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TECHNICAL-ECONOMIC ASSESSMENT OF THE PRODUCTION
OF METHANOL FROM BIOMASS

Final Research Report

Executive Summary

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

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Volume I - Executive Summary

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Biomass Energy System Branch
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ABSTRACT

This report presents the results of a comprehensive systems study which assessed the engineering and economic feasibilities of the production of methanol from biomass utilizing existing technology. The three major components of the biomass to methanol system assessed are the availability of biomass feedstocks, the thermochemical conversion of biomass to methanol fuels, and the distribution and markets for methanol fuels.

The results of this study show that methanol fuel can be produced from biomass using commercially available technology in the near term, and could be produced economically in significant quantities in the mid-to-late 1980's when advanced technology is available.

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 and other alcohol fuels.

During the past few years, much interest has been generated in the possibility of producing alcohol fuels from renewable biomass resources. As a result, many new and improved biomass gasification concepts and catalytic conversion technologies have emerged. These new technologies may play a significant role in improving methanol production economics, and can also provide conversion process alternatives for the production of higher alcohols and gasoline products. Thus, the development and integration of new conversion processes could be one of the determining factors in the economic production of chemicals and fuels from biomass.

1.2 OVERALL STUDY PROGRAM

In view of the need for transfer and integration of current and new technologies to biomass applications, SAI proposes a three-phase thermochemical alcohol fuel research program. These are:

- Phase I - Technical and economic feasibility study of current technology for the production of methanol from biomass;
- Phase II - Conceptual process design and economic assessment of advanced and innovative thermochemical conversion processes for producing alcohol fuels and gasoline from biomass;
- Phase III - Pilot plant studies and process demonstration of commercially feasible advanced alcohol fuels and gasoline production processes.

The Phase I program, the completed biomass-to-methanol study described in this report, is directed toward the assessment of the applicability of conventional technology for production of methanol. The emphasis of the Phase I study was placed on the development of conceptual conversion processes and the assessment of economic feasibilities of several alternative process configurations. The results of the study are presented in three volumes:

- Volume I - Executive Summary
- Volume II - Biomass resource and methanol fuel market analyses
- Volume III - Conversion process development and analysis

1.3 STUDY OBJECTIVES AND APPROACH

The overall objectives of this program are:

- Develop alternative thermochemical processes for the production and introduction of methanol and other alcohol fuels from biomass.
- Develop a systems model to assess the economic feasibility of the production and marketing of alternative alcohol fuels.
- Assess the technical and economic feasibility of biomass based alcohol as a fuel and as a chemical feedstock.
- Develop recommendations for an RD&D plan to minimize the economic impacts of the introduction of biomass based alcohol as a new fuel into our national economy.

The approach and analysis steps utilized in the Phase I program in each of three specific topic areas are outlined as follows:

Biomass Resources Analysis

- Characterization of regional biomass resources
- Projection of near-term and long-term biomass resources suitable for methanol production
- Screening potential biomass production regions.

Methanol Fuel Market Analysis

- Evaluation of existing and potential methanol end uses
- Analysis of methanol market penetration
- Assessment of potential methanol demand and supply.

Conversion Process Analysis

- Assessment of the state-of-the-art conversion technology
- Development of alternative conceptual process configurations
- Technical-economic comparison of conceptual biomass-to-methanol processes.

1.4 SIGNIFICANT FINDINGS AND RECOMMENDATIONS

1.4.1 Summary of Main Findings

Methanol fuel produced from domestic, renewable biomass resources can contribute to and extend U.S. energy supplies of clean liquid fuels. Methanol fuel can be produced from biomass using commercially-available technology in the near term (by 1985), and could be produced in significant quantities in the mid-to-late 1980's when advanced technology is available.

Biomass Resource Availability and Economics

In the near term (1980-1985), the major source of biomass resources available in the U.S. for methanol production will be silvicultural and agricultural crop residues. This represents approximately 423 million dry tons in 1985 (i.e., 7 quad). Forestry residues (wood) and agricultural residues contribute equally to this total. Assuming a continuation of biomass energy farm development, additional biomass could

become available from silvicultural energy farms, the annual output of which could reach 265 million dry tons by the end of the century. The projected biomass resources suitable for methanol production are summarized in Table I.

The lowest cost biomass feedstock currently suited to methanol production are forest residues (\$1.2-\$3.2 per MMBTU) and crop residues (\$1.5-\$2.4 per MMBTU). Based on current conversion technology, these feedstock costs approximately correspond to 20 to 30 percent of methanol production costs. Table II shows the feedstock cost range for several representative methanol conversion sites.

