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Mission Analysis for the Federal Fuels From Biomass Program

Volume I: Summary and Conclusions

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Prepared by:
SRI International
Menlo Park, California

Prepared for:
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Distributed Solar Technology
Fuels from Biomass Systems Branch
Washington, D.C. 20545

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ABSTRACT

SRI International prepared this overview report on biomass derived fuels likely to achieve future market penetration and commercialization for the DOE, Solar Energy Division, Fuels From Biomass Systems Branch. Fifteen feedstock-to-product routes were studied in detail, and economic data were summarized for 53 missions.* Using SRI's market penetration model and assuming base case feedstock availability (without federal incentives), it was determined that seven of the 53 missions studied penetrate the market in 1985, 15 missions penetrate in 2000, and 15 penetrate in 2020, producing about 0.7, 3.5, and 5.4 quadrillion Btu of useful fuel products, respectively, in each of the years.

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*A mission is defined here as a specific conversion route from biomass feedstock to a useful fuel or chemical product to end use markets. Data on 25 missions were developed by SRI and data on 28 missions were taken from contractor reports by others.

PREFACE

This document is Volume I of seven volumes reporting the results of the DOE mission analysis study. Volumes I and VII were written by Fred A. Schooley and reviewed by Ronald L. Dickenson, Stephen M. Kohan, and Jerry L. Jones of SRI International, Menlo Park, California. The complete list of mission analysis documents is shown below.

Volume #	Title
I	Summary and Conclusions
II	Mission Selection, Market Penetration, Modeling, and Economic Analysis
III	Feedstock Availability
IV	Thermochemical Conversion of Biomass to Fuels and Chemicals
V	Biochemical Conversion of Biomass to Fuels and Chemicals
VI	Mission Addendum
VII	Program Recommendations

The following individuals also have provided assistance in the review of specific final report volumes:

Volume	
III	Dr. Robert S. Loomis, The University of California at Davis
III and V	Mr. Edward S. Lipinsky, Battelle Memorial Institute, Columbus, Ohio
V	Dr. Perry McCarty, Stanford University, Stanford, California
V	Dr. Donald Wise, Dynatech R/D Company, Cambridge, Massachusetts
V	Alan N. Thompkins, General Electric Company, Philadelphia, Pennsylvania
III	Thomas A. McClure, Battelle Columbus Laboratory, Columbus, Ohio
IV	Sabri Ergun, University of California, Lawrence Berkeley Labs, Berkeley, California
III	Robert Inman, Solar Energy Research Institute, Golden, Colorado
V	Dr. Herman F. Feldman, Battelle Memorial Institute, Columbus, Ohio

IV	Donald C. Thomas, Tennessee Valley Authority, Chattanooga, Tennessee
All	Dr. Richard S. Hockett, Monsanto, St. Louis, Missouri

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Dr. Roscoe Ward and Nello Del Gobbo of the DOE Fuels from Biomass Systems Branch provided valuable project guidance and review of the draft final reports. Mr. Del Gobbo also served as the study Technical Manager.

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GLOSSARY

The following terms are used frequently within the seven volumes published on this study:

Btu	British thermal unit (1 Btu = 0.252 Kcal)
COD	Chemical Oxygen Demand
DAF	Dry Ash-Free
DCF	Discounted Cash Flow
DOE	Department of Energy
ECOMOD	Economic Model (Facility Investment and Operating Analysis)
FFBSB	Fuels from Biomass Systems Branch
HHV	Higher Heating Value
IBG or IBtu Gas	Intermediate-Btu Gas
IGT	Institute of Gas Technology
kWh	Kilowatt-hour
LBG	Low-Btu Gas
MSW	Municipal Solid Waste
ODT	Oven-Dried Tons
ppm	parts per million
psi	pounds per square inch
PFI	Plant Facilities Investment
Quad	10^{15} (quadrillion) Btu
SCF	Standard Cubic Foot

SNG	Synthetic Natural Gas
SRT	Solids Retention Time (in anaerobic digester)
TPD	Tons Per Day

I EXECUTIVE SUMMARY

This study, conducted by SRI for the U.S. Department of Energy (DOE), Fuels from Biomass Systems Branch (FFBSB), was designed to examine processes for producing useful fuels and chemicals from agricultural crops and residues to assist the FFBSB in identifying the missions capable of contributing to U.S. energy supplies by 1985, 2000, and 2020.

Biomass offers a significant potential for reducing national dependence on imported fossil fuels through the conversion of a renewable energy source to direct heat, liquid and gaseous fuels, electric power, process steam, and chemicals. Several previous studies have indicated that feasible national goals could be the production of about 5 quadrillion Btu (quads) of energy by the year 2000 and about 10 quads of energy by the year 2020. The results of this study indicate that these are realistic and achievable goals provided federal incentives are successfully applied to increase biomass feedstock availability.

The study entailed the identification of over 1,100 possible missions (specific conversion routes from biomass feedstock to useful fuel and chemical products to end-use markets) before the selection of 15 missions for detailed analysis.

The specific purposes of the study were to:

(1) Determine the biomass missions most likely to result in market penetration in the years 1985, 2000, and 2020.

(2) Estimate the level of market penetration expected in those years.

(3) Provide R&D Program recommendations for the FFBSB.

The method of approach used by the study team entailed the projection of biomass feedstock availability by market price within nine U.S. census regions and the development of a computerized model to estimate regional biomass fuel product market penetration in five year increments. This effort required the regional projection of market prices and demands for ten conventional fuels and chemicals as well as the development of biomass fuel production data on 53 missions. Fifteen missions were selected for detailed analysis based on the application of ranking criteria which required the consideration of various factors, including biomass availability, process cost reduction potential, process energy balance, product marketability, and process environmental impact. The fifteen missions were examined in detail with the development of technology process flow diagrams, technology descriptions, economics, and energy and material balances. The costs of energy production for the 15 missions under regulated utility financing and a 65 to 35 percent debt to equity ratio are shown in Tables 1 and 2. The optimistic estimates reflect high by-product values and product yields for the biochemical missions and a 20 percent reduction in base case capital costs for the thermochemical missions.

Results

Using the base case assumptions for feedstock availability (without federal incentives) 15 of the 53 missions penetrate the market by the year 2020, producing approximately 5.4 quads Btu of fuel and chemical products, including electricity and steam. Assuming federal incentives and optimistic but achievable feedstock availability, 17 of the 53 missions penetrate the market by year 2020, producing approximately 10.3 quads Btu of fuel and chemical products. The penetration expected by type of fuel for the "base case" and "optimistic" scenarios are shown in Table 3. Seven missions penetrate the market in year 1985, and 15 missions penetrate the market in year 2000 producing 0.74 and 3.46 quads Btu of fuel, respectively.

The levels of market penetration shown are the result of model routines that simulate the competitive fuels environment and project usable energy demand as a function of energy price and historical market relationships (including product acceptance patterns). The model formulations allow a consistent comparison of projected market prices (marginal costs) with biomass derived product revenue requirements and compute product demand levels considering numerous factors, including mission commercialization dates, conversion process thermal efficiencies, and the time lag between the introduction of a technology and its widespread commercialization. However, the relationship between expected biomass product price (revenue required) and alternative fuel and chemical market price is the most important factor in determining annual market penetration levels (see Volume II, Section III, description of static economic analysis).

The current program of the FFBSB is directed at specific research development and demonstration (RD&D) goals in both biomass production and conversion. In both areas, processes, techniques, and technologies exist in which there is near-term potential to accelerate commercialization. Therefore, it is likely that increased program emphasis as well as an expansion of the current RD&D program would result in increased energy production over a relatively short time period. Unless the program effort is significantly expanded, less effort should be placed on options with low market penetration potential and distant commercialization dates.

Based only on estimated market penetration projections, the missions that appear to have the greatest near term commercialization potential are:

Table 1

DETAILED MISSION ANALYSIS RESULTS OF THERMOCHEMICAL FACILITIES
(Feedstock = 3000 Dry Tons Per Day)

Route	Conversion* Process	Revenue Required ($/MM Btu)† Base Case	No Feedstock Cost Case	Optimistic‡
Wood to:				
Steam	DC	$ 3.00	$ 1.70	$ 2.70
Steam and electricity (total product basis)	DC	3.40§	2.10	3.10
Oil and char by-product	P	4.50**	1.40**	4.00**
Oil and char (total product basis)	P	2.70§	1.30§	2.50§
Intermediate-Btu Gas				
High pressure (280 psia)	P	4.00	2.60	3.60
Low pressure (25 psia)	P	3.40	2.10	3.00
Heavy fuel oil	CL	5.40	3.50	4.80
SNG	GOB	6.50	4.80	5.60
Methanol	GOB	7.80	6.00	6.70
Ammonia ($/short ton)	GOB	164.00	126.00	141.00
Electricity	DC	16.40 (5.6¢/kWh)	11.60 (4.0/kWh)	14.40 (4.9¢/kWh)

*Key: CL = catalytic liquefaction; GOB = gasification--oxygen blown; DC = direct combustion; P = pyrolysis.

†1977 dollars in year 1985. Data source, SRI Detailed Analysis--Regulated Utility Financing. Plant size = 3,000 dry tons/day of feedstock (See Appendix C)

‡Capital cost = 80% of base case. Feedstock cost = $1.00/MMBtu

§Revenue required is on a total product basis.

**Char valued at $1.25 per million Btu (higher than current but less than projected future coal price).

Table 2

DETAILED MISSIONS ANALYSIS RESULTS:
BIOCHEMICAL FACILITIES

Route	Conversion Process*	Feedstock Dry Tons/Day	Revenue Requires ($/MM Btu)† Base Case	No Feedstocks Cost Case	Optimistic‡
Cattle manure to SNG--100,000 head environmental feedlot	AD	$ 450	$ 7.00	$ 5.90	$ 2.80
10,000 head environmental feedlot	AD	45	14.40	13.40	7.50
Cattle manure to IBG	AD	450	4.90	3.90	4.40
Wheat straw to IBG (40% conversions)	AD	3000	22.10	11.10	9.00
Corn stover to ethanol (Purdue Process)	F(A)	1562	25.55	18.35	16.20
Sugar cane to ethanol	F	2756	27.00	11.30	20.00
Wheat straw to ethanol	F(E)	3270	52.60	43.50	29.20§
Kelp to SNG** (Speculative design case)	AD	3000	21.20	3.00	12.00
Algae to ethanol**	F(A)	1126	25.90	11.00	17.40

*Key: AD = anaerobic digestion; F = fermentation (E = euzymatic hydrolysis, A = Acid hydrolysis)

†1977 dollars in year 1985. Data source: SRI Detailed Analysis--Regulated Utility Financing.

‡Assumes refeed by-product values and high product yields.

§Does not assume continuous fermentation processes which could reduce the optimistic estimates.

**These missions entailed the use of conceptual process designs based on minimal experimental data and numerous process design assumptions in the technoeconomic analysis.

Table 3

MARKET PENETRATION--BIOMASS PRODUCTS

Product	Estimated Biomass Derived Products Quads Btu (Excludes Existing)		
	1985	2000	2020
Base Case Scenario			
Gaseous products (SNG, IBG, LBG)*	0	0.13	0.29
Methanol/ethanol	0	0	0
Ammonia†	0.02	0.40	0.56
Process steam or steam/ electric cogeneration	0.68	2.32	4.01
Pyrolytic fuel oils‡	0.04	0.61	0.53
Total quads	0.74	3.46	5.39
Optimistic Scenario			
Gaseous products (SNG, IBG, LBG)*	0	0.21	0.45
Methanol/ethanol	0	0	0
Ammonia†	0.13	0.41	0.58
Process steam or steam/ electric cogeneration	0.10	4.17	8.39
Pyrolytic fuel oils‡	0.04	0.87	0.83
Total quads	1.27	5.66	10.25

*SNG = synthetic natural gas; IBG = intermediate Btu gas; LBG = low-Btu gas.

†Assumes 18.3 million Btu/ton of ammonia.

‡Char valued at $1.25 per million Btu.

- Combustion of wood and low moisture plants to produce steam and cogenerated steam and electricity.
- Gasification of wood and low moisture plants to produce IBG, SNG, LBG, and ammonia.
- Pyrolysis of wood and low moisture plants to produce IBG fuel oil, and char.
- Anaerobic digestion of manure and high moisture terrestrial crops to produce IBG and SNG.

Increased RD&D emphasis and federal commercialization incentives appear to be justified for all the above missions. However, probably only limited additional RD&D support is necessary for the direct combustion mission because its commercialization potential is firmly established.

Missions that appear to offer minor future contributions are marine crop production, catalytic liquefaction, and fermentation to produce ethanol. However, careful assessment of the value of ethanol in gasoline blends and of credits given for fermentation process by-products is necessary before a final decision on mission viability is made. Claims regarding increased mileage per gallon of alcohol and gasoline blend cannot currently be substantiated, but increases in octane level will add quantifiable value because they permit the use of unleaded base stocks (see Volume VII discussion on fermentation). In the future, government subsidies for ethanol production may be made available to promote national programs designed to increase former self sufficiency and to utilize potential farm crop surpluses.

II INTRODUCTION

The current crude oil and natural gas situation in the United States and the realization that low-cost energy is no longer available have caused government and industry to place increasing emphasis on developing alternative sources of energy. Among these alternative sources, renewable energy resources have received enthusiastic public support and increased government research, development, and demonstration (RD&D) funding. Through the program of the FFBSB, the DOE is developing various technologies associated with several renewable biomass resources--including organic residues and terrestrial and marine energy crops purposely grown for their energy values. Other organizations within DOE are responsible for such functions as basic biomass research, technology demonstration, and process commercialization.

Early in the administration of the former NSF/ERDA and current DOE Fuels from Biomass Program (FFBP), it became apparent that systems studies were needed to provide positive program direction and guidance. SRI International participated in several of these early studies; developed basic program data, definitions, assumptions, and guidelines; identified limitations; and provided program recommendations. Several of these published studies are cited numerically throughout the report and listed in the bibliography in Appendix A.

Although great interest exists in the concepts of fuels from biomass, there is a notable lack of agreement on which resources or biomass conversion process technologies should be pursued or what level and type of DOE support is warranted. Previous studies sponsored by NSF, ERDA, and others have addressed only specific resources, processes, and resource/process combinations. Therefore, a rational and defensible overall evaluation of resource/process options was needed in a single comprehensive study to define more clearly the role of biomass-derived fuels as a national energy resource.

