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COAL CONVERSION PRODUCTS
INDUSTRIAL APPLICATIONS

FINAL REPORT

JULY 1980

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NASA CONTRACT NAS8-33843
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FOREWORD

THIS FINAL REPORT IS SUBMITTED TO GEORGE C. MARSHALL SPACE FLIGHT CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, BY THE TECHNOLOGY DEVELOPMENT CORPORATION (TDC). THIS DOCUMENT SERVES AS THE FINAL REPORT OF THE STUDY ENTITLED "COAL CONVERSION INDUSTRIAL APPLICATIONS" UNDER CONTRACT NAS8-33843. TECHNICAL DIRECTION FOR THIS STUDY EFFORT WAS PROVIDED BY MR. JOSEPH HAMAKER. QUESTIONS OF A TECHNICAL NATURE SHOULD BE DIRECTED TO EITHER MR. DENNIS WARREN OR MR. JOSEPH DUNKIN OF TDC AT (205) 837-7762.

CONCLUSIONS

THIS STUDY'S PRIMARY EMPHASIS WAS ON THE DEVELOPMENT OF THE SYNFUELS ECONOMIC EVALUATION MODEL (SEEM). HOWEVER, THE MODEL WAS UTILIZED FOR ANALYSIS OF THE TVA COAL CONVERSION FACILITIES COST AND PRODUCT ECONOMICS. ALSO, SIX MANWEEKS OF EFFORT WERE DEVOTED TO CUSTOMER GAS CONSTITUENT REQUIREMENTS AND NEW INDUSTRY ENERGY REQUIREMENTS. MAJOR CONCLUSIONS FROM THIS STUDY ARE SHOWN ON THE FACING PAGE.

CONCLUSIONS

- MODERATE YEARLY FUTURE ESCALATIONS ($>$ 6%) IN CURRENT NATURAL GAS PRICES WILL RESULT IN MEDIUM-BTU GAS BECOMING COMPETITIVE WITH NATURAL GAS AT THE PLANT BOUNDARY.
- UTILIZING DRI PRICE PROJECTIONS, THE ALTERNATE SYNFUEL PRODUCTS, EXCEPT FOR ELECTRICITY, WILL BE COMPETITIVE WITH THEIR COUNTERPARTS.
- CENTRAL-SITE FUEL CELL GENERATION OF ELECTRICITY, UTILIZING MBG, IS ECONOMICALLY LESS ATTRACTIVE THAN THE OTHER SYNTHETIC FUELS, GIVEN PROJECTED PRICE RISES IN ELECTRICITY PRODUCED BY ALTERNATE MEANS.
- BECAUSE OF THE ESTIMATED NORTHERN ALABAMA SYNFUELS MARKET DEMAND, EXISTING CONVENTIONAL FUELS, INFRASTRUCTURE AND INDUSTRIAL SYNFUELS RETROFIT PROBLEMS, A DIVERSITY OF TRANSPORTABLE SYNFUELS PRODUCTS SHOULD BE PRODUCED BY THE COAL CONVERSION FACILITY.

TECHNICAL APPROACH

THE STUDY OBJECTIVES AND THREE PRIMARY TASKS ARE ILLUSTRATED. MAJOR SUBTASKS ARE ALSO DEPICTED

TECHNICAL APPROACH

STUDY OBJECTIVES

- DEVELOP SYNTHETIC FUELS PRODUCT MIX MODEL
- ANALYZE REGIONAL INDUSTRY BENEFITS
- IDENTIFY CUSTOMER GAS CONSTITUENT REQUIREMENTS

TASK 1

SYNFUEL ECONOMICS MODEL

- OBTAIN/EXPAND DATA ON SUPPLY, DEMAND, COST & PRICE
- COMPUTERIZE ECONOMIC ESTIMATING RELATIONSHIPS
- FORMULATE & EXECUTE SYNFUEL PRODUCTION SCENARIOS
- COMPARE WITH SELLING PRICE OF COMPETING FOSSIL FUELS

TASK 2

NEW INDUSTRY ENERGY REQUIREMENTS

- EXAMINE NATIONAL & REGIONAL INDUSTRY GROWTH
- IDENTIFY NEW LARGE INDUSTRY USERS
- DESCRIBE NEW INDUSTRIES BY SYNFUEL USE

TASK 3

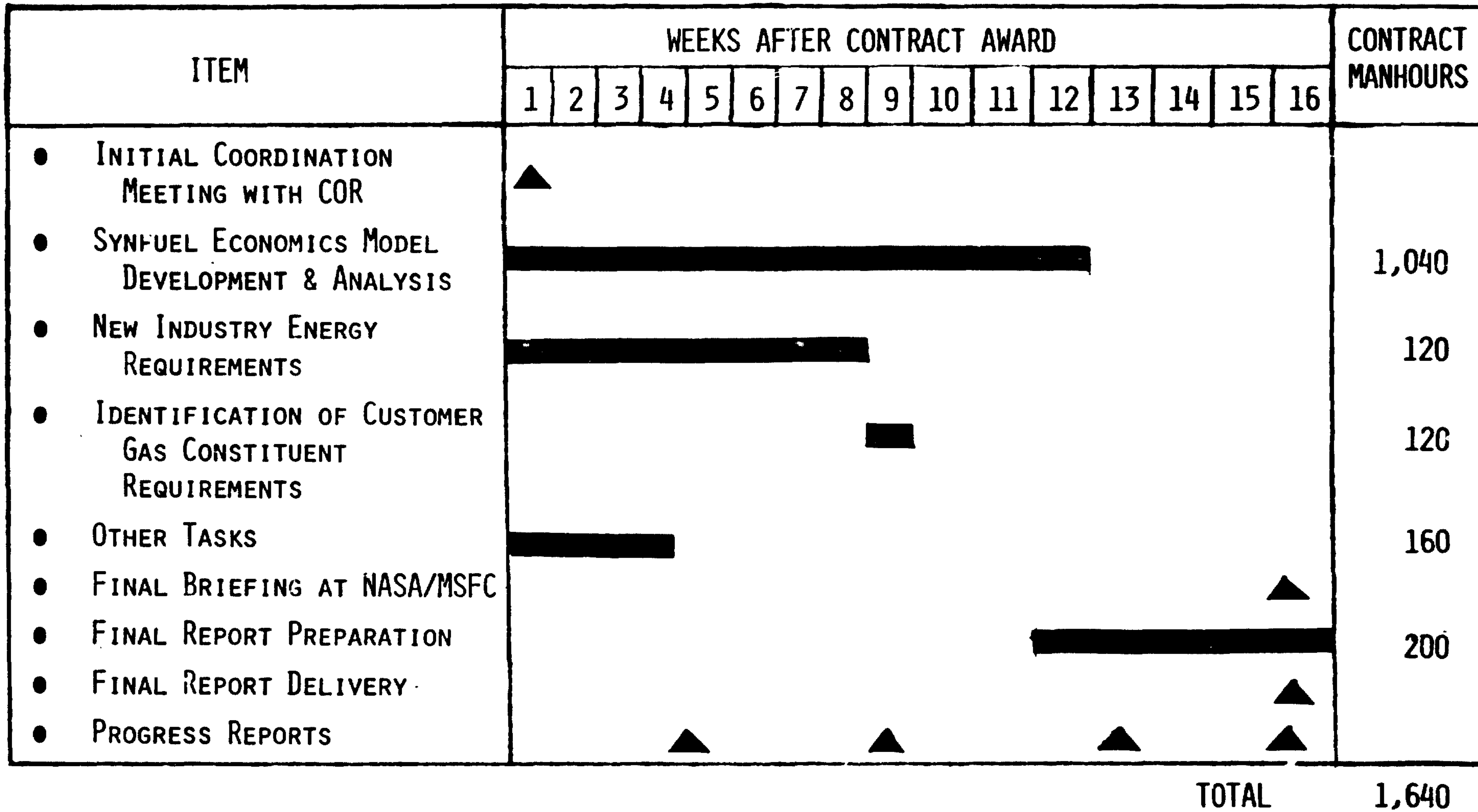
GAS CONSTITUENT REQUIREMENTS

- IDENTIFY GAS REQUIREMENTS FOR SPECIFIC INDUSTRIES

PROJECT SCHEDULE

THE STUDY PROJECT FOUR-MONTH SCHEDULE, MILESTONES, AND CONTRACT MANHOURS ARE SHOWN. AGAIN, THE MAJOR RESOURCES WERE ALLOCATED TO DEVELOPMENT OF THE SYNFUELS ECONOMIC EVALUATION MODEL.

