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DSE-3002-T1 (Vol.2)

**TECHNICAL-ECONOMIC ASSESSMENT OF THE PRODUCTION
OF METHANOL FROM BIOMASS**

Final Research Report

Assessment of Biomass Resource and Methanol Market

By

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July 12, 1979

Work Performed Under Contract No. ET-78-C-01-3002

**Science Applications, Inc.
McLean, Virginia**

U.S. Department of Energy

Solar Energy

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Technical-Economic Assessment of
the Production of Methanol from Biomass
Final Research Report

Volume II - Assessment of Biomass
Resource and
Methanol Market

DOE Contract ET-78-C-3002

Work Performed for:

Biomass Energy System Branch
U.S. Department of Energy

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1. INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

Science Applications, Inc. (SAI) has conducted a comprehensive engineering system study to assess various thermochemical processes suitable for converting biomass to methanol fuel. The study results are presented in three volumes. Volume I is an executive summary. This report, Volume II, contains results related to biomass resource analysis and methanol fuel market analysis. Volume III deals with technical and economic analyses of conceptual biomass to methanol processes. The approach and steps utilized in the analysis of biomass resources and methanol markets are outlined as follows:

Biomass Resources Analysis

- Characterization of regional biomass resources
- Projection of near-term and long-term biomass resources
- Screening representative potential biomass resource areas

Methanol Fuel Market Analysis

- Evaluate existing and potential methanol end uses
- Comparison of potential methanol demand and supply
- Methanol market penetration analysis

1.2 SIGNIFICANT FINDINGS AND RECOMMENDATIONS

1.2.1 Biomass Resource Assessment

- In the near term (before 1985), the major source of biomass will be agricultural and silvicultural residues. This represents approximately 423 million dry tons of biomass per year in the United States.

In the long term (after 2000), additional biomass could be available from biomass energy farms, the output of which could reach 265 million dry tons per year.

- Biomass from existing forest resources is adequate for the initial development of methanol fuel. It is estimated that 25 percent of the combined forest and crop residues would be sufficient for a nationwide market for a 10 percent methanol-gasoline blend.
- Analysis of residue resources has shown that several suitable methanol plant sites exist. These sites have different supply potentials, ranging from 1100 to 13000 ODT per day. Similarly, several sites based on energy farm production with capacities greater than 8000 ODT per day could be available.

1.2.2 Resource Development Strategy

- Near term priority should focus on selection of sites in each region which are suitable for initial methanol development. Several types of sites, optimally located with respect to markets, should be identified, including:
 - Biomass-methane hybrid production site
 - Biomass-hydrogen hybrid production site
 - Forest residue production site
 - Agricultural residue production site
- Long-term priority should be on the development of large energy farms to produce sufficient biomass resources to satisfy long-term markets.

For the purpose of supplying large quantities of biomass for methanol production, specific resource development efforts are suggested:

- Identify priorities and policies for biomass residue harvesting, including delineation of optimal harvesting areas and technology.

- Assess regional and seasonal methanol requirements and biomass availability to determine the relationships between supply and demand at various locations. From this, a profile of biomass farm development and forest management can be identified.
- Initiate regional biomass farm development, and identify institutional and environmental impacts which may result from factors such as shorter rotation periods and extensive silvicultural activities.
- Determine biomass gasification characteristics for high potential biomass materials including wood, straw, corn stover, bagasse, sugar cane, and others.

Integrated resource and conversion demonstration projects will be useful for studying:

- Local biomass availability at an acceptable cost for smooth methanol plant operation.
- Factors for reducing transportation costs of biomass and product.
- Market arrangements to assure a steady outlet for the methanol product.
- Site environmental impacts in terms of resource utilization and process emissions:
 - Land, water, and material resource impacts
 - Labor and employment impacts

1.2.3 Methanol Fuel Market Assessment

- Potential future markets for methanol vary, but most indicate a high demand. By 1985, demand for methanol in applications such as peak power generation and automotive fuel could be ten times as large as the demand for methanol in the manufacture of established chemicals.
- The Mid-Atlantic, South-Atlantic, East North-Central, and West South-Central regions have the potential for gaining the largest share of the methanol market between 1985-2000, based on their existing and projected markets for liquid fuels.

- The methanol gasoline blend option presents the best market penetration potential and could be developed within 5 years. For a 10 percent blend in gasoline, a total market of 13.4 billion gallons per year is projected by 1985. Other additional uses for methanol as a fuel would result in a still greater demand.

1.2.4 Methanol Market Development Strategy

Priority should be focused on the development of the gasoline substitute market. This should include the following:

- Geographic distribution of methanol fuel markets.
- Federal assistance in market development and tax incentives.
- Regulatory considerations regarding the distribution of the methanol-gasoline blend, pricing and tax policies.
- Assessment of future market competition from other alternative transportation fuels.

1.3 SUMMARY AND DISCUSSION OF RESULTS

This section summarizes the detailed information presented in subsequent sections. The specific topics covered are:

- Biomass Resource Analysis (Section 2, Vol. II)
 - Feasibility of biomass feedstocks for methanol production
 - Biomass availability and costs
- Methanol Fuel Market Analysis (Section 3, Vol. II)
 - Potential demand for methanol from biomass
 - Comparison of potential methanol demand and supply
 - Market penetration assessment

1.3.1 Feasibility of Biomass Feedstocks for Methanol Production

- Biomass exhibits unique chemical and physical characteristics which are suitable for thermo-chemical processing. The major characteristics of biomass feedstocks are:
 - There is a high degree of similarity between most available biomass materials
 - Many biomass materials have a chemical composition similar to that of cellulose
 - Sulfur and ash components generally are low
 - H/C mole ratio equals approximately 1.5
 - H/O mole ratio equals approximately 2.0.
- Comparison of biomass with other feedstocks shows a similarity to urban refuse and its components, but a dissimilarity to coals. The major difference between biomass and coal are a higher water content, a higher oxygen content, size and density, and chemical characteristics such as higher volatility for biomass.
- Biomass feedstock cost vary widely, depending upon the feedstock type, transportation, and collection methods. In general, crop residues appear to be the most expensive due to relatively high market values and high collection costs.
- For methanol production, relatively large quantities (thousands or tons per day) of feedstocks will be required. Estimated delivered costs for biomass feedstocks suitable for methanol conversion range from \$1.2 to \$3.2 per MMBtu (\$20 to \$54 per dry ton) for residue type biomass. Lower cost ranges, e.g., from \$1.4 to \$2.0 per MMBtu (\$24 to \$37 per dry ton) are expected for energy farm biomass.

- In light of near-term biomass costs, it appears that initial plants should be located in areas with low cost and plentiful biomass such as certain forest lands, where biomass is available at \$1.5 per MMBtu or less. Site selection studies for first generation demonstration plants should also look into the possibility of locations next to potential demonstration sites for biomass farms, in order to establish an integrated resource/conversion study area.
- Transportation costs for biomass feedstocks and methanol product were examined in four transportation scenarios:
 - Dispersed conversion plants and dispersed markets
 - Centralized conversion plants and dispersed markets
 - Dispersed conversion plants and centralized market
 - Centralized conversion plant and centralized market

The transportation analyses show that the contribution from biomass transportation is larger than that from methanol product transportation. The sums of these transportation costs range from \$.04 to \$.07 per gallon of methanol. The variation from one scenario to another appears small relative to the total estimated production cost of methanol from biomass.

- The seasonality of crop residues suggests that a methanol conversion facility would benefit from the installation of equipment for handling a variety of residues.

1.3.2 Biomass Availability

- In the near to mid-term (before 2000), the major source of biomass will be agricultural and silvicultural residues. This represents approximately 423 million dry tons of biomass per year in the United States. In the long term (after 2000), additional biomass could be available from biomass energy farms, the output of which could reach 265 million dry tons per year.

- The existing resource base for forestry biomass shows that the South Atlantic, East South Central, West South Central, and East North Central regions dominate. Agricultural residues are most abundant in the West North Central, followed by the East North Central, West South Central, and Mountain regions.
- Short rotation silvicultural farms, when taken into account, could contribute significantly, ranging from 18 percent of the existing biomass base (West North Central) to 60 percent (West South Central) in 2000.
- A preliminary survey of residue resources has shown that several suitable methanol conversion sites exist, based on adequacy and availability of resources. These sites have differing supply potentials ranging from 1100 to 13000 ODT per day of residue. Similarly, examination of representative sites for energy farms has indicated that sites producing up to 8000 ODT per day, could be available in the near and mid-term.

1.3.3 Potential Demand for Methanol from Biomass

- The potential end uses of methanol include transportation fuels, heating fuels, electricity generation, chemical feedstocks and other miscellaneous uses such as for fuel cells and single cell protein feedstocks.
- Methanol consumption in the U.S. totaled 1150 million gallons in 1975. Methanol requirements for traditional chemical uses are estimated to grow at modest annual rates of 7.7 percent during the years 1970-1980, and at 5.4 percent during the years 1980-2000.
- Estimates of potential future markets for methanol vary, but most indicate a high potential demand. By 1985, demand for methanol in applications such as peak power generation and automotive transportation, could be ten times as large as the demand for methanol in the manufacture of established chemicals.
- The Mid-Atlantic, South-Atlantic, East North-Central, and West South-Central regions have the potential for gaining the largest share of the methanol market between 1985-2000. For 10 percent in gasoline, a total market of 13.44 billion gallons per year is projected by 1985. Other additional uses for methanol as a fuel would result in a still greater demand.