Biomass available from existing forest resources is adequate for initial development of methanol fuel. It is estimated that 25 percent of the combined forest and crop residues (106 million dry tons in 1985) would supply sufficient feedstock for a nationwide market of 10 percent methanol/gasoline blend (13.0 billion gallons per year in 1985). The potential regional methanol production from biomass is shown in Table III.

Methanol Production Technologies and Economics

Methanol can be produced from biomass in the near term (1980-1985) using commercially available technology. Significant methanol fuel production could be realized in the mid-to-late 1980's when advanced technologies specifically developed for biomass feedstocks are utilized. Table IV summarizes the methanol production economics from biomass. The costs of methanol production from biomass using existing technology are expected to be between \$0.59 to \$0.84 per gallon when a low cost biomass feedstock (\$1 per MMBTU) is available. Therefore, methanol produced from biomass could be attractive as the alcohol component of a 10 percent blend with no-lead gasoline. Since the giant coal to methanol plants are not

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

	Forestry	Existing Resource Base Agriculture			Total		Potential Biomass Farms	
	<u>1985 - 2000</u>	<u>1985</u>	<u>1990</u>	<u>2000</u>	<u>1985</u>	<u>1990</u>	<u>2000</u>	<u>2000</u>
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	<u>4.3</u>	<u>20.6</u>	<u>21.0</u>	<u>21.9</u>	<u>24.9</u>	<u>25.3</u>	<u>26.2</u>	<u>7.0</u>
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.

Table II 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	Piscataquis 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 III 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

Table IV Economic Summary of Methanol Production from Biomass (\$1979)

	Near Term (1979-1985)			Long Term (1985-1995)	
	Existing Technology		Biomass Methane Hybrid Plant	Advanced Gasification	Advanced Gasification + Methanol Technology
Methanol Capacity					
MMG/Y	42.6	198	198	198	198
ST/D	430	2000	2000	2000	2000
Feedstock Requirements					
Wood, ODT/D	1000	4650	1284	4092	3160
Natural Gas, MMBtu/D	-	-	2.36 x 10 ⁴	-	-
Methanol Selling Price, \$/gal					
Biomass Cost, \$/MMBtu					
1.0	0.84	0.59	0.39	0.41	0.34
1.5	0.91	0.66	0.45	0.47	0.38
2.0	0.98	0.73	0.51	0.52	0.43
2.5	1.05	0.79	0.57	0.58	0.47

expected to be available until the late 1980's, the growing regional market for 10 percent gasohol and favorable federal and state tax incentives will likely stimulate several small-scale (15-20 million gallons/year) biomass to methanol developments from private sources. During this period, methanol production will be limited primarily by the biomass residue availability and cost. Commercial production of methanol from biomass likely will succeed regionally, especially in the areas where low cost forest residues are available.

The data presented in Table V shows the potential economic advantages of alternative production concepts and new technologies. The alternative production route employing the biomass-methane hybrid system could potentially lower the methanol selling prices to be between \$0.34 to \$0.52 per gallon corresponding to \$1 and \$3 per MMBTU feedstock costs. The biomass-methane hybrid system utilizes both biomass and natural gas feedstocks. Proper combination of the synthesis gases produced from steam reforming of natural gas and biomass gasification would allow the maximum methanol yield. The advantages of this hybrid production route stems from the improvements of both biomass and methane conversion efficiencies. This results in a substantial reduction (50 percent) in the capital investment required. Another benefit of such a hybrid production concept is that a net saving of natural gas consumption for new methanol production can be realized in the near term.

The potential beyond 1985 appears quite encouraging. In the long term, the availability of large quantities of low cost silvicultural farm products (at \$1.5 per MMBTU) along with the technological advancements in biomass gasification and methyl fuel synthesis could lower the methanol price to \$.38 per gallon. At this price, methanol fuel production from a medium size (2000 TPD methanol) biomass plant could effectively compete with any other feedstocks including giant-size coal to methanol plants. A comparison of methanol production economics for various feedstocks is shown in Table VI.

