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ASSESSMENT OF COSTS AND BENEFITS OF FLEXIBLE AND ALTERNATIVE FUEL USE IN THE U.S. TRANSPORTATION SECTOR

TECHNICAL REPORT FIVE:

COSTS OF METHANOL PRODUCTION FROM BIOMASS

United States Department of Energy
Office of Policy, Planning and Analysis
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CONTENTS

INTRODUCTION AND EXECUTIVE SUMMARY

Purpose of This Report

In 1988 the Department of Energy (DOE) undertook a comprehensive technical analysis of a flexible-fuel transportation system in the United States. During the next two decades, alternative fuels such as alcohol (methanol or ethanol), compressed natural gas (CNG), and electricity could become practical alternatives to oil-based fuels in the U.S. transportation sector. The DOE Alternative Fuels Assessment is aimed directly at questions of energy security and fuel availability, but covers a wide range of issues as illustrated in Figure S-1. To keep interested parties informed about the progress of the DOE Alternative Fuels Assessment, the Department periodically publishes reports dealing with particular aspects of this complex study. This report provides an analysis of the expected costs to produce methanol from biomass feedstock (part of element 3 in Figure S-1).

There has been considerable controversy regarding the potential competitiveness of methanol as a transportation fuel. It is already in common use as a fuel additive, either in the form of methanol or as methyl-tertiary butyl ether (MTBE). However, its uncertain cost, on an equivalent energy basis, requires careful consideration of its use as a neat (essentially undiluted) transportation fuel.

The data in this report will be used to analyze the relative economic feasibility of all alternative fuel options (including CNG, electricity, and fuel alcohol derived from nonbiomass feedstocks) in the DOE Alternative Fuels Assessment.

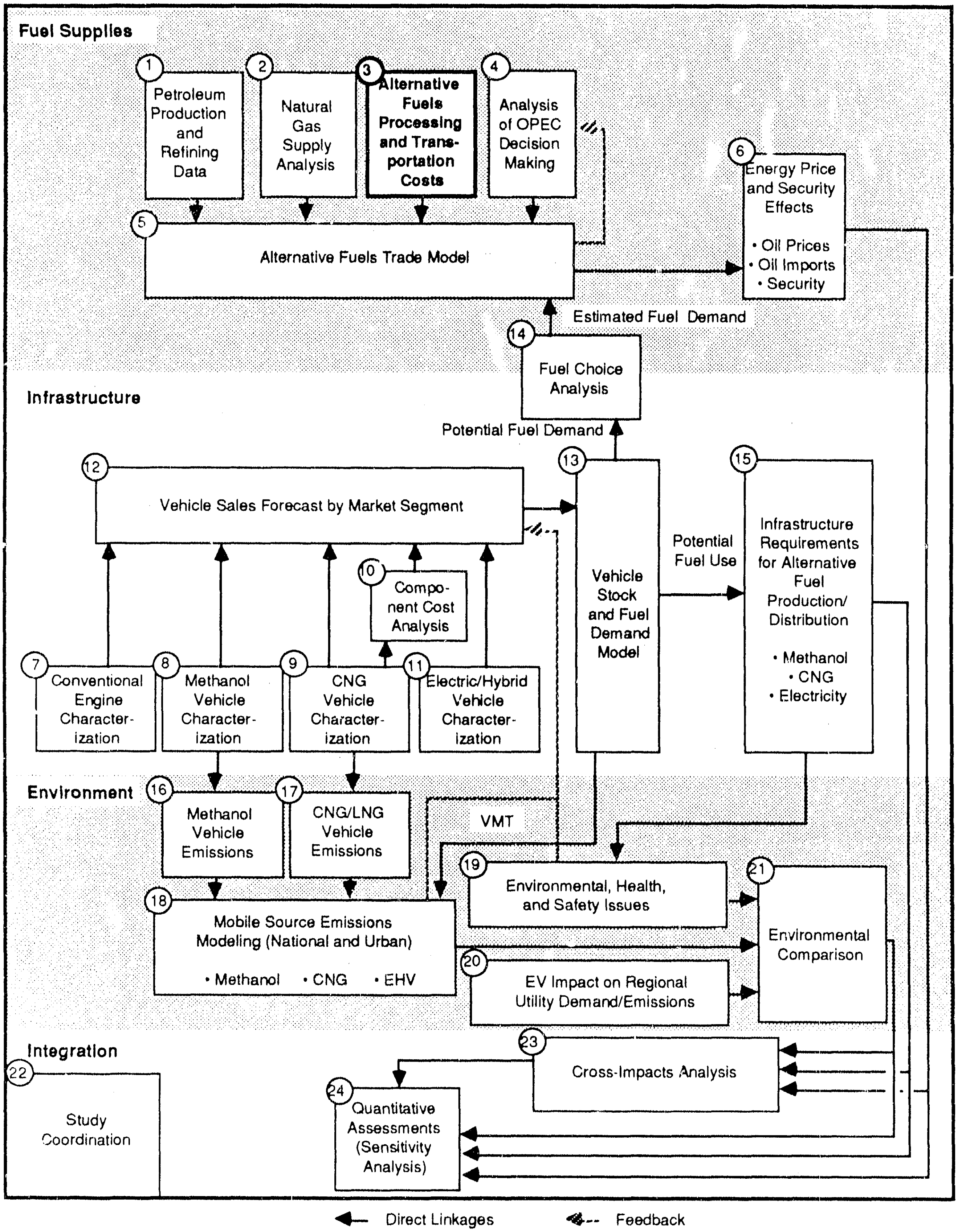
The information provided is required to estimate the future cost of methanol from biomass. However, the report does not provide forecasts of the future price of biomass feedstock and, consequently, does not provide cost projections for methanol. The report does assume plausible feedstock prices so that the probable cost of methanol can be put into perspective.

The future price of biomass materials is dependent on many factors. It is our intention to analyze these factors, with the data provided in this report, using an integrating model of world oil and gas trade called the Alternative Fuels Trade Model (AFTM). The description and discussion of this analysis will be provided in a subsequent report.

In developing the biomass-to-methanol conversion costs for use in the AFTM, assessments have been made of what types of cost improvements might be achieved in the future given the likely expansion of the methanol industry required to supply a motor fuel market. Since a major portion of the conversion costs is related to the required capital investment, construction costs are estimated for various methanol plant configurations. From this and estimates of process efficiencies and other operating cost requirements, methanol production costs are estimated and then simplified into a generalized formula for incorporation into the AFTM.

The DOE Alternative Fuels Assessment is a work in progress. This report covers portions of the background information being gathered by the Department for the overall study, and it is being published so individuals and organizations interested in this subject can evaluate the information provided and the direction the study is taking. It is recognized also that interested parties may find this information useful outside the context of DOE's Alternative Fuels Assessment. The Department welcomes comments.

Figure S-1 — Relationships Among the Elements of the DOE Alternative Fuels Assessment



Methanol Production Costs

The technology for commercial production of methanol from wood biomass exists today, and renewed interest in converting biomass into fuels and chemical feedstocks has prompted additional research into biomass conversion.

The existing biomass resource base comprises agricultural crop residues and manures; wood, bark, and logging residues; noncommercial components of standing forests; and the organic portion of municipal solid wastes. Future biomass supplies could be supplemented by feedstock produced on energy farms. Many of these resources are not promising feedstocks for biomass gasification because of their seasonability, the high cost of collecting and transporting them, their current value for other uses, and their limited supply. By far the largest existing resources are standing forests. The harvest of forests for energy production would probably be closely associated with timber harvest and timber stand improvement practices, with some of this resource being managed as a renewable energy feedstock source or energy farm. This report only considers whole-tree green chips as a gasifier feedstock.

A biomass-to-methanol plant consists of two main components, a biomass gasifier to convert the feedstock to synthesis gas and a methanol synthesis plant. The current technology for gasification of wood biomass is well developed, and several commercially available coal gasifiers also can produce fuel from biomass feedstock. In addition, several advanced biomass-gasification processes could be available in the near future.

Compared with coal, wood biomass has a higher water content, lower density, and lower sulfur and ash content. The increased water content may reduce the efficiency of gas production if waste heat is unavailable, because the net energy available for gas production decreases as water content increases. The size and density of biomass may present a problem because some existing gasifiers require finely ground, high-density feedstocks. However, the lower sulfur and ash content of biomass reduces the need for treatment to counteract sulfur and particulate emissions.

Among the currently available systems for conversion of biomass to synthesis gas are entrained-bed, fluidized-bed, and moving-bed gasifiers. Entrained-bed gasifiers, such as the Koppers-Totzek (K-T) coal gasifier, are readily adaptable to use with biomass feedstock. Gasification in this process, which operates at atmospheric pressure, occurs at high temperatures with short residence times. This gasifier produces no slag, and nearly all the ash is entrained with the gas. The process requires high amounts of oxygen, however, and extensive treatment of the feed to attain low moisture content and small particle size. In addition, the gasifier feed system, designed for coal, does not work well with low-density biomass.