PROJECT SCHEDULE



TASK 1

SYNFUEL ECONOMIC EVALUATION MODEL (SEEM)

TASK 1

SYNFUEL ECONOMIC EVALUATION MODEL (SEEM)

TASK OBJECTIVE: DESIGN, CODE, EXECUTE, AND DOCUMENT A COMPUTERIZED SIMULATION WHICH WILL MODEL THE FUTURE MARKETABLE SELLING PRICES OF DIFFERENT SYNTHETIC FUEL PRODUCTS, THEIR RESPECTIVE PRODUCTION COSTS, AND THE MARGIN FOR PROFIT AVAILABLE FROM EACH PRODUCT, IDENTIFY THE MOST ATTRACTIVE SYNFUEL PRODUCTS.

SYNFUEL ECONOMIC EVALUATION MODEL

- MATRIX-ORIENTED PROGRAM STRUCTURE -

THE SYNFUEL ECONOMIC EVALUATION MODEL (SEEM) IS ORIENTED AROUND THE CHANGE IN VALUES OF THE ELEMENTS OF CERTAIN MATRICES. THE COSTS OF BUILDING AND OPERATING THE PLANT ARE COMPUTED IN THE FUNDAMENTAL COST MATRIX. PRICES OF FUELS, SUCH AS NATURAL GAS, WHICH COMPETE WITH SYNTHETIC FUELS, ARE CALCULATED IN THE COMPETING FUEL PRICE MATRIX. THE QUANTITY OF SYNFUEL WHICH IS MANUFACTURED EACH YEAR IS COMPUTED IN THE SYNFUELS SUPPLY MATRIX. THE AMOUNT OF ANNUAL REVENUE WHICH WOULD BE GENERATED BY SELLING THE SYNFUELS AT THE MARKET PRICE OF THE COMPETING FOSSIL FUEL IS CALCULATED IN THE SYNFUELS REVENUE MATRIX. THE CASH FLOW MATRIX THEN CONTAINS THE REVENUE MINUS COST, ON A YEARLY BASIS, OF THE PLANT FACILITY OVER THE LIFETIME OF THE PLANT.

SYNFUEL ECONOMIC EVALUATION MODEL

- MATRIX-ORIENTED PROGRAM STRUCTURE -

- FCM - FUNDAMENTAL COST MATRIX
- CFP - COMPETING FUEL PRICE MATRIX
- SSM - SYNFUELS SUPPLIES MATRIX
- SPM - SYNFUELS PRICE MATRIX
- SRM - SYNFUELS REVENUE MATRIX
- CFM - CASH FLOW MATRIX

SYNFUEL ECONOMIC EVALUATION MODEL

- BASIC PROGRAM INPUT -

THE BASIC PROGRAM INPUTS INCLUDE THE PLANT CONSTRUCTION SCHEDULE, THE COSTS OF OPERATING THE PLANT, THE PRODUCT TYPE, AND THE QUANTITY OF COAL WHICH IS CONSUMED ON AN ANNUAL BASIS. ESCALATION RATES ARE EITHER READ INTO THE PROGRAM OR INTERNALLY GENERATED FOR BOTH SYNFUEL PRODUCT COSTS AND PRODUCT PRICES.

THE PROGRAM REQUIRES NUMEROUS INPUTS IN ADDITION TO THE ABOVE VARIABLES. HOWEVER, ALL OF THE DATA FOR A SAMPLE RUN IS ALREADY EMBEDDED WITHIN THE PROGRAM CODE, SO THE PROGRAM CAN BE RUN WITHOUT ANY ADDITIONAL DATA INPUT BY THE USER, IF HE DESIRES A SAMPLE RUN.

SYNFUEL ECONOMIC EVALUATION MODEL

- Basic Program Input -

- For Each Module
  - Construction Start, Stop
  - Operation Start, Stop
  - Construction Cost
  - Operating Cost
  - Coal Cost
  - Product Type
  - Process Efficiency
  - Product Transportation Cost
  - Coal Quantity
  - Escalation Rates
  - Premium/Subsidy Factor

- For Each Competing Fuel
  - 1980 Market Price
  - Escalation Rates

- Miscellaneous
  - General Inflation Rate
  - Number of Data Cases

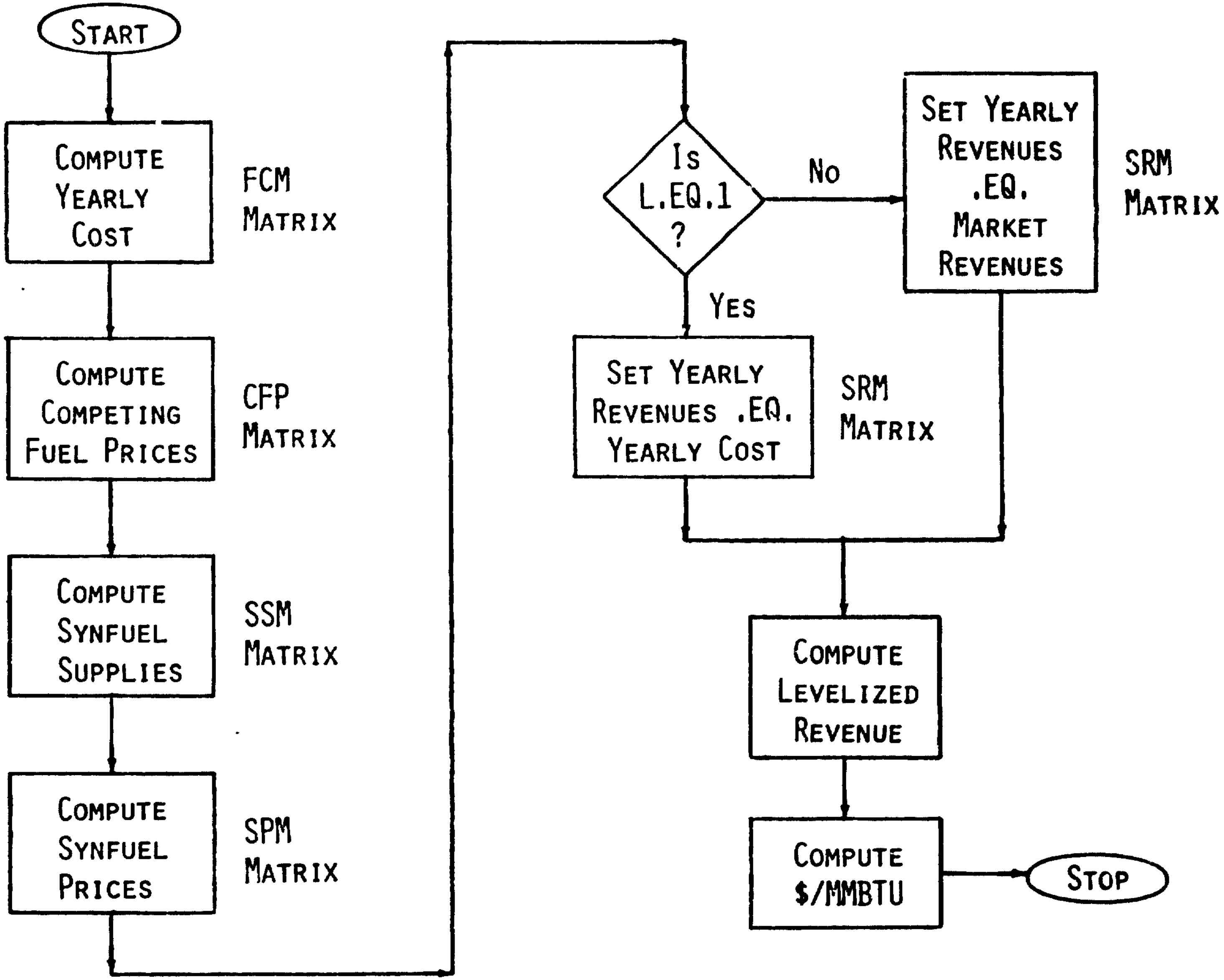
SYNFUEL ECONOMIC EVALUATION MODEL

- Program Sequence -

The computational flow of the program proceeds as follows. The yearly costs of building and operating the synfuel facility are computed and placed in the elements of the Fundamental Cost Matrix (FCM). The projected prices of competing fossil fuels, such as natural gas, are computed and placed in the Competing Fuel Price Matrix (CFP). Next, the amounts of synfuels in millions of BTU's which are generated by the facility on an annual basis are calculated. The marketable selling price of the synfuel during each year is found by setting the price of the synfuel equal to the price of its fossil fuel counterpart. At this point, the program takes one of two alternate paths. If "L = 1", the yearly revenues of the plant are set equal to the year costs of the plant; this is a "Yearly Break-Down" analysis. If "L = 2", the yearly revenues are set equal to the income produced by selling the plant product at the marketable selling price of the competing fossil fuel. After this step, a levelized revenue (cost) value is computed to obtain a levelized $/MMBTU number. This number is utilized as a single figure of merit to describe the entire life cycle economics of the synfuel facility.