This study provides an overall evaluation of resource/process options using a consistent set of design and economic bases. All dollar amounts reflect fourth quarter 1977 values. The study results are published in seven volumes covering mission selection, market penetration modeling, and economic analysis (Volume II), feedstock availability (Volume III), thermochemical conversion (Volume IV), biochemical conversion processes (Volume V), Mission Addendum (Volume VI), Program Recommendations (Volume VII), and this volume covering a summary and conclusions (Volume I). Future research will allow the detailed analysis of more biomass missions and a reexamination of the conclusions resulting from this initial effort.

III STUDY OBJECTIVES

The current study extends the scope of previous SRI research by examining the commercialization potential of specific routes (or missions) from biomass production to conversion, to product market penetration. Specific objectives of the study are to:

- Determine the biomass missions that are likely to lead to future market penetration within the competitive fuels environment
- Quantify the market penetration of biomass products, based on assumptions regarding future energy market development
- Provide R&D program recommendations.

A "mission" is defined as a possible technical route from a biomass feedstock through conversion to a specific energy or chemical product. A mission includes biomass production, acquisition, prepreparation, conversion to useful fuels or chemicals, and product marketing. The study is designed to identify specific biomass products that could penetrate the markets for U.S. conventional fuels and provide increases in domestically produced energy beginning in 1980.

IV THE COMPETITIVE FUELS ENVIRONMENT

Estimation of market penetration and mission commercial potential is made difficult by a variety of major uncertainties that must be dealt with during the evaluation. These uncertainties result from:

- Competition between biomass derived energy products and energy products produced from conventional sources (e.g. coal, petroleum, natural gas, uranium) for the same end use markets
- Competition between biomass and conventional or advanced processes available to produce the same fuel product
- Competition for feedstocks available for use in supplying numerous alternative demands, including food, fiber, fertilizer, and fuels.

Moreover, expected values for specific variables must be considered to assure a complete analysis of alternative impacts. These variables include:

- Current and future costs of delivered conventional and biomass-derived fuel products
- Expected energy demand growth by type of fuel
- Possible and actual institutional barriers, state agency actions, national governmental policies, and regulatory agency directives
- Environmental factors and resource requirements such as process air pollution impacts and land and water requirements
- Social and consumer preference factors such as perceived fuel convenience and market demand elasticity regarding fuel substitutions
- Feedstock availability, including regional supplies and market price impacts.

SRI considered these competitive uncertainties and variables in preparing the method of approach used in this study.

V METHOD OF APPROACH

The methodology for determining an overall figure of merit (R&D cost-benefit ratio) used to rank each mission is described below. In general, the emphasis is placed on economic impacts and future quad market penetration rather than on social and institutional and consumer preference factors.

Market penetration has been calculated in five-year increments from 1980 to 2020; more important, the quadrillion Btu (quad Btu) impact of each mission has been reported for 1985, 2000, and 2020.

SRI's evaluation methodology included the following steps:

- Literature review and DOE fuels from biomass contractor contacts
- Mission definition, product and process flow charting, and preferred route selection
- Feedstock availability by region and market price
- The detailed evaluation of 15 "preferred route" missions
- Market penetration modeling requiring process economic and feedstock price inputs, as well as regional alternative fuel market price and demand inputs
- Determination of an overall figure of merit for each mission and mission ranking
- Program recommendations.

Each step is discussed briefly below to provide a study overview. The balance of this report concerns market penetration model inputs, and results.

Literature Review and Biomass Contractor Contacts

Before preparing detailed flow charts of potential biomass routes, SRI reviewed most of the readily available fuels from biomass literature and obtained information about currently funded FFBP projects. Cost and design data from FFBP contractors were obtained by letter and telephone contacts. This procedure allowed the study team to examine existing and potential conversion routes and to consider major feedstock-to-fuel product routes under active study, development, or commercialization by U.S. academic, industrial, commercial, or governmental organizations. In addition, foreign publications and papers were reviewed to obtain data on conversion systems under development within other countries.

Mission Definition, Flow Charting, and Preferred Route Selection

Based on the data review and the study team's extensive experience in analyzing numerous conversion projects, a set of product and process flow charts was prepared to illustrate possible biomass conversion routes. Figures 1 and 2 provide examples of these charts which illustrate the major conversion routes and provide the basis for narrowing the choice of missions for detailed analysis. Volume II discusses the mission selection process and contains a complete set of the process and product flow charts.

The "preferred routes," indicated by the heavy lines connecting the sequence steps on the flow diagram, were determined by feedstock-to-conversion process compatibility and from the number and apparent size of markets designated for the product. The study team subjectively measured the feedstock-to-conversion process and product-to-market compatibility by using the following criteria: An "A" rating indicates highest perceived process compatibility and product market potential. A "B" rating indicates secondary product market potential and marginal compatibility, and a "C" indicates little perceived process compatibility and product market potential (see ratings in Figure 2).

The number of possible missions for each conversion route was calculated by multiplying the number of markets by the number of conversion processes, and then multiplying the result by the number of compatible (A rated) feedstocks. Using this system, SRI identified almost 1,200 missions. Of these, 295 feedstock-to-market combinations were identified as "preferred routes," or routes with both "A" feedstock compatibility and "A" product-to-market compatibility.

Feedstock Availability by Region and Market Price (See Volume III)

Regional feedstock availability was calculated by market price within contiguous states, based on two possible future scenarios and related assumptions. The first, or base case, scenario assumes continued crop production under existing market and business as usual conditions. The second assumes government actions and incentives designed to increase energy crop production and use of currently available high and medium potential crop lands. Specifically, the second or optimistic scenario assumes an investment tax credit designed to increase the farm owners' and the conversions plant owner/operators' net rate of return, at the same time increasing the demand for biomass feedstock by a 20 percent decrease in the cost of its production. The optimistic scenario also assumes the availability of leases on public commercial timber lands at attractive rates. It is assumed that in 2020, 10 percent of the total publicly owned commercial timber lands (130 million acres) will be available on favorable lease terms. The optimistic scenario also assumes that noncommercial timber, including dead and diseased trees, will be used to produce energy in specific U.S. regions. In 2020 at $30 per dry ton, 75 million dry tons of noncommercial timber will be available, in addition to the 125 million dry tons of forest crops and residues projected in the base case scenario.

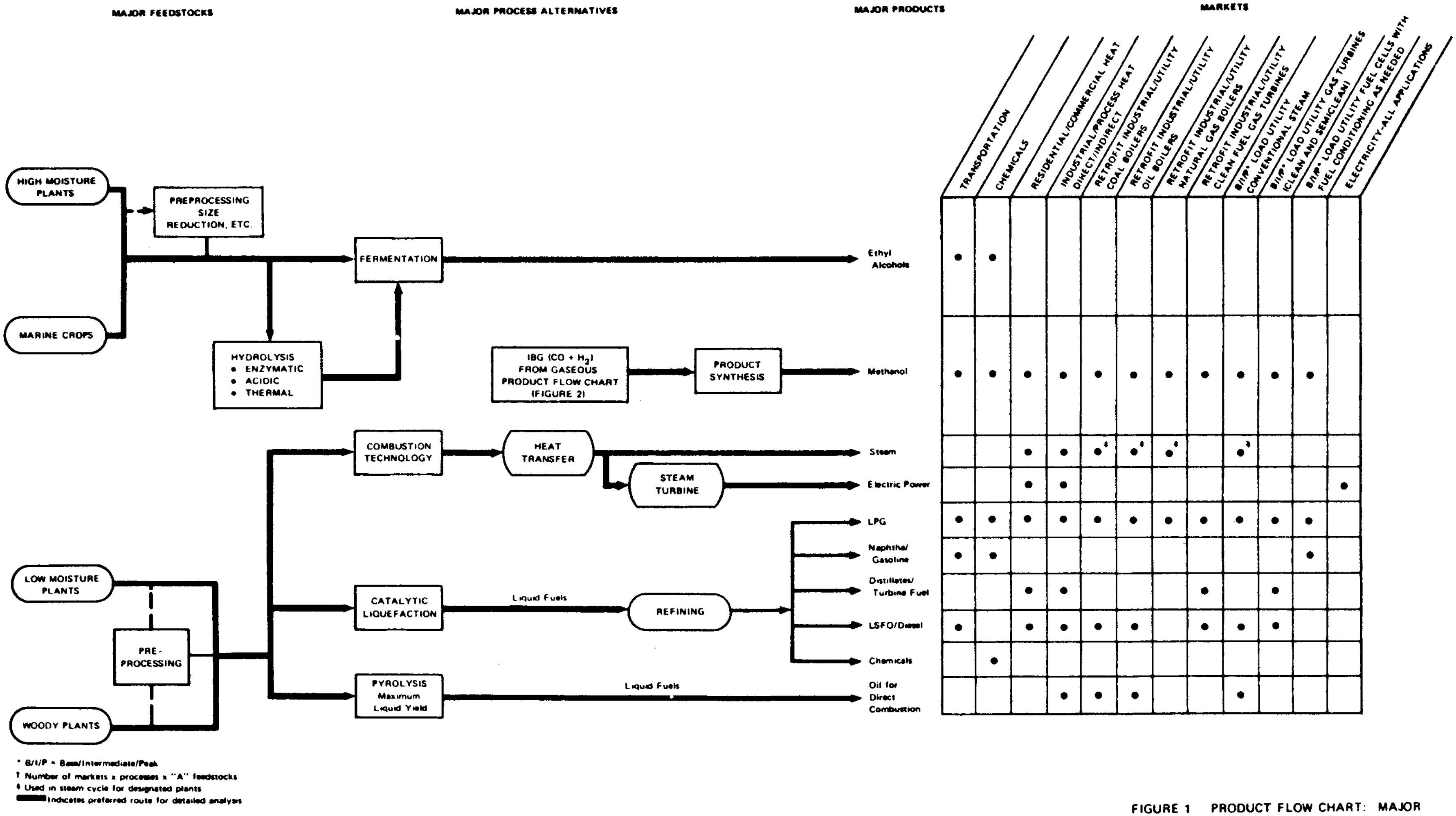

FIGURE 1 PRODUCT FLOW CHART: MAJOR LIQUID FUELS AND ELECTRICITY (GASOLINE, LPG, OILS, CHEMICALS ALCOHOLS, STEAM, AND ELECTRICITY)

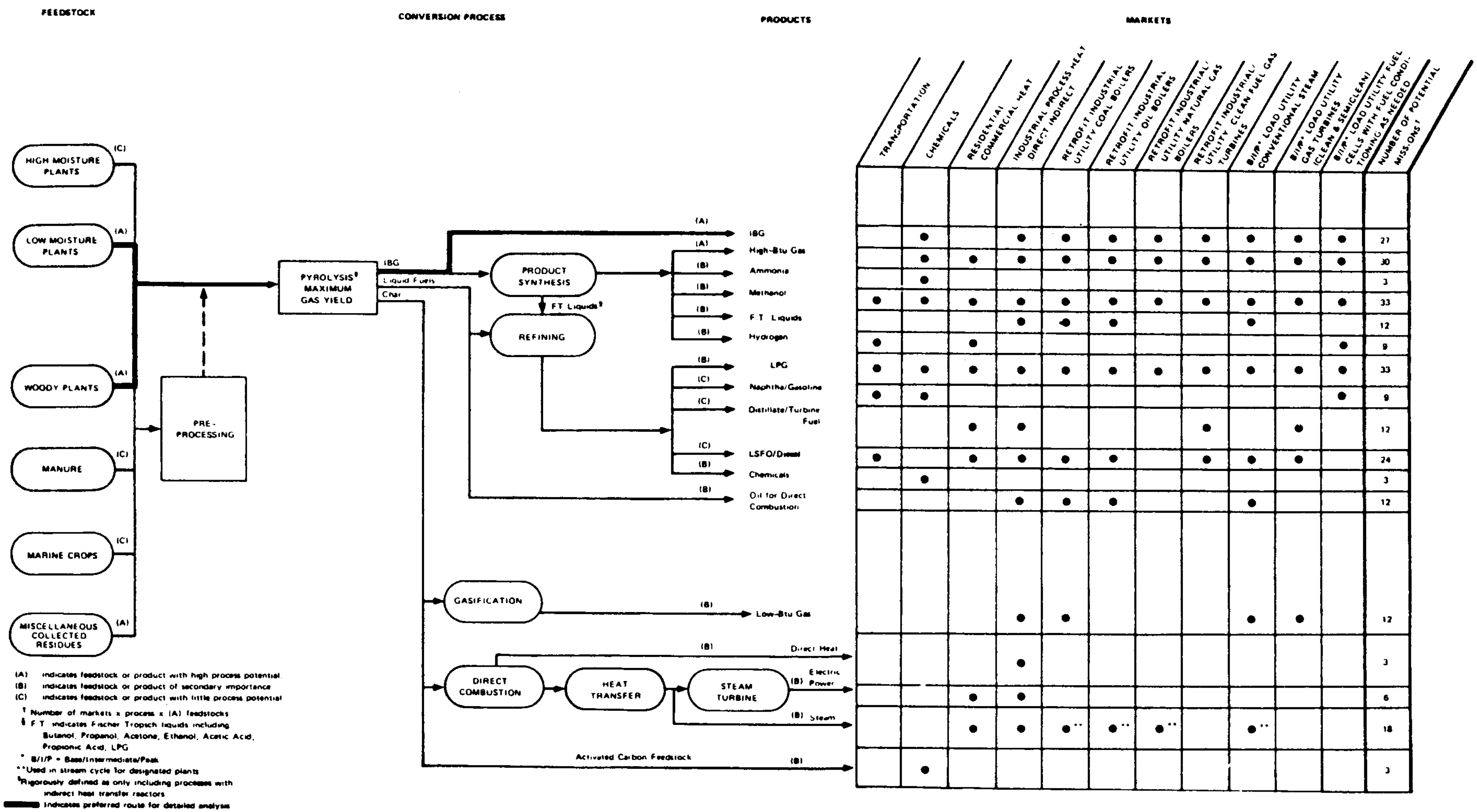

FIGURE 2 PROCESS FLOW CHART: THERMOCHEMICAL TECHNOLOGY FOR PYROLYSIS — MAXIMUM GAS YIELD

Detailed Evaluation of 15 Missions (See Volumes IV and V)

Of the 295 preferred routes from feedstock to market, 15* were selected for detailed evaluation, and process descriptions and material and energy balances were developed. Scoping study economic estimates were completed, including estimated capital investment, operating cost, and revenue requirements. All economic results were uniformly developed by using a consistent set of costing bases† and an SRI facility economics model (ECOMOD). This model facilitated the preparation of cost sensitivity studies, and the effects of variations in plant size, feedstock cost, capital investment costs, operating factor (on-stream hours), and facility life were calculated. A typical tabulated output for ECOMOD is shown in Appendix B.