1.3.4 Comparison of Potential Methanol Demand and Supply

- Three market penetration scenarios were developed to assess future methanol requirements:

Scenario 1: 10 percent automotive gasoline displacement
Scenario 2: 44 percent displacement of the automotive gasoline market and 30 percent displacement of the automotive diesel market
Scenario 3: Same as scenario (2) plus 30 percent displacement of distillates and 5 percent of the residual oil market.
- Scenario (1) methanol requirements can be satisfied by a reasonable projection of future biomass availability, equivalent to 25 percent of projected total biomass resources in the near and mid term (1985-2000).
- Scenario (2) and Scenario (3) requirements cannot be satisfied by the above projected availability of U.S. biomass resources. It is concluded that a 10 to 15 percent displacement of automotive gasoline or equivalent volumes in other markets represent a reasonable target based on resource constraints.
- The value of methanol to each category of consumers is a function of the prices of the petroleum fuel for which methanol is intended as a substitute. Methanol appears to be most valuable as a blend fuel with gasoline. Its market value is estimated at between \$0.83 and \$1.53 per gallon in 1985 (\$1979) for this end use. Methanol market values, as a substitute for distillates in diesel vehicles, utility gas turbines and residential heating, will be much lower (\$0.3 per gallon in 1985).
- The volume of methanol for 10 percent gasoline displacement is equivalent to the output from 65 plants with a capacity each of 2000 short tons of methanol per day.

2. BIOMASS RESOURCE ANALYSIS

The availability of biomass for methanol production was assessed, using the following approach:

- A thorough review of the available literature
- Acquisition of up-to-date results from DOE contractors
- National and regional level analysis
- County level analysis for typical resource regions
- Consideration of physical characteristics, costs, and uncertainties of supply

Major publications on biomass resources by SRI, MITRE, Midwest Research Institute, and others were reviewed(1-13). In addition, current information was obtained through contractors' conferences, and other meetings and workshops. Projections of future availability were scaled down, where appropriate, to reflect more realism for the near future.

The analysis focuses on land based biomass including crop and forestry residues, and conceptual biomass farms. Aquatic biomass systems are characterized by expected high yields, hoped-for low cost cultivation, and potentially very large impacts on national energy demands. However, confident predictions about yields and economics of aquatic systems cannot be made at this time(1). Therefore, no aquatic biomass farms are included in the projected resource availability, although their potential impact could be large.

2.1 FEASIBILITY OF BIOMASS FEEDSTOCKS FOR METHANOL PRODUCTION

Biomass exhibits a composition of combustibles (carbon, hydrogen, and oxygen) fairly similar to that of coal and municipal

solid wastes (MSW). It is reasonable to assume that reaction conditions which gasify coal and solid wastes will also gasify biomass. In that regard, the thermal gasification of biomass has been demonstrated during World War II in Europe⁽¹⁾. In the United States, certain coal gasifiers, such as the Wellman-Galusha gasifier, have been used to gasify sawdust, corn cobs, cotton seed husks and other biomass feedstocks⁽¹⁴⁾. Other gasifiers, including Battelle and Pullman-Kellogg designs, have also been used to gasify biomass.

2.1.1. Chemical and Physical Characteristics of Biomass Feedstocks

Plant biomass is composed of three basic polymers: cellulose, lignin, and hemicellulose. In addition, there are smaller amounts of resins, terpenes, fats, and ash minerals which have potential effects on the conversion of biomass to synthetic fuel.

Proximate analytical methods identify and quantify water, volatile components, fixed carbon and ash constituents, while ultimate analytical methods identify chemical constituents of dry material. The above two analyses provide a basis for characterizing the biomass feed material. The analytical results, together with density data, have been collected and assembled in Table 2.1 for a variety of biomass feed materials.

The data show several characteristics of biomass feeds, the major ones being:

- There is a high degree of similarity between various biomass feeds
- All biomass has a chemical composition similar to that of cellulose
- Sulfur and ash components are low
- H/C mole ratio equals approximately 1.5
- H/O mole ratio equals approximately 2.0.

Table 2.1 Constituents of Biomass Feeds

	<u>Hardwood Maple</u>	<u>Western Hemlock</u>	<u>White Pine Sawdust</u>	<u>Pine Sawdust</u>	<u>Balsam Spruce</u>	<u>Hardwood Leaf Mixture</u>	<u>Millrun Bagasse</u>	<u>Cellulose</u>
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 C	19.6	23.6	14.1	20.1	15.52	12.29	-	-
Ash	4.3	2.2	.14	.5	3.06	3.82	2	-
ULTIMATE ANALYSIS								
(wt%)								
C	50.4	50.4	52.32	51.8	53.3	51.63	48.2	44.44
H	5.9	5.8	6.05	6.3	6.65	6.05	6.7	6.22
O	39.1	41.4	40.05	41.3	35.05	30.04	45.1	49.34
N	.5	.1	.56	.1	1.49	6.92	-	-
S	0.0	.1	.39	0.0	.20	.16	-	-
Ash	4.1	2.2	.15	.5	3.18	4.2	2	-
DENSITY (g/cc)								
Bulk	-	-	-	-	-	-	-	-
Particle	.68	.47	.43	.43-.67	.45	-	-	-

Sources: References 4 and 13

Comparison of biomass to other feedstocks further illustrates the nature of biomass. Tables 2.2 and 2.3 present such data. This shows the similarity of urban refuse and its components with biomass, and the dissimilarity between coals and biomass.

The major differences between biomass and coal are:

- Water Content - The high moisture content of biomass is one of the major differences between biomass and coal. The efficiency of the gasification process is influenced by the feed moisture content. The net energy available for syngas production decreases as the moisture content of the feed increases. It was estimated that approximately 25 percent of total available heat energy in biomass is consumed for the preheating and vaporization of H_2O (average 50 percent moisture in feedstock) in the biomass gasification process(18).

Biomass moisture content is found to vary both between species and within an individual plant, depending on the plant part being examined. As a result, only approximate values can be determined for biomass feedstock moisture. Furthermore, the treatment of the material before processing must be taken into account, as this significantly affects the bulk moisture content.

- Size and Density - Size and density affect the performance of thermal gasification reactors. Most existing gasifiers allow only feedstocks which have undergone size reduction. 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 undesired entrainment for certain types of reactors. Furthermore, plant biomass is quite variable in terms of its density as compared to coal.
- Chemical Characteristics - As can be seen, biomass generally has a larger, volatile component than does coal. Therefore, the reactivity of biomass may be higher than that of coal. The chemical composition of the biomass feedstock affects the reaction products in thermochemical gasification. The requirements for pollution controls are subsequently influenced by the chemical characteristics of the feedstock. The low sulfur content of biomass is an advantage over many

Table 2.2 Composition of Coal and Urban Refuse

	<u>Coal</u>		<u>Urban Waste Components</u>					<u>Average Urban Refuse</u>
	<u>Low Vol Bituminous</u>	<u>Hi Vol Bituminous</u>	<u>Newspaper</u>	<u>Corrugated Box Paper</u>	<u>Brown Box Paper</u>	<u>Magazine Paper</u>	<u>Lawn Grass</u>	
<u>PROXIMATE ANALYSIS</u> (wt%)								
Moisture	3.6	3.56	5.97	5.2	5.83	4.11	5.47	7.3
Volatile Matter	17.41	37.18	81.12	77.47	83.92	66.39	71.16	76.0
Fixed C	74.84	56.55	11.48	12.27	9.24	7.03	17.18	11.4
Ash	4.14	2.71	1.43	5.06	1.01	22.47	6.19	7.3
<u>ULTIMATE ANALYSIS</u> (wt%)								
C	83.68	79.61	48.97	43.62	44.74	32.86	46.04	41.2
H	4.57	5.54	6.08	5.7	6.06	4.93	7.11	5.5
O	5.73	9.83	42.88	44.78	47.68	38.48	35.15	30.7
N	1.12	1.61	.05	0.09	0.00	.07	4.45	.5
S	.76	.70	.15	.21	.11	.09	.42	.2
Ash	4.14	2.71	1.52	5.32	1.07	23.39	6.53	13.9
<u>DENSITY</u> (g/cc)								
Bulk	0.65	0.65						.2-.3
Particle	1.35	1.35	.7-1.15	.7-1.15	.7-1.15	.7-1.15	-	-

Table 2.3 Comparison of Biomass, Municipal Solid Wastes and Coal Characteristics

	1/ <u>Wood</u>	2/ <u>Bark</u>	3/ <u>Kentucky Blue Grass</u>	3/ <u>Pure Cellulose</u>	5/ <u>Bagasse</u>	3/ <u>Municipal Solid Wastes</u>	3/ <u>Reed Sedge Peat</u>	4/ <u>Lignite</u>	4/ <u>Bituminous Coal</u>
Ultimate Chemical Analysis, %									
Hydrogen	5.8 - 6.3	5.4 - 6.2	5.9	6.2	6.6	5.5	5.45	6.6	5.1
Carbon	50.4 - 53.5	51.2 - 57.2	45.8	44.4	47.2	41.2	52.8	42.1	72.8
Nitrogen	0.1 - 0.3	0.1 - 0.3	4.8	-	-	0.5	2.54	0.6	2.3
Oxygen	40.0 - 43.0	36.0 - 40.0	29.6	49.3	44.2	38.7	31.24	43.4	7.2
Sulphur	nil - 0.1	nil - 0.1	0.4	-	-	0.2	0.23	0.7	4.2
Ash & Inerts	0.2 - 2.0	0.4 - 5.0	13.5	-	2.0	13.9	7.74	6.6	8.4
Moisture Content, %	2 - 60	25 - 75	10 - 70	-	49.0	18 - 20	84	35.6	6.4
Heating Value BTU/lb (dry)	8,400 - 9,110	9,400 - 10,260	8,052	7,526	8,350	5,447	8,940	12,060	14,440