SYNFUEL ECONOMIC EVALUATION MODEL

- PROGRAM SEQUENCE -



SYNFUEL ECONOMIC EVALUATION MODEL

- BASIC PROGRAM OUTPUT -

THE BASIC OUTPUT OF THE SYNFUEL ECONOMIC EVALUATION MODEL IS THE ANNUAL PLANT CONSTRUCTION AND OPERATING COSTS, THE REVENUES GENERATED BY SELLING THE SYNFUEL PRODUCTS ON THE MARKET AND THE NET CASH FLOW OF THE PLANT. AS A <u>SINGLE</u> FIGURE OF MERIT, THE LEVELIZED REVENUE, WHICH IS EQUAL TO THE LEVELIZED COST OF THE PLANT OVER ITS LIFE CYCLE, IS ALSO OUTPUT.

SYNFUEL ECONOMIC EVALUATION MODEL

- Basic Program Output -

- By Year
  - Plant Costs
  - Synfuel Supplies
  - Competing Fuel Prices
  - Synfuel Prices
  - Synfuel Revenues
  - Net Cash Flow

- Summary Output
  - Levelized Inflated Revenue
  - Levelized Inflated $/MMBTU
  - Levelized Revenue (1980 Dollars)
  - Levelized $/MMBTU (1980 Dollars)

SYNFUEL ECONOMIC EVALUATION MODEL

- BASIC PROGRAM MODELING CAPABILITIES -

THIS CHART ILLUSTRATES SOME OF THE BASIC MODELING CAPABILITIES OF THE SYNFUEL ECONOMIC EVALUATION MODEL. THE DARK DOTS BY THE NUMBERS INDICATE THOSE SENSITIVITY STUDIES WHICH WERE PERFORMED DURING THIS CONTRACT.

SYNFUEL ECONOMIC EVALUATION MODEL
- Basic Program Modeling Capabilities -

- ● (1) Different Capital Cost Estimates
- (2) Different Construction Schedules
- ● (3) Delays in Construction & Operation
- (4) Cost of Construction Funds, Raw Materials, & Operation & Maintenance
- (5) Different Types of Coals
- ● (6) Projected Future Prices of Competing Fuels
- ● (7) Partial Plant Completion
- (8) Partial Plant Operation
- (9) Synfuel Production Costs
- (10) Synfuel Selling Prices
- (11) Market Price Premiums/Discounts
- ● (12) Non-Uniform Escalation Rates
- ● (13) Different Synfuel Products
- (14) Transportation Costs of Synfuels
- (15) Differential Rates of Inflation
- (16) Yearly Plant Costs
- (17) Yearly Plant Revenues
- (18) Yearly Production Quantities
- ● (19) Different Process Efficiencies
- ● (20) Cross-Over of Production Cost & Market Price
- ● (21) Single or Multiple Module Evaluation
- (22) Levelized Expense Streams
- (23) Levelized Revenue Streams
- (24) Levelized Product Cost - $/MMBTU
- (25) Levelized Product Price - $/MMBTU

SYNFUEL ECONOMIC EVALUATION MODEL

- MODEL ASSUMPTIONS -

SOME OF THE FUNDAMENTAL UNDERLYING ASSUMPTIONS WHICH ARE PRESENTLY INCORPORATED IN THE SYNFUEL ECONOMIC EVALUATION MODEL ARE SHOWN ON THIS CHART.

SYNFUEL ECONOMIC EVALUATION MODEL

- Model Assumptions -

- Designed to Support Parametric Synfuels Facility Analysis
- TVA Module Schedules & Economic Guidelines
- No Tax or Debt/Equity Considerations
- Each Module Will Have 90% Operating Capacity
- Synfuels Prices Can Include Subsidies and Premiums
- Competing Fuel Prices Based on DRI Projections
- Synfuels Transportation Cost Considered
- Escalation Rates Based on TVA & DRI Projections
- Program Output in Then Year Dollars and 1980 Present Value
- Cash Flows Disbursed at Beginning of Each Calendar Year
- Inflation and Interest Expense Considered During Construction

SYNFUEL ECONOMY EVALUATION MODEL

- Test Case Assumptions -

For purposes of illustrating the capabilities and output of the Synfuels Economic Evaluation Model, the test case data which is shown on this chart was input into the simulation. All of the basic capital cost and operating costs estimates which were input to the model in this study were obtained from estimates produced for NASA/MSFC by the BDM Corporation and the Mittelhauser Corporation.

SYNFUEL ECONOMIC EVALUATION MODEL

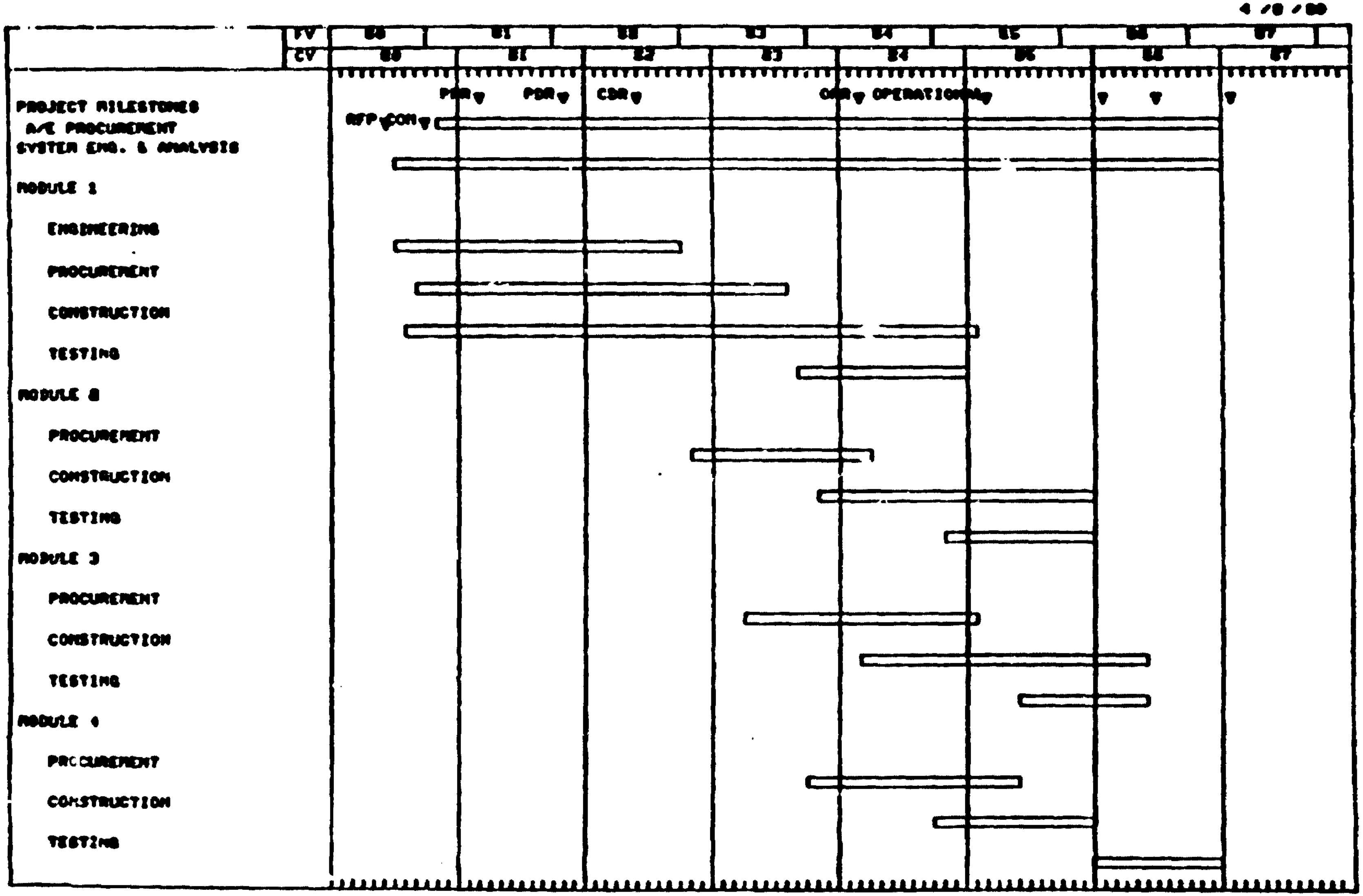
- Test Case Assumptions -

- Koppers-Totzek Gasifiers
- Total Capital Construction Cost = $1.8 Billion Dollars (1980 Dollars) for Four-Module MBG Plant
- Interest Rate on Construction Loan is 12%
- Coal Cost = $30/Ton (1980 Dollars)
- The Four Modules Become Operational in 1985, 1986, 1987, and 1988 Respectively
- Each Module Has a Twenty-Year Operational Life
- Prices of Competing Fossil Fuels Are Based on Market Projections by Data Resources, Inc. (DRI)