In selecting the missions for detailed analysis, SRI used three steps:

- Development of a set of ranking criteria for evaluating each possible feedstock-to-product-to-market (mission) combination
- Evaluation of each mission, using the ranking criteria
- Selection of missions for detailed evaluation by using the relative rankings.

The evaluation criteria and the weighting assigned to each factor are shown in Table 4. Systematic use of the ranking criteria and factor weights led to overall ranking of the preferred routes within conversion process categories and to the selection for detailed analysis of the missions shown in Table 5. Appendix C records the results of the cost sensitivity studies of each mission; data are provided on variations in investment, operating, and feedstock costs for each mission resulting from changes in facility operating assumptions. The 15 missions shown in Table 5 were expanded to 25 for market penetration model input purposes by conservatively assuming the results shown for woody crops also applied to low moisture feedstocks.

Market Penetration Modeling (See Volume II)

Market penetration is an extremely complex issue, including numerous interrelated competitive factors. Therefore, to assure the uniform treatment of all potential missions, SRI refined a model of the fuels market, based on previous SRI work in energy market behavior.[1] To model the competition between products, processes, and feedstocks,

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*See Table 2.

†See Economic Design Basis, Appendix, Volume IV.

Table 4

MISSION RANKING FACTORS
(For Selecting 15 Missions for Detailed Analysis)

Factor	Relative Weighting*
Biomass Availability and Characteristics--Perceived abundance of the feedstock resource and its apparent compatibility with process conversion requirements.	95
Potential Environmental Impact--Requirements of the mission for chemicals, fertilizers, catalysts, water, and other materials. Also process impacts including air, water, or land pollution factors.	85
Commercialization Potential--Possibility of reducing feedstock, processing, capital and other costs, and the feasibility of producing a useful and competitively priced product.	80
Potential Energy Output--Ability of the process to provide a favorable energy balance and contribute to a significant portion of U.S. energy supply.	80
Product Slate and Marketability--Feasibility of producing a product with an established and broadly based market demand or the feasibility of penetrating or establishing a new market demand.	75
Potential Competition from Alternatives--Ability of the mission to survive the introduction of competitive processes and product alternatives.	60
Process Simplicity--Requirements for minimum processing steps.	30

*Scale: 0 to 100.

Table 5

MISSIONS SELECTED FOR DETAILED ANALYSIS

Mission	Biomass Feedstock*	Conversion Process Category	Product	Major Market
1	Woody or low moisture	Catalytic lique-faction	Heavy fuel oil	Industrial, utility
2	Woody or low moisture	Gasification in oxygen blown reactors (OBRs)	Methanol from intermediate-Btu gas (IBG)	Transportation, utility
3	Woody or low moisture	Gasification in OBRs	Ammonia from IBG	Chemical--agricultural
4	Woody or low moisture	Gasification in OBRs	SNG from IBG	Industrial, commercial, and others
5	Woody or low moisture	Direct combustion	Steam	Utility, industrial
6	Woody or low moisture	Direct combustion	Electricity	Residential, industrial, commercial, etc.
7	Manure (from environmental feedlots)	Anaerobic digestion	IBG (CH_4 + CO_2)	Industrial utility
8	Manure (from environmental feedlots)	Anaerobic digestion	SNG	Industrial, utility, and others
9	Wheat straw (low moisture)	Anaerobic digestion	IBG (CH_4 + CO_2)	Industrial, utility, and others
10	Wheat straw (low moisture)	Fermentation	Ethanol	Transportation
11	High sugar content plants	Fermentation	Ethanol	Transportation
12	Woody or low moisture	Pyrolysis for maximum liquid yield	Oil for direct combustion and char	Industrial, utility
13	Marine crop (kelp) or high moisture	Anaerobic digestion	SNG	Industrial, utility
14	Aquatic biomass or high moisture	Fermentation	Ethanol	Transportation
15	Woody or low moisture	Direct combustion	Steam and electricity cogeneration	Utility, industrial

Missions 17 and 18 are described in Mission Addendum-Volume #VI.

*Woody plants were studied in detail (see Appendix C) in missions 1 through 6, and another feedlot type was also considered in missions 7 and 8. For market penetration modeling purposes, the 15 missions shown were expanded to 25 by considering all the feedstocks shown in this list. This methodology provided conservative market penetration results.

as well as such factors as delivered energy cost, market growth, and resource availability, the analysis has drawn on previously developed analytical approaches. These approaches are used in forecasting the expected market potential of newly introduced technologies and commodities. The work thus focused on development of a methodology and a computer model that uses an iterative process to converge toward equilibrium biomass supply-demand price conditions (see Section VI for model description).

Mission Ranking

One of the most important model outputs is market penetration in quads of Btu for each mission by year and by region. Assuming a development facility would be desirable to demonstrate commercial feasibility for each market-penetrating mission, SRI calculated a figure of merit (cost-benefit ratio) by dividing the development program cost by the forecast market penetration (in terms of quads) in the year 2020 (see Section VIII for analysis results).

Program Recommendations

Program recommendations were developed in regard to specific conversion processes, levels of DOE support, and incentives needed for mission development. These recommendations are summarized in Volume VII.

VI MARKET PENETRATION MODEL CHARACTERISTICS AND INPUTS

Basically, the market penetration model allocates product demand to various missions by using a market share relationship between the biomass product price and the assumed market price for the conventional fuel* product. Using the product to market price ratio, biomass product demand is allocated to regional fuel markets; then, biomass feedstock is allocated to various missions by using the regional feedstock supply curves. The steps in assessing product penetration are presented in Figure 3; each of the main model components and model operation is described in Volume II.

The model requires specific inputs, including:

- Feedstock supply curves, showing quantities and prices by category and by region
- Projected fuel prices and demands by region for conventional fuels*
- Mission conversion process economics, including capital and operating costs
- Conversion process efficiencies
- Expected commercialization dates for each conversion process.

Model outputs comprise:

- Equilibrium marginal prices for biomass feedstocks and products
- Expected consumption of each biomass fuel
- Amount of fuel produced from each feedstock†
- Quantity of each feedstock demand by region
- Amount of fuel produced by each conversion process†
- Market penetration in quads for each mission by year and by region.

Through an iteration procedure that requires the analyst's manual interaction, the program determines the equilibrium point at which feedstock and product prices allow the feedstock demands to equal feedstock supplies. The steps required to achieve equilibrium biomass supply-demand-price conditions are:

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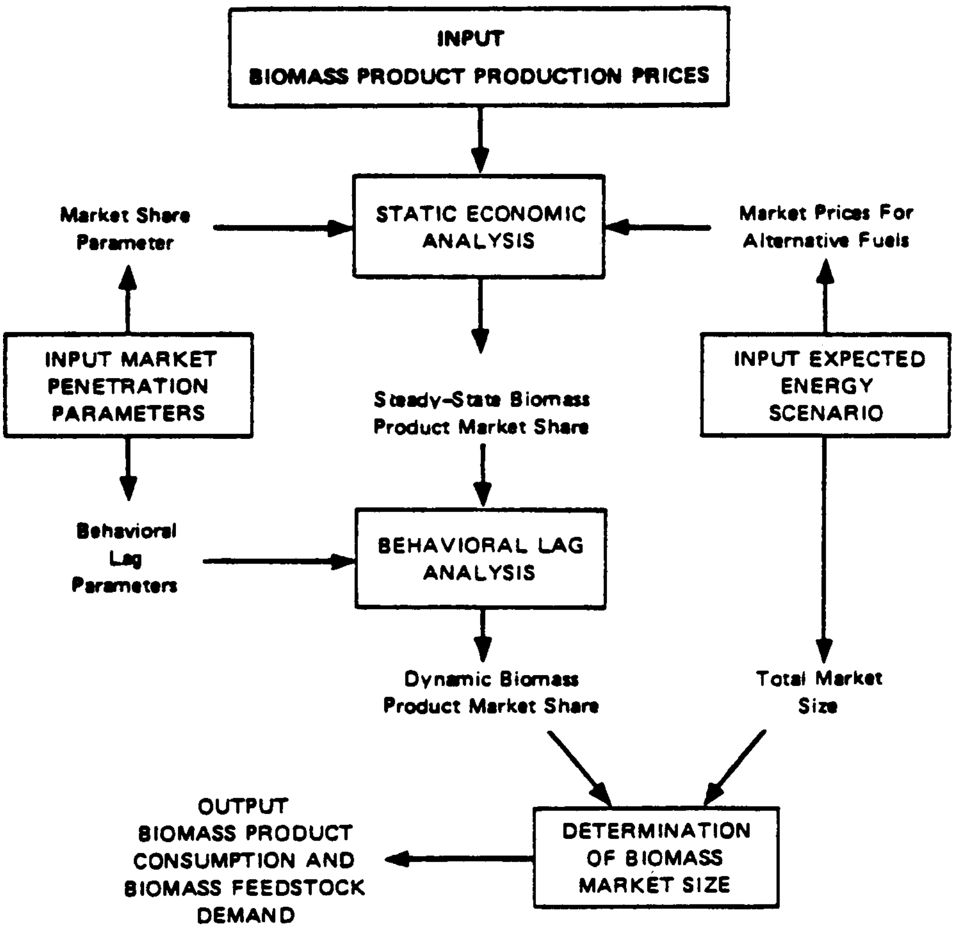
*Also unconventional fuels such as SNG from coal. See Appendix D, Product Demand and Price Data Sources.

†Requires manual summation of individual mission data.

FIGURE 3

LOGIC USED IN BIOMASS PRODUCT PENETRATION ANALYSIS



(1) Marginal production prices and supply quantities are estimated for each feedstock over time.

(2) The model determines feedstock demand quantities required at those marginal prices.

(3) If supply-demand imbalances occur, the analyst adjusts biomass feedstock price and supply quantities

(4) Steps 1, 2, and 3 are repeated until the feedstock supply and demand are equal.

(5) The equilibrium condition produces a balanced allocation of available feedstock quantities to the various products on a regional basis.

Any time a basic input to the model is altered, the procedures must be repeated to determine the market penetration in quads for each mission by year and by region.

Feedstock price quantity inputs are summarized in Tables 6 through 9. The actual model inputs were broken out by region as well as market price and are shown in Appendix A of Volume III.

Table 6

MARKET PRICE VERSUS BIOMASS AVAILABILITY IN THE CONTIGUOUS UNITED STATES--BASE CASE SCENARIO (Millions of Dry Tons)

Market Price ($/dry ton)	1975	1985	2000	2020
$10	146	152	177	200
20	272	246	291	326
30	383	362	429	484
40	463	460	547	607
50	512	506	632	707

Table 7

MARKET PRICE VERSUS BIOMASS AVAILABILITY IN THE CONTIGUOUS UNITED STATES--OPTIMISTIC SCENARIO (ASSUMES GOVERNMENT INCENTIVES) (Millions of Dry Tons)†

Market Price ($/dry ton)	1975	1985	2000	2020
$10	146	152	177	200
20	272	255	338	390
30	383	480	676	792
40	463	1018	1498	1715
50	512	1884	2539	2783

Table 8

BIOMASS AVAILABILITY BY TYPE OF CROP IN THE CONTIGUOUS UNITED STATES* (Millions of Dry Tons)

	Low Moisture	High Moisture	Woody Biomass	Manure	Aquatic	Optimistic Total	Base Case Total
1975	110	37	79	46	--	272	272
1985	69	32	97	57	--	255	245
2000	91	49	126	72	--	338	291
2020	102	60	151	77	--	390	326

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*Price, $20 per dry ton.

†~67 million dry tons = 1 quad.

Table 9

BIOMASS AVAILABILITY BY REGION IN THE CONTIGUOUS UNITED STATES, YEAR 2000*
(Millions of Dry Tons)

Region		Base Case Scenario	Optimistic Scenario
1	North East	23	34
2	Middle Atlantic	0	5
3	South Atlantic	14	53
4	East South Central	38	81
5	East North Central	28	67
6	West South Central	51	76
7	West North Central	99	163
8	Pacific	105	122
9	Mountain	71	74
	Total dry tons--United States	429	675
	Quad equivalent	6.4	10.1

*Price, $30 per dry ton.

The optimistic scenario assumptions result in only a 20 percent increase over the base case in feedstock availability at the $20 per dry ton market price; however, availability increases by 64 percent over the base case at $30 per dry ton. A doubling in market price (e.g., from $10 to $20 per dry ton) produces a 60 to 90 percent increase in the quantities available.

Woody crops and residues constitute the largest quantity of low-cost biomass in both the base case and optimistic scenarios.

In the base case estimate, only a small percentage (less than 2 percent) of total tonnage is expected to consist of crops grown specifically for energy because of competing demands from food and fiber crops. In the optimistic scenario, energy crops constitute about 10 percent of the total at $20 per ton market price and about 30 percent of the total at $30 per ton (in 2020).

Although the market penetration model requires the input of regional fuel price and quanitity data, only the national totals are reported for this summary (see Volume II, Appendix C, for regional fuel prices and demand).

The fuel prices and demand projections shown in Tables 10 and 11 represent the midpoints of a range of prices and quantities expected because of distinct regional variations and uncertainty in the estimates. Appendix D contains a list of product demand and price data sources.

Tables 12 and 13 record the results of SRI's detailed analysis of the 15 feedstock-to-conversion product routes. Because only summary results are reported here, the reader is referred to Appendix C of this volume for more explicit data. Regulated utility financing was assumed with a 65 to 35 percent debt to equity ratio. SRI used a 9 percent interest rate on debt and a 15 percent (Discounted Cash Flow) return on equity.

Table 10

FUEL BASE CASE MARKET PRICES
(Midpoint of Range--1977 Dollars per Million Btu)

	1975	1985	2000	2020
Gasoline	$2.87	$3.80	$ 4.70	$ 4.90
Coal	1.10	1.40	1.60	1.60
Natural gas	1.88	3.00	3.90	4.00
Crude oil	1.97	2.60	3.20	3.60
Low-sulfur residual	2.30	2.70	2.50	4.00
Electric power (avg)	8.80	9.80	10.60	11.70
IBG/LBG	--	2.70	3.70	3.80
Steam*	3.60	3.70	4.40	4.50
Ammonia	2.70	3.30	4.30	4.80

*Coal derived.

Sources of data: see Appendix D

See Volume II, Appendix A, for regional price and demand estimates.

