment for the capacity plant is scaled as follows:

$$\$150.8\ \text{MM} \times (1085/101.5)^{0.7} = \$791.9\ \text{MM}$$

The raw materials used in the Hynol process consist of wood and natural gas. The wood consumption, as mentioned previously, is 0.443 kg per kg of methanol product and the natural gas consumption is 0.43 kg/kg MeOH. Thus, the daily consumption of the feedstocks would be:

$$1.25\times10^4 \times 0.79 \times 0.443 = 4374.6 \text{ tons/day of dry wood}$$

and

$$1.25\times10^4 \times 0.79 \times 0.43 = 4246.3 \text{ tons/day of natural gas}$$

Assuming their prices are \$71.26 per ton of dry wood and \$2.50 per 1000 ft^3 of natural gas, the daily raw material costs are

$$4374.6 \times \$71.26 = \$0.31\ \text{MM} \qquad \text{for wood}$$

$$4246.3 \div 0.0203 \times \$2.50 = \$0.52\ \text{MM} \qquad \text{for natural gas}$$

The O & M costs and the capital charge are assumed to be 4% and 6%

of the total capital investment, respectively. By summation of the raw material costs, the O&M costs and the capital charge, the total daily operating cost is obtained as:

$$\underset{\text{Wood Cost}}{\$0.31\text{MM}} + \underset{\text{NG Cost}}{\$0.52\text{MM}} + \underset{\text{O\&M Costs}}{\$0.1\text{MM}} + \underset{\text{Capital Charge}}{\$0.14\text{MM}} = \$1.07\text{MM}$$

For a 15% return on investment (or a 25% return on equity for a debt/equity ratio 80/20 including taxes) the methanol production cost can be obtained as follows:

$$[(0.15\times791.9\times10^{6}/328.5)+1.07\times10^{6}]/(1.25\times10^{7}\times0.2642)=\$0.43/\text{Gal}$$

The above methanol production cost data for the Hynol are summarized in Table 3. This is a competitive production cost compared to the present U.S. price of methanol of $0.45/Gal. Assuming a 30% improvement in efficiency for the use of methanol instead of gasoline as an automotive fuel as reported by EPA (1.54 Gal of methanol = 1 Gal of gasoline), the equivalent cost of methanol is 1.54×0.43 = $0.66/Gal. The 1992 refinery price of gasoline based on $20/bb of oil was $0.73/Gal. Thus, the Hynol methanol cost as determined above is also competitive with the price of gasoline.

ADVANTAGES OF THE HYNOL PROCESS

The Hynol process has a number of advantages over the conventional processes for methanol production. Tables 4 compares the Hynol process with the two conventional biomass processes, the natural gas reforming process and the IGT/DOE process using biomass alone. The following conclusions can be drawn:

(1)<u>Process Flexibility</u>.

As mentioned in the previous section, the Hynol process can use almost any condensed carbonaceous materials as feedstocks. When municipal solid waste (MSW) is processed, its composition may vary greatly from time to time. This would have little effect on the performance of the Hynol process because approximately the same amount of natural gas is simultaneously used as the process co-feedstock and natural gas dominates the feedstock input. The simulation also shows that Hynol can operate under quite a wide range of conditions without a significant reduction in productivity and efficiency.

(2)<u>Moderate Operating Conditions</u>.

In the conventional process for methanol production, although steam reforming or gasification in some cases may operate under relatively low pressure, the methanol synthesis usually requires at least 50 atm in order to achieve high CO conversion. The Hynol process can operate in all the three steps at 30 atm. The unconverted gas is recycled and is reprocessed in the HGR. The more moderate operating conditions make the process design and operation easier than the conventional processes that require higher pressure up to 100 atm.

(3)<u>High Methanol Yields</u>.

Recycling the unconverted process gas from the MSR condenser to the HGR insures the completion of the process conversion. Most of the carbon input will appear in the methanol product, and only small amounts of carbon are withdrawn from the process in the form of char from the HGR and purge gas after methanol synthesis.

The two consecutive steps of hydrogasification followed by steam reforming produces a high CO yield. In the HGR, Reactions (ii) and (iii) convert carbon from the feedstock into CO. The CH_4 produced in the HGR by reaction (i) is then further reacted with steam in the SPR to make more CO and hydrogen. As presented in Table 4, the methanol yield by the Hynol process based on the total material inputs including biomass and natural gas is 1.15 kg/kg which is 12% higher than the sum of each of the individual conventional process, 1.03 kg/kg. Furthermore, the yield of methanol per unit of biomass is 4.4 times higher for Hynol than for IGT biomass gasification process and the methanol per unit natural gas is also 1.49 times higher.