Fluidized-bed reactors, such as the Winkler gasifier, operate at higher temperatures and pressures than entrained-bed systems, reducing the levels of tars and oils in the gas. The higher pressure (eight times atmospheric pressure) is an advantage because the gas from a fluidized-bed gasifier needs less compression before passing to the methanol synthesis stage.

Moving-bed gasifiers, such as the Lurgi gasifier, circulate the feedstock in patterns that transfer heat among the gaseous and solid reactants more efficiently than fluidized-bed reactors. Because these gasifiers work at atmospheric pressures, the synthesis gas requires further compression before entering the methanol-production stage.

Various organizations are exploring the feasibility of new gasifier processes to produce synthesis gas from biomass feedstock. The new gasifiers can produce medium-Btu gas undiluted by other gases, such as nitrogen, with lower tar levels, and at higher pressures than some currently available gasifiers.

This report looks at three cases to estimate methanol-production costs: a low-volume plant using present technology, a low-volume plant using near-future (available within the next 5 to 10 years) technology, and a large-volume plant using near-future technology. The low-volume designs are based on a feed of 2,000 short tons per day (STPD) of dry wood, and the large-volume design is based on a feed of

10,850 STPD of dry wood. Methanol costs of production have been evaluated for a range of possible wood costs, with the current cost set at $42 per short ton. For all three plants, the oxygen used in forming the synthesis gas is supplied by two parallel oxygen plants.

The present-technology design features a commercially available gasifier converted for use with biomass feed; it produces synthesis gas that is converted to fuel-grade methanol at a production rate of 87.0 million gallons of methanol per year. This case assumes an entrained-bed system, such as the K-T coal gasifier, and a generic low-pressure methanol-synthesis plant. The main components of the present-technology design include facilities for wood preparation, oxidant feed, gasification, gas cleanup and cooling, shift conversion, acid-gas removal, compression, and methanol synthesis and purification. Whole-tree green chips are dried and milled to an 8-percent moisture content and a -30 mesh, and then passed to the gasifier, where they are gasified in the presence of oxygen and steam. The hydrogen level of the gas is increased to achieve the proper hydrogen/carbon monoxide ratio and the gas is cleaned of hydrogen sulfide and excess carbon dioxide, after which it is passed to the methanol-synthesis unit.

The near-future design features a high-pressure gasifier that is designed specifically for biomass feedstock and linked to an advanced-technology methanol plant. Methanol production for such a plant would be 101.5 million gallons per year. This case assumes a fluidized-bed gasifier developed specifically for biomass feedstock and an advanced methanol-production system, such as liquid-phase synthesis. The main components of the near-future design include facilities for wood preparation, oxidant feed, gasification, gas cleanup, methane reforming, acid-gas removal, cooling, compression, and methanol synthesis and purification. Whole-tree green chips are dried to a 15-percent moisture content and fed to the gasifier at a pressure of 500 pounds per square inch. The gas passes to an acid-gas-removal system for removal of hydrogen sulfide and excess carbon dioxide, after which it passes to the liquid-phase methanol synthesis section.

The large-volume design is a near-future technology single-train methanol plant producing 555.6 million gallons per year. Economies of scale allow this larger plant to produce methanol more cheaply than the 101.5-million-gallon future-technology plant can. This case provides a direct comparison to similar-sized plants using coal or natural gas as feedstocks.

Methanol costs of production for the three designs are shown in Figure S-2 for a 20-percent and a 30-percent capital recovery factor.

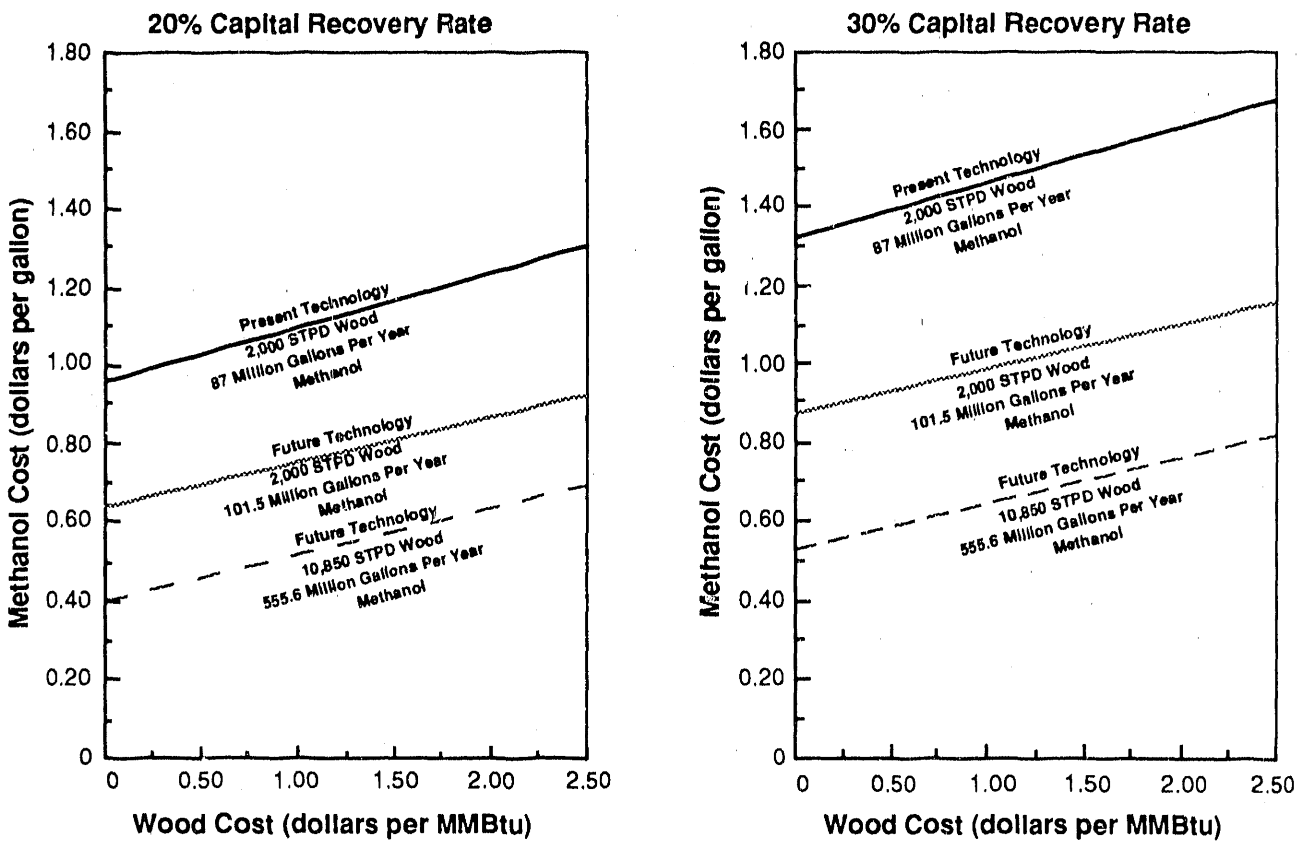
Production costs for the three plants include the costs of raw materials and utilities, which vary with plant operating capacity, and operating costs and overhead expenses, which are fixed regardless of operating rate. Wood cost is the major factor affecting methanol production costs. For this study, production costs were evaluated for a range of decreasing wood prices, starting at $42 per short ton (about $2.46 per million Btu). The present-technology case assumes byproduct steam is used within the plant, and the two near-future cases assume that excess steam will be sold for other uses. For all cases, as wood prices are reduced, operating costs are correspondingly lowered.

Evaluation of the cases shows that near-future technology offers significant economic benefits over the present technology. While an 87-million-gallon-per-year plant using current technology operating at a 20-percent rate of capital recovery and using wood at $42 per short ton could produce methanol for $1.29 per gallon, the 101.5-million-gallon-per-year near-future plant could produce methanol for $0.93 per gallon. Because of economies of scale, a 555.6-million-gallon-per-year plant using near-future technology could produce methanol for $0.68 per gallon.

The methanol production costs drop significantly with decreasing wood cost. With a wood cost of $32 per short ton and a 20-percent capital recovery rate, the 87-million-gallon-per-year present-technology plant would produce methanol for $1.21 per gallon, and the 101.5-million-gallon-per-year near-future plant would produce it for $0.88 per gallon. For the 555.6-million-gallon-per-year near-future case, the methanol cost would be $0.61 per gallon.

A further evaluation was made that considered use of a single oxygen plant, rather than the

Figure S-2 — Costs of Methanol from Wood



parallel plants used in the three cases. Although such a configuration would require a high level of operating reliability, it would result in significant capital-cost reductions. With this arrangement, methanol costs were reduced to $0.87 per gallon for the 101.5-million-gallon-per-year near-future case and $0.65 per gallon for the 555.6-million-gallon-per-year near-future case for wood at a cost of $42 per short ton and at a 20-percent capital recovery rate. With the cost of wood reduced to $32 per short ton, the methanol costs would drop to $0.80 per gallon for the 101.5-million-gallon-per-year plant and $0.58 for the 555.6-million-gallon-per-year cases.