COAL GASIFICATION PROJECT-SUMMARY SCHEDULE

THIS CONSTRUCTION SCHEDULE WAS UTILIZF' .S THE NOMINAL SCHEDULE FOR MODULE CONSTRUCTION IN ALL OF THE DAT HICH WILL BE PRESENTED IN THIS REPORT.

COAL GASIFICATION PROJECT-SUMMARY SCHEDULE



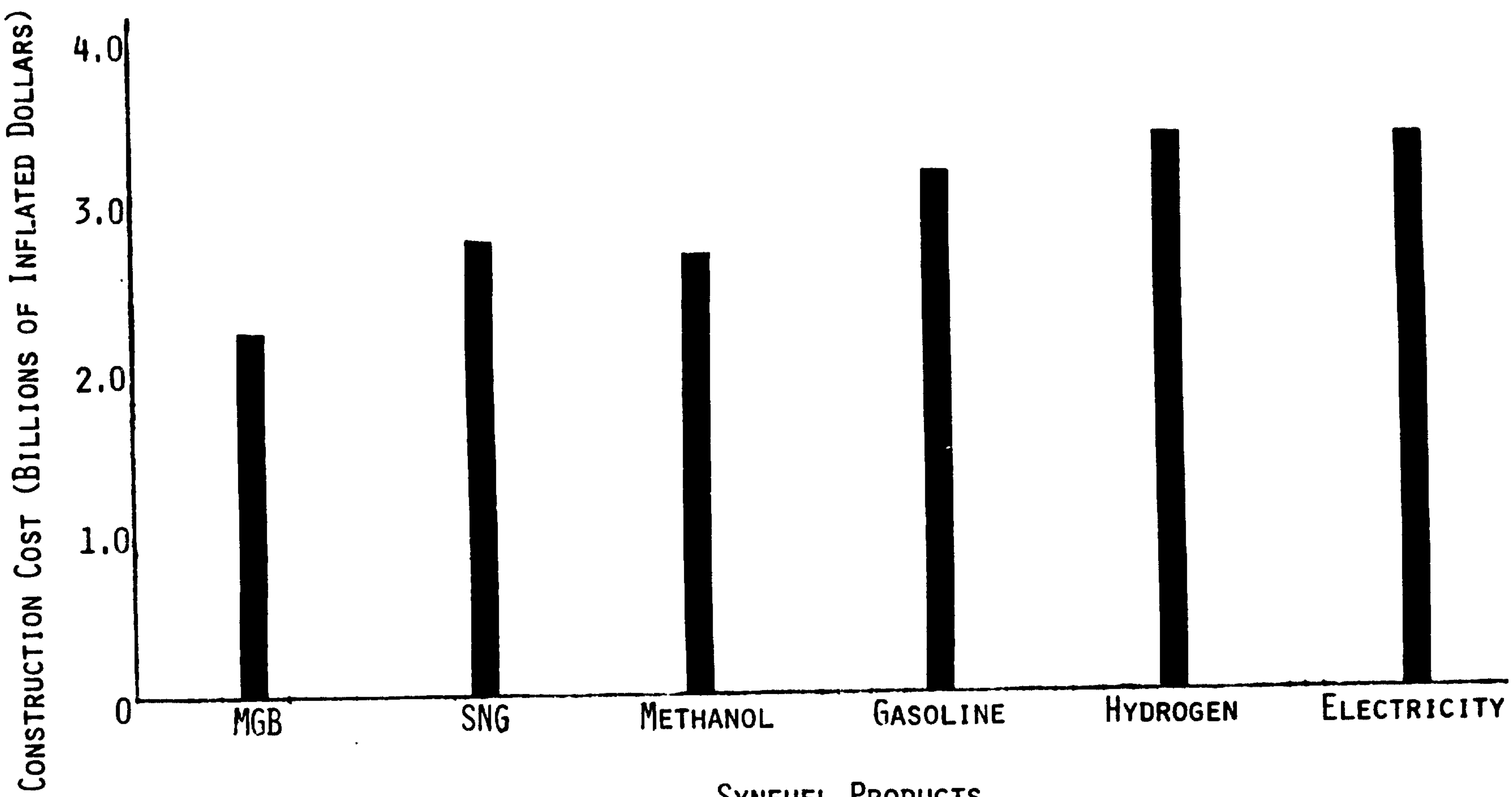
ECONOMIC ANALYSIS
OF
A FOUR-MODULE
MBG PLANT

FOUR-MODULE SYNFUEL FACILITIES COST

THIS FIGURE SHOWS THAT THE TOTAL COST, IN INFLATED DOLLARS, OF BUILDING THE BASIC FOUR-MODULE MBG PLANT IS APPROXIMATELY 2.25 BILLION DOLLARS.

THIS FIGURE ALSO ILLUSTRATES THAT THE CONSTRUCTION COSTS OF PRODUCING ADD-ON EQUIPMENT TO THE BASIC FOUR-MODULE MBG FACILITY IS WITHIN APPROXIMATELY ONE BILLION DOLLARS OF BUILDING THE MBG FACILITY, ASSUMING THE SAME CONSTRUCTION SCHEDULE FOR THE MODULES.