(4)<u>High Thermal Efficiency</u>.

In the Hynol process, the heat from the hot process gas from the SPR is recovered to heat up the cold recycled gas from the methanol condenser by means of the heat exchanger and generates the steam required for the SPR and HGR. This results in a higher thermal efficiency than the conventional biomass process.

(5) Low Capital Cost.

The Hynol process recycles H_2-rich gas through the hydrogasifier. The heat produced by reaction of the recycle hydrogen with the feedstocks balances the endothermic heat required by Reactions (ii) and (iii) so that there is no need for external energy to drive the gasification process in the reactor. The HGR can be designed to be energy neutral. Thus, compared to the conventional processes, no expensive oxygen plant is needed for the Hynol process. In addition, since the H_2-to-CO ratio of the feed gas for the MSR of the Hynol process is not a critical parameter, the shift reactor which is commonly used in conventional gasification-methanol plants is no longer needed. As shown in Table 2, the total capital investment for a Hynol plant is only about 60% of that for a biomass gasification plant of same capacity.

The operation cost is also lower for the Hynol process. As we discussed previously, the methanol production cost for a 3.3 million Gal/day methanol plant is estimated to be $0.43/Gal which is competitive with the present U.S. price of methanol and the gasoline price.

(6) Reduced CO_2 Emissions.

The Hynol process, by taking advantages of combining biomass gasification and methane steam reforming as consecutive steps and recycling the uncondensed gas from the methanol synthesis, becomes an attractive feature from greenhouse gas CO_2 emission point of view. Since the process is under reducing conditions and uses no oxygen, the emission of CO_2 is reduced and SO_2 and NO_X are not found. Furthermore, as reported by the EPA[11], when methanol is used as an alternative automotive fuel, a 30% improvement in energy efficiency is obtained which reduces an overall 41% reduction in CO_2 emission compared to use of conventional gasoline fuel.

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TABLE 1. TYPICAL BIOMASS COMPOSITION AND HIGH HEATING VALUE.

Composition (wt.%)	
C	45.81
H	5.28
O	35.87
H2O	11.80
Ash	0.66
S	0.16
N	0.42
Heating Value (kcal/kg-MF)	4850.6
Heat of Formation (kcal/kg-MAF)	1263.3

TABLE 2 CAPITAL COST OF THE WOOD-TO-METHANOL PLANTS BY THE IGT PROCESS AND BY THE HYNOL PROCESS. (CAPACITY: (2,000 SHORT TONS PER DAY OF WOOD, 101.5 MM GALLONS PER YEAR OF METHANOL) ($MM)

Component	IGT/ DOE[9]	Hynol
Wood receiving & preparation	15.9	5.6
Oxygen plant	40.3	0
Gasification	27.3	9.6
Solids removal	0.7	0.6
Reformer	29.7	26.5
Acid-gas removal	11.0	8.6
Gas cooling	1.9	10.0
Gas compression	7.6	3.0
Methanol synthesis & purification	22.5	22.5
Utilities & offsites	39.2	30.0
Total erected plant cost	196.1	116.4
Owners' cost, fees, profit	19.6	11.6
Land	2.0	2.0
Startup cost	6.0	6.0
Total capital investment (1987)	223.7	136.0
(1993)	248.1	150.8

Note: Hynol includes 397 T/D natural gas.

TABLE 3. PRODUCTION COST OF HYNOL PLANT.

Plant Capacity: 1085 MM Gal/yr. (3.3 MM Gal/D)
Feedstock Wood (Dry): 4375 T/D
Feedstock Natural Gas: 4246 T/D (209 MM SCF/D)

Capital Cost of Plant = $792 MM
Plant Factor: 90% (328.5 D/yr operation)

Component		$MM/Day
Feedstock		
Dry Wood	4375×$71.26/Dry ton =	0.31
Nat. Gas	209×$2.50/MM SCF =	0.52
O & M - 4% of cap. cost	0.04×$792MM/328.5 =	0.10
Total Capital Charge - 21% of cap. cost	0.21×$792MM/328.5 =	0.51
Total		1.44

Unit Production Cost of Methanol
$1.44MM/3.3MM Gal = $0.43/Gal

TABLE 4. COMPARING BIOMASS/NATURAL GAS HYNOL PROCESS WITH THE CONVENTIONAL GASIFICATION AND STEAM REFORMING PROCESSES FOR METHANOL PRODUCTION.