- 1/ Based on the analysis results of California Redwood, Western Hemlock, Douglas Fir and Pine. U.S. Bureau of Mines.
- 2/ Based on the analysis results of Western Hemlock, Douglas Fir, Loblolly Pine, Longleaf Pine, and Slash Pine.
Source: "Forest and Mill Residues as Potential Sources of Biomass", Georgia-Pacific/MITRE Corp., McLean, Va. 1977.
(Reference 4)
- 3/ Source: Klass, D.L., IGT, Biomass and Wastes as Energy Resources: 1977 Update, Paper presented at the conference on Clean Fuels from Biomass and Wastes, Jan. 25-28, 1977 at Orlando, Florida. (Reference 13)
- 4/ Source: U.S. Bureau of Mines, Information Circular 8376.
- Note: Characteristics affecting the suitability of biomass thermal chemical conversion include moisture content, chemical analysis, bulk density, size analysis, carbon reactivity & heating value.
- 5/ Source: Lipinsky, E.S., Nathan, R.A., Sheppard, W.J., and Otis, J.L., Systems Study of Fuels From Sugarcane, Sweet Sorghum, and Sugar Beets, Battelle Memorial Institute (Reference 6).

coals and solid wastes in the methanol production process. Sulfur would impair the performance of the catalysts used in methanol synthesis and would require sulfur emission control. The relatively low ash and inert matters of biomass will result in less particulate emissions and less ash disposal problems. A C-H-O weight percent diagram, Fig. 2.1, illustrates these chemical characteristics and further emphasizes the biomass and urban waste similarities.

Some unique characteristics of biomass feedstocks will also affect their performance in gasification processes. Unlike most coals, biomass feedstocks generally do not cake, thus can be used in fixed bed reactors without pretreatment, although some types of fibrous biomass such as sugar crop residues may perform poorly in fluidized bed processes because of their tendency to mat. Biomass may present problems for slagging reactors because of the mineral constituents of biomass, especially calcium oxide, which form ash and which may have adverse effect on slag flow. The ash analyses are reported in Table 2.4.

2.1.2 Economics of Biomass Feedstock

Previous studies have shown that the delivered cost of feedstock is one major factor to be considered in the development of a biomass production/conversion system(1,3,4). Figure 2.2 shows a simplified flow diagram for the production of biomass on energy farms and its delivery to the conversion plant. The sequence of collection and delivery of forest and agriculture residues to the conversion facility is presented in Fig.2.3.

The total costs of biomass farm production can be broadly broken down into three major cost components: production, harvesting, and transportation/storage. Parameters affecting each of these cost components are delineated in Table 2.5. For agricultural and forestry wastes, the major cost components include residue prices, collection, reduction, transportation,

Figure 2.1 C-H-O wt% Diagram for Synthesis Gas Feeds

Table 2.4. Ash Analyses of Biomass (Ref. 16)

Species	% Oxide of						
	Si	Al	Fe	Ca	Mg	Na&K	CO ₃
Corn	53.9	4.7	5.4	6.0	6.4	23.8	-
White fir bark	1.7	3.2	3.2	60.8	3.0	10.4	11.5
Spruce bark	32.0	11.0	6.4	25.3	4.1	10.4	7.0
Pine bark	39.0	14.0	3.0	25.5	6.5	7.3	-
Oak bark	11.1	0.1	3.3	64.5	1.2	9.2	-
Redwood bark	18.3	4.0	3.5	6.0	6.6	28.6	-

Figure 2.2 Production of Biomass on Biomass Energy Farms and Its Delivery to A Conversion Facility

Figure 2.3 Collection and Delivery of Agricultural and Forest Residues to A Conversion Facility

Table 2.5. Parameters Affecting the Delivered Cost of Biomass Feedstock,
Produced on Energy Farms

<u>Cost Component</u>	<u>Affecting Parameters</u>
Production	Productivity, seasonality, continuity, total yield per year, farm site, harvest rotation period, land cost (purchase or lease), land cleaning and preparation, planting, cultivating, irrigation, fertilization, pest control, roads, equipment, labor, materials.
Harvesting/Size Reduction	Species, particle size, distribution and concentration in the field, terrain characteristics, methods (manual, mechanized) of harvesting and size reduction equipment, labor, fuel consumption.
Transportation and Storage	Distance to the conversion facility, mode, terrain characteristics, bulk density, moisture, storability, drying requirement.

and storage. Each of these components is a function of site-specific parameters shown in Table 2.6. For the purpose of this effort, a few illustrative sensitivity analyses will be carried out based on feedstock types, prices, and conversion center location relative to hypothetical markets.

Table 2.7 summarizes the reported delivered costs for major types of biomass feedstocks. The values were based on a number of assumptions and are intended to demonstrate the relative magnitude of each of the cost components. Based on these reported values, mill residues in general have the lowest delivered cost, because they are readily available, thus eliminating any harvesting and reduction costs. However, 30 to 40 percent of mill residues are currently used as raw material for pulp and building board manufacture. Should the demand for these uses increase in the future, the delivered cost of mill residue is likely to increase. Mill residue transportation costs typically have the form $\$/\text{ODT-mile} = -0.0012(\#\text{miles}) + 0.20$ for 0 to 80 miles⁽⁷⁾.

The second lowest cost feedstocks could be biomass produced on conceptual energy farms, and standing biomass*. For biomass produced on energy farms, most of the delivered cost would be associated with production (irrigation and fertilization are the major factors). In general, the estimated production costs of biomass from energy farms are much higher than those of other types of biomass feedstock. However, collection and transportation costs can be expected to be lower than for other types because of higher concentration of biomass on energy farms. Therefore the delivered cost has been estimated to be lower than that of most other biomass types.

The estimated delivered costs for standing biomass are slightly less than those of logging residues because a new mechanized, whole-tree harvesting method is assumed. Logging residues are generally dispersed in the field; hence a more expensive, conventional method will have to be used in most cases.

*Dead, diseased, cull or surplus trees

Table 2.6. Parameters Affecting the Delivered Cost of Forest and Agricultural Residues

<u>Cost Component</u>	<u>Affecting Parameters</u>
Acquisition, Collection and Reduction	Distribution and concentration of residues in the field, terrain characteristics, market values of residue, stumpage values of standing biomass, method of collection, method of size reduction, labor, equipment, materials.
Transportation and Storage	Distance to the conversion facility, mode, terrain characteristics, bulk density, moisture, storability, drying requirement.

1/

Table 2.7. Typical Costs for Various Biomass Feedstocks

Cost Components	Types of Biomass	Logging Residues 2/	Standing Biomass 2/	Crop Residues 4/	Mill Residues 2/	Biomass Farms (silviculture) 3/
Acquisition or Production Cost (1977 \$/ODT*)		nil	3.2	3.3 - 32.4	3.4 - 14.7	14.6 - 26.7
Collection and Reduction Cost (1977 \$/ODT)		19.0 - 50.9	5.4	8.5 - 24.1	nil	2.0 - 2.7
Transportation@ Cost (1977 \$/ODT)		5.9 - 10.0	4.9	3.2 - 8.6	3.0 - 8.0	1.7 - 3.4
Total Delivered Cost (1977 \$/ODT)		24.9 - 60.9	13.5 - 24.0**	15.0 - 65.1	6.4 - 22.7	18.3 - 32.8
Cost per MM BTU (1977 \$/MM BTU)	5/	1.46 - 3.58	0.79 - 1.41	0.94 - 4.1	0.38 - 1.4	1.1 - 1.9

* Oven dry ton.

@ Transportation distance ranges from 20 to 50 miles.

** Cost for each component not available for this higher value.

1/ Costs are escalated to 1977 dollars assuming an annual inflation rate of 8%.

2/ Source: Silvicultural Biomass Farms, Vol. VI: Forest and Mill Residues as Potential Sources of Biomass, George-Pacific Corp./The MITRE Corp., McLean, Va. May, 1977. (Reference 4).

3/ Source: Derived from Silvicultural Biomass Farms, Vol. IV: Site Specific Production Studies and Cost Analyses, MITRE/METREK, McLean, Va., 1977. (Reference 12)

4/ Source: Systems Descriptions and Engineering Costs for Solar-Related Technologies, Vol. IX: Biomass Fuels Production and Conversion Systems, The MITRE/METREK, June, 1977 (Reference 7)

5/ Assuming 16 million BTU - 1 DTE for crop residues and 17 million BTU - 1 DTE for all other types of biomass.

Crop residues appear to be the most expensive, because of relatively high sales prices and high collection/reduction costs. Seasonality of crop residues implies high storage costs. Certain types of crop residues (straw, cotton gin trash, etc.) may require densification such as cubing, pelleting, briquetting, or extrusion in order to be used satisfactorily in certain types of fixed bed gasifiers. This will increase the feedstock costs, by the order of \$6 to \$15 per ton⁽¹⁹⁾, or \$0.4 to \$0.9 per MM Btu, a significant amount relative to the delivered costs of most biomass.

Manure constitutes the smallest source of biomass residues, about 8 percent of total residues, because the only economically collectible manure is that from animals in confinement operations, i.e., feedlots, dairies, and hog and poultry operations.