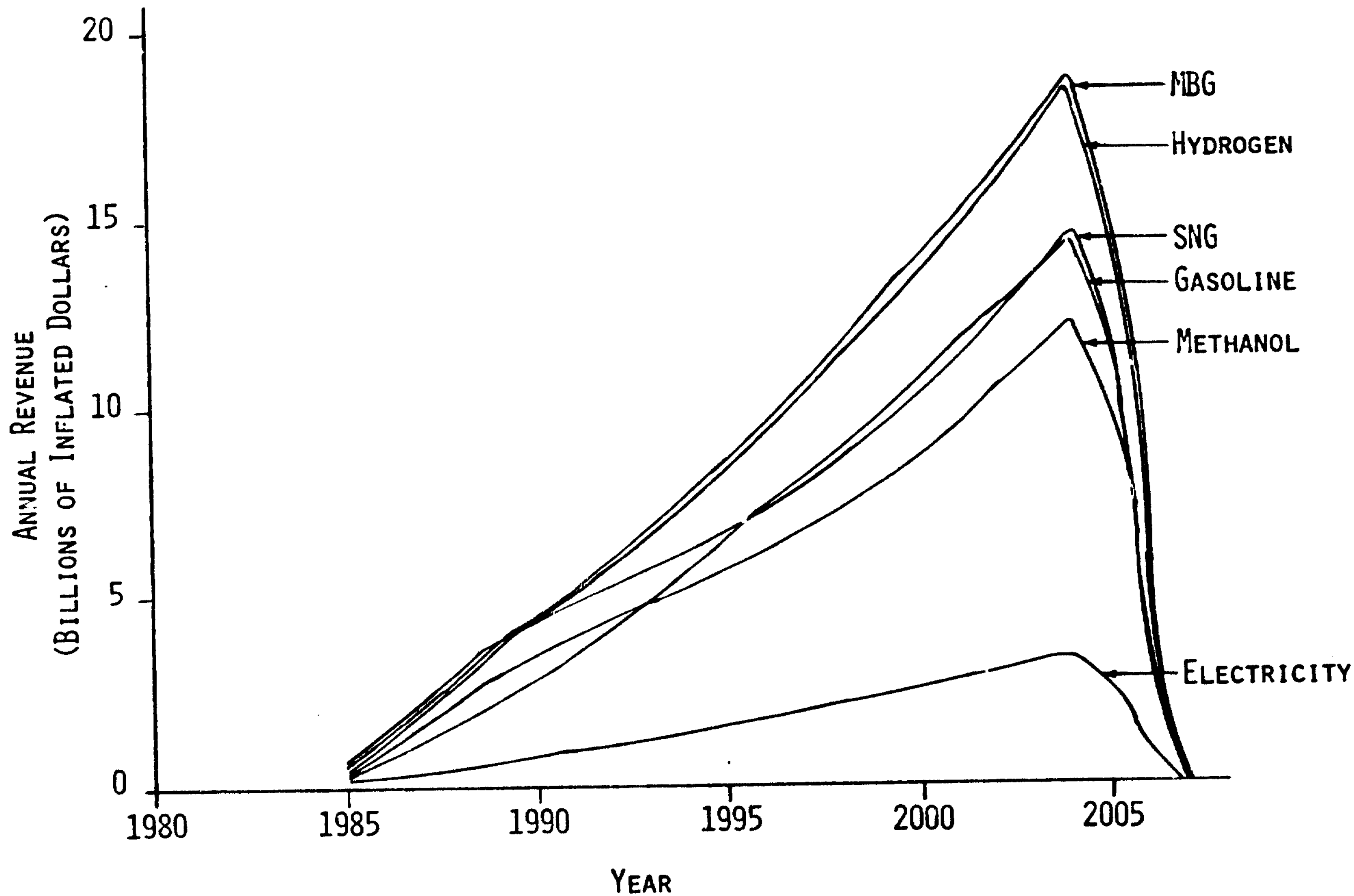
FOUR MODULE SYNFUEL FACILITIES COSTS



YEARLY REVENUE FOR VARIOUS FOUR-MODULE PLANTS

THE LARGEST ANNUAL REVENUE IS GENERATED BY THE SALE OF MEDIUM-BTU GAS. REVENUE FROM THE SALE OF HYDROGEN IS ALMOST EQUAL TO THAT OF THE MBG PRODUCT. ELECTRICITY GENERATED AT THE COAL CONVERSION FACILITY, UTILIZING FUEL CELLS, GENERATES THE LEAST REVENUE BECAUSE IT IS ASSUMED THAT THIS ELECTRICITY IS SOLD AT THE SAME RATES AS ELECTRICITY FROM OTHER SOURCES. THESE FUTURE RATES ARE PROJECTED TO BE LOWER THAN NG RATES.

YEARLY REVENUE FOR VARIOUS
FOUR-MODULE PLANTS



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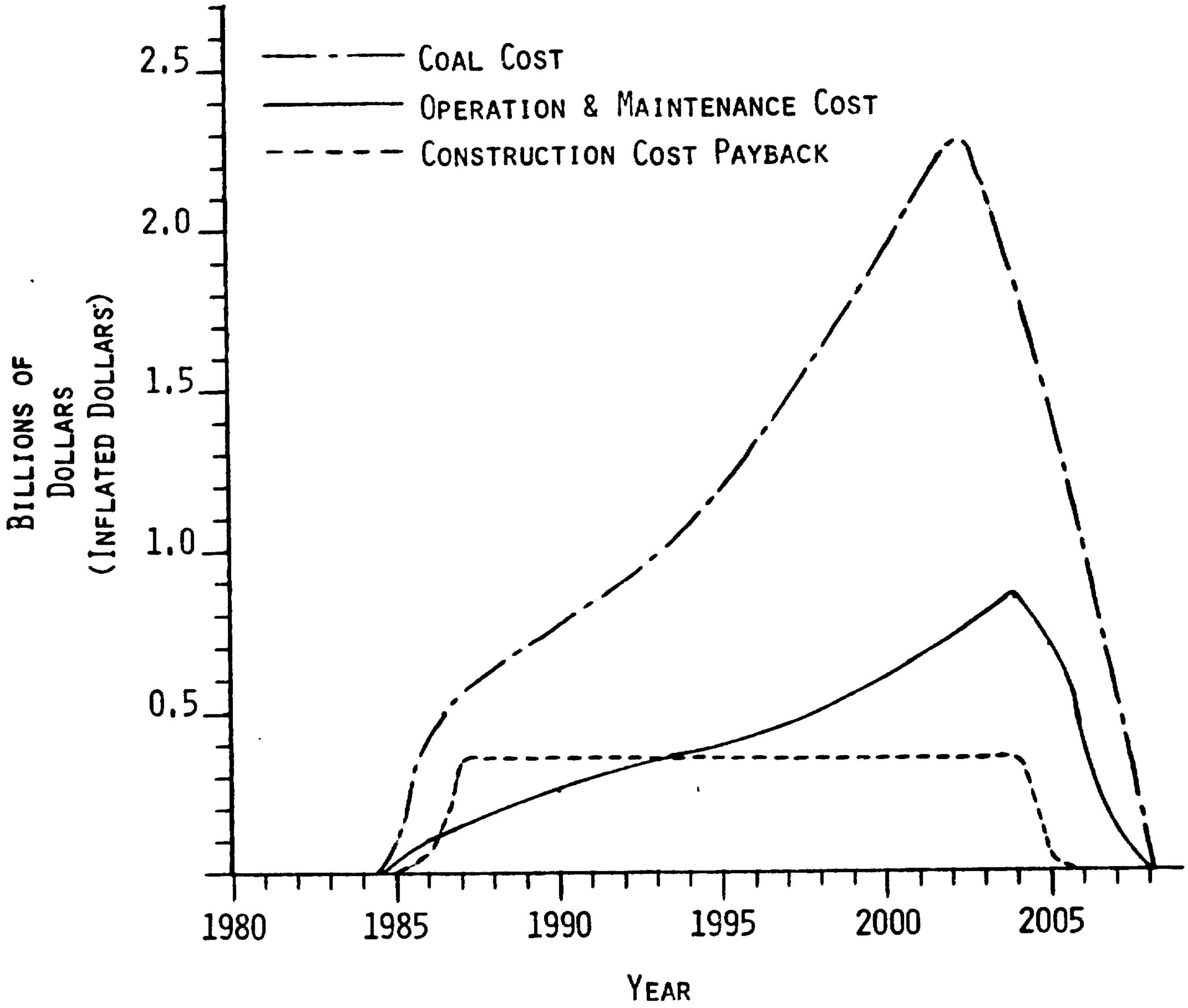
FOUR-MODULE MBG
SYNFUELS FACILITY COSTS