Table 11

FUEL BASE CASE QUANTITIES
(Btu in Quads)

	1975	1985	2000	2020
Gasoline*	12.9	10.9	8.2	8.1
Coal	14.0	20.8	26.5	37.4
Natural gas	17.9	21.8	22.1	22.0
Crude oil	26.4	35.6	38.3	39.2
Low-sulfur residual	5.5	2.9	2.4	1.6
Electric power (avg)	5.9	10.2	17.2	25.9
IBG/LBG	--	8.5	10.0	11.5
Steam	3.8	5.9	9.4	17.0
Ammonia				
Millions of tons	15.6	18.6	23.1	30.0
Quads†	0.3	0.4	0.4	0.6

*Excludes aviation gasoline and reflects a current U.S. energy demand of 72 quads and an estimated 110 quads in 2000.

†Assumes 18.3 mm Btu/ton.

Sources of data: See Appendix D.

Table 12

BIOCHEMICAL PRODUCT REVENUE REQUIREMENTS DEVELOPED BY SRI[*]

Mission	Route	Conversion Process[‡]	Feedstock Dry Tons/Day	Base Case	Revenue Required ($/MM Btu)[†] Base Case, No Feedstock Cost	Revenue Required ($/MM Btu)[†] Most Optimistic[§]
8	Cattle manure to SNG--					
	100,000 head environmental feedlot	AD	450	$ 7.00	$ 5.90	$ 2.80
	10,000 head environmental feedlot	AD	45	14.40	13.40	7.50
7	Cattle manure to IBG	AD	450	4.90	3.90	4.40
9	Wheat straw to IBG (40% conversion)	AD	3000	22.10	11.10	9.00
16	Corn stover to ethanol (Purdue Process)	F(A)	1562	25.55	18.35	16.20
11	Sugar cane to ethanol	F	2756	27.00	11.30	20.00
10	Wheat straw to ethanol	F(E)	3270	52.60	43.50	29.20[**]
13	Kelp to SNG	AD	3000	21.00	3.00	12.00
14	Algae to ethanol	F(A)	1126	25.90	11.00	17.40

[*]See Appendix C and Volume V.

[†]1977 dollars in year 1985. Data source: SRI Detailed Analysis-Regulated Utility Financing.

[‡]Key: AD = anaerobic digestion; F = fermentation (E = enzyuratic hydrolysis, A = Acid hydrolysis).

[§]Assumes refeed by-product values and high product yields.

[**]Does not assume continuous fermentation process which could reduce the optimistic estimates.

Table 13

THERMOCHEMICAL PRODUCT REVENUE REQUIREMENTS DEVELOPED BY SRI*
(Feedstock = 3000 Dry Tons/Day)

Mission	Route	Conversion† Process	Base Case	(Revenue Required ($/MM Btu)‡ Base Case, No Feedstock Cost	Optimistic§
	Wood to:				
5	Steam	DC	$ 3.00	$ 1.70	$ 2.70
15	Steam and electricity††	DC	3.40	2.10	3.10
12	Oil and char by-product	P	4.50**	1.40	4.00**
	Total product basis	P	2.70	1.30	2.50
17	Intermediate Btu gas				
	High Pressure (280 psia)	P	4.00	2.60	3.60
	Low Pressure (25 psia)	P	3.40	2.10	3.00
1	Heavy fuel oil (low sulfur)	CL	5.40	3.50	4.80
4	SNG	GOB	6.50	4.80	5.60
2	Methanol	GOB	7.80	6.00	6.70
3	Ammonia ($/short ton)	GOB	164.00/ton	126.00/ton	141.00/ton
6	Electricity	DC	16.40(5.6¢/kWh)	11.60(4.0¢/kWh)	14.40(4.9¢/kWh)

*See Appendix C and Volume IV.

†Key: CL = catalytic liquefaction; GOB = gasification--oxygen blown; DC = direct combustion; P = pyrolysis.

‡1977 dollars in year 1985. Data source, SRI Detailed Analysis.

§Capital cost = 80% of base case. Values assigned to by-products are discussed in Appendix C and Volume IV.

**Assumes char at 1.25 per million Btu.

††Revenue required is on a total product basis.

The base case estimates are shown with and without feedstock cost to indicate its influence in each case. For some missions, feedstock represents 85 percent of the final product cost (see kelp to SNG mission), and for others it is a minor factor constituting only 20 percent of the total (see cattle manure to IBG). Only the base case data were used in the market penetration analysis. In general, feedstock cost represents about 40 percent of total product cost.

The optimistic estimates reflect high by-product values and product yields for biochemical facility missions and a 20 percent reduction in base case capital costs for the thermochemical missions. Table 14 shows additional examples of biomass product cost data developed by others and used as inputs in the market penetration analysis.

Thermal efficiencies for the conversion processes are a model input and are important in determining the potential impact of the biomass resource on U.S. energy supplies. Conversion thermal efficiency is defined as: The higher heating value of the product divided by higher heating value of the feedstock plus the energy equivalent of purchased electricity* (if any). The specific thermal efficiencies used in the market penetration analysis are shown in Table 15 and Appendix C of Volume II of this series. In practice, thermal efficiencies are expected to vary significantly depending on several factors, including (1) feedstock composition; (2) assumptions concerning conversion plant design; and (3) the amount of electricity, steam, gas, and other energy inputs required.

The thermal efficiences used in the 15 missions analyzed in detail during this study are shown in Table 15. Since most biomass conversion processes were not well developed, they were analyzed on the basis of pilot studies and in some cases experimental data. This lack of specific data added to the uncertainty concerning efficiencies. Therefore, for studies of this type, a range of thermal efficiencies can be expected, depending on feedstock composition, process design, process energy inputs required, and uncertainty regarding data reliability. The range of thermal efficiencies possible for each biomass process and product is shown in Table 15.

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*Included at 3413 Btu/kWh.

Table 14

SUMMARY OF BIOMASS PRODUCT COST INPUTS TO THE MARKET PENETRATION MODEL OBTAINED FROM OTHERS*
(1977 Dollars)

Mission	Product	Process	Feedstock	Data Validity Code†	Specific Capital Cost‡ ($/Million Btu)	Thermal Efficiency (percent)	Operating Cost* ($/Million Btu)	Approximate Revenue Required§ ($/Million Btu)
26	SNG	Direct gasification (oxygen blown)	High moisture plants	II	$14.47	63.5	$ 1.49	$ 5.26
27	SNG	Direct gasification (oxygen blown or split flow)	Low moisture plants	III	15.22	61.0	1.40	5.89
28	SNG	Pyrolysis (maximum gas yield)	Woody plants	I	6.18	60.0	1.60	4.21
29	SNG	Pyrolysis (maximum gas yield)	Low moisture plants	I	6.07	60.0	1.54	5.24
30	SNG	Anaerobic digestion	High moisture plants	II	12.20	45.0	1.18	7.76
31	Ammonia	Direct gasification (air blown)	Woody plants	II	10.02	63.5	2.32	5.41
32	Ammonia	Direct gasification (oxygen blown)	High moisture plants	II	18.60	63.2	1.76	6.17
33	IBG	Direct gasification (oxygen blown)	Woody plants	II	9.84	73.0	1.48	4.35
34	IBG	Direct gasification (oxygen blown)	High moisture plants	II	10.53	75.0	1.54	4.47
35	IBG	Direct gasification (oxygen blown or split flow)	Low moisture plants	II	8.75	75.0	1.03	4.59
36	IBG	Direct gasification (air blown staged)	Low moisture plants	III	5.59	61.0	1.77	5.36
37	IBG	Pyrolysis (maximum gas uield)	Woody plants	I	5.92	50.0	1.50	4.40
38	IBG	Pyrolysis (maximum gas yield)	Low moisture plants	IV	4.77	51.0	1.45	5.45
39	IBG	Anaerobic digestion	High moisture plants	II	8.58	50.0	1.22	7.18
40	IBG	Anaerobic digestion	Marine crops	II	8.55	50.0	1.50	10.80
41	LBG	Direct gasification (air blown)	Woody plants	II	5.92	57.0	1.85	4.50
42	LBG	Direct gasification (air blown)	High moisture plants	II	6.05	60.0	1.84	6.64
43	Oil	Pyrolysis (maximum liquid yield)	Woody plants	II	5.92	35.0	1.30	5.06
44	Oil	Catalytic liquefaction	Low moisture plants	II	9.69	48.0	2.40	7.35
45	Oil	Pyrolysis (maximum gas yield)	Low moisture plants	I	5.37	25.0	1.29	8.79
46	Methanol	Direct gasification (oxygen blown or split flow)	Low moisture plants	III	29.18	38.0	3.42	12.25

Table 14 (Concluded)

Mission	Product	Process	Feedstock	Data Validity Code[†]	Specific Capital Cost[‡] ($/Million Btu)	Thermal Efficiency (percent)	Operating Cost[*] ($/Million Btu)	Approximate Revenue Required[§] ($/Million Btu)
47	Methanol	Direct gasification (oxygen blown)	High moisture plants	II	$34.99	38.0	$ 3.79	$15.24
48	Methanol	Pyrolysis (maximum gas yield)	Low moisture plants	IV	9.26	46.5	2.18	7.18
49	Methanol	Pyrolysis (maximum gas yield)	Woody plants	I	12.32	47.0	2.14	6.14
50	Ethyl alcohol	Fermentation	Manure	II	24.69	22.0	56.39	61.64
51	Fischer-Tropsch liquids	Pyrolysis (maximum gas yield)	Low moisture plants	II	7.89	35.0	1.30	7.27
52	Fischer-Tropsch liquids	Pyrolysis (maximum gas yield)	Woody plants	II	8.22	34.0	1.37	5.56
53	Char	Pyrolysis (maximum gas yield)	Woody plants	III	3.40	32.0	0.41	4.06

*No detailed SRI process analysis--See Volume II and Appendix C in that volume. Assumes year 2000 capital and operations cost and thermal efficiencies.

†Data Validity Code (see Appendix B of Volume II for Data Sources):
- I = By-product credit not specified
- II = Cost data validity unknown
- III = Cost data appear valid and complete
- IV = Feedstock type and by-product credits not specified.

‡Specific capital cost = total capital investment ÷ Annual MM Btu in primary product (year 2000). Total capital investment = plant facilities plus land plus start up expenses, etc. (see Appendix Table B-1).

§Approximate numbers--actual revenue requirements will vary by region, depending on feedstock type, cost and other factors. These totals reflect feedstock costs defined in the Appendix to Volume IV, Economic and Design Bases of Conversion Plants.

Table 15

CALCULATED AND PROBABLE RANGE OF THERMAL EFFICIENCIES

Feedstock*	Product	Process	Thermal Efficiencies: SRI Design Value	Thermal Efficiencies: Probable Range†
Wood	SNG	Gasification--oxygen blown	63	60 to 70
Manure	SNG	Anaerobic digestion	~30	24 to 36
Wood	Methanol	Gasification--oxygen blown	58	52 to 65
Aquatic Biomass	Ethanol	Fermentation	~24	15 to 35
Wood	Ammonia	Gasification--oxygen blown	49	45 to 55
Wood	Steam	Direct combustion	77	70 to 85
Wood	Electricity	Direct combustion	21	20 to 25
Wood	Oil and charcoal	Pyrolysis	74	70 to 80
Wood	IBG--(25 psia)§	Gasification--oxygen blown	80	75 to 85
Wood	IBG--(280 psia)§	Gasification--oxygen blown	71	64 to 78
Wheat, Straw	IBG	Anaerobic digestion	~19	12 to 32‡
Manure	IBG	Anaerobic digestion	33	26 to 40

*Wood moisture content = 50 percent (wet basis).

†Range of probable values for the process, assuming reasonable feedstock type, moisture content, and chemical composition.

‡30 to 60 percent conversion of organic solids.

§Gas delivery pressure.

VII ESTIMATED MARKET PENETRATION

The results of the market penetration analysis using the inputs described in Section V and both the base case and optimistic feedstock availability scenarios are shown in Tables 16 through 19. These tables reflect the market penetration model results, using the SRI generated biomass product costs (25 missions) or the biomass product costs generated by others (28 missions). Tables 16 and 17 reflect the results of the SRI generated biomass product costs and Tables 18 and 19 reflect the model results from the input of data on all 53 missions.

As might be expected, the results indicate a heavy penetration (capture of market demand) by currently commercial products and processes. Of the 53 missions, 17 showed penetration in 2020 with the capture of 0.01 quads of energy market demand or more. Fermentation and catalytic liquefaction missions did not penetrate because of high biomass conversion process operating and capital costs.

To determine the influence of lower capital costs, the model was run with optimistic investment costs (assuming either costs at 80 percent of the base case or high by-product values and product yields). This reduction resulted in an overall 5 percent increase in quad penetration in 2020, but the catalytic liquefaction and fermentation missions still did not penetrate.

Tables 20 and 21 show feedstock demand by type of feedstock for the base and optimistic cases. Of the 11.9 quads of feedstock (792 million dry tons) available in 2020 at $30 per dry ton (optimistic scenario), the model showed a demand for 13.6 quads. This indicates an average competitive market price slightly higher than $30 per dry ton, possibly $33 per dry ton, or about $2.20 per million Btu.

Table 16

MARKET PENETRATION BY PRODUCT TYPE--
SRI MISSIONS ONLY
(Regulated Utility Economics)

Product	Quad Btu Biomass Product Demand (Excludes Existing)					
	1985		2000		2020	
	Base Case*	Optimistic Scenario*	Base Case	Optimistic Scenario	Base Case	Optimistic Scenario
SNG	--	--	0.01	0.01	0.19	0.24
IBG	--	--	0.07	0.07	0.15	0.16
Methanol/ethanol	--	--	--	--	--	--
Ammonia	0.02	0.02	0.41	0.41	0.56	0.58
Steam/electricity cogeneration	0.34	0.56	1.32	2.77	2.40	6.04
Process steam	0.25	0.45	0.66	1.36	0.97	2.16
Electricity		--			--	--
Fuel oils (pyrolytic)	0.03	0.04	0.58	0.87	0.48	0.82
Total	0.64	1.07	3.05	5.49	4.75	10.00

*Refers to the base case or optimistic feedstock scenarios (see Volume III).

Table 17

MARKET PENETRATION BY CONVERSION PROCESS--
SRI MISSIONS ONLY
(Regulated Utility Economics)

Process	Quad Btu of Biomass Product Demand (Excludes Existing) 1985 Base Case*	1985 Optimistic Scenario*	2000 Base Case	2000 Optimistic Scenario	2020 Base Case	2020 Optimistic Scenario
Gasification, air blown	--	--	--	--	--	--
Gasification, oxygen blown	0.02	0.02	0.41	0.41	0.57	0.62
Pyrolysis, maximum liquids	0.03	0.04	0.58	0.87	0.48	0.82
Direct combustion	0.59	1.01	1.98	4.13	3.37	8.20
Catalytic liquefaction	--	--	--	--	--	--
Anaerobic digestion	--	--	0.08	0.08	0.33	0.36
Fermentation	--	--	--	--	--	--
Total	0.64	1.07	3.05	5.49	4.75	10.00

*Refers to the base case or optimistic feedstock scenarios (see Final Report, Volume III).