2.1.3 Feedstock Transportation Considerations

Transportation cost can account for 20 percent to 50 percent of delivered biomass cost, depending on feedstock type (Table 2.7). For residues with low market value and collection costs, factors such as hauling distance, and road construction and maintenance, are important considerations. There is no general criterion for determining the maximum economical biomass haul distance. Rather, the characteristics of each site need to be examined. As fossil fuels become more expensive, biomass fuel becomes attractive, even at relatively long distances from the conversion plant.

The cost of transporting wood chips by truck and rail have been examined in a Dartmouth College study⁽²¹⁾. No system appeared definitively better than the other one (Table 2.8).

Table 2.8 Summary of Direct Transportation Costs for Wood Chips

	<u>Cost/Ton Mile</u>	<u>Annual Cost</u>	<u>Capital Cost</u>
<u>TRUCK SYSTEM</u>			
Private Haulers Contracted	\$0.04-0.06	\$960,000 - 1,440,000	0
Trucks Owned			
New	0.058	1,071,445	\$1,732,500
Used	0.056	1,207,445	763,000
Trucks Leased	0.071	1,752,100	0
Unloading Equipment (for all the above)	--	--	250,000
<u>RAIL SYSTEM</u>			
Commercial Service Used	\$0.02 - 0.19	\$472,500 - 4,488,750	0
Unit Trains Operated			
Cars Owned	--	100,000	\$1,925,000 - 2,630,000
Cars Leased	--	453,350 - 509,750	0
Sidings (for all the above)	--	--	220,000
Truck-Rail Transfer and Railcar Unloading Equipment (for all the above)	--	--	1,000,000

OTHER CONSIDERATIONS

- Heavier trucks - Direct costs would be lower because fewer trucks and/or fewer trips would be needed.
- Site - Direct costs for both truck and rail systems will vary with distance between harvest sites and plant. In addition, with rail, costs depend on the rates offered by the rail company serving the site and on harvest site/tracks and tracks-plant distances.

Source: Reference 21

Indirect costs, e.g., noise, congestion, and structural damage to roads and bridges are harder to assess (Table 2.9). Experience with a 500 ODT per day electricity plant in Eugene, Oregon indicates that trucks must come in every half hour, causing traffic problems(21). Those are the types of considerations relevant to a methanol conversion plant using biomass feedstock.

Biomass transportation considerations and methanol product transportation and distribution are examined below. Unlike coal, which is available in huge quantities at mine mouths, the resource base for biomass is smaller and more dispersed. For coal conversion, it is economical to envision unit trains carrying large amounts of coal to a conversion plant, and unit trains or pipelines transporting large quantities of liquid fuel product to major bulk terminals. Conversely, the biomass based methanol system should be examined as a smaller and more dispersed system, with the following representative possibilities (Fig. 2.4):

- a. Dispersed conversion plants and dispersed markets
- b. Centralized conversion plant and dispersed markets
- c. Dispersed conversion plants and centralized market
- d. Centralized conversion plant and centralized market.

Using the transportation cost equation on page 2-13, and assuming \$.009 per gallon for methanol short haul by tank trucks, and \$.022 per gallon for longer haul(22), the transportation costs of biomass and methanol are estimated as shown in Table 2.10. The contribution from biomass transportation is larger than that from methanol product transportation. However, the sums of those transportation costs range from only \$.04 to \$.07 per gallon of methanol produced for the above four representative market/resource/conversion scenarios. The

Table 2.9 Summary of Indirect Costs for Wood Chips

	<u>Roadway Maintenance Costs</u>		<u>Noise Impacts</u>	<u>Roadway Structural Problems</u>
	<u>Cost/ton mile</u>	<u>Total cost</u>	Low - high	Low - high
<u>TRUCK SYSTEM</u>	\$0.00018-0.0053	\$4,200 - 126,500		
Effect of Site -	Lower if trucks travel over higher quality roads, i.e., interstates	Lower if power plant close to harvest areas.	Lower if trucks avoid sensitive land use areas. Lower if few grades and stops. Lower for different topographies.	Lower if bridges have acceptable design ratings. Lower if roadways have few grades and little traffic.
<u>RAIL SYSTEM</u>	<u>Low</u>		<u>Low - medium</u>	<u>Low - medium</u>
Effect of Site -	Lower for sidings closer to harvest area (minimizes truck transport distance).		Lower if yard at plant is located away from sensitive land use areas.	Lower if bridges near harvest area are designed to support weight of trucks bringing chips to rail sidings.
<u>OTHER CONSIDERATIONS</u>				
Heavier Trucks -	Proportionately higher than for standard weight trucks.		Higher per truck; offset by fewer trips.	Higher if bridges cannot carry extra weight, or if there are many grades.
Use of Private Haulers -	Greater risk of weight limit violation, so possibly higher. Difficult for plant to control.		Higher if sensitive land use not avoided and reasonable operating schedules not used. Difficult to control these factors.	Higher if bridge weights are ignored. Difficult for plant to control.

Source: Reference 21

(a) Dispersed conversion plants and dispersed markets

(b) Centralized conversion plant and dispersed markets

(c) Dispersed conversion plants and centralized market

(d) Centralized conversion plant and centralized market

Figure 2.4 Biomass Methanol Systems Logistics

Table 2.10 Contributions to Methanol Delivered Costs from Transportation of Biomass and Methanol*

	(a)	(b)	(c)	(d)
Biomass Transportation Cost				
\$/ODT	3.10	5.50	3.10	5.50
\$/MM BTU Biomass	0.19	0.33	0.19	0.33
\$/Gallon MeOH	0.025	0.046	0.025	0.046
\$/MM BTU MeOH	0.46	0.82	0.46	0.82
Methanol Transportation Cost				
\$/gallon MEOH	0.009	0.022	0.022	0.009
\$/MM BTU MeOH	0.13	0.39	0.39	0.13
Total Transportation Cost Contributions				
\$/gallon MeOH	0.034	0.068	0.047	0.055
\$/MM BTU MeOH	0.59	1.2	0.85	0.95

* Assumed mill residues as biomass feedstocks.
See Fig. 2.5 for logistics.

variation from one scenario to another appears small relative to the estimated production cost of methanol from biomass, generally reported to be near the figure of \$0.7 per gallon.

2.1.4 Supply Considerations for Biomass Based Methanol Plants

The seasonality of crop residues suggests that a methanol conversion facility should be designed with size reduction equipment designed for a combination of different crop feedstocks and/or forest biomass. Certain agricultural areas produce 80 percent of their annual field residues in the third quarter. To gain an appreciation of the potential storage problem the following example is considered: for a typical residue density of 19 lb per ft³, if 80 percent of the annual biomass requirements for a 1000 ODT per day plant are stored as 10-foot piles, a storage area of 0.25 square mile is required (0.5x0.5 mile). Forestry biomass presents less seasonality. However, a 30 day storage facility would be useful because of potential supply interruptions due to weather, strikes, etc. The economics of storage needs to be investigated, taking into consideration the degradation of the stored residues and the resulting effect on methanol conversion.

Most published works do not address the question of potential additional supply in the context of likely cost increases on a local basis. In other words, with one exception,⁽²³⁾ no supply curve as a function of price level was determined for biomass residues. Figure 2.5⁽²³⁾ illustrates the usefulness of this type of analysis. The increase in cost is a result of longer haul and increased procurement difficulties. Therefore, a tentative cost can be assigned to the biomass in each region as a function of increased requirement.

Methanol production from biomass is constrained by competing end uses. For example: of the 428 million dry tons

Figure 2.5 Supply Costs of Biomass for Northern Michigan and Upper Wisconsin

of agricultural residues generated in 1975, about 52 percent is returned to the soil as fertilizers or soil conditioners; 30 percent is sold, fed to animals, or burned as fuel; while 18 percent is disposed of at a cost. Future energy end uses will also compete with methanol conversion. For example, at the present time, electricity production from residues appears to be one of the economically and technically preferred bio-conversion processes⁽¹⁾. The desirability of an assured biomass supply suggests that institutional arrangements with farmers and the forest industries should be looked into, to resolve the issue of supply and competing end uses.

2.2 BIOMASS AVAILABILITY

2.2.1 Near Term and Long Term Availability of Biomass

The existing sources of biomass include residues from agricultural and silvicultural activities. Right now they are the only major biomass resources available, as no biomass farms exist yet. By 1990, with major R&D efforts, biomass farm outputs could equal the amount of biomass residues currently wasted or returned to the soil for the whole U.S. Projected biomass availability by those categories is shown in Table 2.11, assuming the establishment of silvicultural farms on 10 percent of better quality forest, range, and pasture land.

It has been estimated that the output from agricultural energy farms (grasses on 10 percent of marginal cropland) is of the same order of magnitude as the above projected silvicultural farm potential^(1,5). However, the economics of conceptual grains and grasses farms appears unfavorable compared to silvicultural farms, at the present time. Therefore, only silvicultural farms are considered in this section.

Table 2.11 Projected Regional Biomass Availability (million dry tons per year)(1)

	Forestry	Existing Resource Base Agriculture			Total		Potential Biomass Farms	
	1985 - 2000	1985	1990	2000	1985	1990	2000	2000
NE	14.1	0.3	0.3	0.3	14.4	14.4	14.4	7.0
MATL	16.8	3.3	3.4	3.5	20.1	20.2	20.3	13.0
SATL	54.3	10.0	10.2	10.8	64.3	64.5	65.1	70.0
ENC	21.9	37.8	38.6	40.2	59.7	60.5	62.1	32.4
ESC	39.6	6.5	6.6	6.9	46.1	46.2	46.5	37.8
WNC	14.1	97.0	99.0	103.0	111.1	113.1	117.1	26.4
WSC	24.5	23.0	23.5	24.4	47.5	48.0	48.9	72.0
MT	14.0	21.0	21.4	22.9	35.0	35.4	36.9	0
PAC	4.3	20.6	21.0	21.9	24.9	25.3	26.2	7.0
Total U.S.	203.6	219.5	224.2	233.9	423.1	427.6	437.5	265.6
MM Acres	500	400	400	400	900	900	900	32.4
Percent of U.S. Land Area	22	18	18	18	40	40	40	1.4
Equivalent (2) Energy (10 ¹⁵ Btu)	3.5	3.7	3.8	4.0	7.2	7.2	7.5	4.5

(1) Reference 1 through 13. One tenth of diseased and dead trees assumed economically available.