Factor	Hynol	Biomass Gasif.	Nat.Gas Reforming
Dry Wood, kg	88.2	88.2	-
CH_4, kg	85.7	-	85.7
O_2, kg	-	44.1	-
Thermal Efficiency, %	67.9	52.4	64.0
Carbon Conversion, %	69.0	38.0	78.0
Methanol Yield			
MeOH/Wood, kg/kg	2.26	0.51	-
MeOH/CH_4, kg/kg	2.32	-	1.56
MeOH product, kg	199.2	44.8	133.7
CO_2 emission, lb/MMBTU	107	-	180

Carbon Efficiency	**67.9%**
Thermal Efficiency	**69.0%**
CO2 Emission	**106.8 lb/MMBTU**

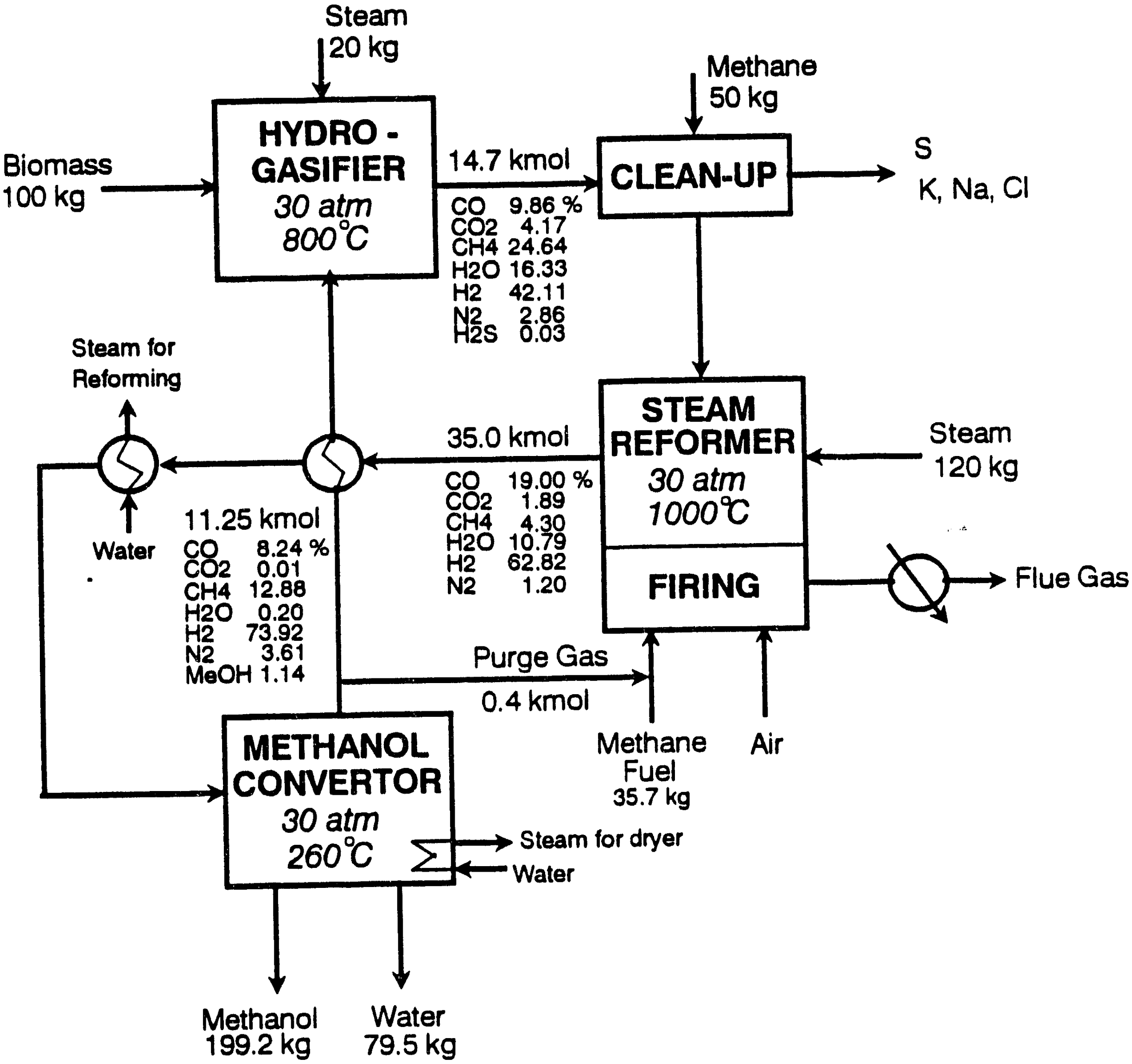

Figure 1. Flowsheet and simulation results for the Hynol process using biomass and natural gas as feedstocks.

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