Table 18

MARKET PENETRATION BY PRODUCT TYPE--
SRI MISSIONS PLUS DATA OBTAINED FROM OTHERS
(Regulated Utility Economics)

Product	Quad Btu of Biomass Product Demand (Excludes Existing)					
	1985		2000		2020	
	Base Case*	Optimistic Scenario*	Base Case	Optimistic Scenario	Base Case	Optimistic Scenario
SNG	--	--	0.03	0.04	0.11	0.20
IBG	--	--	0.09	0.15	0.16	0.20
LBG	--	--	0.01	0.02	0.02	0.05
Methanol/ethanol	--	--	--	--	--	--
Ammonia	0.02	0.13	0.40	0.41	0.56	0.58
Steam with electricity by-product	0.29	0.63	1.55	2.82	2.88	6.17
Process steam	0.39	0.47	0.77	1.35	1.13	2.22
Electricity		--		--		--
Fuel oils (pyrolytic)	0.04	0.04	0.61	0.87	0.53	0.83
Total	0.74	1.27	3.46	5.66	5.39	10.25

*Refers to the base case or optimistic feedstock scenarios (see Volume III).

Table 19

MARKET PENETRATION BY CONVERSION PROCESS
SRI MISSIONS PLUS DATA OBTAINED FROM OTHERS
(Regulated Utility Economics)

Process	Quad Btu of Biomass Product Demand (Excludes Existing)					
	1985		2000		2020	
	Base Case*	Optimistic Scenario*	Base Case	Optimistic Scenario	Base Case	Optimistic Scenario
Gasification, air blown	--	0.11	0.06	0.13	0.08	0.16
Gasification, oxygen blown	0.02	0.02	0.37	0.39	0.54	0.56
Pyrolysis, maximum liquids	0.04	0.04	0.61	0.87	0.53	0.83
Pyrolysis, maximum gas	--	--	0.01	0.01	0.05	0.11
Direct combustion	0.68	1.10	2.32	4.17	4.01	8.39
Catalytic liquefaction	--	--	--	--	--	--
Anaerobic digestion	--	--	0.09	0.09	0.18	0.20
Fermentation	--	--	--	--	--	--
Total	0.74	1.27	3.46	5.66	5.39	10.25

*Refers to the base case or optimistic feedstock scenarios (see Final Report, Volume III).

Table 20

FEEDSTOCK DEMAND BY TYPE OF FEEDSTOCK--BASE CASE SCENARIO
(Quad Btu)

Type of Feedstock	SRI Missions Only			All Missions		
	1985	2000	2020	1985	2000	2020
Low moisture	0.5	2.3	3.6	0.5	2.2	3.5
High moisture	0	0.2	0.4	0	0.6	0.9
Woody	0.4	1.8	2.2	0.4	1.8	2.4
Manure	0	0.2	0.5	0	0.2	0.5
Aquatic	0	0	0	0	0	0
Total	0.9	4.5	6.7	0.9	4.8	7.3

Table 21

FEEDSTOCK DEMAND BY TYPE OF FEEDSTOCK--OPTIMISTIC SCENARIO
(Quad Btu)

Type of Feedstock	SRI Missions Only			All Missions		
	1985	2000	2020	1985	2000	2020
Low moisture	0.6	3.1	5.3	0.7	2.9	5.1
High moisure	0	0.2	0.5	0	0.6	1.0
Woody	0.9	4.2	7.1	0.8	3.9	7.0
Manure	0	0.2	0.5	0	0.2	0.5
Aquatic	0	0	0	0	0	0
Total	1.5	7.7	13.4	1.5	7.6	13.6

VIII MISSION RANKING

SRI assumed that a large development facility would be desirable to demonstrate the feasibility of each high potential mission and to assure the achievement of future commercial conversion operations. Table 22 shows a figure of merit (cost-benefit ratio), calculated by dividing the program funding requirement for each mission (based on the cost of a large development facility operating for five years) by the 2020 annual quad penetration. The results of this analysis provided the ranking of missions shown in Table 23.

As indicated previously, the total overall market penetration did not vary significantly when the model input data prepared by SRI were supplemented by input data prepared by others and normalized by SRI. Using the optimistic feedstock scenario, the total biomass product demand in year 2020 increased from 10.00 to 10.25 quad Btu with the addition of input data prepared by others on 28 missions. Operation of the model with uniformly optimistic investment costs increased the market penetration for biomass fuel but did not change the relative ranking of individual missions. It is possible that the relative rankings of individual missions could change with the addition of new missions or with changes in mission process thermal efficiencies, operating costs, capital investment costs, or expected commercialization dates. However, these changes would have to be large in size and affect several missions before a significant change in total quad penetration levels could be expected.

The model outputs and market demand levels are extremely sensitive to feedstock scenario assumptions* as indicated by the doubling in product demand with a change from base case to optimistic scenario (see Table 24). However, separating SRI generated mission input data from data generated by others resulted in only a slight change in model results (an increase in biomass fuel product penetration from 10.00 to 10.25 quads in the year 2020 and a change in total feedstock demand from 13.4 to 13.6 quads of biomass). As indicated by the ratio of fuel product demand to feedstock demand, the overall conversion efficiency percentage is about 75 percent, reflecting the strong influence of direct combustion mission penetration.

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*As well as other factors such as end use demand projections and foreign oil prices.

Table 22

RESEARCH AND DEVELOPMENT COST-BENEFIT RATIO CALCULATIONS
(Missions Penetrating Market in Year 2020)

Mission*	Feedstock	Product	Commercialization Date†	Estimated Development Program Funding Required (millions of dollars): Feedstock Preparation and Production	Pilot Plant	Large Demo Plant‡	Demo Operation (5 years)	Total Dollars	Total Btu Quads 2020	Development Cost-Benefit Ratio ($/Million Btu)
Direct gasification--oxygen blown										
26	High moisture	SNG	1985	$5	--	$170	$ 96	$266	0.05	$ 5.32
32	High moisture	Ammonia	1985	5	--	86	59	150	0.47	0.32
34	High moisture	IBG	1985	5	--	151	113	264	0.03	8.80
35	Low moisture	IBG	1985	5	--	116	15	131	0.01	13.10
Subtotal								$811	0.56	$ 1.45
Direct gasification--air blown/staged										
31	Wood	Ammonia	1985	--	--	135	170	$305	0.11	$ 2.77
42	High moisture	LBG	1985	5	--	65	107	172	0.15	1.15
Subtotal								$477	0.26	$ 1.83
Pyrolysis--maximum gas yield										
28	Wood	SNG	1985	--	--	78	111	$189	0.11	$ 1.72
Pyrolysis--maximum liquids										
18	Wood	Oil and Char	1985	--	--	61	52	113	0.68	0.17
19	Low moisture	Oil and Char	1985	5	--	61	52	113	0.15	0.75
Subtotal								$226	0.84	$ 0.27
Direct combustion			(earlier than)							
9	Wood	Steam	1975	--	--	94	59	$153	1.21	$ 0.13
10	Low moisture	Steam	1975	5	--	94	59	153	1.01	0.15
24	Wood	Steam/electric	1975	--	--	109	60	169	3.36	0.05
25	Low moisture	Steam/electric	1975	5	--	109	60	169	2.81	0.06
Subtotal								$644	8.39	$ 0.08
Anaerobic digestion										
13	Manure	IBG	1985	--	--	11	10	$ 21	0.15	$ 0.14
14	Manure	SNG	1985	--	--	14	13	27	0.02	1.35
30	High moisture	SNG	1985	--	--	97	50	147	0.02	7.35
39	High moisture	IBG	1980	5	$5	74	58	132	0.01	13.20
Subtotal								$327	0.20	$ 1.64

*Missions number 1 through 25 were evaluated by SRI.

†Date estimated to reflect initial mission technical and economic feasibility for modeling purposes.

‡Demonstration plant costs assume largest design practicable--500 to 3,000 dry tons per day of feedstock. Source of cost data--Appendix C.

Table 23

MISSION RANKING

Product	Feedstock	Process	Evaluated By
Highest ranking (mission with lowest cost-benefit ratios)			
Process steam with electrical by-product	Wood or low moisture plants	Combustion	SRI
Steam	Wood or low moisture plants	Combustion	SRI
IBG	Manure	Anaerobic digestion	SRI
Oil and charcoal	Wood or low moisture plants	Pyrolysis (maximum liquid yields)	SRI
Other missions showing penetration (higher cost/benefit ratios)			
Ammonia	Wood or high moisture	Gasification staged air/or oxygen blown	SRI
SNG	Manure	Anaerobic digestion	SRI
SNG	High moisture	Anaerobic digestion	SRI
IBG	Low moisture	Gasification (oxygen blown)	SRI
LBG	High moisture	Gasification air blown	Others
SNG	Wood	Pyrolysis (maximum gas yield)	Others
SNG	High moisture	Gasification (oxygen blown)	Others
IBG	High moisture	Gasification (oxygen blown)	Others
IBG	High moisture	Anaerobic digestion	Others

Table 24

FEEDSTOCK AVAILABILITY AND DEMAND IN YEAR 2020

Feedstock Availability (Model Input)		
Market	Millions of Dry Tons	
Price ($/ton)	Base Case	Optimistic Case
$10	200	200
20	326	390
30	484	792
40	621	1715
50	718	2783

Biomass Feedstock Demand (Model Results)		
	Quad Btu	
Type	Base Case	Optimistic Case
Low moisture	3.5	5.1
High moisture	0.9	1.0
Woody	2.4	7.0
Manure	0.5	0.5
Aquatic	0	0
Total	7.3	13.6

Biomass Fuel Product Demand (Model Results)		
	Quad Btu	
Product	Base Case	Optimistic Case
Gases (SNG, IBG, LBG)	0.29	0.45
Ammonia	0.56	0.58
Steam and electricity	3.91	8.39
Fuel oil (L.S.)	0.53	0.83
Total	5.39	10.25

The current program of the FFBSB is directed at specific RD&D goals in both the biomass production and conversion areas.[2] In both areas, processes, techniques, and technologies exist in which there is near-term potential to accelerate commercialization. Therefore, it is likely that increased program emphasis as well as an expansion of the current RD&D program would result in increased energy production over a relatively short time period. Unless the program effort is significantly expanded, less effort should be placed on options with low market penetration potential and distant commercialization dates.

Based only on market penetration projections, the missions that appear to have the greatest near-term commercialization potential include:

- Combustion of wood and low moisture plants to produce steam and cogenerated steam and electricity.
- Gasification of wood and low moisture plants to produce IBG, SNG, LBG, and ammonia.
- Pyrolysis of wood and low moisture plants to produce SNG, fuel oil and char.
- Anaerobic digestion of manure and high moisture terrestrial crops to produce IBG and SNG.

Increased RD&D emphasis and federal commercialization incentives appear to be justified for all of the above missions. However, only limited additional RD&D support is probably necessary for the direct combustion mission because its commercialization potential is firmly established.

Missions that appear to offer minor future contributions are marine crop production, catalytic liquefaction, and fermentation to produce ethanol.

APPENDICES

Appendix A

REFERENCES

1. J. G. Witwer, F. A. Schooley et al., "A Comparative Evaluation of Solar Alternatives Implications for Federal RD&D," prepared by SRI for U.S. Dept. of Energy Solar Working Group, January and February 1978.

2. "Fuels from Biomass Program Summary," DOE, Division of Solar Energy, Washington, D.C., DOE/ET-0022/1 (January 1978).

Appendix B

TYPICAL TABULATED OUTPUT FOR THE SRI FACILITY ECONOMIC MODEL

The following pages present a computer output for the Energy Center Facility Economic Model for a typical study mission.

Example Shown:

SNG from Wood

Assumptions:

- 3,000 dry ton/day (6,000 wet)
- Feedstock price, $1.00/MMBtu
- Regulated utility economics
- Debt to equity ratio = 65/35
- Operating capacity = 90%

Table B-1

TYPICAL ECONOMIC MODEL OUTPUT INVESTMENT COSTS

6000 Tons/Day Wood to SNG (3000 Dry tons)

Service Factor, Hours/Year 7884. Feedstock Price, $/Unit 1.00

	Million $	
Plant facilities investment		
Year		
1	$ 38.98	
2	97.44	
3	58.46	
Total plant facilities	$194.88	
Total capital investment		
Plant facilities	194.88	
Land	0.40	
Interest during construction	28.57	
Organization and startup expenses	9.74	
Working capital requirements	4.92	
Total capital investment	$238.51	
	Utility	Nonregulated
Depreciable investment	233.19	194.88
Debt capital	155.03	0.00
Equity capital	83.48	209.94
Average equity capital	41.74	
Regulated utility rate base	238.51	

Table B-2

TYPICAL ECONOMIC MODEL OUTPUT
ANNUAL OPERATING COSTS

6000 Tons/Day Wood to SNG (3000 Dry tons)

Service Factor, Hours/Year 7884. Feedstock Price, $/Unit 1.00

	Millions of Dollars per Year	Cents/MMBtu
Raw materials		
Wood	$18.84	$158.8
Water	1.00	8.4
Catalysts and chemicals	1.91	16.1
Maintenance materials	3.90	32.8
Total raw materials	$25.65	$216.1
Labor		
Operating labor (25.0 men/shift, $8.00/hr)	1.75	14.8
Operating labor supervision	0.26	2.2
Maintenance labor	3.90	32.8
Administrative and support labor	1.18	10.0
Payroll burden	2.48	20.9
Total labor	$ 9.58	$ 80.7
Purchased electric power (2.50 cents/kWh)	0.00	0.0
Fixed costs		
General administrative expenses	3.90	32.8
Property taxes and insurance	4.87	41.1
Plant depreciation (20 yr life)	11.66	98.2
Total fixed costs	$20.43	$172.1
Subtotal annual operating costs, excluding raw materials	35.82	301.8
Total annual operating costs	55.66	469.0

Appendix C

SUMMARY OF COST SENSITIVITY DATA ON 15 MISSIONS

This appendix contains the results of the SRI cost sensitivity analysis for the following missions:

<u>Mission</u>	
1	Wood to oil
2	Wood to methanol
3	Wood to ammonia
4	SNG from wood
5	Steam from wood
6	Electricity and steam from wood
7	IBG from cattle manure
8	SNG from cattle manure
9	Wheat straw to IBG
10	Wheat straw to ethanol
11	High sugar content plant to ethanol
12	Wood to oil via pyrolysis (maximum liquid yield)
13	Kelp to SNG via anaerobic digestion
14	Kelp to alcohol via fermentation
15	Cogeneration of electricity and steam from wood