(2) Based on 17 million Btu per dry ton of biomass.

The existing resource base for forestry biomass (residues, excess growth) shows that the South Atlantic, East South Central, West South Central and East North Central regions dominate.* Agricultural residues are the most abundant in the West North Central region, followed by the East North Central, West South Central, and Mountain regions. On the whole, biomass residues are most abundant in the West North Central, South Atlantic, East North Central, and West South Central regions.

Short rotation (6 years) silvicultural farms, when taken into account, could contribute significantly in the long term. In 2000, the potential biomass farm resources could account for between 18 percent (West North Central) and 60 percent (West South Central) of residues and excess growth. The two exceptions are the Mountain and Pacific regions where climatic and other factors preclude extensive biomass farming.

2.2.2 Potential Regional Methanol Production From Biomass

The potential of methanol production from biomass depends largely on the efficiency of converting the biomass to carbon monoxide and hydrogen. For the purposes of this study, Table 2.12 shows the methanol production potential equivalent to the projected quantities of biomass, assuming 2.5 dry tons biomass gasified per ton methanol produced.

* The Pacific region has abundant forestry residues, however its annual timber cut exceeds its net growth, and therefore the future potential is somewhat reduced.

Table 2.12 Potential Methanol Supply From Biomass
By Region: 1985 - 2000 (Billion Gallons
Per Year)

Region	25 Percent Biomass Available for Methanol Conversion			
	1985	1990	1995	2000
NE	0.43	0.43	0.43	0.64
MATL	0.61	0.61	0.61	1.00
SATL	1.93	1.94	1.95	4.06
ENC	1.79	1.82	1.84	2.84
ESC	1.38	1.39	1.39	2.53
WNC	3.34	3.40	3.46	4.31
WSC	1.43	1.44	1.46	3.63
MTC	1.06	1.09	1.09	1.12
PAC	0.75	0.76	0.77	0.98
All Regions	12.73	12.88	13.00	21.11

2.2.3 Representative County-Level Potential

A number of counties with varied land areas and biomass residue compositions were selected for resource assessment. Several counties were grouped into more or less circular areas of varying average radius, 25 to 80 miles. For each group of counties, methanol potential was assessed for the locally produced residues which are wasted or returned to the soil. Weighted average residue costs, corrected for distance, were also estimated. Next, silvicultural farm methanol potentials were estimated for ten representative county groupings with an average radius of 50 miles each.

The results are shown in Tables 2.13 and 2.14. As expected, biomass farms form denser biomass resource areas. However, biomass residues also appear abundant, at delivered costs, from \$1.2 to \$3.2 per MM Btu (\$20 to \$54 per ODT). Most sites feature one or more rivers which can provide cooling and process water to the plants. No further economic assessment was performed with respect to other competitive end uses and market demands. Detailed site-specific studies would be necessary in order to select a demonstration site.

Table 2.13 Representative Methanol Conversion Sites Based on Biomass Residue Availability and Costs (\$1979)

Site#	State	Plant Location ⁽¹⁾	Percent ⁽²⁾		ODT/Day	Typical Transportation (Miles)	Delivered Cost ⁽³⁾	
			Crop	Forestry			\$/ODT	\$/MM Btu
1	Maine	Piscataquas Co.	18	82	3300	60	19-55	1.2-3.2
2	Illinois	Woodford Co.	100	0	3200	80	30-40	1.8-2.4
3	Indiana	Delaware Co.	99	1	1100	45	27-37	1.6-2.2
4	Iowa	Palo Alto Co.	100	0	2600	75	30-40	1.8-2.4
5	Kansas	Barber Co.	100	0	13000	65	26-36	1.5-2.1
6	California	Trinity Co.	5	95	11000	80	24-47	1.4-2.8
7		Fresno Co.	86	14	5000	75	22-37	1.3-2.2

¹ Listed county name is assumed to be the site of the conversion plant which uses the feedstock from that county and adjacent counties selected by SAI.

² Based on site-specific data from SRI's - An Evaluation of Agricultural Residues as an Energy Feedstock-A Ten-Site Survey and county by county inventory of residues. Multi-county aggregation, and transportation costs corrected for residue density and distance by SAI.

³ Weighted average for major residues. Estimated by SAI using relatively low cost crop residues such as barley, wheat and oat straw, and major forestry residues.

Table 2.14 Representative Methanol Conversion Sites Based on
Energy Farm Biomass Availability and Costs
(Average Radius: 50 Miles* 1979 \$)

Site #	State	Plant Location	Acres	ODT/day		Near-Term		Long-Term	
				Present	Future	\$/ODT	\$/MMBtu	\$/ODT	\$/MMBtu
1	Wisconsin	Rusk	439000	6600	13000	39	2.3	26	1.5
2	Missouri	Polk	248000	6000	11000	33	2.0	23	1.4
3	Louisiana	Sabine	325000	8900	16000	27	1.6	22	1.3
4	Georgia	Hancock	297000	9000	16200	31	1.8	22	1.3
5	Connecticut	Windsor	123000	1900	3800	43	2.5	29	1.7
6	Washington	Lewis	129000	3900	7800	32	1.9	24	1.4
7	Illinois	McLear	64000	1200	2400	53	3.1	34	2.0
8	California	Kern	39000	1200	2400	43	2.5	33	1.9
9	Florida	Levy	299000	9100	16300	23	1.6	23	1.4
10	Mississippi	Perry	299000	9100	16300	23	1.6	23	1.4

*Not maximum radius. One tenth of suitable permanent pasture, forest, range, rotation hay and pasture, hayland and open land formerly cropped. County data from MITRE, Silvicultural Biomass Farms, Vol.III, 1977. Multi-county aggregation and delivered cost adjusted for distance by SAI.

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3. METHANOL FUEL MARKET ANALYSIS

3.1 OVERVIEW OF METHANOL FUEL PROSPECTS AS A REPLACEMENT FOR TRADITIONAL LIQUID FUELS

Petroleum liquid fuels, because of their mobility and storability, have captured major shares of the energy market. Petroleum has largely replaced coal and steam in marine and railway applications, and now dominates the highway transportation and aviation markets. In 1977, liquid petroleum fuels accounted for 18 percent of all fuels used to generate electricity⁽¹⁾.

The era of cheap petroleum fuels, however, is coming to an end for many nations. Continued dependence on oil as the prime source of world energy supply is not a feasible long-term solution in light of (a) the current assessment of impending oil depletion, (b) the problems in acquiring and moving large-scale supply from the Organization of Petroleum Exporting Countries (OPEC), and (c) the balance of payments problems in financing such large amounts⁽¹⁾.

In the short term, conservation measures will help reduce the demand for energy. In the longer term, a replacement for petroleum fuels must be found, in light of the constraints on world oil supply and long term potential. Some potential substitutes for liquid petroleum fuels include coal, solar, electricity from non-petroleum sources, and biomass used in furnaces and boilers. For certain end uses, including transportation fuels and chemical feedstocks, the existing technology such as internal combustion engines favors liquid fuel substitutes for petroleum. Candidates include synthetic fuels from coal, oil shale, municipal solid waste, and biomass resources. The assessment of market penetrations for each type of synthetic fuel, whether coal, biomass, or shale derived, is subject to uncertainties in terms of technology, costs, future world oil

prices, financing issues, and public support or opposition. This study concentrates on biomass-based methanol systems, including potential market shares by end uses. The approach that has been adopted involves the use of scenarios based on assumed market penetration rates.

The assumed market penetration rates are bounded by the technical feasibility of various schemes (e.g., when could a pure methanol automotive engine be available, etc.) as perceived by SAI after reviewing the literature. The actual rates will be determined largely by the availability and economics of each technology. Nevertheless, the scenario approach enables the assessment of various hypothetical futures and associated requirements with the focus on methanol fuel from renewable biomass. The postulated scenarios range from limited future market shares (e.g., 10 percent gasoline displacement) to larger market shares (e.g., displacement of 44 percent gasoline, 30 percent diesel, 30 percent distillate and 5 percent residual) in order to gain adequate perspectives of likely futures.

3.2 POTENTIAL DEMAND FOR METHANOL FROM BIOMASS

This section identifies potential end uses of methanol, and analyzes existing and projected petroleum-product markets in which methanol is a potential substitute. Potential market shares are also estimated, based on several market penetration scenarios.

3.2.1 Potential End Uses for Methanol from Biomass

The potential end uses of methanol include transportation, heating, electricity generation, chemical feedstock

and other end-uses. The largest potential end uses are those that currently consume large amounts of nonrenewable petroleum fuels. Compared to other forms of synthetic fuels, methanol represents the highest compatibility with in place storage, transport and distribution systems for current liquid and gaseous hydrocarbon fuels(2).