This report has examined a wide range of methanol plant sizes from 2,000 STPD of wood to 10,800 STPD. This was done to test the sensitivity of expected methanol costs to plant size (economies of scale). While the lowest methanol costs are achieved at the largest scale, the report should be viewed as a parametric analysis and not a feasibility study (that is, additional study is required to establish the feasibility of delivering 10,000 TPD of biomass to a given site). Cost for feedstocks are assumed to be $42 per ton on a dry weight basis. This is not inconsistent with actual market prices, which are somewhat regionally dependent and do vary above and below this number.

Although they have not been evaluated in this report, other biomass gasifier concepts exist that might further reduce the cost of methanol. For instance, indirectly heated gasifiers, although a higher technological risk than the design used in the future-technology case, eliminate the need for oxygen production and therefore might reduce capital and operating costs. Indirectly heated gasifiers might also be capable of producing 15 to 20 percent more methanol from the same amount of biomass. The combination of lower capital costs and higher productivity when using indirectly heated gasifiers could potentially reduce methanol costs further. Such technology could warrant more evaluation in the future.

I. PRODUCTION OF METHANOL FROM BIOMASS

The technology for commercially producing gas from wood biomass, which advanced along with that for coal gasification, was well developed by the time the discovery of large reserves of natural gas rendered it uneconomic. Gas produced in nearly all early commercial gasifiers had a low Btu content because these gasifiers used air, rather than oxygen, as the oxidizing agent.

Renewed interest in converting biomass into fuels such as methanol and into chemical feedstocks has prompted research into several advanced biomass gasification processes. In addition, several commercially available coal gasifiers can be modified to use biomass feedstock.

The main components of a biomass-to-methanol plant are the biomass gasifier and the methanol synthesis plant. This report looks at two complete plant designs to evaluate the methanol production costs of present technology and that of future, nearly available, technology.

The present-technology design features a commercially available Koppers-Totzek entrained-bed gasifier converted from coal feed to biomass feed. The synthesis gas (syngas) produced by this gasifier is then converted into fuel-grade methanol via low-pressure methanol synthesis. This design produces 87 million gallons of methanol per year from 2,000 short tons per day (STPD) of dry wood.

The future-technology design features a high-pressure fluidized-bed gasifier specifically designed for biomass feedstock by the Institute of Gas Technology. The gas from this gasifier is converted through an advanced methanol technology such as the Liquid Phase Methanol (LPMEOH) process or the Mitsubishi gas/chemical fluidized-bed process. The future-technology design converts wood to methanol more efficiently than does the present technology, resulting in a methanol production rate of 101.5 million gallons of methanol per year from 2,000 STPD of dry wood.

The report also looks at variations of the future-technology case, one assuming a large-volume methanol plant that would require approximately 10,850 STPD of wood to produce 555.6 million gallons of methanol per year and one assuming a single-train oxidant feed system for both the base case and large-volume designs.

The large-volume future-technology design is comparable in size and output to a design considered in a previous study(1) that evaluated the costs of producing methanol from natural gas and from coal. Economies of scale would allow this 555.6-million-gallon-per-year plant to produce methanol more cheaply than could the 101.5-million-gallon-per-year future-technology plant.

The second variation of the future-technology case assumes a single oxygen plant, rather than the parallel plants assumed otherwise. This design would require a high level of operating reliablity, but it would provide some reduction in capital costs.

BIOMASS RESOURCES

Although an indepth review of existing biomass resources is beyond the scope of this report, this section gives a brief overview.

The existing biomass resource base comprises agricultural crop residues, manures from confined livestock and poultry operations, wood and bark mill residues from primary wood product manufacturing plants, bark residues from the wood pulp industry, logging residues from timber harvesting operations, noncommercial components of standing forests, and the organic fraction of municipal solid wastes. In addition to the existing base, future biomass supplies could be supplemented by feedstock produced on energy farms. Overall, there is a possible resource base of significant size that could expand in the future as timber harvests increase and as energy farming needs and technologies develop.

For various reasons, many of these resources must be eliminated as promising feedstocks for biomass gasification. Crop residues are excluded because they are seasonable, expensive to collect and transport, and ecologically valuable *in situ.* Animal manure is excluded because of limited supply and high collection costs. Mill residues are preferred gasification feedstocks, but most of these are used for pulp manufacture or for direct combustion for process steam or electric power generation. Logging residues would also be an ideal gasification feedstock, but because of the high cost of collecting them and the lack of appropriate collection machinery, virtually none of this resource is currently used as an energy feedstock. Municipal solid waste could be a biomass resource only in large metropolitan areas where the quantity available can provide sufficient disposal credits and support a large-scale gasifier.

The largest existing biomass resource by far is the Nation's standing forests. The harvest of this resource for energy production would probably be closely associated with both commercial timber harvest and timber stand improvement practices. Environmental concerns would also have to be addressed. Some of this resource could conceivably be managed as a renewable energy feedstock source or energy farm.

For the purpose of this report, only whole-tree green chips have been considered as gasifier feedstock.

BIOMASS PROPERTIES

Both the physical and chemical characteristics of biomass have to be considered in comparing it with alternative feedstocks such as coal and municipal solid waste.

Two types of analysis provide a basis for characterizing biomass feed material. Proximate analytical methods identify and quantify water, volatile components, fixed carbon, and ash constituents, while ultimate analytical methods identify chemical constituents. The proximate and ultimate analysis of a variety of biomass feed materials, together with density data, are shown in Table I-1.

The data show several characteristics of biomass feeds, the major ones being the high degree of similarity among various biomass feeds, chemical compositions similar to that of cellulose, low sulfur and ash contents, a hydrogen/carbon mol ratio of approximately 1.5, and a hydrogen/oxygen mol ratio of approximately 2.0.

Comparing biomass feed to other feeds illustrates the nature of biomass. Table I-2 compares biomass with urban refuse and coal.

The main differences between biomass and coal are in moisture content, size and density, and chemical characteristics. The high moisture content of biomass is one of the most important differences between biomass and coal. The moisture content of gasifier feed influences the efficiency of the gasification process because the net energy available for gas production decreases as the water content of the feed increases. Biomass has an average 50-percent moisture content, so approximately 25 percent of the available heat energy in the feed consumed during gasification is for preheating and vaporizing water.

The size and density of feedstocks are other factors influencing the performance of thermal gasification reactors. Most existing gasifiers allow only relatively fine feedstocks, so biomass must be finely ground, but for fluffy or fibrous biomass such as bagasse, shredding presents a difficulty. In addition, the generally low bulk density of biomass feedstocks can result in undersized entrainment in certain types of gasifiers.

The chemical characteristics of biomass also affect the efficiency of gasification. Biomass generally has a larger volatile component than does coal, so the reactivity of biomass might be higher than that of coal. In thermochemical gasification, the chemical composition of the feedstock also affects the reaction products, subsequently influencing the requirements for pollution controls. The low sulfur content of biomass will require less treatment to meet regulated sulfur emissions levels. The relatively low ash and inert content will also require less treatment for particulate emission and will create fewer ash disposal problems.

Table I-1 — Constituents of Some Biomass Feeds

	Hardwood Maple	Western Hemlock	White Pine Sawdust	Pine Sawdust	Balsam Spruce	Hardwood Leaf Mixture	Millrum Bagasse	Cellulose
Proximate analysis, wt %								
Moisture	*	*	7.0	—	3.67	9.97	49	—
Volatile matter	76.1	74.2	78.76	74.4	77.75	66.92	—	—
Fixed Carbon	19.6	23.6	14.1	20.1	15.52	12.29	—	—
Ash	4.3	2.2	0.14	0.5	3.06	3.82	2	—
Ultimate analysis, wt %								
Carbon	50.4	50.4	52.32	51.8	53.3	51.63	48.2	44.44
Hydrogen	5.9	5.8	6.05	6.3	6.65	6.05	6.7	6.22
Oxygen	39.1	41.4	40.05	41.3	35.05	30.04	45.1	49.34
Nitrogen	0.5	0.1	0.56	0.1	1.49	6.92	—	—
Sulfur	0.0	0.1	0.39	0.0	0.20	0.16	—	—
Ash	4.1	2.2	0.15	0.5	3.18	4.2	2.0	—
Particle density, g/cc	0.68	0.47	0.43	0.43-0.67	0.45	—	—	—

* Dry basis analysis, typically moisture content is 50 wt percent on a wet basis.