Table V Potential Economic Advantage of Some New Technologies and Integrated Production Concepts for the Conversion of Biomass to Methanol (Cost in \$1979, 90% Plant Factor)

	<u>New Technologies</u>				
	<u>Average Case Biomass</u>	<u>Natural Gas Reforming</u>	<u>Hybrid Plant</u>	<u>Advanced Gasification</u>	<u>Advanced Gasification and Methanol Synthesis</u>
Methanol Capacity, tons/day	2000	2000	2000	2000	2000
Total Investment, MM\$	353.7	134.7	181.4	215.0	179.6
Feedstock Requirements and Costs					
Biomass, ODT/day	4650	-	1284	4092	3160
\$/ODT	25.5	-	255	25.5	25.5
\$/MMBtu	1.50	-	1.50	1.50	1.50
Natural Gas, MMBtu/day	-	7.09×10^4	2.36×10^4	-	-
\$/MMBtu	-	3.21	3.21	-	-
Production Cost, \$/gal					
Feedstock	0.198	0.384	0.180	0.174	0.134
Operating	0.033	0.036	0.049	0.031	0.030
Capital	0.429	0.163	0.220	0.261	0.218
Total Cost	0.660	0.583	0.449	0.466	0.382

**Table VI Comparison of Methanol Conversion Economics - Effects
of Various Feedstock Prices in 1985 and 1995
(\$1979, 90% Plant Factor)**

Status of Technology S. Tons Methanol Per Day	Average Case Biomass Gasification		Bituminous Coal Gasification				Residual Partial Oxidation	Natural Gas Reforming
	Reference (1) 2000	Improved 2000	Reference 2000	8000	Improved 2000	8000	Reference 2000	Reference 2000
Total Investment, \$ Millions								
1985	353.7	(2)	338.9	945.6	(2)	(2)	230.7	134.7
1995	353.7	179.6	338.9	945.6	300.4	835.3	230.7	134.7
Feedstock Cost (7)								
1985 (8) - \$/Unit	25.50/ODT (3)	(2)	23.2/T	23.2/T	(2)	(2)	26.41/bbl	3.21/MM Btu
- \$/MM Btu	1.50	(2)	1.02	1.02	(2)	(2)	4.19	3.21
1995 (9) - \$/Unit	31.45/ODT	25.50/ODT (4)	29.02/T	29.02/T	29.02/T	29.02/T	36.63/bbl	4.54/MM Btu
- \$/MM Btu	1.84	1.50	1.27	1.27	1.27	1.27	5.81	4.54
Production Cost, \$/gallon								
1985 - Feedstock	0.197	(2)	0.132	0.132	(2)	(2)	0.546	0.384
- Operating (5)	0.033		0.032	0.026			0.032	0.036
- Capital (6)	0.429		0.410	0.286			0.279	0.163
- By-Product Credit	0		-0.008	-0.008			-0.005	0
Total	0.659		0.566	0.436			0.852	0.583
1995 - Feedstock	0.242	0.134	0.165	0.165	0.154	0.154	0.758	0.544
- Operating	0.033	0.030	0.032	0.026	0.031	0.024	0.032	0.036
- Capital	0.429	0.218	0.410	0.286	0.363	0.253	0.279	0.163
- By-Product Credit	0	0	-0.008	-0.008	-0.008	-0.008	-0.005	0
Total	0.704	0.382	0.599	0.469	0.540	0.423	1.064	0.743

(1) Koppers Totzek gasification

(2) Technology not expected to be available in 1985

(3) Assumed forestry residues

(4) Assumed biomass farms with improved yield are operational

(5) Include utilities, chemicals and labor

(6) Include overhead, maintenance, return on investment, and other capital related charges.

(7) DOE/EIA-0102/52, Series C, high oil prices, escalated to \$1979 - Coal prices adjusted to Illinois coal. Biomass residue price assumed to increase at the same rate as coal.

(8) World wide oil at \$23.22/bbl in \$1979.

(9) World crude oil at \$34.02/bbl in \$1979.

Methanol Fuel Market and Incentives

The methanol blend with gasoline presents the best market penetration potential and could be developed regionally within 5 years. For a 10 percent blend in gasoline, a total U.S. methanol market of 13.4 billion gallons per year is projected by 1985. Other potential demands for methanol for peak power generation and heating would result in a still greater demand. Table VII summarizes the potential the potential regional Methanol Market shares in the U.S.

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 and 2000, based on projected demand for petroleum fuels. These market penetrations likely will increase through a wide range of government incentives. These include:

- The National Energy Act motor fuel excise tax exemption on gasohol (worth \$.04 per gallon of methanol or \$0.40 per gallon for a 10 percent alcohol gasoline blend).
- Eligibility of alcohol fuel for Department of Energy entitlements (worth \$.02 - \$.03 per gallon).
- Possible federal loan guarantees for methanol pilot plant developments.
- Energy Tax Act of 1978 which allows a 20 percent investment tax credit.
- Possible state tax exemption on gasohol (worth \$0.40 - \$0.60 per gallon of methanol for a 10 percent alcohol blend).