- Transportation

Gasoline: Recent data(3,4,5) indicate that existing vehicles could use up to about a 10 percent blend of methanol in gasoline without significant performance reduction. In the future, vehicles could be designed to run on pure methanol without major technological innovations. As an indication of the market size, in 1972, gasoline accounts for 42 percent of all domestic petroleum Btu's consumed, and 65 percent of expenditures on all petroleum products.

For pure methanol applications in car engines, higher compressions are suggested to take advantage of the very high octane values of 100 percent methanol. With the much lower air/fuel ratios that are required, a different carburation or fuel injection system is necessary to handle the large amounts of fuel that must be metered to the engine. It is generally believed that a fuel injection system is most appropriate. It has also been reported that methanol fueled vehicles are very hard to start. This problem could be solved by the injection of a special kind of highly volatile fuel during starting.

Volkswagen has modified the engine of their SIROCCO model to use pure methanol. Besides lower emissions of hydrocarbons and nitrogen oxides, an increase in power and efficiency has been reported for those VW tests(5). Many United States, Brazilian, and European organizations have conducted tests with methanol-gasoline blends and also pure methanol(3,5,8).

Pure methanol use in automotive engines has the following advantages:

- 1) Better efficiency, lower emissions, and higher compression ratio design than is feasible with gasoline.
- 2) The vapor lock and phase separation problems associated with blends (caused by the presence of small amounts of water) do not affect pure methanol.

In addition to the higher compression ratio and fuel injection requirements associated with internal combustion engines, it appears that stratified charge engines and uniform charge engines could also be potential candidates because of improved fuel economy with pure methanol. Gas turbine and Stirling engines, on the other hand, will not offer any significant fuel efficiency gains relative to operation with petroleum or synthetic hydrocarbon fuels.

Based on cumulative research results, it appears that VW, General Motors, Volvo, Mercedes, and other car manufacturers would be able to provide a pure alcohol car by the mid 1980's, if required. Such an engine would achieve a 25 percent gain in fuel energy efficiency relative to gasoline powered engines(3).

Diesel Fuel: Methanol could be used as a dual fuel with diesel in new or retrofitted vehicles and machines. At the present time, diesel fuel is used in railroad engines, ships, commercial transports, farm uses, mining and forestry uses, government (including military) uses, and retail automotive uses. The latter end-use is increasing rapidly because diesel cars exhibit higher fuel efficiency relative to gasoline cars(12). The diesel fuel market accounted for 1,400 trillion Btu's in 1972, or 4.6 percent of total U.S. petroleum Btu's(6).

Recent research indicates that dual uses with about 50 percent methanol are feasible. Diesel engines will feature

an operation mode involving the injection of ordinary diesel fuel in sufficient quantities to provide ignition, with methanol being used for the balance of the charge. Experiments using dual fuels in diesel engines at the University of Minnesota showed major reductions in the emissions of carbon particulates or smoke, and of the intake manifold temperature(3,8). Since the tank will contain separate phases of alcohol and diesel, with separate injection systems to the engine, water contamination does not present any special problem for this fuel option. The high compression ratio present in a diesel engine will permit full use of the high octane quality of methanol. Stratified charge engines are also likely candidates, in addition to internal combustion engines. Based on successful tests in the United States and other countries, it appears possible to introduce engines designed for dual alcohol-diesel use by the mid 1980's, if required(3).

- Domestic Heating

Furnaces used for domestic heating can be modified so that methanol can replace fuel oil. A Canadian Combustion Research Laboratory Review notes that methanol offers efficiency advantages in oil-fired domestic heating. The retrofitting costs for existing household furnaces are on the order of \$250(3). In 1972, domestic heating accounted for 10 percent of all petroleum Btu's consumed in this country.

- Electricity Generation

Boilers could be modified slightly to accommodate methanol fuel with only a slight decrease in efficiency; typically 9.6 percent reduction with respect to oil and 3 percent reduction with respect to natural gas(3,8). Gas turbines constitute another promising market for methanol. Conventional turbines need some minor modifications, but will result in cleaner combustion and better performance.

In 1972, the electric utilities' share accounts for 3074 trillion Btu's or 10 percent of total petroleum Btu's. The 1972 demonstration of methanol use for a 49 MW utility boiler by Vulcan Cincinnati proved that boiler retrofit technology is well known. Tests on gas turbines by United Technology demonstrated the feasibility of using methanol for that purpose⁽⁸⁾. Recent studies showed that large plants now burning a low grade fuel (residual or coal) should avoid conversion to methanol. In many such cases where substitution for residuals are feasible, it would be more cost-effective to utilize biomass directly rather than convert it to methanol⁽³⁾. Therefore, methanol is considered in this study primarily as a potential substitute for distillates, with only limited potential as a residual substitute.

- Other Potential Uses

Those potential uses include industrial process heat, fuel cell electricity generation, LPG substitution, single cell protein feedstocks, chemical feedstocks, and others. Because methanol flame has lower radiant properties than an oil flame, methanol is not suited for direct-fired industrial processes, and should be considered solely for indirect firing and non-radiative heat needs⁽³⁾. The projected methanol requirements for the production of chemicals is 4.6 billion gallons by 2000. Chemical grade methanol needs extensive purification; something that methanol fuel does not need. However, the concentration of the chemical manufacturers in a few Gulf Coast and other locations appears to facilitate the distribution of methanol to those users.

Fuel cell applications, single cell protein manufacture, and LPG substitutes are also potential market sectors. However, they are not further evaluated because of uncertainties in terms of technology, economics and/or the small

size of the potential domestic market relative to major potential end uses such as transportation, heating, and electricity generation.

3.2.2 Potential Market Shares for Methanol Fuel

The market analysis begins by examining past petroleum demand patterns and then considers future demands utilizing projections by FEA⁽⁹⁾ and SRI⁽¹⁰⁾. The FEA projections were made for the year 1985, while the SRI study projected demands until 2000 for the United States on a regional basis.

The SRI projections differ somewhat from the FEA projections, probably because of different economic and market assumptions. SRI's numbers indicate, between 1985 and 2000, a predicted decrease of gasoline consumption (by 30 percent), an 83 percent increase in diesel use, a 20 percent increase in distillate uses, and a 15 percent decrease in residual consumption.

The following potential methanol fuel penetration scenarios are postulated on the basis of market demand for liquid fuels, and market penetration rate, based on the technology assessment in Section 3.2.1:

1. 10 percent blend of alcohol in gasoline. This scenario could be implemented in the near term, based on technical considerations.
2. 44 percent displacement of gasoline, and 30 percent displacement of diesel. The 44 percent displacement results from the assumption that 70 percent of the gasoline-using vehicles will use instead 20 percent methanol in gasoline, and 30 percent of the gasoline vehicles will switch to pure methanol. This scenario will require relatively more accelerated research and development than scenario 1. It is also assumed that 30 percent of the projected diesel fuel market is displaced by the introduction of methanol as a dual fuel for diesel engines in trucks, cars, trains, farming equipment and other diesel engines.

3. Market volume as in scenario 2, plus displacement of 30 percent of the distillate market for domestic heating and industrial use, and displacement of 5 percent of the residual market. The residual market penetration is assumed low because substituting residual with direct combustion or gasification of biomass is likely to be more economic than going through the methanol step.

Table 3.1 summarizes the market share projections for 1985, 1990, 1995 and 2000 for scenarios 1, 2, and 3. The volume of petroleum which would be displaced is also estimated. The Table shows that in 1990 the potential methanol requirement in scenario 1 amounts to 11 billion gallons, as compared to a 70 billion gallon requirement in scenario 2. The equivalent volumes of crude oil displaced by methanol in those cases are estimated to be about 180 million barrels and one billion barrels, respectively. As a comparison, present petroleum consumption is approximately 7 billion barrels per year, of which 2.4 billion barrels are imported⁽⁸⁾. Scenario 2 requires 6 to 7 times more methanol than scenario 1, and scenario 3 requires approximately 25 percent more methanol than scenario 2. The declining methanol requirement with time for scenarios 1 and 2 are caused by the projected decline in gasoline demand, as gasoline is increasingly replaced by diesel and electricity; and also as a result of increased future vehicle efficiencies and reduced use.

In April 1979, the Department of Energy issued a report, Energy Supply and Demand in the Midterm: 1985, 1990, and 1995⁽¹³⁾. The aggregate projections from that report are compared with FEA's and SRI's in Table 3.2. The major discrepancies between the three sets of projections lie in the forecasted gasoline consumption. For example, SRI's projection is lower than DOE's by 43 percent for the year 1995. However, SRI's 1985 gasoline projection differs from DOE's by only 18 percent. In any case, the differences are certainly not nearly as large as the differences in projected market shares between

Table 3.1 Potential Methanol Market Shares by Region, 1985-2000
(Billion Gallons/Year)