Table I-2 — Composition of Coal and Urban Refuse

	Bituminous Coal		Urban Waste Components					
	Low Volatiles	High Volatiles	News-paper	Corrugated Box Paper	Brown Box Paper	Magazine Paper	Lawn Grass	Average Urban Refuse
Proximate analysis, wt %								
Moisture	3.6	3.56	5.97	5.2	5.83	4.11	5.47	18.4
Volatile	17.41	37.18	81.12	77.47	83.92	66.39	71.16	75.3
Fixed Carbon	74.84	56.55	11.48	12.27	9.24	7.03	17.18	10.8
Ash	4.14	2.71	1.43	5.06	1.01	22.47	6.19	13.9
Ultimate analysis, wt %								
Carbon	83.68	79.61	48.97	93.62	44.74	32.86	46.04	41.2
Hydrogen	4.57	5.54	6.08	5.7	6.06	4.93	7.11	5.5
Oxygen	5.73	9.83	42.88	4.78	47.68	38.48	35.15	30.7
Nitrogen	1.12	1.61	0.05	0.09	0.64	0.07	4.45	0.5
Sulfur	0.76	0.70	0.15	0.21	0.11	0.09	0.42	0.2
Ash	4.14	2.71	1.52	5.32	1.07	23.39	6.53	13.9
Particle density, g/cc	1.35	1.35	0.7-1.15	0.7-1.15	0.7-1.15	0.7-1.15	—	—

PROCESS TECHNOLOGIES

Chemistry

Biomass is converted to methanol by transforming the biomass to synthesis gas and then converting the synthesis gas to methanol. Synthesis gas can be made from a variety of solid carbonaceous substances, as well as from liquid and gaseous hydrocarbons, all of which contain, besides carbon, complicated mixtures of chemicals and polymeric substances. The methanol-conversion process requires synthesis gas to be a simple mixture, ideally containing only the active gases, hydrogen and carbon monoxide, together with water vapor and carbon dioxide (both of which can be removed fairly easily), and a minimum of diluent gases such as nitrogen, argon, and methane. Decomposition of the biomass feedstock works best at high temperatures and in the presence of oxygen and steam. Oxygen is used instead of air to minimize the amount of diluent nitrogen introduced into the synthesis gas. In effect, part of the feedstock is "burned" to carbon dioxide and water vapor to provide heat to raise the temperature, to decompose the chemicals and polymers, and to provide heat for the endothermic gasification reactions. Some simplified reactions can be written as follows:

$C + O_2 \rightarrow CO_2$ (exothermic)

$C + CO_2 \rightarrow 2CO$ (endothermic)

$C + H_2O \rightarrow H_2 + CO$ (endothermic)

Biomass can be converted to synthesis gas in other ways, such as by first using biological or chemical means to convert biomass to hydrocarbons and then converting the hydrocarbons to synthesis gas. However, for the near future the only practical route to synthesis gas from biomass is via high-temperature gasification.

After the biomass is converted to gas, various other steps are taken to adjust the composition of the gas. The catalytic water-gas shift reaction brings the gas to the desired hydrogen/carbon monoxide ratio. Catalytic reforming converts the diluent methane in the gas to additional amounts of hydrogen and carbon monoxide. Gas cleanup removes impurities, and the gas is finally ready for methanol synthesis.

Gasification Technology

Present Technology. Several commercial gasification processes that use coal as a feedstock could be adapted to use wood feed. These include the entrained-bed gasifier, such as the Koppers-Totzek; the fluidized-bed gasifier, such as the high-temperature Winkler gasifier; and the moving-bed gasifier, such as the Lurgi gasifier. The performance data for these gasifiers are summarized in Table I-3.

Koppers-Totzek. The commercial Koppers-Totzek (K-T) coal gasifier, licensed by Krupp-Koppers of West Germany as the GKT process, is an entrained-bed reactor that operates at atmospheric pressures. The gasification takes place at the highest temperatures and involves short residence times. At the reaction temperature of 1,800°F, no slag is formed and virtually all the ash is entrained with the gas.

The most serious drawbacks of the K-T process are its high oxygen consumption, the extensive feed pretreatment needed to attain the required low moisture content (as low as 8 percent), and the milling required to reduce the wood to a minus 30 mesh size. The low density of the feedstock compared with coal also presents a problem for the K-T feed system.(2)

Winkler. The Winkler gasifier (Hoechst-Uhde Corp.) is a fluidized-bed reactor that operates at high temperatures as a completely mixed reactor system. This results in higher gas temperatures, reducing the levels of tars and oils. The high-temperature Winkler differs from the standard Winkler by operating at high pressure and slightly higher temperatures.The Winkler gas generator regulates the bed temperature by varying the primary blast at the bottom of the gasifier without disturbing the shaft temperature, which is controlled by the secondary blast just above the fluidized bed. The shaft temperature controls the gas composition through hydrocarbon conversion, shift reaction, and entrained gasification of fines.

An advantage of the Winkler gasifier is its operation at 8 atmospheres (approximately 118 pounds per square inch absolute). The synthesis gas, which needs to be compressed for the methanol-synthesis stage, is already partially compressed, and this saves on equipment sizing and compression costs.(2)

Table I-3 — Comparison of Wood Gasifiers

Gasifier Type	Winkler(8) Fluidized bed	Lurgi(3) Circulating fluidized bed	Koppers-Totzek(2) Entrained bed	IGT(7) Fluidized bed	Syn-Gas (SERI)(6) Stratified downdraft gas	Univ. Missouri(5) Indirect fired fluidized bed	Battelle Columbus(4) Entrained bed
Gasification medium	Steam, oxygen	Air	Steam, oxygen	Steam, oxygen	Oxygen	Steam	Steam
Gasifier heating mechanism	Oxygen-blown	Air-blown	Oxygen-blown	Oxygen-blown	Oxygen-blown	Internal bundle	heated sand
Gasifier conditions							
Temperature, °F	1,600	1,510	1,800	1,800	1,351	1,300	1,429
Pressure, psia	118	atm	atm	500	atm	atm	21.5
Gasifier results							
Scf/hr				27,472	624.3	3,000	211,894.5
Scf/lb d.w. (dry)	21.7	41.0	24.4	19.3	23.3	11.11	12.7
Scf/sq. ft. gasifier				38,156	885	1,376	12,952
Gas comp, mole (vol) %							
Hydrogen	18.20	17.54	28.70	20.80	27.82	19.98	11.57
Carbon monoxide	13.60	21.50	35.27	15.00	34.71	39.96	25.67
Carbon dioxide	25.70	9.82	15.17	23.90	12.99	19.98	6.14
Methane	10.50	2.72	0.20	8.19	4.09	12.96	8.66
Water vapor	31.90	12.28	20.55	31.80	20.39		44.17
Nitrogen	0	35.43	0.11	0	0		0.44
Inerts	0.10	0.71		0.31	0	7.02	3.31
Tar, lb/lb d.w.	0	0	0	0.011	0.005	0.08	0.01
Char, lb/lb d.w.	0.007		0		0.06	0.06	
Steam, lb/lb d.w.	0.18	0	0.03	0.3	0	1.5	0.61
Oxygen, lb/ib d.w.	0.46	0	0.56	0.3	0.38	0	0
Carbon conversion to gas, %	95	98		96.2	95	80	55

However, the low density of the feed causes problems with the Winkler gasifier. The biomass feed has poor fluidization properties, and entrainment of the fuel and wood is a drawback. A considerable problem in the oxygen-blown fluidized-bed technology is sintering or clinker formation, which is caused mainly by local hot spots even at temperatures much lower than the ash-fusion temperature.

Lurgi. The Lurgi moving-bed gasifier (Lurgi GmbH) has a circulating air-blown fluidized-bed design with a countercurrent flow pattern that efficiently circulates heat among gaseous and solid reactants and products. As the wood feedstock is gasified in the reactor, high gas velocities carry solid particles out with the gas to a series of cyclones for separation and recycle.

Because of the Lurgi's atmospheric operation and air-blown design, the resulting gas lacks necessary compression and has a higher nitrogen content.(3)

Future Technology. Because of renewed interest in biomass as an alternative energy source, research activities, studies, and projects on biomass have proliferated. To make biomass-to-methanol conversion a practical alternative, work has been directed toward producing less methane and fewer hydrocarbon byproducts in the gasifier and toward minimizing the levels of tars and inerts. Some of the more advanced developments in dedicated biomass gasifiers are those designed by Battelle Columbus, the University of Missouri-Rolla, the Solar Energy Research Institute, and the Institute of Gas Technology. The performance data for these systems are also shown in Table I-3.

Battelle Columbus. Battelle Columbus Research Institute in Columbus, Ohio, is developing an entrained-bed gasifier heated by a stream of sand that circulates between a separate combustion vessel and the gasifier. The gas produced by this system has a heating value of between 450 and 500 Btu's per standard cubic foot. After gasification of the wood, the char remaining is burned as fuel for the combustor.