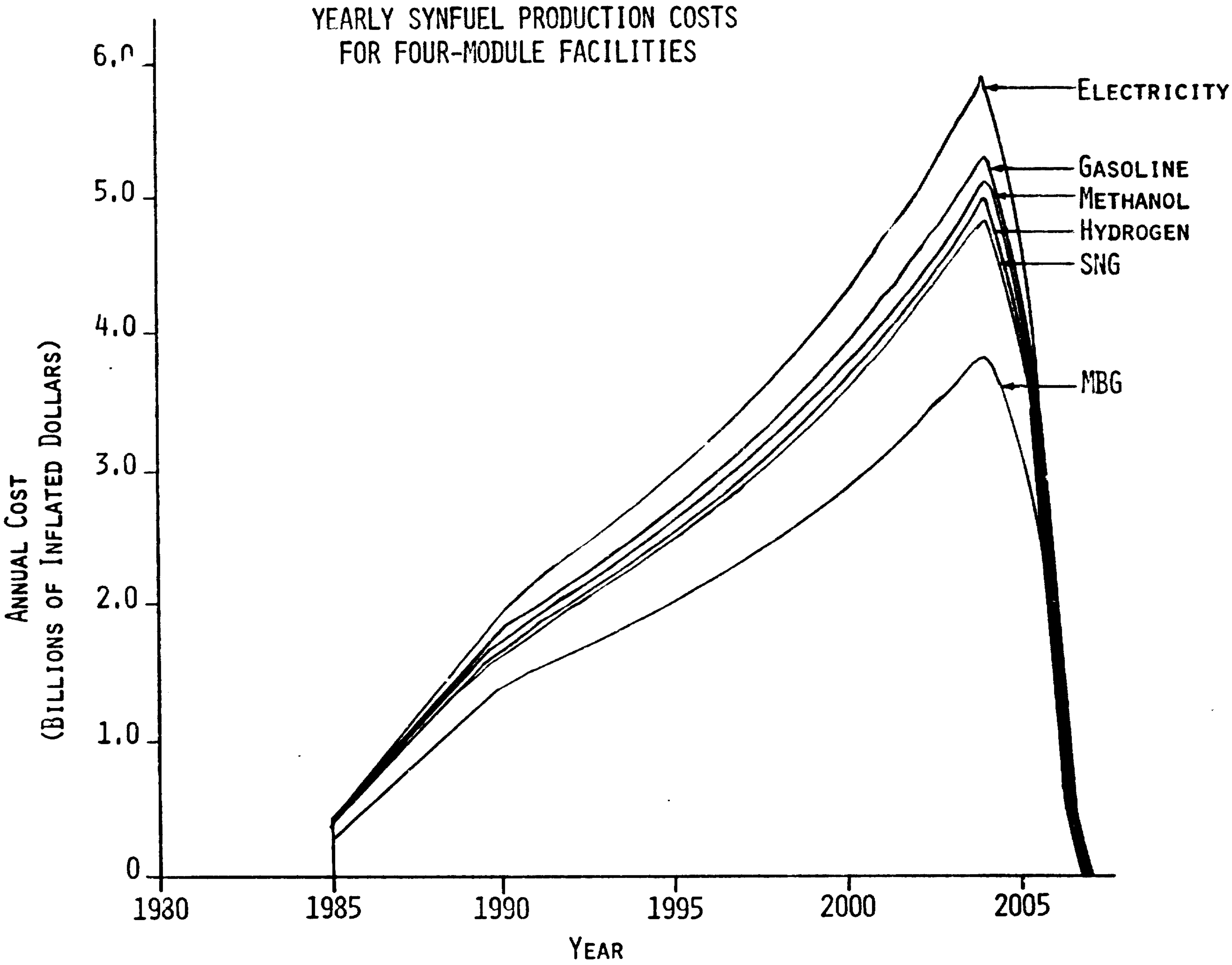
THIS CHART SHOWS THAT IN THE TEST CASE, THE LARGEST COST DRIVER OVER THE SYNFUEL PLANT LIFE CYCLE COST IS THE COST OF COAL. THE SECOND LARGEST COST DRIVER IS THE O&M COSTS (EXCLUDING COAL) AND THE THIRD LARGEST DRIVER IS PAYBACK OF THE CONSTRUCTION LOAN PLUS INTEREST ON THIS LOAN.

Four-Module MBG
Synfuels Facility Costs



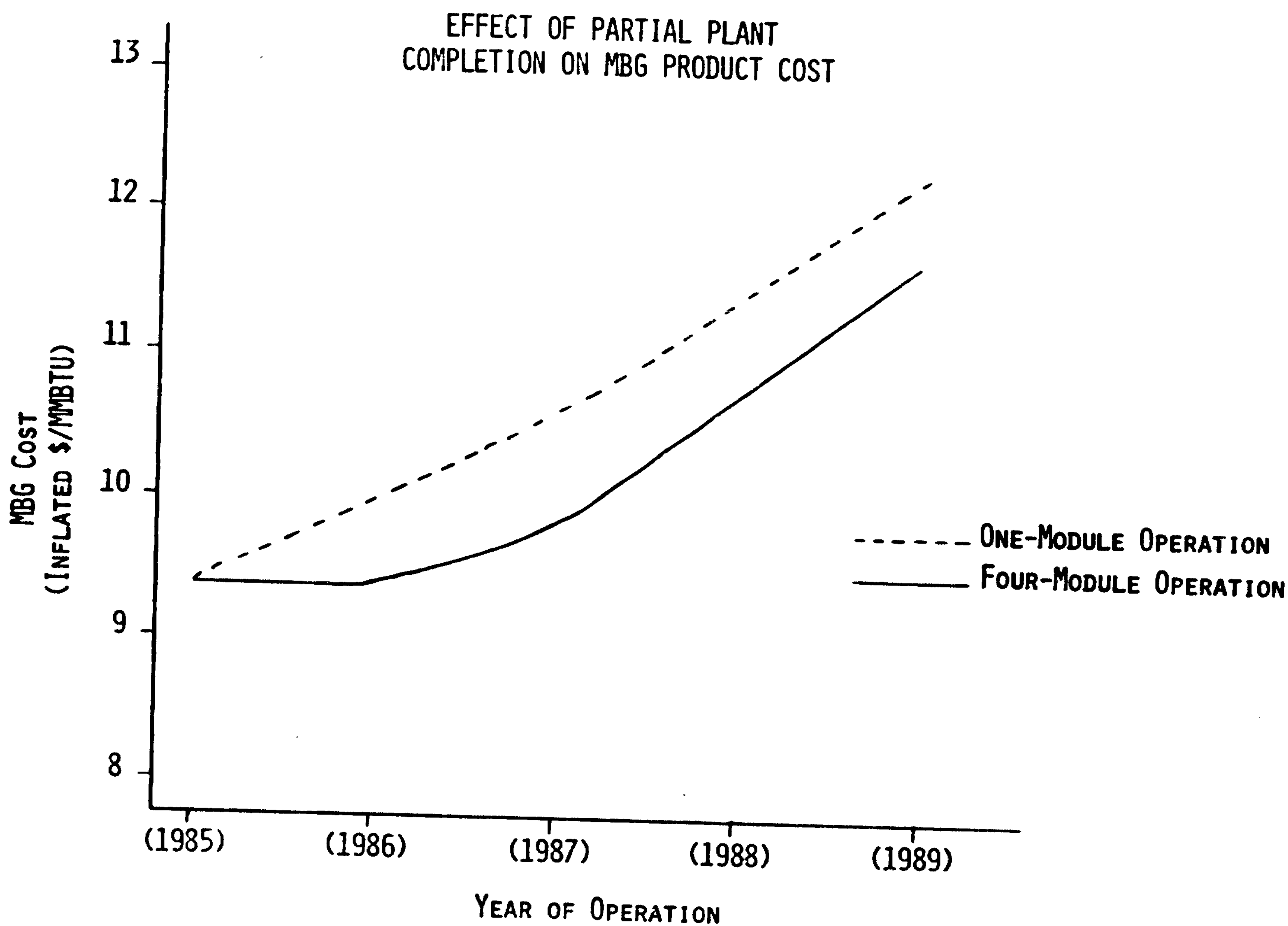
YEARLY SYNFUEL PRODUCTION COSTS FOR FOUR-MODULE FACILITIES

THIS FIGURE ILLUSTRATES THAT CENTRAL SITE FUEL CELL GENERATION OF ELECTRICITY HAS THE HIGHEST ANNUAL PRODUCTION COST. MEDIUM-BTU GAS (MBG) HAS THE LOWEST ANNUAL PRODUCT COST.


YEARLY SYNFUEL PRODUCTION COSTS
FOR FOUR-MODULE FACILITIES
ANNUAL COST
(BILLIONS OF INFLATED DOLLARS)
6.0
5.0
4.0
3.0
2.0
1.0
0
ELECTRICITY
GASOLINE
METHANOL
HYDROGEN
SNG
MBG
1980
1985
1990
1995
2000
2005
YEAR