Region	Scenario 1					Scenario 2				Scenario 3			
	10 Percent Blend with Gasoline					44 Percent Gasoline Displacement & 30 Percent Diesel Displacement (2)				Multi-Market Penetration Scenario Gasoline, Diesel, Distillate and Residual (3)			
	1985	1990	1995	2000		1985	1990	1995	2000	1985	1990	1995	2000
New England	0.81	(0.79) (1)	0.67	0.61	0.59	4.13	3.75	3.68	3.81	6.26	5.83	5.73	5.83
Mid Atlantic	1.59	(2.25)	1.31	1.18	1.14	8.80	8.10	7.44	8.43	13.64	13.07	12.54	13.67
South Atlantic	2.09	(2.76)	1.72	1.53	1.48	11.83	10.87	10.87	11.27	13.57	12.70	12.73	13.31
East North Central	2.71	(3.06)	2.24	2.02	1.96	14.94	13.70	13.60	14.18	18.36	17.63	18.01	18.76
East South Central	0.84	(1.14)	0.68	0.60	0.57	4.89	4.47	4.39	4.56	5.34	5.00	4.99	5.20
West North Central	1.31	(1.52)	1.06	0.92	0.87	7.75	7.09	6.96	7.20	8.70	8.08	8.06	8.43
West South Central	1.81	(1.83)	1.46	1.24	1.17	10.01	8.96	8.50	8.60	10.60	9.56	9.08	9.18
Mountain	0.57	(0.88)	0.46	0.41	0.40	3.58	3.36	3.41	3.63	4.02	3.78	3.82	4.04
Pacific	1.72	(3.55)	1.46	1.38	1.38	9.91	9.48	10.03	10.86	11.08	10.80	11.48	12.38
All Regions	13.44	(17.78)	11.06	9.89	9.56	75.84	69.78	68.81	72.54	91.57	86.45	86.44	90.80

Petroleum Fuel Displacement (Million Barrels Per Year)

Gasoline	208.1	(275.1)	171.2	153.1	147.8	915.6	753.4	673.8	650.4	915.6	753.4	673.8	650.4
Diesel	-	-	-	-	-	187.5	237.3	284.0	342.6	187.5	237.3	284.0	342.6
Distillates	-	-	-	-	-	-	-	-	-	156.9	168.1	179.8	187.9
Residuals	-	-	-	-	-	-	-	-	-	17.2	16.4	15.6	14.7
Equivalent Crude Oil (4)	218.5	(288.9)	179.8	160.8	155.2	1158.3	1040.3	1005.7	1042.6	1341.1	1234.0	1153.2	1255.4

- (1) Numbers in parentheses are based on FEA estimates, they are shown here for comparison purposes. Other projections were derived from predicted petroleum demands by the SRI energy model.
- (2) Assumed 70 percent of non-diesel vehicles use 20 percent methanol blend, and 30 percent of non-diesel vehicles use pure methanol. Also assumed 30 percent of diesel demand projected by SRI to be displaced by methanol.
- (3) Assumed to be methanol requirement for scenario 2 plus requirement equivalent to 30 percent of distillate market and 5 percent of residual market.
- (4) Equals total volume of displaced petroleum products plus 5 percent assumed refinery losses.

TABLE 3.2 Comparison of Reference or Base Case of FEA, SRI
and DOE Projections of Petroleum Product Demand (Quads)

a) Transportation

	1985			1990			1995		
	<u>Gasoline</u>	<u>Diesel</u>	<u>Total</u>	<u>Gasoline</u>	<u>Diesel</u>	<u>Total</u>	<u>Gasoline</u>	<u>Diesel</u>	<u>Total</u>
FEA, 1976	14.4	n.a	n.a	n.a	n.a	n.a	n.a.	n.a.	n.a.
SRI, 1977	10.9	3.98	14.9	8.99	5.0	13.99	8.0	6.0	14.0
DOE, 1979	13.25	4.12	17.37	13.23	4.95	18.18	14.09	5.47	19.56

b) Other Sectors

	1985			1990			1995		
	<u>Distltes.</u>	<u>Residls</u>	<u>Total</u>	<u>Distltes.</u>	<u>Residls.</u>	<u>Total</u>	<u>Distltes.</u>	<u>Residls.</u>	<u>Total</u>
FEA, 1976	n.a.	3.90	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SRI, 1977	3.05	2.16	5.21	3.26	2.05	5.31	3.49	1.95	5.44
DOE, 1979	3.57	2.67	6.24	3.32	3.07	6.39	3.11	4.06	7.16

Source: References 9, 10, 13

scenario 1 and scenario 2. In addition, recent concerns regarding oil supply and prices indicate that the trend toward lower petroleum product consumption is more likely to become dominant. Therefore, it is felt that Table 3.1 presents a reasonable range of possible futures for the purpose of the analysis.

3.2.3 Institutional Considerations Affecting Various Markets

Historically, the forest product industries, such as pulp and paper mills, have been switching more and more to forestry residues as fuel for their boilers⁽¹⁴⁾. For example, residues accounted for 54 percent of the Btu's used in generating process steam for the paper and board mills in 1974⁽¹⁵⁾. Since the forest industries benefit from their proximity to forest residues, it is expected that they will continue to be the major users of biomass for energy purposes, which in the future, could also include liquid fuels for machinery and vehicles.

A recent Wall Street Journal article, (June 14, 1979)⁽¹⁶⁾ reported the first use of crop residues by an individual farmer to make alcohol fuel for farming purposes. Farmers appear to prefer an assured supply of liquid fuels because of the tight schedule involved in farming operations. Any delay in obtaining fuels could be catastrophic to farming operations. It appears that the producers of biomass residues, both crop and forestry, would be those who would benefit the most from their use for energy conversion, in light of the prospects of shortages and of higher prices for petroleum products.

Table 3.3 shows the historical pattern for liquid fuel use in the forestry, paper, crop, livestock, and fishing industries. The potential for replacing gasoline and distillates for that market with methanol would amount to 55 percent

Table 3.3 Historical Liquid Fuel Use Patterns for the Forestry, Crop, Livestock, Fishing, and Paper Industries (1974)¹ and Methanol Equivalent

	Space Heating	Machine Drive	Farm Vehicles	Process Steam	Electricity Generation	Direct Heat	Others	Total
Gasoline	0.0	44.2	389.4	0.0	0.0	0.0	0.0	433.6
	0.0	3.09	27.25	0.0	0.0	0.0	0.0	30.35
	0.0	0.68	6.01	0.0	0.0	0.0	0.0	6.69
Distillates	10.6	61.7	292.2	11.9	3.5	0.0	133.3	502.6
	0.74	4.32	20.45	0.83	0.24	0.0	9.33	35.17
	0.16	0.96	4.53	(2)	(2)	0.0	(2)	5.65
Residuals	0.0	0.0	0.0	330.4	81.4	66.9	14.0	492.7
	0.0	0.0	0.0	23.12	5.70	4.68	0.98	34.48
	0.0	0.0	0.0	(2)	(2)	(2)	(2)	(2)
All Petroleum Fuels	10.6	105.9	681.6	342.3	84.9	66.9	147.3	1428.9
	0.74	7.41	47.70	23.96	5.94	4.68	10.31	100.0
	0.16	1.64	10.54	(2)	(2)	(2)	(2)	12.3

1. Reference 15. First line is trillion Btu's, second line is percent, third line is equivalent billion gallons of methanol. In addition, wood residues were also used in generating steam (836.5 trillion Btu's), and electricity (28.7 trillion Btu's).

2. Methanol is not a substitute.

of the petroleum fuel share for that market, or 788 million Btu's; equivalent to 158 million barrels of crude oil per year or 6.6 percent of current U.S. annual oil imports.

The electric utility market is characterized by the fact that their personnel is highly technically oriented, and hence need only a small amount of additional training with respect to switching to methanol. The relatively small number of power stations helps minimize any fuel distribution problems. In addition, electric utilities are closely regulated by Federal and State governments, indicating a relative ease of implementation of an alcohol fuels program⁽¹⁸⁾. The methanol substitution potential for gas turbine applications is projected, as shown in Table 3.4, to be on the same order of magnitude as the forestry and farm end uses shown in Table 3.3, and the 10 percent gasoline blend market in Table 3.1.

The transportation sector is potentially a very large market, even at the 10 percent gasoline blend level. However, the petroleum and automobile industries in North America have generally favored methanol applications in large industrial/commercial/electricity generation systems, in order to minimize conversion costs and release petroleum for alternative uses. Potential distribution problems associated with blended fuels are the major factor in their reservations⁽¹⁹⁾.

Experiences with blended fuels in Nebraska and Brazil, however, indicate that alcohol blends can offer an adequate near-term, large-scale application of alcohols from biomass. For the longer term, pure methanol vehicles seem attractive from the fuel handling and material compatibility standpoint. In addition, they offer the potential for increased independence with regard to foreign oil supplies. Still, an assessment needs to be performed in order to evaluate the merits of the pure methanol approach, relative to those involving synthetic gasoline from methanol (Mobil process).

Table 3.4 Projected Energy Requirements (Quads)
for Electric Utility Peaking Gas Turbine
(1980-2000) and Methanol Equivalent
(Billion Gallons)

	1980	1985	1990	2000
<hr/>				
General Research Corp.				
Quads	0.280	0.358	0.411	0.573
Billion Gallons	4.33	5.54	6.36	8.86
<hr/>				
Oak Ridge Associated University (IEA)				
Quads	0.727	1.02	1.43	2.81
Billion Gallons	11.24	15.77	22.11	43.45
<hr/>				

Source: Mueller Associates, March 1979(18).

3.3 COMPARISON OF POTENTIAL METHANOL DEMAND AND SUPPLY

The demand results shown in Table 3.1 are compared here with the projected supply scenarios shown in Table 2.14. The following analysis is intended to provide an insight into the regional methanol supply/demand picture. This is based on the requirement scenarios developed in Section 3.2.2.

The total U.S. methanol requirement for scenario 1, (10 percent blend of methanol in 90 percent gasoline), can be potentially satisfied by 25 percent of the projected available biomass*. The result is an excess supply of 3 billion gallons per year in 1995 (based on SRI's projection), and an excess of 11 billion gallons in 2000. Regions SATL, ESC, WNC, and MT appear to be potentially self-sufficient or close to self-sufficiency for the methanol demand in scenario 1 (Fig.3.1). Regional deficits could be satisfied by surpluses from adjacent regions. Economics of transportation and distribution aside, the supply situation, as projected, appears satisfactory on a country-wide basis in 1985, for scenario 1. From 1990 on, the situation improves further as overall gasoline demand decreases.