Battelle Columbus carried out research in 6-inch and 10-inch gasifiers. The system uses steam, together with nitrogen, to mix the sand and wood and to transport the wood-sand suspension through the gasifier. A major advantage of this system is that even without an oxygen plant, it can produce synthesis gas undiluted by nitrogen, unlike the gas produced by other air gasifiers.(4)

University of Missouri-Rolla. The University of Missouri-Rolla has conducted tests on a 20-inch indirectly fired fluidized-bed gasifier to produce medium-Btu gas. A U-tube bundle, heated by flue gases from a propane burner system, is inserted into the bed of the reactor to heat it. Superheated steam fluidizes the wood. As in the Battelle Columbus design, synthesis gas is undiluted by nitrogen even though the system does not use an oxygen plant.(5)

Syn-Gas. The Syn-Gas gasifier, based on research and design by the Solar Energy Research Institute, is an air- or oxygen-stratified downdraft gasifier. The downdraft design was developed as an improvement over coal-burning updraft gasifiers, which produce high amounts of pyrolysis oils when operating on biomass feed. In the downdraft gasifier, the incoming air or oxygen burns the pyrolysis oils, resulting in lower tar levels.(6)

Institute of Gas Technology. The Institute of Gas Technology (IGT) has developed a pressurized, medium-Btu steam-oxygen-blown fluidized-bed gasifier. The gasifier bed contains alumina sphere inerts that act as the heat reservoir for the process and also offer uniform fluidization over the entire range of biomass feed rates. IGT conducted tests of the gasifier at temperatures ranging from 1390°F to 1800°F and pressures up to 300 pounds per square inch gauge. With modifications to the equipment, higher operating pressures appear feasible, but tests were not conducted at higher pressures because of limitations of the test equipment. Because the methanol-conversion stage operates at pressures in the range of 50 to 100 atmospheres, the ability to gasify initially at higher pressures is an economic advantage.(7)

II. WOOD-TO-METHANOL CONVERSION

The economics of converting wood to methanol were evaluated for two cases. The first assumes a present-technology commercial coal gasifier converted to wood feed. The gasifier produces synthesis gas that is converted to methanol by current commercially available methanol synthesis technology. The second case assumes a future-technology design featuring technologies that are not commercially available now but are expected to be available within the next 5 to 10 years, assuming impetus for further development exists. The costs of production for a large-volume future-technology design and for both current and future designs using single-train oxidant feed systems are also considered.

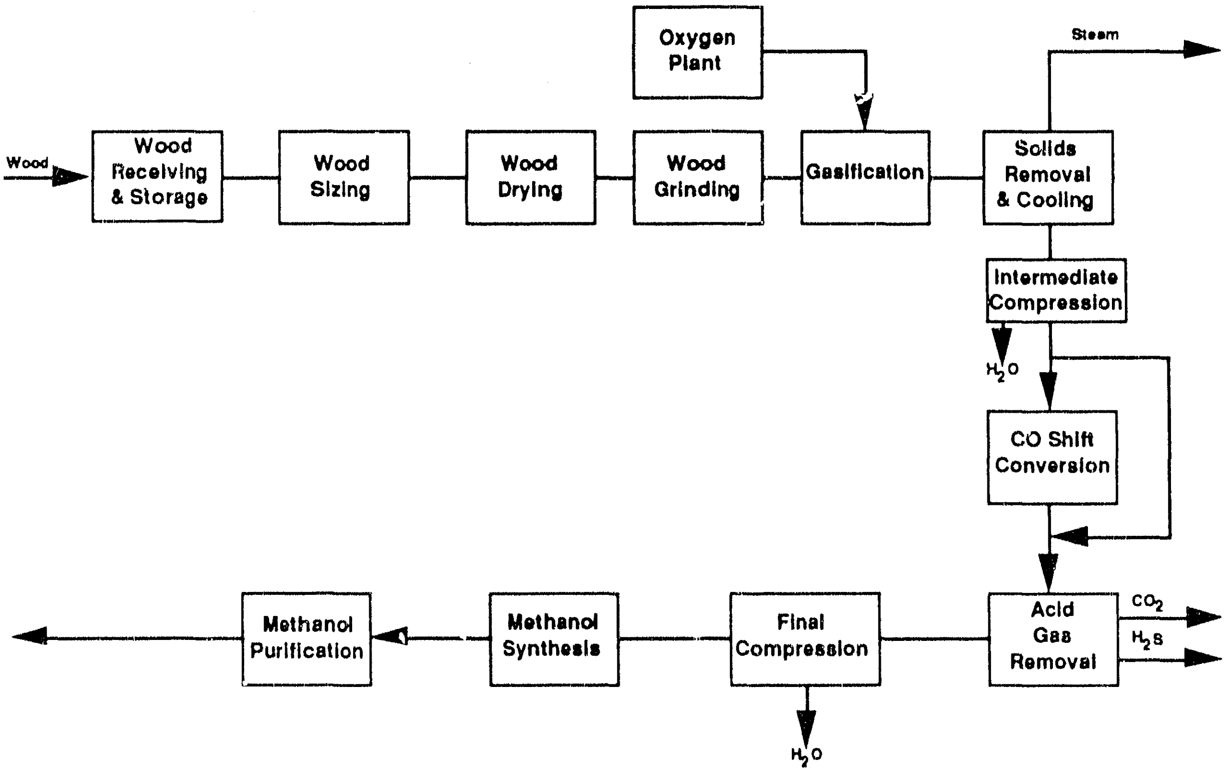
PRESENT-TECHNOLOGY CASE

The selection of a commercially available gasifier that uses biomass feedstock depends largely on the feedstock type and on the characteristics desired in the product gas. The Koppers-Totzek gasifier burns a wood feedstock to produce a medium-Btu gas suitable for methanol synthesis.

Figure II-1 is a highly simplified block-flow diagram of a wood-to-methanol facility using a K-T entrained-bed gasifier and a generic low-pressure (50 to 100 atmospheres) methanol synthesis plant, such as the ICI (Imperial Chemical Industries) or Lurgi processes.

Whole-tree green chips are delivered to the facility, where they are milled, dried to 8-percent moisture content, then further reduced to a minus 30 mesh size. The feedstock then goes to the gasifier, where it is gasified in the presence of oxygen and steam. The synthesis gas leaving the K-T gasifier also passes through a waste-heat boiler before going to solids removal and cooling.

Figure II-1 — Present-Technology Case



The wet syngas next enters the shift conversion section, where some of the carbon monoxide reacts with steam to form hydrogen and carbon dioxide. This gives the gas the proper hydrogen/carbon monoxide ratio for methanol synthesis.

The shifted gas goes to the acid-removal section, where hydrogen sulfide and excess carbon dioxide are removed before methanol synthesis.

The major processing equipment for methanol synthesis consists of a zinc-oxide guard chamber, a syngas compressor, and the methanol synthesis unit. Synthesis gas comes from the acid-gas removal units at 750 pounds per square inch gauge and 230°F. The gas then flows from a preheater through the zinc-oxide guard chamber to remove traces of hydrogen sulfide that might contaminate the methanol synthesis catalyst.

Recycled gas combines with the synthesis gas downstream of the zinc-oxide guard chamber and is fed to a methanol converter. The converter effluent is then sent to a methanol condenser. The mixture from the condenser is separated in a condensate knockout drum, where the gas flow is split into two streams.

The bulk of the gas from the condensate knockout drum is compressed by a recycle gas compressor and returned to the synthesis gas preheater. The remaining gas from the drum is purged from the system to prevent inerts from building up inside the synthesis unit.

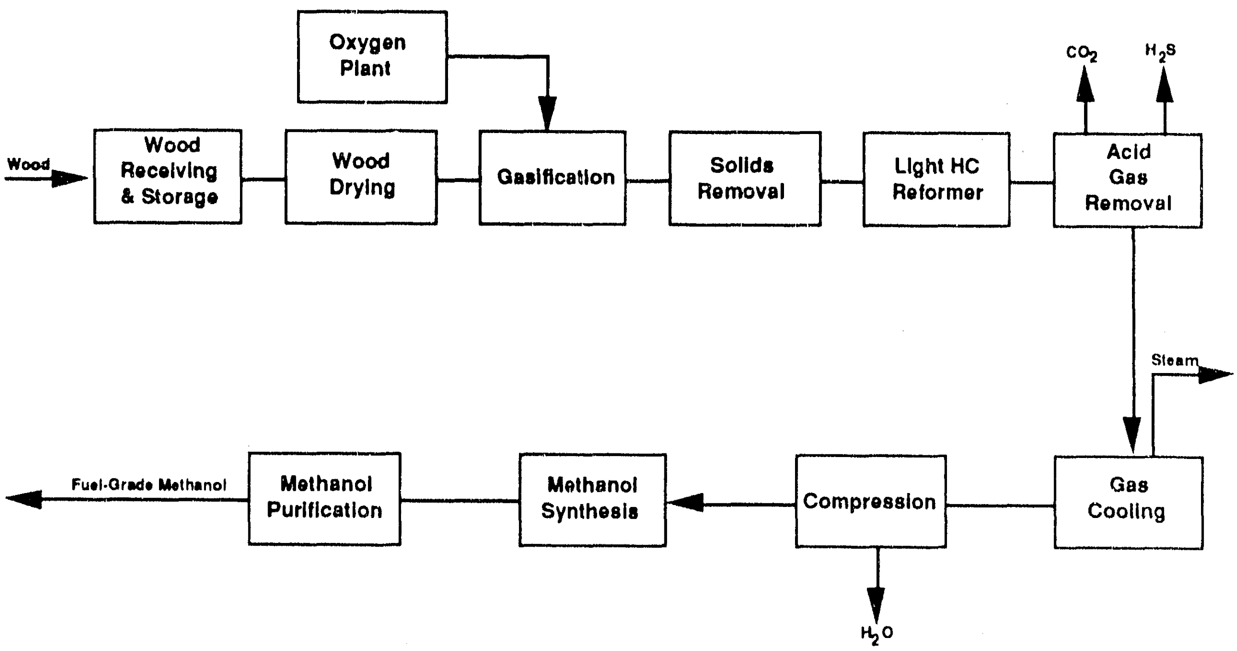
The liquid methanol in the condensate knockout drum containing water and dissolved inerts is flashed to a flash drum, where the two-phase mixture is separated.