See Addendum-Volume #VI for a description of Missions 17 and 18

MISSION 1--SELECTED SUMMARY DATA
WOOD TO OIL VIA CATALYTIC LIQUEFACTION

	Base Case	Sensitivity To: Feedstock Price			Operating Percent		Capital Investment		Project Life
Product									
Output/day Bbls of oil	5,268	5,268	5,268	5,268	5,268	5,268	5,268	5,268	5,268
Equivalent Btu/day (10^9)	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6
Feedstock									
ODT per day*	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu/day (10^9)	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6
Cost (dollars/million Btu)	$1.0	2.0	1.5	0	1.0	1.0	1.0	1.0	1.0
Total Capital Investment							-20%	+30%	
Millions of dollars†	$144.9	$146.5	$145.7	$143.4	$144.7	$144.5	$116.5	$189.6	$144.9
Dollars/million Btu‡	$1.95	$1.98	$1.97	$1.93	$2.22	$2.52	$1.57	$2.52	$1.72
Annual Cost of Feedstock									
Millions of dollars	$18.8	$37.7	$28.3	0	$16.8	$14.7	$18.8	$18.8	$18.8
Dollars/million Btu	$1.88	$3.76	$2.82	0	$1.87	$1.87	$1.88	$1.88	$1.88
Annual Operating Cost§									
Millions of dollars	$15.5	$15.5	$15.5	$15.5	$15.3	$15.1	$13.2	$18.9	$15.5
Dollars/million Btu	$1.54	$1.54	$1.54	$1.54	$1.70	$1.93	$1.31	$1.88	$1.54
Operating percent	90%	90%	90%	90%	80%	70%	90%	90%	90%
Revenue Requirements†									
Dollars/Bbl of oil	$31.2	$42.2	$36.7	$20.1	$33.6	$36.6	$27.6	$36.5	$29.8
Regulated utility, dollars/million Btu**	$5.37	$7.28	$6.33	$3.47	$5.79	$6.32	$4.76	$6.29	$5.14
Plant Life (Years)	20	20	20	20	20	20	20	20	30

*Assumes a 50% moisture content feedstock and 19.2 million Btu/dry ton - process efficiency = 53%.

†Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and 9% return on debt (65% debt and 35% equity). Income tax = 52%.

‡Capital component of product cost.

§Excludes feedstock cost and plant depreciation.

**Assumes 5.8×10^6 Btu/barrel.

MISSION 2--SELECTED SUMMARY DATA

WOOD TO METHANOL VIA GASIFICATION (OXYGEN BLOWN REACTOR)

	Base Case			Sensitivity To: Feedstock Price			Operating Percent		Capital Investment		Project Life
Product											
Gallons of methanol/day* (10^3)	100	200	600	600	600	600	600	600	600	600	600
Btu/day (10^9)	5.5	10.06	33.2	33.2	33.2	33.2	33.2	33.2	33.2	33.2	33.2
Feedstock											
ODT per day†	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu/day (10^9)	9.6	19.2	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6
Cost (dollars/million Btu)	$1.0	$1.0	$1.0	$2.0	$1.5	0	$1.0	$1.0	$1.0	$1.0	$1.0
Total Capital Investment									-20%	+30%	
Millions of dollars‡	$58.13	$100.76	$268.71	$270.26	$269.48	$267.16	$268.50	$268.28	$215.61	$348.36	$268.71
Dollars/million Btu§	$4.33	$3.51	$3.35	$3.37	$3.36	$3.32	$3.76	$4.31	$2.69	$4.34	$2.95
Annual Cost of Feedstock**											
Millions of dollars	$3.14	$6.28	$18.84	$37.69	$28.26	0	$16.75	$14.66	$18.84	$18.84	$18.84
Dollars/million Btu	$1.73	$1.73	$1.73	$3.47	$2.60	0	$1.73	$1.73	$1.73	$1.73	$1.73
Annual Operating Cost											
Millions of dollars	$6.88	$8.98	$29.38	$29.38	$29.38	$29.38	$28.88	$28.38	$25.10	$35.80	$29.39
Dollars/million Btu	$3.81	$2.72	$2.69	$2.69	$2.69	$2.69	$2.98	$3.33	$2.30	$3.28	$2.69
Operating percent	90%	90%	90%	90%	90%	90%	80%	70%	90%	90%	90%
Revenue Requirements											
Dollars/million Btu, regulated utility	$9.87	$7.96	$7.77	$9.53	$8.65	$6.01	$8.47	$9.37	$6.72	$9.35	$7.37
Plant Life (Years)	20	20	20	20	20	20	20	20	20	20	30

*Assumes 55,610 Btu/gallon.

†Assumes a 50% moisture content feedstock and 19.2 MMBtu/dry ton - process efficiency = 58%.

‡Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and a 9% return on debt (65% debt and 35% equity). Income tax = 52%.

§Capital component of product cost.

**Excludes feedstock cost and plant depreciation.

MISSION 3--SELECTED SUMMARY DATA

AMMONIA FROM WOOD VIA GASIFICATION WITH AN OXYGEN BLOWN REACTOR

	Base Case			Sensitivity To: Feedstock Price			Operating Percent		Capital Investment		Project Life
Product											
Tons of ammonia/day	250	500	1,542	1,542	1,542	1,542	1,542	1,542	1,542	1,542	1,542
Btu/day (10^9)*	4.6	9.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
Feedstock											
ODT per day	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu/day (10^9)	$9.6	$19.1	$57.3	$57.3	$57.3	$57.3	$57.3	$57.3	$57.3	$57.3	$57.3
Cost (dollars/million Btu)	1.00	1.00	1.00	2.00	1.50	0	1.00	1.00	1.00	1.00	1.00
Total Capital Investment									- 20%	+ 30%	
Millions of dollars	$65.0	$110.1	$267.3	$268.9	$268.0	$265.7	$267.1	$266.9	$214.4	$346.5	$267.3
Dollars/million Btu†	$6.95	$5.96	$4.71	$4.74	$4.73	$4.68	$5.52	$6.57	$3.86	$6.00	$4.24
Dollars/ton	$127.40	$109.02	$86.24	$86.75	$86.49	$85.73	$101.17	$120.38	$70.53	$109.77	$77.64
Annual Cost of Feedstock											
Millions of dollars	$3.1	$6.3	$18.8	$37.7	$28.3	0	$16.8	$14.7	$18.8	$18.8	$18.8
Dollars/million Btu	$2.09	$2.09	$2.03	$4.06	$3.04	0	$2.03	$2.03	$2.03	$2.03	$2.03
Dollars/ton	$38.27	$38.27	$37.14	$74.28	$55.71	0	$37.14	$37.14	$37.14	$37.14	$37.14
Annual Operating Cost‡											
Millions of dollars	$5.7	$9.6	$20.6	$20.6	$20.6	$20.6	$20.6	$20.6	$17.2	$25.7	$20.6
Dollars/million Btu	$3.78	$3.18	$2.22	$2.22	$2.22	$2.22	$2.22	$2.22	$1.85	$2.76	$2.22
Dollars/ton	$69.08	$58.18	$40.55	$40.55	$40.55	$40.55	$40.55	$40.55	$33.88	$50.57	$40.55
Operating percent	90%	90%	90%	90%	90%	90%	80%	70%	90%	90%	90%
Revenue Requirement											
Regulated utility:§											
Dollars/million Btu	$12.82	$11.23	$8.96	$11.02	$9.99	$6.90	$9.77	$10.82	$7.74	$10.79	$8.49
Dollars/ton	$235	$205	$164	$202	$183	$126	$179	$198	$142	$197	$155
DCF											
Dollars/million Btu	$18.93	$16.39	$13.60	$15.67	$14.64	$11.52	$15.00	$16.79	$11.46	$16.81	$13.60
Dollars/ton	$346	$300	$249	$287	$268	$211	$274	$307	$210	$308	$249
Plant Life (years)	20	20	20	20	20	20	20	20	20	20	30

*Assumes 18.3 million Btu/ton - process efficiency = 49%.

†Capital component of product cost.

‡Excludes feedstock cost and plant depreciation.

§Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and a 9% rate of return on debt (65% debt and 35% equity - income tax = 52%.

MISSION 4--SELECTED SUMMARY DATA

SNG PRODUCTION FROM WOOD VIA GASIFICATION (OXYGEN BLOWN REACTOR)

	Base Cases			Sensitivity To: 30 Year Facility Life	Sensitivity To: Plant Investment Cost		Sensitivity To: Feedstock Cost			Sensitivity To: Operating % of Capacity	
Product											
Output per day (SCF) 10^6	6.4	12.7	38.2	38.2	38.2	38.2	38.2	38.2	38.2	38.2	38.2
Equivalent Btu (10^9)	6.0	12.0	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1
Feedstock											
ODT per day*	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu per day* (10^9)	9.6	19.2	57.4	57.4	57.4	57.4	57.4	57.4	57.4	57.4	57.4
Cost (Dollars per million Btu)	$1.00	$1.00	$1.00	$1.00	$1.00	$1.00	$2.00	$1.50	$1.00	$1.00	$1.00
Total Capital Investment Millions of dollars †	$50.1	$88.5	$238.5	$238.5	$191.4 - 20 %	$309.2 + 30 %	$240.1	$239.3	$237.0	$238.3	$238.1
Dollars per million Btu‡	($3.40)	($3.01)	($2.70)	($2.70)	($2.16)	($3.49)	($2.71)	($2.71)	($2.68)	($3.03)	($3.46)
Annual Cost of Feedstock Millions of dollars	$ 3.14	$ 6.3	$18.8	$18.8	$18.8	$18.8	$37.7	$28.3	-0-	$16.8	$14.7
Dollars per million Btu	($1.59)	($1.59)	($1.59)	($1.59)	($1.59)	($1.59)	($3.18)	($2.39)	---	($1.59)	($1.59)
Annual Operating Cost§ Millions of dollars	$ 5.9	$10.3	$25.2	$21.2	$21.4	$30.9	$25.2	$25.1	$25.1	$24.9	$24.5
Dollars per million Btu	($2.97)	($2.61)	($2.12)	($1.79)	($1.81)	($2.61)	($2.13)	($2.12)	($2.12)	($2.36)	($2.66)
Operating percent	90%	90%	90%	90%	90%	90%	90%	90%	90%	80%	70%
Revenue Requirements Dollars per million Btu, regulated utility	$7.96	$7.21	$6.41	$6.08	$5.56	$7.69	$8.02	$7.22	$4.80	$6.98	$7.71

*Assumes a 50% moisture content feedstock and 19.2 million Btus per dry ton - process efficiency = 63%.

†Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and a 9% return on debt (65% debt - 35% equity). Income tax = 52%. Facility Life = 20 years.

‡Capital component of product cost.

§Excludes feedstock cost and plant depreciation.

MISSION 5--SELECTED SUMMARY DATA

STEAM PRODUCTION FROM WOOD VIA DIRECT COMBUSTION

	Base Cases			Sensitivity To: Plant Investment Cost		Sensitivity To: Feedstock Cost		Sensitivity To: Operating % of Capacity	
Product - Steam									
Output day (000 lb/hr)	239	478	1,434	1,434	1,434	1,434	1,434	1,434	1,434
Equivalent Btu per day* (10^9)	7.4	14.8	44.4	44.4	44.4	44.4	44.4	44.4	44.4
Feedstock									
ODT per day†	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu/day (10^9)	9.6	19.2	57.4	57.4	57.4	57.4	57.4	57.4	57.4
Cost (dollars per million Btu)	1.00	1.00	1.00	1.00	1.00	1.50	-0-	1.00	1.00
Total Capital Investment									
Million dollars‡	$17.4	$32.3	$94.1	$76.0 - 20%	$121.3 + 30%	$94.9	$92.6	$93.7	$93.3
Dollars per million Btu§	($0.98)	($0.90)	($0.89)	($0.71)	($1.13)	($0.89)	($0.86)	($1.12)	($1.56)
Annual cost of feedstock									
Millions of dollars	$3.1	$6.3	$18.9	$18.9	$18.9	$28.3	-0-	$14.7	$10.5
Dollars per million Btu	($1.30)	($1.30)	($1.30)	($1.30)	($1.30)	($1.95)	-0-	($1.30)	($1.30)
Annual operating costs									
Millions of dollars**	$ 2.6	$ 4.5	$11.8	$10.2	$14.1	$11.8	$11.8	$11.2	$10.6
Dollars per million Btu	($1.08)	($0.95)	($0.81)	($0.72)	($0.98)	($0.82)	($0.82)	($1.00)	($1.33)
Operating percent	90%	90%	90%	90%	90%	90%	90%	70%	50%
Revenue Requirements									
Dollars per million Btu, regulated utility	$ 3.36	$3.13	$ 3.00	$ 2.73	$ 3.41	$ 3.66	$ 1.68	$ 3.42	$ 4.19

*450 lb psia - 810°F.

†Assumes a 50% moisture feedstock - 19.2 million Btu per dry ton - process efficiency = 77%. Total Annual Cost = ~ $15.38 million.

‡15% return on equity (35% of total) and 9% return on debt (65% of total) - facility life = 20 years.

§Capital component of product cost.

**Excludes feedstock cost and plant depreciation.

MISSION 6--SELECTED SUMMARY DATA

ELECTRICITY PRODUCTION FROM WOOD VIA DIRECT COMBUSTION

	Base Cases			Sensitivity To: Plant Investment Cost		Sensitivity To: Feedstock Cost		Sensitivity To: Operating % of Capacity		
Product Plant size MW =	25	50	150	150	150	150	150	150	150	150
Output per day (MWh)	600	1,200	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600
Equivalent Btu per day (10^9)	2.04	4.08	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24
Feedstock										
ODT per day[*]	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu per day (10^9)	9.6	19.2	57.4	57.4	57.4	57.4	57.4	57.4	57.4	57.4
Cost (dollars per million Btu)	$1.00	1.00	1.00	1.00	1.00	1.50	-0-	1.00	1.00	1.00
				- 20%	+ 30%					
Total Capital Investment	$30.7	$58.2	$165.6	$133.3	$214.2	$166.3	$164.3	$165.4	$165.1	$164.8
Millions of dollars[†]										
Dollars per million Btu[‡]	(7.00)	(6.61)	(6.25)	(5.03)	(8.09)	(6.29)	(6.19)	(7.15)	(9.08)	(12.44)
Annual Operating Cost	$ 2.8	$ 5.6	$16.8	$16.8	$16.8	$25.1	-0-	$14.7	$11.5	$ 8.4
Millions of dollars										
Dollars per million Btu	(4.70)	(4.70)	(4.70)	(4.70)	(4.70)	(7.05)	—	(4.70)	(4.70)	(4.70)
Annual Operating Cost	$ 4.1	$ 7.6	$19.3	$16.6	$23.4	$19.3	$19.3	$18.8	$18.1	$17.4
Millions of dollars[§]										
Dollars per million Btu	(6.93)	(6.43)	(5.43)	(4.67)	(6.57)	(5.43)	(5.43)	(6.04)	(7.39)	(9.77)
Operating percent	80%	80%	80%	80%	80%	80%	80%	70%	55%	40%
Revenue Requirements	$18.63	$17.74	$16.38	$14.40	$19.36	$18.77	$11.62	$17.89	$21.17	$26.91
Dollars per million Btu, regulated utility										

[*] Assumes a 50% moisture content feedstock - 19.2 MM Btu/dry ton - plant efficiency = 21%.