With the proper consideration of these economic incentives, methanol from biomass should become very attractive as a renewable clean liquid transportation fuel and could have significantly larger energy and economic impacts than the small-scale ethanol production from biomass.

Table VII 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	150.8	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.

1.4.2 Recommended Development Strategy

In view of the market readiness of alcohol fuels and the potential technological improvement of producing methanol from biomass, it is recommended that methanol development strategies should be constructed to take advantage of nearterm opportunities (e.g. hybrid system, advanced gasification, etc.) in order to accelerate the commercial demonstration of large scale capacity. For these reasons, a three-phase methanol-from-biomass pilot plant demonstration program is proposed. Table VIII shows the relationship and timing of key development elements and demonstration phases.

Resource Development

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

Methanol Market Development

Market development should be focused on the gasoline market. This should include the following activities:

Table VIII Near-Term Methanol from Biomass Development Strategies and Conversion Plant Demonstration

- Federal market development assistance and related tax incentives.
- Methanol-gasoline blend distribution regulation, pricing, and tax policies.
- Assessment of future market competition from other alternative transportation fuels.
- Assessment of alcohol fuel impacts on future U.S. petroleum industry.

Conversion Technology Development

In view of the significant potential for technological improvements, it is recommended that future research and development be directed toward five types of efforts:

1. Fundamentals of Gasification Processes and Properties: Continue pursuit of research and development of biomass gasification processes which take advantage of the high reactivity, and low sulfur and ash content of biomass. The goal should be to develop a gasifier which can produce a synthesis gas directly suitable for methanol and other catalytic conversion processes.
2. Materials and Mechanical Systems: Develop new and improved concepts for an economical and reliable system for continuous feed of biomass and removal of ash and residues.
3. Catalyst Development: Continue research on laboratory and pilot plant scales, to develop improved alcohol fuel systems catalysts for efficient utilization of biomass synthesis gas.
4. Hybrid Feedstocks for Methanol Fuel Production: Develop and evaluate conceptual process designs and strategies for implementation of biomass hybrid feedstock processes, including the methane hybrid and hydrogen hybrid alternatives.
5. New and Innovative Processes: Perform technical and economic feasibility studies of new and improved catalytic processes for liquid fuel and gasoline production from biomass gas.

1.4.3 Recommended Methanol Conversion Plant Demonstration Program

The recommended methanol program involves three explicit demonstration phases and a pre-demonstration study phase.

Pre-demonstration phase. This phase would require about 1 year. The key objectives are to:

- a. Select and evaluate appropriate existing methanol plant sites, compatible with biomass feedstocks availability and markets, for biomass-methane hybrid methanol production.
- b. Evaluate and develop conceptual processes incorporating new and innovative gasification and subsequent conversion technologies for producing alcohol fuels and gasoline from biomass.

Phase I demonstration program. This phase would require about 1-1/2 to 2 years. The major objective of this phase would be to:

- a. Demonstrate the technical and economic feasibility of a biomass-methane hybrid methanol facility using commercially available biomass gasifiers in the size range of 100 to 150 TPD.
- b. Demonstrate the economics of collection and transport of 500 TPD biomass to a centralized gasification system retrofitted with an existing small-scale methanol plant (200 TPD capacity).

Phase II demonstration phase. This phase would require about 2-3 years. The key objectives would be to:

- a. Demonstrate one or more advanced biomass gasifiers for producing a synthesis gas with H_2 to CO ratio equal to 2, in the size range of 100 to 150 TPD.

- b. Demonstrate an advanced methanol synthesis process using a new catalyst or innovative process in a 200 TPD plant size.

Phase III demonstration program. This phase would require approximately 3 to 4 years. The key objective of this phase would be to:

- a. Demonstrate an integrated advanced biomass-to-methanol production technology, together with the feedstock collection and product distribution, at a methanol capacity of 2000 TPD.
- b. Demonstrate the economic and operational advantages of a commercial-scale biomass-to-methanol plant when compared with other methanol production technologies.

1.5 HIGHLIGHTS OF ANALYSIS RESULTS IN VOLUMES II AND III

The significant results of the analysis of the biomass based methanol processes detailed in Volumes II and III are summarized in the following.