FUTURE-TECHNOLOGY CASE

The Institute of Gas Technology fluidized-bed biomass gasifier has been selected for evaluation as the future-technology gasifier case. The IGT gasifier operates at high temperatures to produce a synthesis gas with some methane content. It could potentially produce a gas with a sufficient hydrogen/carbon monoxide ratio to obviate the need for the shift reaction. The gasifier operates at higher pressures, which minimizes the compression of the synthesis gas before methanol conversion and thereby reduces the cost of associated equipment.

Figure II-2 represents the proposed scheme for the future-technology plant, consisting of an

Figure II-2 — Future-Technology Case



IGT gasifier and an advanced methanol technology such as liquid phase methanol synthesis. All technology used in this scheme is expected to be available in the near future.

Whole-tree green chips are delivered to the plant site, where they are classified and dried to 15-percent moisture. The dried chips are pressure fed to the gasifier, which is assumed to operate at 500 pounds per square inch gauge and 1,800°F. 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 reformer, where methane is converted to carbon monoxide and hydrogen over a nickel catalyst, thus maximizing the usable components of methanol synthesis. The reformed gas is cooled, producing medium-pressure steam, and then goes to acid-gas removal for removal of hydrogen sulfide and excess carbon dioxide. The purified syngas is then ready for methanol synthesis.(9)

In the liquid-phase methanol section, the syngas is compressed to 1,500 pounds per square inch gauge; purged of water, trace sulfur, and metal carbonyls; and passed to the methanol synthesis unit. In the synthesis unit, the fresh syngas combines with recycled gas and enters a reactor containing a slurry of catalyst particles entrained in an inert oil. The slurry absorbs the heat of reaction and releases it by exchange with boiler feed water through an internal tube bundle. This arrangement results in medium-pressure steam production, and the slurry ensures a uniform, efficient control of reactor temperatures. The hot reactor exit gas interchanges heat with the feed gas, and then, in a series of flashes, is condensed and purified to fuel-grade methanol.

III. CAPITAL AND PRODUCTION COSTS

CAPITAL COSTS

The capital costs used in this report were derived from several sources, including quotes from vendors of specialized equipment. Methanol plant capacities for comparisons of present-technology and future-technology designs were based on dry wood feed of 2,000 short tons per day (4,000 short tons per day for green wood with a 50-percent moisture content). The methanol production of the present-technology case is 87 million gallons per year and that of the future-technology case is 101.5 million gallons per year.

Cost estimates are based on a U.S. Gulf Coast location; material, subcontracts, labor, and construction under fourth quarter 1987 conditions; a clear and level site; and a water supply from a nearby river. Indirect costs are based on Chem Systems' data base.

The main components of the present-technology plant include facilities for wood preparation, oxidant feed, gasification, gas cleanup and cooling, shift conversion, acid-gas removal, gas compression, and methanol synthesis and purification.

The plant consists of two gasification trains. The wood is dried in four rotary drum dryers, then three grinders mill the dried wood in two trains, each train feeding a gasification train. Downstream processing sections consist of a single train supplied from the two gasifiers, including a single-train methanol plant. Oxygen comes from two parallel oxygen plants, as were used in previous studies on methanol produced from coal.(1)

The major sections of the future-technology plant include facilities for wood preparation, oxidant feed, gasification, gas cleanup, methane reforming, acid-gas removal, gas cooling and compression, and methanol synthesis and purification.

In the future-technology system, green wood is dried in four rotary dryers, then goes to two gasifiers through two double lockhopper systems per gasifier. Synthesis gas leaves the gasification section to be processed in a single train, including a single-train methanol plant. Oxygen comes from two parallel oxygen plants.

Tables III-1 and III-2 summarize the capital cost estimates for the present-technology and future-technology wood-to-methanol plants. The IGT gasifier, in contrast to the K-T gasifier, can operate on larger, less uniform chips with a higher moisture content. This results in major cost reductions for the future-technology case, as does the simpler and less expensive design of the IGT gasifier. The capital cost of this case provided the basis for estimating the capital cost of the large-volume future-technology plant using capacity scale factors.

PRODUCTION COSTS

The costs of methanol production can be divided into several categories, including the raw materials, primarily wood; utilities, primarily electricity and steam; operating costs, including labor for operating the plant as well as materials and labor for annual maintenance costs; and overhead expenses, including plant overheads, taxes, and insurance.

Raw materials and utilities are considered as variable costs because they are a function of the plant's operating capacity. Operating costs and overhead expenses are considered as fixed costs because they are independent of the plant's operating rate. The sum of the variable and fixed costs is usually called the cash cost of production. This is the actual out-of-pocket cost an owner incurs before considering profits and the depreciation of the capital investment.

Table III-3 summarizes all bases used to develop methanol production costs for this report.

Methanol costs of production at present-technology and future-technology plants using

Table III-1 — Capital Cost of Present-Technology Wood-to-Methanol Plant
(2,000 short tons per day of wood, 87 million gallons per year of methanol)

Component	$MM
Wood receiving and preparation	35.6
Oxygen plant	46.4
Gasification	90.7*
Shift conversion	0.7
Acid-gas removal	10.3
Gas compression	10.1
Methanol synthesis and purification	19.9
Utilities and offsites	53.4
Total erected plant cost	**267.1**
Owners' costs, fees, profit	26.7
Land	2.0
Startup costs	6.0
Total capital investment	**301.8**

* Includes solids removal and cooling.

Table III-2 — Capital Cost of Future-Technology Wood-to-Methanol Plant
(2,000 short tons per day of wood, 101.5 million gallons per year of methanol)

Component	$MM
Wood receiving and preparation	15.9
Oxygen plant	40.3
Gasification	27.3
Solids removal	0.7
Reformer	29.7
Acid-gas removal	11.0
Gas cooling	1.9
Gas compression	7.6
Methanol synthesis and purification	22.5
Utilities and offsites	39.2
Total erected plant cost	**196.1**
Owners' costs, fees, profit	19.6
Land	2.0
Startup costs	6.0
Total capital investment	**223.7**

2,000 short tons per day of dry wood feed at a cost of $42 per short ton are presented in Tables III-4 and III-5.

As in earlier reports evaluating the conversion of natural gas and coal to methanol, a capital charge of 20 percent of total fixed investment plus working capital is taken as an overall capital recovery factor.(1) This format, as previously, results in an approximate 10-percent discounted cash flow (DCF) after-tax rate of return. The DCF rates of return are essentially the same for either a 3-year or 4-year construction period.

Methanol costs have been evaluated for a range of decreasing wood prices. The cost-of-production worksheet for the present-technology case assumes that byproduct steam is used within the plant. Economics for the future-technology case show the actual breakdown of steam consumption and production. In this case, there is excess steam that could be sold for other uses, and this has been taken as a byproduct credit at $3.43 per thousand pounds, which is the value of steam generated by natural gas at $1.71 per million Btu.

The large-volume methanol plant offers a more equitable comparison to similar-sized methanol plants using coal and natural gas as feedstock. The cost-of-production worksheet for this variation is presented in Table III-6 for a wood price of $42 per short ton.

Methanol cost comparisons for the three plant designs are shown in Figure III-1 for 20-percent and 30-percent capital recovery factors. As shown by the figure, the future-technology design offers a significant improvement over the present commercial technology ($0.93 versus $1.29 per gallon of methanol at a 20-percent capital recovery factor with wood at $42 per short ton). The economies of scale of the large-volume future-technology design offer a further reduction to $0.68 per gallon of methanol.

The figure also shows how the methanol production costs drop significantly with decreasing wood cost. For example, at a wood

Table III-3 — Bases for Methanol Production Costs

- Fourth quarter 1987
- Operating factor: 91 percent, 8,000 hours per year.
- Direct overhead at 45 percent of labor and supervision.
- General plant overhead at 65 percent of operating costs.
- Maintenance at 3 percent of inside battery limits cost.
- Insurance and property taxes at 1.5 percent of total fixed investment.
- Working capital is recovered at the end of the life of the project and is calculated as the sum of the following four items:
  1. **Feedstock Inventory**—One month's supply of raw materials valued at delivered prices.
  2. **Finished Product Inventory**—Half a month's supply of principal product and byproduct (if any) valued at gross cost of production. This is also based on liquid or solid product storage and excludes items that are not normally stored.
  3. **Accounts Receivable**—One month's gross cost of production.
  4. **Cash**—One week's out-of-pocket expenses estimated at gross cost of production less depreciation.