[†] 15% return on equity (35% of total) and 9% return on debt (65% of total) - facility life = 20 years.

[‡] Capital component of product cost.

[§] Excludes feedstock cost and plant depreciation.

MISSION 7--SELECTED SUMMARY DATA

IBTU GAS PRODUCTION FROM CATTLE MANURE VIA ANAEROBIC DIGESTION

				Sensitivity To						
	Base Cases			Plant Investment Cost		Feedstock Cost			Operating % of Capacity	
Product (No. of Head of Cattle)	10,000	100,000	250,000	10,000	10,000	100,000	100,000	100,000	10,000	10,000
Output per day (10^6 scf)	0.226	2.26	5.65	0.226	0.226	2.26	2.26	2.26	0.226	0.226
Equivalent Btu per day (10^6)*	226	2260	5650	226	226	2260	2260	2260	226	226
Feedstock										
ODT per day	45	450	1125	45	45	450	450	450	45	45
Btu in per day (10^6)	675	6,750	16,875	675	675	6,750	6,750	6,750	675	675
Cost (dollars per million Btu)	$0.33	$0.33	$0.33	$0.33	$0.33	$0.165	$0.67	0	$0.33	$0.33
Total Capital Investment-				- 20 %	+ 30 %					
Millions of dollars†	$1.83	$10.82	$23.91	$1.48	$2.34	$10.82	$10.82	$10.82	$1.83	$1.83
Dollars per million Btu‡	($2.68)	(1.35)	(1.13)	(2.01)	(3.60)	(1.35)	(1.35)	(1.35)	(3.19)	(3.66)
Annual Cost of Feedstock										
Millions of dollars	$0.07	$0.74	$1.86	$0.07	$0.07	$0.37	$1.48	0	$0.07	$0.06
Dollars per million Btu	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(0.50)	(1.99)	(0)	(1.06)	(1.04)
Annual Operating Cost§										
Millions of dollars	$0.39	$1.87	$3.45	$0.36	$0.44	$1.87	$1.87	$1.87	$0.38	$0.38
Dollars per million Btu	($5.26)	(2.52)	(1.86)	(4.86)	(5.94)	(2.52)	(2.52)	(2.52)	(5.75)	(6.62)
Operating percent	90%	90%	90%	90%	90%	90%	90%	90%	80%	70%
Revenue Requirements										
Dollars per million Btu, regulated utility	$ 8.94	$ 4.87	$ 3.99	$ 7.87	$ 10.54	$ 4.37	$ 5.86	$ 3.87	$ 10.00	$ 11.32

*Plant efficiency = 33.5%.

†Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and 9% return on debt (65% debt - 35% equity) facility life = 20 years.

‡Capital component of product costs.

§Excludes feedstock costs and plant depreciation.

MISSION 8--SELECTED SUMMARY DATA

SNG PRODUCTION FROM CATTLE MANURE VIA ANAEROBIC DIGESTION

				Sensitivity To						
	Base Cases			Plant Investment Cost		Feedstock Cost			Operating % of Capacity	
No of Head of Cattle	10,000	100,000	250,000	10,000	10,000	100,000	100,000	100,000	10,000	10,000
Product										
Output per day (million scf)	0.204	2.04	5.10	0.204	0.204	2.04	2.04	2.04	0.204	0.204
Equivalent Btu per day (millions)*	204	2,040	5,100	204	204	2,040	2,040	2,040	204	204
Feedstock										
ODT per day	45	450	1,125	45	45	450	450	450	45	45
Btu in per day	675	6,750	16,875	675	675	6,750	6,750	6,750	675	675
Cost (dollars per million Btu)	0.33	0.33	0.33	0.33	0.33	0.165	0.67	0	0.33	0.33
Total Capital Investment				- 20 %	+ 30 %					
Millions of dollars†	$ 2.4	$ 13.6	$ 29.3	$ 1.9	$ 3.1	$ 23.8	$ 23.8	$ 23.8	$ 2.4	$ 2.4
Dollars per million Btu‡	(4.17)	(2.11)	(2.01)	(3.28)	(5.43)	(2.26)	(2.18)	(2.05)	(4.82)	(5.51)
Annual Cost of Feedstock										
Millions of dollars	$0.07	$0.70	$1.75	$0.07	$0.07	$0.35	$1.40	0	$0.06	$0.05
Dollars per million Btu	(1.04)	(1.04)	(1.04)	(1.04)	(1.04)	(0.52)	(2.08)	-	(1.04)	(1.04)
Annual Operating Cost§										
Millions of dollars	$ 0.6	$ 2.6	$ 4.9	$ 0.6	$ 0.7	$ 2.6	$ 2.6	$ 2.6	$ 0.6	$ 0.6
Dollars per million Btu	(9.23)	(3.87)	(2.90)	(8.49)	(10.42)	(3.87)	(3.87)	(3.87)	(10.24)	(11.70)
Operating percent	90 %	90 %	90 %	90%	90 %	90 %	90 %	90 %	80 %	70 %
Revenue Requirements										
Dollars per million Btu, regulated utility	$ 14.44	$ 7.02	$ 5.95	$ 12.81	$ 16.89	$ 6.65	$ 8.13	$ 5.92	$ 16.10	$ 18.25

*Plant efficiency - 30.2%.

†Calculated to yield a 9% return on debt and 15% dcf return on equity (65% debt - 35% equity) - Plant life 20 years.

‡Capital component of product cost.

§Excludes feedstock cost and plant depreciation.

MISSION 9--SELECTED SUMMARY DATA

WHEAT STRAW TO IBTU GAS VIA ANAEROBIC DIGESTION

60% Conversion

	Base Case	Sensitivity To: Feedstock Prices			Capital Costs		Operating Percent		Base Case	Sensitivity To: Feedstock Prices		
Product												
Cubic ft gas/day (500 Btu/cu ft)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	30.0	30.0	30.0	30.0
Btu per day (10^9)*	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	15.0	15.0	15.0	15.0
Feedstock												
ODT per day	500	500	500	500	500	500	500	500	3,000	3,000	3,000	3,000
Btu per day (10^9)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	45.0	45.0	45.0	45.0
Cost per ton	$25	15	35	0	25	25	25	25	$25	15	35	0
Total Capital Investment					+30%	-20%						
Millions of dollars†	$12.6	12.6	12.6	12.6	15.7	10.6	12.6	12.6	65.7	65.6	65.7	65.5
Dollars per million Btu‡	$2.10	2.10	2.10	2.10	2.61	1.76	2.36	2.70	1.82	1.82	1.82	1.81
Annual Cost of Feedstock												
Millions of dollars	$4.1	2.5	5.8	0	4.1	4.1	3.6	3.2	$24.7	14.8	35.6	0
Dollars per million Btu	4.99	2.99	6.99	0	4.99	4.99	4.99	4.99	4.99	2.99	6.99	0
Annual Operating Cost§												
Millions of dollars	$5.1	5.1	5.1	5.1	5.4	5.0	4.7	4.3	$27.4	27.4	27.4	27.4
Dollars per million Btu	6.21	6.21	6.21	6.20	6.52	6.01	6.48	6.80	5.55	5.55	5.55	5.55
Operating percent	90%	90%	90%	90%	90%	90%	80%	70%	90%	90%	90%	90%
Revenue Requirements												
Dollars per million Btu, regulated utility	$13.30	11.30	15.30	8.30	14.12	12.76	13.83	14.49	$12.36	10.36	14.36	7.38

40% Conversion

	Base Case	Sensitivity To: Feedstock Prices			Capital Costs		Operating Percent		Base Case	Sensitivity To: Feedstock Prices		
Product												
Cubic ft gas/day (500 Btu/cu ft)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	16.8	16.8	16.8	16.8
Btu per day (10^9)*	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	8.4	8.4	8.4	8.4
Feedstock												
ODT per day	500	500	500	500	500	500	500	500	3,000	3,000	3,000	3,000
Btu per day (10^9)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	45.0	45.0	45.0	45.0
Cost per ton	$25	15	35	0	25	25	25	25	$25	15	35	0
Total Capital Investment					+30%	-20%						
Millions of dollars†	$12.6	12.6	12.6	12.6	15.7	10.6	12.6	12.6	65.68	65.63	65.74	65.55
Dollars per million Btu‡	3.74	3.74	3.74	3.74	4.56	3.05	4.23	4.84	3.25	3.25	3.25	3.25
Annual Cost of Feedstock												
Millions of dollars	$4.1	2.5	5.8	0	4.1	4.1	3.7	3.2	$24.75	14.85	34.65	.01
Dollars per million Btu	8.92	5.35	12.50	0	8.92	8.92	8.92	8.92	8.92	5.35	12.50	0
Annual Operating Cost§												
Millions of dollars	$5.1	5.1	5.1	5.1	5.4	5.0	4.7	4.3	$27.4	27.4	27.4	27.4
Dollars per million Btu	11.10	11.10	11.10	11.10	11.74	10.73	11.56	12.13	9.90	9.90	9.90	9.90
Operating percent	90%	90%	90%	90%	90%	90%	80%	70%	90%	90%	90%	90%
Revenue Requirements												
Dollars per million Btu, regulated utility	$23.76	20.19	27.34	14.84	25.22	22.79	24.71	25.89	$22.07	18.50	25.65	13.15

*Process efficiency = 34%.

†Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and a 9% return on debt (65% debt and 35% equity). Income tax = 52%.

‡Capital component of product cost.

§Excludes feedstock costs and plant depreciation.

MISSION 10--SELECTED SUMMARY DATA

WHEAT STRAW TO ETHANOL (4% SUGAR SOLUTION) VIA ENZYMATIC HYDROLYSIS AND FERMENTATION
25 MM Gallons Per Year of Ethanol
(Facility Daily Outputs: 500 Tons of Sugar and 75,768 Gallons of Ethanol)

	Base Case	Sensitivity To: Feedstock Prices			Capital Costs		Operating Percent		
Product									
Gallons of ethanol/day (000)	75.8	75.8	75.8	75.8	75.8	75.8	75.8	75.8	75.8
Btu per day (10^9)*	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Feedstock									
ODT per day-wheat straw	3,270	3,270	3,270	3,270	3,270	3,270	3,270	3,270	3,270
Btu per day (10^9)	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
Cost ($/dry ton-wheat straw)	$15.0	$9.0	0	$30.0	$15.0	$15.0	$15.0	$15.0	$15.0
Total Capital Investment†					+30%	-20%			
Sugar plant ($ 10^6)	$94.9	$94.6	$94.2	$95.5	$121.8	$76.9	$94.3	$94.6	$94.7
Ethanol plant ($ 10^6)	32.9	32.6	32.2	33.6	43.2	26.2	33.2	33.0	33.0
Total capital investment	$127.8	$127.2	$126.2	$129.1	$165.0	$103.1	$127.5	$127.5	$127.7
Dollars per million Btu‡	$8.90	$8.86	$8.79	$9.00	$11.50	$7.18	$11.38	$9.98	$9.52
Annual Cost of Feedstock									
Millions of dollars	$16.2	$9.7	0	$32.4	$16.2	$16.2	$12.5	$14.3	$15.2
Dollars per million Btu	$9.00	$5.40	0	$18.00	$9.00	$9.00	$6.94	$7.95	$8.44
Annual Operating Costs ($$10^6$)§									
Sugar plant	$54.4	$54.4	$54.4	$54.4	$56.6	$53.0	$44.2	$49.3	$51.7
Ethanol plant	8.2	8.2	8.2	8.2	8.2	8.2	6.7	7.4	7.8
Total annual operating costs	$62.6	$62.6	$62.6	$62.6	$64.8	$61.2	$50.9	$56.7	$59.5
Operating percent	90%	90%	90%	90%	90%	90%	70%	80%	84%
Dollars per million Btu	$34.70	$34.70	$34.70	$34.70	$36.00	$33.92	$36.15	$35.31	$35.29
Revenue Requirements***									
Sugar costs ($/lb), regulated utility	$0.25	$0.23	$0.20	$0.30	$0.27	$0.24	$0.27	$0.26	$0.26
Dollars per million Btu ethanol	$52.60	$48.96	$43.49	$61.70	$56.50	$50.10	$54.47	$53.24	$53.25

*Process efficiency = 11%.

†Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and a 9% return on debt (65% debt and 35% equity). Income tax = 52%.

‡Capital component of product cost - assumes 30-year plant operation.

§Excludes feedstock cost and plant depreciation.

MISSION 11--SELECTED SUMMARY DATA

SUGAR CANE MILL

High Sugar Content Plant to Ethanol (10.7% Sugar Solution) Via Fermentation
(165 Day/Year Sugar Plant - 330 Day/Year Ethanol Plant)

	Base Case	Sensitivity To: Feedstock Prices			Sensitivity To: Capital Cost	
Product						
Daily Output						
Tons of sugar	500	500	500	500	500	500
Gallons of ethanol (000)	75.8	75.8	75.8	75.8	75.8	75.8
Btu/day (10^9)*	5.5	5.5	5.5	5.5	5.5	5.5
Feedstock						
ODT per day (cane)	2756	2756	2756	2756	2756	2756
Btu/day (10^9)	41.3	41.3	41.3	41.3	41.3	41.3
Cost per dry ton	$65.0	50.0	100.	0	65.0	65.0
Total Capital Investment					+30%	-20%
Sugar plant ($ 10^6)	$49.2	$49.2	$49.2	$49.1	$63.8	$39.5
Ethanol plant ($ 10^6)	21.0	20.7	21.7	19.8	21.2	20.8
Total capital investment	$60.2	$69.9	$70.9	$68.9	$84.0	$60.3
Dollars per million Btu	$4.17	$4.84	$4.91	$4.77	$5.82	$4.18
Annual Cost of Feedstock						
Millions of dollars	$29.56	22.74	45.47	0	29.56	29.56
Dollars per million Btu	$16.28	12.53	25.05	0	16.29	16.29
Annual Operating Costs						
Sugar plant ($ 10^6)	6.8	6.8	6.8	6.8	8.4	5.8
Ethanol plant ($ 10^6)	5.0	5.0	5.0	5.0	5.0	5.0
	$11.8	11.8	11.8	11.8	13.4	10.8
Dollars per million Btu	$6.50	6.50	6.50	6.50	7.38	5.95
Revenue Requirements						
Dollars per lb of sugar	$0.13	0.11	0.18	0.04	0.14	0.12
Dollars per million Btu, regulated utility	$26.95	23.87	36.46	11.27	29.49	26.42

*Sugar plant operates 165 day/year at 1000 T/day annual average = 500T/D
Operating percent sugar plant = 45%; Ethanol plant = 90%; Process efficiency = 13.3.