EFFECT OF PARTIAL PLANT COMPLETION ON MBG PRODUCT COST

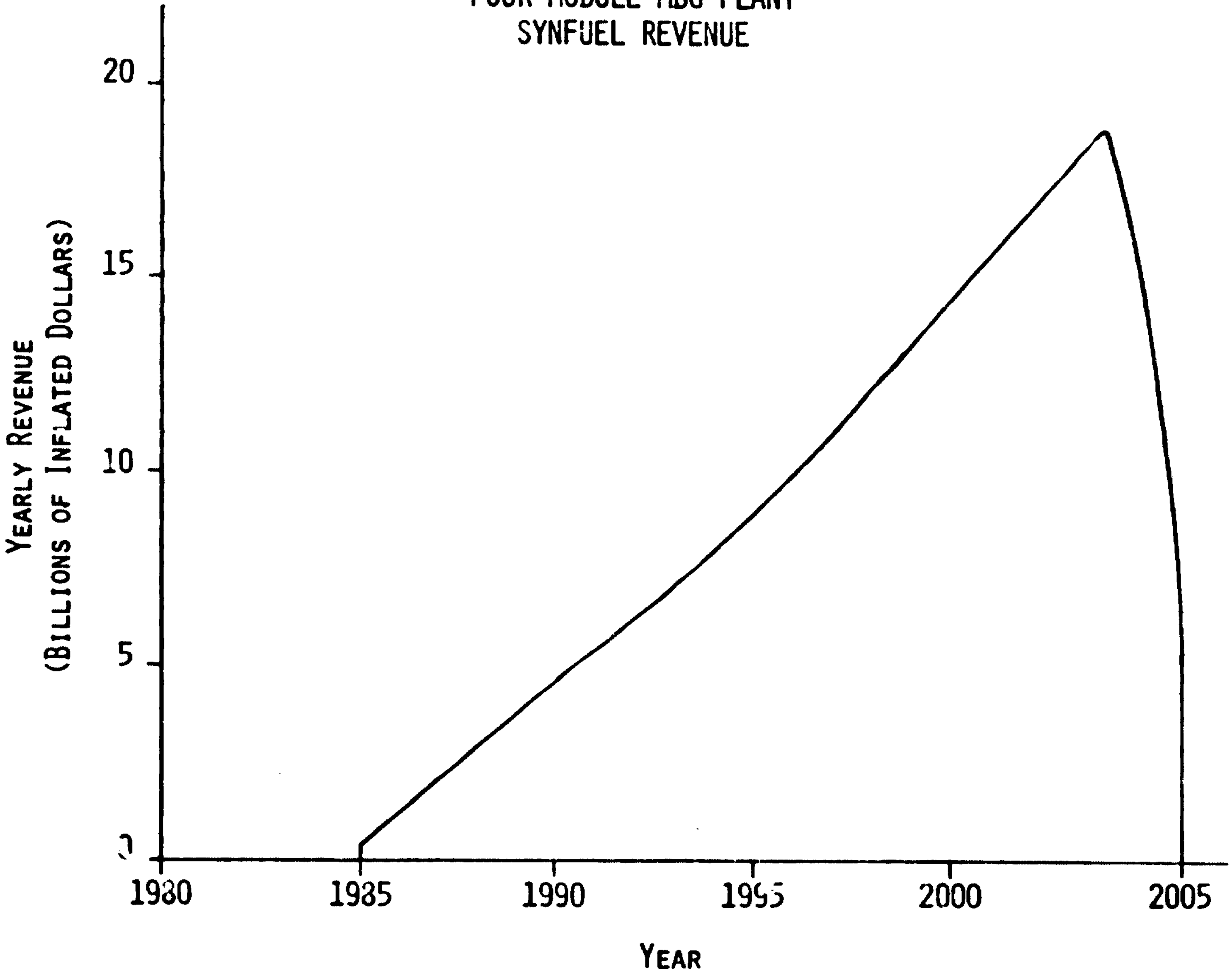
IF PLANT CONSTRUCTION WAS TO CEASE AFTER COMPLETION OF THE FIRST MODULE, THEN THIS FIGURE INDICATES THAT THE MAXIMUM INCREASE IN PRODUCT COST, ON A DOLLAR PER MILLION BTU BASIS, WOULD BE APPROXIMATELY 1 \$/MMBTU.


EFFECT OF PARTIAL PLANT
COMPLETION ON MBG PRODUCT COST
MBG COST
(INFLATED $/MMBTU)
13
12
11
10
9
8
(1985)
(1986)
(1987)
(1988)
(1989)
YEAR OF OPERATION
ONE-MODULE OPERATION
FOUR-MODULE OPERATION

FOUR-MODULE MBG PLANT
SYNFU' REVENUE

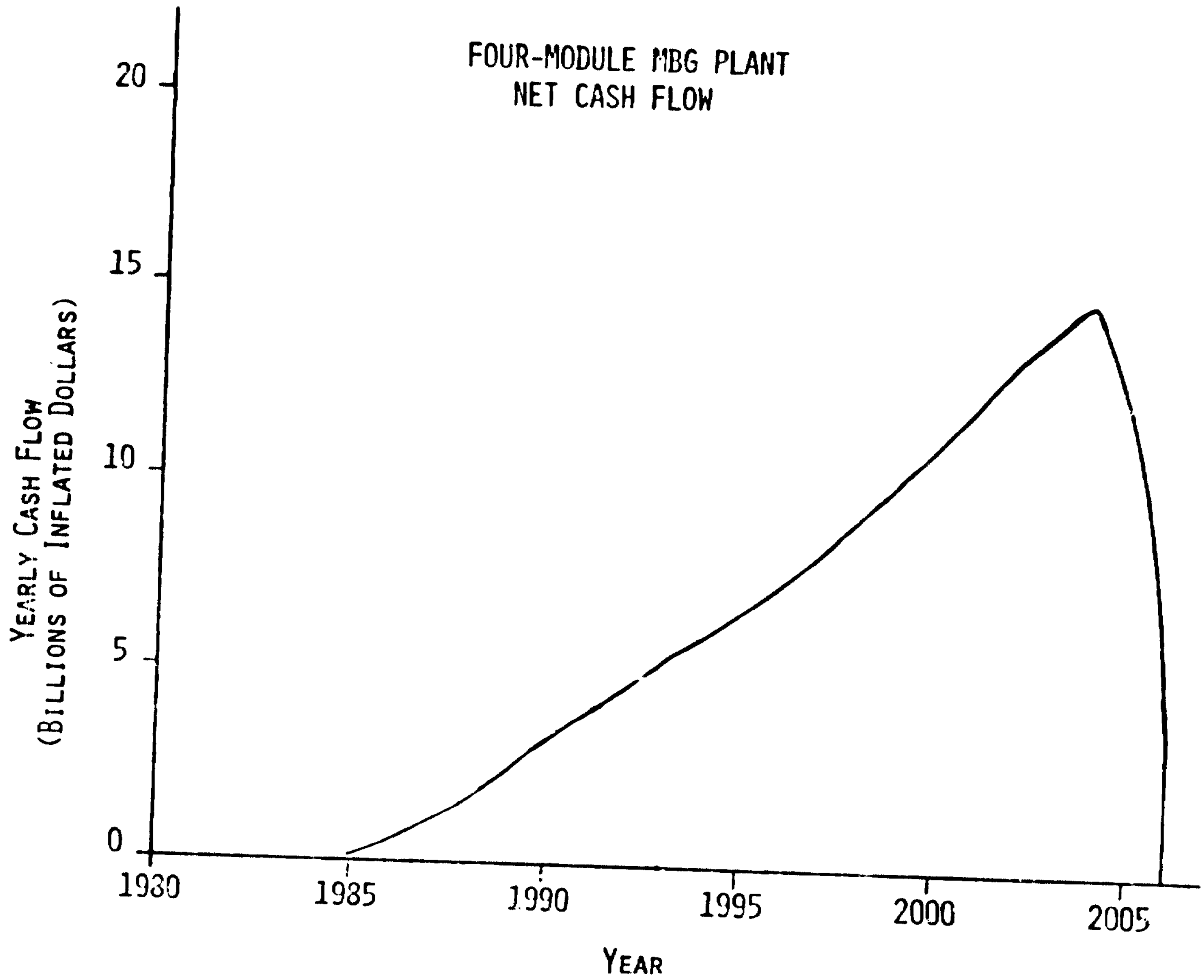
THIS REVENUE IS ASSUMED TO BE GENERATED BY SELLING ALL OF THE PLANT'S OUTPUT AT THE PREVAILING PRICE, ON A $/MMBTU BASIS, OF NATURAL GAS. THE MAXIMUM YEARLY GENERATED REVENUE IS APPROXIMATELY 20 BILLION DOLLARS.

FOUR-MODULE MBG PLANT
SYNFUEL REVENUE



FOUR-MODULE MBG PLANT
NET CASH FLOW

THIS FIGURE ILLUSTRATES TWO KEY POINTS CONCERNING THE YEARLY NET CASH FLOW OF THE MBG PLANT, AFTER THE PLANT STARTS OPERATING. THE FIRST POINT IS THAT THE YEARLY NET CASH FLOW, AFTER THE START OF OPERATION, IS ALWAYS POSITIVE. SECONDLY, THE MAGNITUDE OF THE CASH FLOW IS VERY LARGE, PEAKING OUT AT APPROXIMATELY 15 BILLION DOLLARS PER YEAR. THIS LARGE POSITIVE CASH FLOW IS A CONSEQUENCE OF: (1) ASSUMING THAT, ON A \$/MMBTU BASIS, THE MBG CAN BE SOLD AT THE SAME PRICE AS THE PREVAILING NATURAL GAS PRICES; AND, (2) ASSUMING THAT FUTURE NATURAL GAS PRICES WILL ESCALATE AT THE RATES PREDICTED BY DATA RESOURCES, INC.