  Less a fifth item:

  5. **Accounts Payable**—One month's supply of raw materials at delivered prices.
- Capital charges at 20 percent of total capital requirements (fixed plus working capital). This charge is approximately equivalent to a 10-percent DCF rate of return with the following parameters:
  - Three years for construction with expenditures of 30 percent in the first year, 50 percent in the second year, and 20 percent in the third year.
  - Fifteen years of operation.
  - Income tax rate of 37 percent.
  - No sales expenses.
  - Capacity buildup of 60 percent of nameplate capacity in the first year, 80 percent in the second year, and 100 percent from the third year onward.
  - Depreciation at 5 years straight line for battery limits investment and 15 years straight line for outside battery limits investment.

cost of $32 per short ton, the relative methanol costs at a 20-percent rate of capital recovery are $1.21 per gallon for the present-technology case and $0.88 per gallon for the future-technology case. For the large-volume future-technology case, the methanol cost would be $0.61 per gallon.

A further evaluation was made that considered use of a single oxygen plant, rather than two parallel plants normally assumed. Although such a configuration would require a high level of operating reliability, it would provide some capital-cost reductions. With this arrangement, methanol costs are reduced to $0.87 per gallon for the future-technology case and $0.65 per gallon for the large-volume future-technology case for wood at a cost of $42 per short ton and at a 20-percent capital recovery rate. With the cost of wood reduced to $32 per short ton, the methanol costs drop to $0.80 per gallon for the 87-million-gallon-per-year plant and $0.58 for the large-volume plant. Cost-of-production worksheets with wood at $42 per short ton are presented for these two plants in Tables III-7 and III-8.

Table III-4 — Cost of Production Estimate for Producing Methanol from Wood Using Present Technology

			Capital Cost ($MM)		
			Orig.	Book	Repl.
Plant startup:	1987				
Analysis:	Fourth quarter, 1987				
Location:	U.S.	Battery limits	241.4	241.4	241.4
Capacity:	87.00 million gallons per year	Offsites	60.4	60.4	60.4
	263,297 metric tons per year				
Onstream time:	8,000 hours per year	Total fixed inv.	301.8	301.8	301.8
Throughput:	87.00 million gallons per year	Working capital			14.4

Production Cost Summary

Component		Units per gal.	Price ($/unit)	$ per gal.	Annual Cost ($MM)	$ per met. ton
Raw materials	Wood (dry), ST	0.0078	42.000	0.328	28.50	
	Catalyst & chemicals		0.006	0.006	0.48	
	Total raw materials			0.333	28.98	110
Utilities	Power, kWh	0.53820	0.041	0.022	1.92	
	Cooling water, M Gal	0.00530	0.071	0.000	0.03	
	Boiler feedwater, M Gal	0.00040	1.242	0.000	0.04	
	Total utilities			0.023	2.00	8
Variable cost of production				0.356	30.98	118
Direct cash costs	Labor	23 men	29,800	0.008	0.69	
	Foremen	5 men	34,000	0.002	0.17	
	Supervisors	1 men	40,900	0.000	0.04	
	Maintenance, material & labor	3.0 % of ISBL		0.083	7.24	
	Direct overhead	45 % Labor/supervision		0.005	0.40	
	Total direct cash costs			0.098	8.54	32
Allocated cash costs	General plant overhead	65 % Labor/maintenance		0.061	5.29	
	Insurance, property tax	1.5 % Total fixed inv.		0.052	4.53	
	Total allocated cash costs			0.113	9.82	37
Full cash cost of production				0.567	49.33	187
Net cost of production				0.567	49.33	187
Cost plus 0 % return on total book investment plus working capital				0.567	49.33	187
Cost plus 20 % return on total book investment plus working capital				1.294	112.57	428
Cost plus 30 % return on total book investment plus working capital				1.657	144.19	548

Table III-5 — Cost of Production Estimate for Producing Methanol from Wood Using Future Technology

			Capital Cost ($MM)		
			Orig.	Book	Repl.
Plant startup:	1987				
Analysis:	Fourth quarter, 1987				
Location:	U.S.	Battery limits	179.0	179.0	179.0
Capacity:	101.50 million gallons per year 307,180 metric tons per year	Offsites	44.7	44.7	44.7
Onstream time:	8,000 hours per year	Total fixed inv.	223.7	223.7	223.7
Throughput:	101.50 million gallons per year	Working capital			12.2

Production Cost Summary

Component		Units per gal.	Price ($/unit)	$ per gal.	Annual Cost ($MM)	$ per met. ton
Raw materials	Wood (dry), ST	0.0066	42.000	0.277	28.14	
	Catalyst & chemicals		0.017	0.017	1.68	
	Total raw materials			0.294	29.82	97
Utilities	Power, kWh	0.70640	0.041	0.029	2.94	
	Steam, 150 psig, M Lb	0.01460	3.268	0.048	4.84	
	Steam, 40 psig, M Lb	0.00004	3.220	0.000	0.01	
	Cooling water, M Gal	0.02000	0.071	0.001	0.14	
	Boiler feedwater, M Gal	0.00210	1.242	0.003	0.26	
	Fuel, MM Btu	0.00610	1.710	0.010	1.06	
	Steam, 365 psig, M Lb	(0.01780)	3.430	(0.061)	(6.20)	
	Total utilities			0.030	3.07	10
Variable cost of production				0.324	32.89	107
Direct cash costs	Labor	23 men	29,800	0.007	0.69	
	Foremen	5 men	34,000	0.002	0.17	
	Supervisors	1 men	40,900	0.000	0.04	
	Maintenance, material & labor	3.0 % of ISBL		0.053	5.37	
	Direct overhead	45 % Labor/supervision		0.004	0.40	
	Total direct cash costs			0.066	6.67	22
Allocated cash costs	General plant overhead	65 % Labor/maintenance		0.040	4.07	
	Insurance, property tax	1.5 % Total fixed inv.		0.033	3.36	
	Total allocated cash costs			0.073	7.43	24
Full cash cost of production				0.463	46.99	153
Net cost of production				0.463	46.99	153
Cost plus 0 % return on total book investment plus working capital				0.463	46.99	153
Cost plus 20 % return on total book investment plus working capital				0.928	94.16	307
Cost plus 30 % return on total book investment plus working capital				1.160	117.75	383

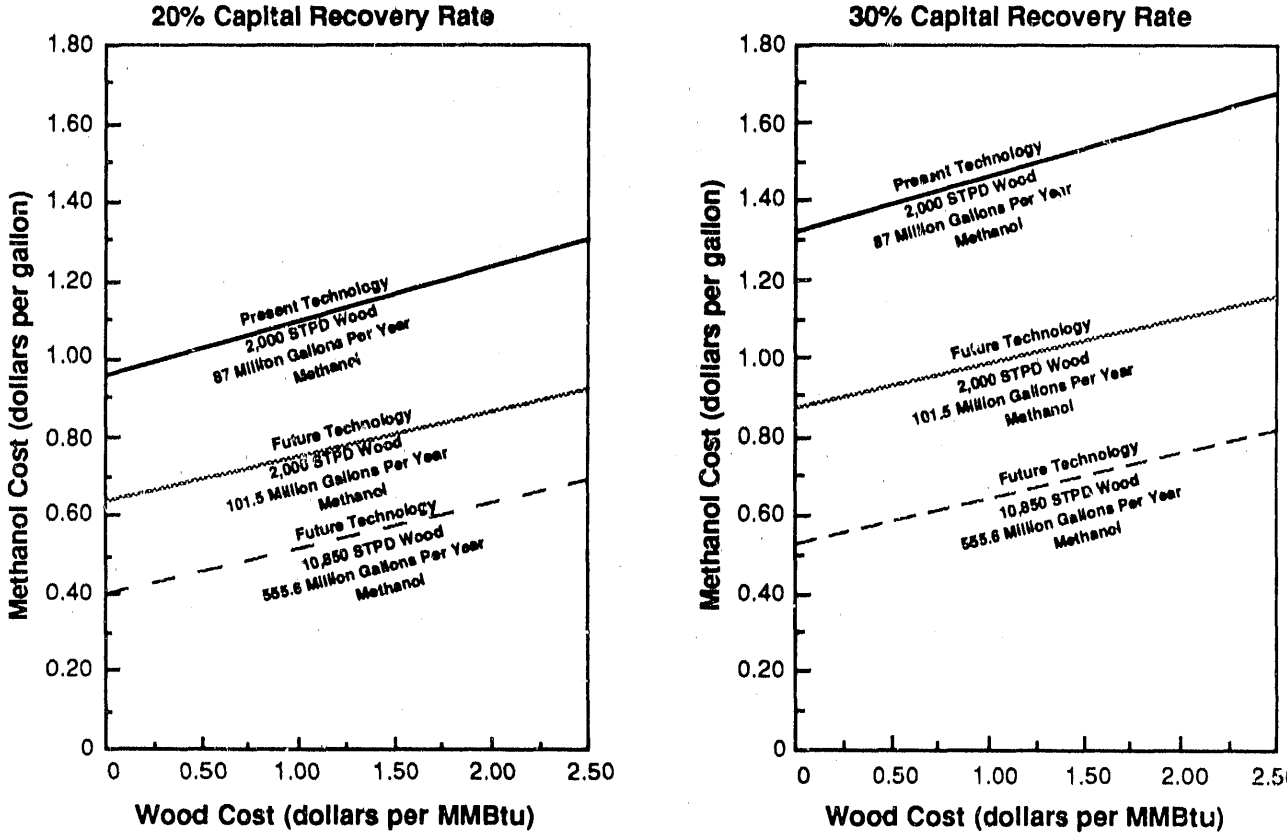
Table III-6 — Cost of Production Estimate for Producing Methanol from Wood Using Future Technology: Large-Volume Plant