Scenario 2, in which 44 percent of the gasoline and 30 percent of the diesel fuel markets are to be captured by methanol from biomass, would result in a potential deficit by 1985, even when maximum biomass availability is assumed. Scenario 3 results in an even larger deficit.

* As previously defined, the available biomass includes all residues wasted or returned to soil, and a scaled-down version of MITRE's projected silvicultural farms.

Figure 3.1

Regional Excess (+) or Deficit (-) in Billion Gallons.

Methanol from Biomass Scenario 1

Year: 1985

25 percent of biomass used for methanol production

Based on Tables 3.1 and 2.13, even a 25 percent displacement of the projected 1985 gasoline market will require up to 66 percent of the projected biomass resources for that period. In light of other competing end uses for biomass, 10 to 15 percent of the gasoline market share seems a more reasonable assessment of the potential of biomass-based methanol. Alternatively, this potential requirement is approximately equivalent to the forestry product industry's and agricultural sector's requirements for liquid fuels (machine drive, farm vehicles, space heating). It is also roughly comparable to the gas turbine requirement for peak load electricity generation.

3.4 MARKET VALUES OF METHANOL FUEL

The value of methanol to each category of consumers is a function of the price of the petroleum fuel for which methanol is intended as a substitute. These are corrected for economic and technical factors, such as increase in efficiency, increased methanol distribution cost due to container modifications and/or blending facilities construction, credit for the octane boosting quality of methanol gasoline blends, and costs of vehicle modification.

Table 3.5 summarizes the values of methanol in various markets for 1985, 1990, and 1995. Tables 3.6, 3.7, and 3.8 show the details of the estimates. A \$.04 per gallon of methanol fuel for gasoline displacement (whether pure or blend) was assumed to illustrate the effect of tax exemption. This amount corresponds to the current \$.04 per gallon Federal tax exemption for gasohol.

Table 3.5 Values of Methanol Fuel in Alternative Markets (\$1979/gallon),
Without and With Gasohol Type Tax Exemption*

<u>Year</u>	<u>10% Blend Methanol in Gasoline</u>	<u>30% Blend Methanol in Gasoline</u>	<u>Pure Methanol in Stratified or Uniform Charge Engines</u>	<u>30% Methanol with Diesel</u>	<u>Utility Gas Turbine</u>	<u>Residential Space Heating</u>
1985						
-No tax credit	1.12	0.83	0.70	0.32	0.27	0.30
-With tax credit	1.53	0.97	0.74	-	-	-
1990						
-No tax credit	1.14	0.84	0.71	0.33	0.29	0.33
-With tax credit	1.54	0.98	0.75	-	-	-
1995						
-No tax credit	1.35	1.00	0.84	0.41	0.38	0.42
-With tax credit	1.75	1.13	0.88	-	-	-

*4 cents per gallon of blend or pure methanol fuel as gasoline substitute, equivalent to the existing gasohol excise tax credit.

Table 3.6 Methanol Fuel Value as Blends in Gasoline and Pure Automotive Fuel (#1979)

	1985			1990			1995		
	10% MeOH	30% MeOH ⁽⁴⁾	Pure MeOH ⁽⁵⁾	10% MeOH	30% MeOH ⁽⁴⁾	Pure MeOH ⁽⁵⁾	10% MeOH	30% MeOH ⁽⁴⁾	Pure MeOH ⁽⁵⁾
Value of gasoline/ gallon at pump ⁽¹⁾	112¢	112¢	112¢	116¢	116¢	116¢	138¢	138¢	138¢
Gallons of gasoline displaced/gallon methanol used ⁽²⁾	0.620	0.676	0.699	0.620	0.676	0.699	0.620	0.676	0.699
Base value of 1 gallon methanol	69.4	75.7	78.3	71.9	78.4	81.1	85.6	93.3	96.5
Cost of vehicle change/gallon methanol ⁽³⁾	-8.6	-6.7	-4.1	-10.4	-8.2	-5.0	-12.7	-9.9	-6.1
Credit for octane boosting/gal methanol	55.8	18.6	0	58.1	19.3	0	68.8	22.9	0
Deduction for incremental distribution cost ⁽⁷⁾	-4.3	-4.3	-4.3	-5.2	-5.2	-5.2	-6.3	-6.3	-6.3
Net value of methanol at pump/gallon	112.3	83.3	69.9	114.4	84.3	70.9	135.4	100.0	84.1
Tax credit, based on 4¢/gallon gasohol	40.0	13.3	4.0	40.0	13.3	4.0	40.0	13.3	4.0
Net value including tax credit/gallon methanol	152.3	96.6	73.9	154.4	97.6	74.9	175.4	113.3	88.1

(1) DOE projections, Series C, high oil prices⁽¹³⁾

(2) 20 percent alcohol efficiency gain for 10 percent methanol, 30 percent efficiency gain for 30 percent methanol, and 35 percent efficiency gain for pure methanol in new engines⁽³⁾.

(3) In 1979 vehicle modification cost \$37/vehicle for 10 percent blend, \$220/vehicle for 30 percent blend, and 5¢/gallon fuel for pure methanol car. Interest potentially earned by the modification spending was taken into account.

(4) Assumed standard compression ratio, and blend fuel octane rating corresponding to present unleaded gasoline.

(5) Assumed higher compression ratio engines than existing engines.

(6) 5 percent of gasoline price per gallon of blended fuel, based on similar values from references 3 and 23.

(7) Based on cost of distributing gasoline from reference 22, after increasing by 20 percent to account for methanol distribution requirements.

Table 3.7 Methanol Fuel Value for Dual Use
with Diesel Automotive Fuel (1979)
30 Percent Methanol/70 Percent Diesel

	<u>1985</u>	<u>1990</u>	<u>1995</u>
Value of diesel/gallon at pump ⁽¹⁾	85.6	91.1	113.5
Gallons diesel displaced per gallon methanol used	0.466	0.466	0.466
Base value of one gallon of methanol	39.9	42.5	52.9
Cost of vehicle change per gallon methanol ⁽²⁾	-4.0	-4.9	-5.9
Deduction for incremental distribution cost ⁽³⁾ per gallon	-4.3	-5.2	-6.3
Net value of methanol at pump per gallon ⁽⁴⁾	31.6	32.4	40.7

(1) DOE projection, Series C, high oil prices⁽¹³⁾.

(2) \$220 per vehicle in 1979. Interest potentially earned by investing this sum was also included in the cost per gallon.

(3) Assumed 20 percent higher than petroleum fuel.

(4) If methanol for this end use receives the same exemption of 4 cents per gallon of blended fuel as gasohol, its market value would be higher.

Table 3.8 Value of Methanol Fuel Used in Residential Heating and Gas Turbine for Peak Loading (1979 cents)

	1985		1990		1995	
	<u>Home Heating</u>	<u>Gas Turbine</u>	<u>Home Heating</u>	<u>Gas Turbine</u>	<u>Home Heating</u>	<u>Gas Turbine</u>
Value of delivered distillate per gallon ⁽¹⁾	72.5	61.4	79.0	66.9	100.4	85.6
Gallons of distillate displaced/gallon methanol used	0.466	0.466	0.466	0.466	0.466	0.466
Base value of 1 gallon methanol	33.8	28.6	36.8	31.2	46.8	39.9
Cost deduction for retrofit ⁽²⁾ per gallon	-1.6	0	-2.0	0	-2.3	0
Deduction due to increased distribution cost ⁽³⁾	-1.8	-1.8	-1.9	-1.8	-2.4	-1.8
Net value per gallon methanol delivered	30.4	26.8	32.9	29.4	42.1	38.1

(1) DOE projections, Series C, high oil prices⁽¹³⁾ Industrial distillate prices assumed 15 percent lower than residential⁽²¹⁾.

(2) 790 gallons distillates per year per household at 5 persons per household, based on 1972 data⁽⁶⁾. Equivalent to 1525 gallons methanol per year or 38100 gallons for 25 year lifetime. Retrofit is \$232 per furnace in 1979. For utility applications, assumed new gas turbines and hence no retrofit cost.

(3) Distribution cost of distillate is 24 percent of distillate price based on 1978 data⁽²⁰⁾. A 10 percent increase is assumed for methanol. This is lower than the difference between methanol and gasoline or diesel, because the stationary end uses would entail less distribution problems than the transportation sector.

From Table 3.5, it is seen that methanol is most valued as a blend fuel with gasoline. Methanol values as a substitute for distillates in diesel vehicles, utility gas turbines, and residential heating are roughly the same for each of the three end uses. Methanol fuel value in dual use with diesel is lower than in blend use with gasoline, because (a) diesel prices are projected to be lower than gasoline prices, (b) no efficiency increase is assumed relative to diesel⁽⁸⁾, and (c) no octane boosting credit is applicable^(3,8). Since the above analysis showed that the blend fuel market appears most promising, methanol would penetrate that market more readily. Even if one market is more readily penetrated than others, the other markets would still benefit indirectly. For example, if methanol can displace 10 percent of the gasoline requirements, then crude oil will be available for distillate production in quantities sufficient to supply (a) the utility peaking turbine market or (b) the forestry product and agricultural sectors distillate market or (c) a portion of each of the above distillate markets. Refinery imbalances may constitute a potential problem in certain areas. However, further evaluation of the problem is beyond the scope of the present study.

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