MISSION 12--SELECTED SUMMARY DATA

WOOD TO OIL FOR DIRECT COMBUSTION AND CHAR VIA PYROLYSIS (MAXIMUM LIQUID YIELD)

	Base Case			Plant Size and Feedstock Price				Sensitivity To: Operating Percent	Sensitivity To: Capital Investment		Sensitivity To: Project Life
Product											
Gallons of oil/day* (10^3)	26	52	156	26	52	156	156	156	156	156	156
Char (tons/day)†	7.7	15.4	46.2	7.7	15.4	46.2	46.2	46.2	46.2	46.2	46.2
Btu/day (10^9)	151	302	918	151	302	918	918	918	918	918	918
Feedstock											
ODT per day‡	500	1,000	3,000	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu/day (10^9)	9.5	19.1	57.3	9.5	19.1	57.3	57.3	57.3	57.3	57.3	57.3
Cost (dollars/MM Btu)	$1.0	$1.0	$1.00	$2.0	$2.0	$2.0	0	$1.0	$1.0	$1.0	$1.0
Total capital investment									-20%	+30%	
Millions of dollars§	$12.3	$22.2	$61.4	$12.6	$22.7	$63.0	$59.9	$61.2	$49.7	$79.0	$61.4
Dollars/MM Btu**	$0.7	$0.7	$0.6	$0.7	$0.7	$0.7	$0.6	$0.7	$0.5	$0.7	$0.5
Annual cost of feedstock††											
Millions of dollars	$3.1	$6.3	$18.8	$6.3	$12.6	$37.7	0	$16.8	$18.8	$18.8	$18.8
Dollars/MM Btu	$1.4	$1.4	$1.4	$2.7	$2.7	$2.7	0	$1.4	$1.4	$1.4	$1.4
Annual operating cost											
Millions of dollars	$3.0	$5.3	$10.3	$3.0	$5.3	$10.3	$10.3	$10.3	$9.0	$12.4	$10.3
Dollars/MM Btu	$1.3	$1.1	$0.7	$1.3	$1.1	$0.7	$0.7	$0.8	$0.6	$0.9	$0.7
Operating percent	90%	90%	90%	90%	90%	90%	90%	80%	90%	90%	90%
Revenue requirements (total product basis)											
Dollars/MM Btu	$3.4	$3.2	$2.7	$4.7	$4.5	$4.1	$1.3	$2.9	$2.5	$3.0	$2.6
Dollars/MM Btu (oil only)‡‡	$6.1	$5.6	$4.5	$8.9	$8.5	$7.6	$1.4	$4.9	$4.0	$5.1	$4.2
Project Life (years)	20	20	20	20	20	20	20	20	20	20	30

*Assumes .250 lb/1 lb dry wood, or 210 gal of oil/dry ton.

†Assumes 0.302 lb/1 lb dry wood.

‡Assumes a 50% moisture content feedstock and 19 MM Btu/dry ton - process efficiency = 73.6%.

§Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity with 9% interest on debt (65% debt & 35% equity). Income Tax = 52%

**Capital component of product cost.

††Excludes feedstock cost and plant depreciation.

‡‡Assumes char valued at 1.25/MM Btu and representing 55% of total output.

MISSION 13--SELECTED SUMMARY DATA

KELP TO SNG VIA ANAEROBIC DIGESTION

	Plant Size			Sensitivity to Feedstock Prices					
Product									
Cubic ft. gas/day (10^6) (1,000 Btu/cu ft.)	5.6	16.8	33.6	33.6	33.6	33.6	16.8	16.8	16.8
Btu/day (10^9)*	5.6	16.8	33.6	33.6	33.6	33.6	16.8	16.8	16.8
Feedstock									
DAFT/day†	1000	3000	6000	6000	6000	6000	3000	3000	3000
Btu/day (10^9)	16	16	16	16	16	16	16	16	16
Cost/ton (DAF)	$100	100	100	$ 25	200	0	$ 25	200	0
Total Capital Investment									
Millions of dollars‡	$30.1	68.9	115.7	$113.6	118.4	113.0	$67.9	70.3	67.6
Dollars/MM Btu§	$ 2.2	1.6	1.3	$ 1.3	1.4	1.3	$ 1.6	1.7	1.6
Anuual Cost of Feedstock									
Millions of dollars	$33.0	99.0	198.0	$ 49.5	396.0	0	$24.7	198.0	0
Dollars/MM Btu	$17.9	17.9	17.9	$ 4.5	35.7	0	$ 4.5	35.7	0
Annual Operating Cost**									
Millions of dollars	$ 4.3	9.3	16.0	$ 16.0	16.0	16.0	$ 9.3	9.3	9.3
Dollars/MM Btu	$ 2.3	1.7	1.5	$ 1.5	1.5	1.5	$ 1.7	1.7	1.7
Operating Percent	90%	90%	90%	90%	90%	90%	90%	90%	90%
Revenue Requirements									
Regulated utility, dollars/MM Btu	$22.4	21.2	20.7	$ 7.3	38.6	2.8	$ 7.8	39.1	3.3

*Process efficiency = 35%.

†Dry ash free tons.

‡Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity and a 9% return on debt (65% debt and 35% equity). Income tax = 52%.

§Capital component of product cost.

**Excludes feedstock costs and plant depreciation; assumes 16 MM Btu/Dry Ash Free Ton of Feedstock.

MISSION 14--SELECTED SUMMARY DATA

ALGAE TO ETHANOL VIA ACID HYDROLYSIS AND FERMENTATION
25 Million Gallons per Year Ethanol Plant

	50% Sugar Conversion							80% Sugar Conversion
	Base Case	Sensitivity to Feedstock Prices		Capital Investment		Operating Percent		Base Case
Product--daily output								
Tons of sugar	500	500	500	500	500	500	500	500
Gallons of ethanol (000)	76	76	76	76	76	76	76	76
Btu per day (10^9)*	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Feedstock								
DAF tons per day	1,126	1,126	1,126	1,126	1,126	1,126	1,126	703
Btu per day (10^9)	18.0	18.0	18.0	18.0	18.0	18.0	18.0	11.25
Cost per dry ton†	75	100	0	75	75	75	75	75
Total capital investment				+30%	-20%			
Sugar plant (\$ 10^6)	\$27.9	\$28.0	\$27.7	\$36.3	\$22.3	\$27.9	\$27.8	\$19.5
Ethanol plant (\$ 10^6)	\$28.0	\$28.0	\$28.0	\$36.4	\$22.4	\$28.0	\$28.0	\$26.5
Total capital investment‡	\$55.9	\$56.0	\$55.7	\$72.7	\$44.7	\$55.9	\$55.8	\$46.0
Dollars per MM Btu§	\$4.5	\$4.5	\$4.5	\$5.9	\$3.6	\$5.1	\$5.8	\$3.7
Annual cost of feedstock**								
Millions of dollars	\$27.9	\$37.2	0	\$27.9	\$27.9	\$24.7	\$21.6	\$17.4
Dollars per MM Btu	\$14.9	\$19.8	0	\$14.9	\$14.9	\$14.9	\$14.9	\$9.2
Annual operating costs (\$$10^6$)								
Sugar plant	\$5.2	\$5.2	\$5.2	\$5.9	\$4.7	\$5.0	\$4.7	\$3.4
Ethanol plant	\$7.0	\$7.0	\$7.0	\$7.9	\$6.4	\$6.4	\$6.3	\$7.0
Total annual operating costs (10^6)	\$12.2	\$12.2	\$12.2	\$13.8	\$11.1	\$11.4	\$11.0	\$10.4
Dollars per MM Btu	6.5	6.5	6.5	7.4	5.9	6.8	7.5	5.5
Operating percent	90%	90%	90%	90%	90%	80%	70%	90%
Revenue requirements								
Dollars per lb of sugar	\$0.11	\$0.14	\$0.03	\$0.12	\$0.11	\$0.12	\$0.11	\$0.08
Dollars per MM Btu of ethanol	\$25.9	\$30.8	\$11.0	\$28.2	\$24.4	\$26.8	\$28.2	\$18.4

*Process efficiency = 32%; assumes 75,600 Btu/gallon of ethanol.

†Assumes 16 MM Btu/DAF ton of feedstock, 80% carbohydrate.

‡Calculated to yield a 15% discounted cash flow (DCF) rate of return on equity with 9% interest on debt (65% debt and 35% equity). Income tax = 52%

§Capital component of product cost.

**Excludes feedstock cost and plant depreciation.

MISSION 15--SELECTED SUMMARY DATA

COGENERATION OF STEAM AND ELECTRICITY FROM WOOD VIA DIRECT COMBUSTION

Product	Base Cases			Sensitivity To: Plant Investment Cost		Sensitivity To: Feedstock Cost		Sensitivity To: Operating % of Capacity		
Plant capacity (MW)	3.65	7.3	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9
Electricity (MWh per day)	87.6	175.	525	525	525	525	525	525	525	525
Steam pounds per hour (000)	210.	420.	1,260	1,260.	1,260	1,260	1,260	1,260	1,260	1,260
Equivalent Btu per day (10^9)	7.2	14.5	43.5	43.5	43.5	43.5	43.5	43.5	43.5	43.5
Feedstock										
ODT per day*	500	1,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Btu in per day (10^9)	9.6	192	57.4	57.4	57.4	57.4	57.4	57.4	57.4	57.4
Cost (dollars per million Btu)	$1.00	$1.00	$1.00	$1.00	$1.00	$1.50	0	$1.00	$1.00	$1.00
Plant Life (years)	20	20	20	20	20	20	20	20	20	20
Total Capital Investment-				-20 %	+ 30 %					
Millions of dollars†	$ 21.6	$ 40.3	$ 109.1	$ 87.9	$ 140.8	$ 109.8	$ 107.7	$ 108.9	$ 108.6	$108.3
Dollars per million Btu‡	(1.37)	(1.29)	(1.16)	(0.94)	(1.49)	(1.17)	(1.15)	(1.33)	(1.68)	(2.30)
Annual Cost of Feedstock										
Millions of dollars	$2.8	$5.6	$16.8	$16.8	$16.8	$25.1	0	$14.7	$11.5	$8.4
Dollars per million Btu	(1.32)	(1.32)	(1.32)	(1.32)	(1.32)	(1.98)	-	(1.32)	(1.32)	(1.32)
Annual Operating Cost§ (Millions of dollars)	$2.9	$5.1	$12.0	$10.2	$14.6	$12.0	$12.0	$11.8	$11.5	$11.3
Dollars per million Btu	(1.36)	(1.19)	(0.94)	(0.80)	(1.16)	(0.94)	(0.94)	(1.06)	(1.32)	(1.78)
Operating percent	80%	80%	80%	80%	80%	80%	80%	70%	55%	40%
Revenue Requirements										
Dollars per million Btu, regulated utility	$ 4.05	$ 3.80	$ 3.42	$ 3.06	$ 3.97	$ 4.09	$ 2.09	$ 3.71	$ 4.32	$ 5.40

*Assumes a 50% moisture content feedstock - 19.2 million Btu per dry ton - Process efficiency = 75.7%.

†15% return on equity (35% of total) and 9% return on debt (15% of total) - Plant life = 20 years.

‡The capital portion of product cost (cents per million Btu of total product steam and electricity).

§Excludes feedstock cost and plant depreciation.

Appendix D

PRODUCT DEMAND AND PRICE DATA SOURCES

1975 Product Demands and Prices were based on the following sources:

Fuel	Source of Data
Coal	U.S. Bureau of Mines--Mineral Industry Surveys Quarterly and Annual Reports: Bituminous Coal and Lignite Distribution Quarterly, Pennsylvania Anthracite Annual, Coke and Coal Chemicals Annual
Natural gas	U.S. Bureau of Mines--Mineral Industry Surveys--Natural Gas Annual
Electric power	Edison Electric Institute Statistical Yearbook--Data adjusted by Gulf Energy Model Outputs to yield base, intermediate, and peak load data
Gasoline	Federal Highway Administration's Highway Statistics Annual and the National Petroleum Factbook Platt's Oilgram Price Service
Residual fuel oil	U.S. Bureau of Mines--Mineral Industry Survey--Fuel Oil Sales Annual, Federal Power Commission--Annual Summary of Cost and Quality of Steam--Electric Plant Fuels
Crude oil	U.S. Bureau of Mines--Mineral Industry Survey--Petroleum Statement Annual, Oil and Gas Journal--Annual Refining Issue, Federal Energy Administration--Monthly Energy Review
Methanol	Chemical Marketing Reporter
Ammonia	Several recent studies by the SRI Chemical Economics Department, SRI Chemical Economics Handbook, U.S. Bureau of Census Data on Ammonia Producers Shipments
IBtu gas	Not applicable for 1975
Steam	Based on the conversion of coal at 85 percent efficiency to satisfy the Industrial Process Steam Market--Fuel and Energy Prices Forecasts, EPRI, EA-411 and EA-443, April and September 1977.

Fuel demand and price projections are based on the following sources:

- Brookhaven National Laboratory, "Regional Reference, Energy Systems," EPRI EA-462 (June 1977).
- ERDA, "Market Oriented Program Planning Study" (September 1977).
- Foster Associates, Inc., "Fuel and Energy Price Forecasts," EPRI EA-411 (April 1977).
- SRI International, "Fuel and Energy Price Forecasts: Quantities and Long-Term Marginal Prices," EPRI EA-433 (September 1977).
- SRI International, "Assessing the Benefits of the Gas Research Institute's Research and Development Programs," SRI Project 6955 (March 1978).

Projections of ammonia demand were made by applying a consumption factor to the Obers projection of crop yields.