1.5.1 Biomass Resource Analysis

A. Feedstock Characteristics

- Biomass exhibits unique chemical and physical characteristics which are ideally suitable for methanol production via thermal-chemical processes.
- Comparison of biomass with other hydrocarbon feedstocks shows the similarity of urban solid wastes and its components with biomass, and the dissimilarity of coal and biomass.

B. Regional Biomass Availability

- In the near term (before 1985), the major source of biomass will be agricultural and silvicultural residues. These represent approximately 423 million dry tons of biomass per year in the United States. The West North-Central region will have the largest available quantity, followed by the South Atlantic region, and then the East North-Central region.

- In the long term (by 2000), additional biomass could be available from biomass energy farms, from which the total national production could reach 265 million dry tons per year. The regions which have the greatest potential for production from energy farms are the South and Southeast regions of the United States.

C. Potential Biomass-to-Methanol Production Sites

- For methanol production purposes, a large quantity of concentrated biomass resources will be required. The examination of residue resource characteristics has shown several suitable methanol conversion sites. These sites have different resource availabilities ranging from 1100 to 13000 ODT per day capacity. Similarly, 10 promising methanol sites up to 8000 ODT per day have been selected based on energy farm resources.
- The 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. For biomass from energy farms, the expected cost range is lower, \$1.4 to \$2.0 per MMBTU (\$24 to \$37 per dry ton).
- Analysis shows that the transportation costs for biomass feedstock and methanol products are a relative small portion of the total methanol costs, ranging from \$.04 to \$.07 per gallon.

1.5.2 Methanol Market Analysis (Section 3, Volume II)

A. Potential Demand for Methanol from Biomass

- Methanol requirements for traditional chemical uses are estimated to grow at a modest annual rate of 7.7 percent during the years 1970-1980 and at 5.4 percent during the years 1980-2000.
- Estimates of the potential future markets for methanol vary, but most estimates indicate a high potential demand. By 1985, demand for methanol in applications such as peak power generation, automotive fuel, single cell protein, steel manufacture and sewage treatment 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 are expected to gain the largest share of the methanol market between 1985-2000. If methanol is blended to 10 percent in gasoline, a total market of 13.44 billion gallons per year is projected by 1985. Other uses for methanol as a fuel would result in a still greater demand.

B. Comparison of Potential Methanol Demand and Supply

- Three market penetration scenarios were developed to assess the 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 distillate and 5 percent of the residual oil market.

- Scenario (1) methanol requirements can be satisfied reasonably by a future biomass availability equivalent to 25 percent of projected total biomass resource in the near-term (1985-1990). Scenario (2) and Scenario (3) requirements cannot be satisfied by the projected availability of U.S. biomass resources.

1.5.3 Conversion Process Analysis (Volume III)

The results of the analysis of conversion processes can be broken down as follows:

A. Biomass Gasification (Section 2.1, Volume III)

- In the near term (before 1985), large scale gasification technologies that have been developed for coal and solid wastes could be adapted for the production of methanol from biomass. Among the commercially available gasification processes, the oxygen-blown Koppers-Totzek entrained bed gasifiers, the oxygen blown Wellman-Galusha fixed-bed gasifiers, and the Purox gasifiers appear to have the greatest potential for commercial applications.
- In the long term, advanced catalytic gasification processes may be a significant improvement in the production of synthesis gas from biomass. Analysis indicates that advanced catalytic and hydro-gasification of biomass could produce a hydrogen-rich synthesis gas suitable for optimal methanol synthesis.

B. Synthesis Gas Modification (Section 2.2, Volume III)

- Biomass materials which are gasified by partial oxidation in the conventional manner will produce a synthesis gas with an insufficient quantity of hydrogen for optimal methanol synthesis. This may necessitate costly gas treatment steps including particulate and mist elimination, hydrocarbon removal, carbon dioxide removal and CO shifting with steam.
- In a low temperature gasification process, substantial quantities of CH₄ and other hydrocarbons, along with oils and tars may form. The cleaning and conditioning of such a gas product requires a costly steam reforming or cryogenic separation process.