			Capital Cost ($MM)		
			Orig.	Book	Repl.
Plant startup:	1987				
Analysis:	Fourth quarter, 1987				
Location:	U.S.	Battery limits	582.8	582.8	582.8
Capacity:	555.60 million gallons per year 1,681 thousand metric tons per year	Offsites	145.7	145.7	145.7
Onstream time:	8,000 hours per year	Total fixed inv.	728.5	728.5	728.5
Throughput:	555.60 million gallons per year	Working capital			49.7

Production Cost Summary

Component		Units per gal.	Price ($/unit)	$ per gal.	Annual Cost ($MM)	$ per met. ton
Raw materials	Wood (dry), ST	0.0066	42.000	0.277	154.01	
	Catalyst & chemicals		0.017	0.017	9.22	
	Total raw materials			0.294	163.24	97
Utilities	Power, kWh	0.70640	0.041	0.029	16.09	
	Steam, 150 psig, M Lb	0.01460	3.268	0.048	26.51	
	Steam, 40 psig, M Lb	0.00004	3.220	0.000	0.07	
	Cooling water, M Gal	0.02000	0.071	0.001	0.79	
	Boiler feedwater, M Gal	0.00210	1.242	0.003	1.45	
	Fuel, MM Btu	0.00610	1.710	0.010	5.80	
	Steam, 365 psig, M Lb	(0.01780)	3.430	(0.061)	(33.92)	
	Total utilities			0.030	16.79	10
Variable cost of production				0.324	180.02	107
Direct cash costs	Labor	30 men	29,800	0.002	0.89	
	Foremen	5 men	34,000	0.000	0.17	
	Supervisors	1 men	40,900	0.000	0.04	
	Maintenance, material & labor	3.0 % of ISBL		0.031	17.48	
	Direct overhead	45 % Labor/supervision		0.001	0.50	
	Total direct cash costs			0.034	19.09	11
Allocated cash costs	General plant overhead	65 % Labor/maintenance		0.022	12.08	
	Insurance, property tax	1.5 % Total fixed inv.		0.020	10.93	
	Total allocated cash costs			0.041	23.01	14
Full cash cost of production				0.400	222.12	132
Net cost of production				0.400	222.12	132
Cost plus 0 % return on total book investment plus working capital				0.400	222.12	132
Cost plus 20 % return on total book investment plus working capital				0.680	377.76	225
Cost plus 30 % return on total book investment plus working capital				0.820	455.58	271

Figure III-1 — Costs of Methanol from Wood



Simplified formulas representing the production costs of present-technology plants, future-technology plants, and large-volume future-technology plants with both a 20-percent and a 30-percent capital recovery factor are as follows:

Metnanol Cost ($/gal.)	Case
0.0080W + 0.96	Present technology, 20-percent capital recovery
0.0081W + 1.32	Present technology, 30-percent capital recovery
0.0068W + 0.64	Future technology, 20-percent capital recovery
0.0069W + 0.87	Future technology, 30-percent capital recovery
0.0068W + 0.40	Large-volume future technology, 20-percent capital recovery
0.0069W + 0.53	Large-volume future technology, 30-percent capital recovery

where W is the cost of wood in dollars per short ton and the wood heating value is 8,550 Btu per pound.

Table III-7 — Cost of Production Estimate for Producing Methanol from Wood Using Future Technology: Single-Train Oxygen Plant

				Capital Cost ($MM)	
			Orig.	Book	Repl.
Plant startup:	1987				
Analysis:	Fourth quarter, 1987				
Location:	U.S.	Battery limits	161.3	161.3	161.3
Capacity:	101.50 million gallons per year 307,180 metric tons per year	Offsites	40.3	40.3	40.3
Onstream time:	8,000 hours per year	Total fixed inv.	201.6	201.6	201.6
Throughput:	101.50 million gallons per year	Working capital			11.5

Production Cost Summary

Component		Units per gal.	Price ($/unit)	$ per gal.	Annual Cost ($MM)	$ per met. ton
Raw materials	Wood (dry), ST	0.0066	42.000	0.277	28.14	
	Catalyst & chemicals		0.017	0.017	1.68	
	Total raw materials			0.294	29.82	97
Utilities	Power, kWh	0.70640	0.041	0.029	2.94	
	Steam, 150 psig, M Lb	0.01460	3.268	0.048	4.84	
	Steam, 40 psig, M Lb	0.00004	3.220	0.000	0.01	
	Cooling water, M Gal	0.02000	0.071	0.001	0.14	
	Boiler feedwater, M Gal	0.00210	1.242	0.003	0.26	
	Fuel, MM Btu	0.00610	1.710	0.010	1.06	
	Steam, 365 psig, M Lb	(0.01780)	3.430	(0.061)	(6.20)	
	Total utilities			0.030	3.07	10
Variable cost of production				0.324	32.89	107
Direct cash costs	Labor	23 men	29,800	0.007	0.69	
	Foremen	5 men	34,000	0.002	0.17	
	Supervisors	1 men	40,900	0.000	0.04	
	Maintenance, material & labor	3.0 % of ISBL		0.048	4.84	
	Direct overhead	45 % Labor/supervision		0.004	0.40	
	Total direct cash costs			0.060	6.14	20
Allocated cash costs	General plant overhead	65 % Labor/maintenance		0.037	3.73	
	Insurance, property tax	1.5 % Total fixed inv.		0.030	3.02	
	Total allocated cash costs			0.067	6.75	22
Full cash cost of production				0.451	45.78	149
Net cost of production				0.451	45.78	149
Cost plus 0 % return on total book investment plus working capital				0.451	45.78	149
Cost plus 20 % return on total book investment plus working capital				0.871	88.39	288
Cost plus 30 % return on total book investment plus working capital				1.081	109.70	357

Table III-8 — Cost of Production Estimate for Producing Methanol from Wood Using Future Technology: Large-Volume/Single-Train Oxygen Plant

			Capital Cost ($MM)		
			Orig.	Book	Repl.
Plant startup:	1987				
Analysis:	Fourth quarter, 1987				
Location:	U.S.	Battery limits	530.2	530.2	530.2
Capacity:	555.60 million gallons per year 1,681 thousand metric tons per year	Offsites	132.5	132.5	132.5
Onstream time:	8,000 hours per year	Total fixed inv.	662.7	662.7	662.7
Throughput:	555.60 million gallons per year	Working capital			47.6

Production Cost Summary

Component		Units per gal.	Price ($/unit)	$ per gal.	Annual Cost ($MM)	$ per met. ton
Raw materials	Wood (dry), ST	0.0066	42.000	0.277	154.01	
	Catalyst & chemicals		0.017	0.017	9.22	
	Total raw materials			0.294	163.24	97
Utilities	Power, kWh	0.70640	0.041	0.029	16.09	
	Steam, 150 psig, M Lb	0.01460	3.268	0.048	26.51	
	Steam, 40 psig, M Lb	0.00004	3.220	0.000	0.07	
	Cooling water, M Gal	0.02000	0.071	0.001	0.79	
	Boiler feedwater, M Gal	0.00210	1.242	0.003	1.45	
	Fuel, MM Btu	0.00610	1.710	0.010	5.80	
	Steam, 365 psig, M Lb	(0.01780)	3.430	(0.061)	(33.92)	
	Total utilities			0.030	16.79	10
Variable cost of production				0.324	180.02	107
Direct cash costs	Labor	30 men	29,800	0.002	0.89	
	Foremen	5 men	34,000	0.000	0.17	
	Supervisors	1 men	40,900	0.000	0.04	
	Maintenance, material & labor	3.0 % of ISBL		0.029	15.91	
	Direct overhead	45 % Labor/supervision		0.001	0.50	
	Total direct cash costs			0.032	17.51	10
Allocated cash costs	General plant overhead	65 % Labor/maintenance		0.020	11.06	
	Insurance, property tax	1.5 % Total fixed inv.		0.018	9.94	
	Total allocated cash costs			0.038	21.00	12
Full cash cost of production				0.393	218.53	130
Net cost of production				0.393	218.53	130
Cost plus 0 % return on total book investment plus working capital				0.393	218.53	130
Cost plus 20 % return on total book investment plus working capital				0.649	360.59	214
Cost plus 30 % return on total book investment plus working capital				0.777	431.62	257

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