C. Methanol Synthesis Conversion (Section 2.3, Volume III)

- Methanol synthesis technology is highly developed, and competitive, with several commercially proven processes as represented by the low pressure ICI and Lurgi processes. Methanol processes operating at higher pressures have a lower process thermal efficiency because of their higher feed gas compression energy requirements.
- Based on comparison of commercially proven technology, the Lurgi process has a slightly higher process thermal efficiency than the ICI process, due primarily to the higher steam energy recovery. However, the capital cost of Lurgi's isothermal reactor system is higher than the ICI's quench type reactor system.
- A recently developed liquid phase methanol process has the highest process efficiency and shows potentially lower capital costs than current, commercial processes. This system employs a circulating liquid to absorb the heat of reaction. This increases the conversion rate and improves the waste energy recovery.
- The current methanol synthesis processes have a process efficiency ranging from 84 to 90 percent, depending on the individual process and plant size. The new liquid-phase process, currently under development, can achieve a higher conversion efficiency, 93 percent.

D. Biomass to Methanol Process (Sections 3, 4, and 5, Volume III)

- The overall processing steps for an integrated biomass-to-methanol plant include biomass preparation, gasification, gas compression, acid gas removal, CO shift, CO₂ removal, and methanol synthesis.
- The overall process efficiency depends primarily on both the synthesis gas composition and the efficient utilization of waste heat for compression power requirements. The largest power requirements are associated with syngas compression and the oxygen plant.
- The high-temperature Koppers-Totzek gasification system gives a highest process efficiency of 49 percent, while the Purox process would have a lower efficiency of 39 percent.
- In each conceptual process examined, a significant amount of biomass must be burned in order to provide the steam required for power and compression energies.

1.5.4 Economics of Methanol Production from Biomass
(Section 6, Volume III)

- Estimated production costs of methanol from biomass range from \$0.91 to \$1.05 per gallon (\$1979) for a 1000 TPD biomass-to-methanol plant, assuming a \$1.5 - \$2.5 per MMBtu biomass feedstock cost. For the 5000 TPD plant, methanol production costs range from \$0.61 to \$0.74 per gallon.
- The methanol product costs are highly sensitive to biomass feedstock costs, varying from \$0.59 to \$0.86 per gallon for the 5000 TPD plant when feedstocks increase from \$1 to \$3 per MMBtu.
- Approximately 70 percent of the production cost is attributed by capital related costs for plant sizes of 1000 TPD and biomass feedstock costs of \$1.5 per MMBtu.
- The estimated production costs of conceptual biomass-to-methanol processes were compared with methanol production from other feedstocks as follows:
 - In 1985, it is estimated that the average costs for biomass-to-methanol will be within 20 percent of the costs for existing coal and natural gas-to-methanol plant, but will remain unfavorable with respect to the large-scale coal process

- In 1995, biomass-based methanol costs will be comparable to the costs of all other methanol production technologies, including the new large-scale coal gasification process.
- The market values and product prices of methanol are compared in 1985 and 1995. The results show that the 10 percent gasoline blend will permit rapid market penetration because of the positive values of the differences between market values and selling prices. For the other end uses, it appears that a larger tax credit will be required to equate selling prices with market values.

1.5.5 Alternative Methanol Fuel Production Concepts (Section 7, Volume III)

- Several new alternative concepts have been suggested which could alleviate the resource constraint problem and reduce the methanol production costs. Of particular interest are the concepts of dispersed gasifiers, hybrid feedstocks, and hybrid product processes.
- A preliminary economic comparison, of dispersed gasifiers versus centralized gasifiers, indicates a marginal economic disadvantage for dispersed gasifiers. This is due to the large capital investment required for a 12-inch pipeline network, which could handle the outputs from all gasifiers for a 1000 ODT per day plant. The high capital requirements stem from the relatively short average pipeline transport distance, and the fact that trucks must still be used to load and collect biomass feedstocks at each gasifier location. However, this economic disadvantage might be reversed for feedstock transportation over longer distances, 100 miles or more.
- Preliminary material conversion analysis indicated that the economics of methanol production from biomass feedstock could be greatly enhanced through implementation of a hybrid syngas process. The most attractive hybrid syngas processes involve the addition of hydrogen or steam reformed methane to the biomass derived syngas.

- From the preliminary synthesis gas analysis, the economic potential of producing multiple products from biomass derived synthesis gas has been narrowed down to coproduction of methanol and acetic acid and the production of methyl tert-butyl ether.

1.5.6 Prospects of Advanced Processing Technology
(Section 7, Volume III)

- Several new technologies have the potential of improving the methanol production economics and can also provide conversion alternatives for the production of higher alcohols and gasoline products. These new technologies include:
 1. Advanced biomass gasification technologies
 2. Advanced methanol synthesis technology
 3. Higher alcohol synthesis
 4. Gasoline and related product synthesis.

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