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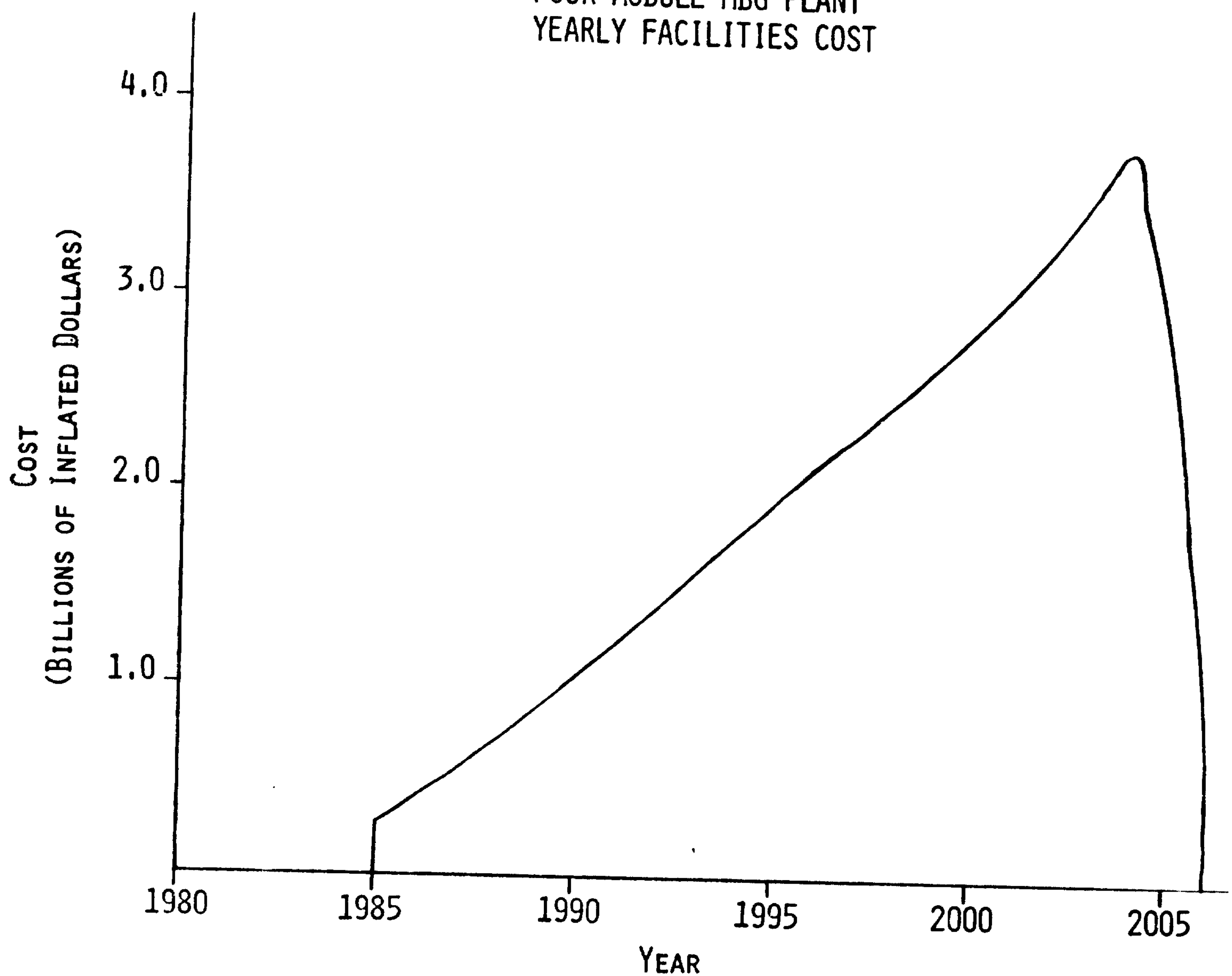
FOUR-MODULE MBG PLANT
YEARLY FACILITIES COST

THE ANNUAL COST OF OPERATING THE MBG FACILITY PEAKS OUT AT APPROXIMATELY 4 BILLION DOLLARS PER YEAR.

FOUR-MODULE MBG PLANT
YEARLY FACILITIES COST



EFFECT OF YEARLY O&M COSTS ON COST OF MBG

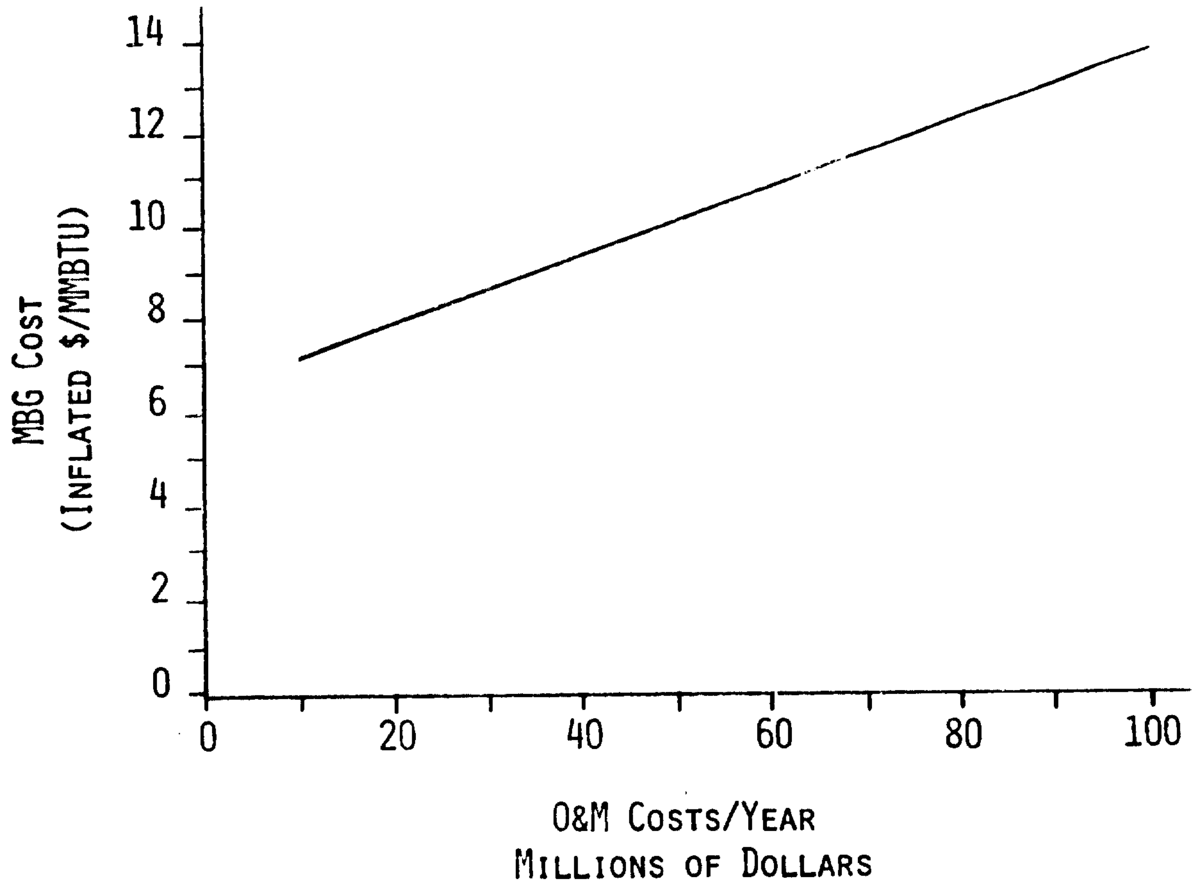
The sensitivity of the overall cost of medium-BTU gas to changes in the cost of operating and maintaining the gasification facility is analyzed in this figure. The yearly O&M costs are in 1980 dollars. From the figure, the following formulas can be derived:

Change in O&M Costs = $\Delta(OM) = 100 - 10 = 90$
(in millions of 1980 dollars)

Change in Overall Costs = $\Delta C = 13 - 7 = 6$ \$/MMBTU

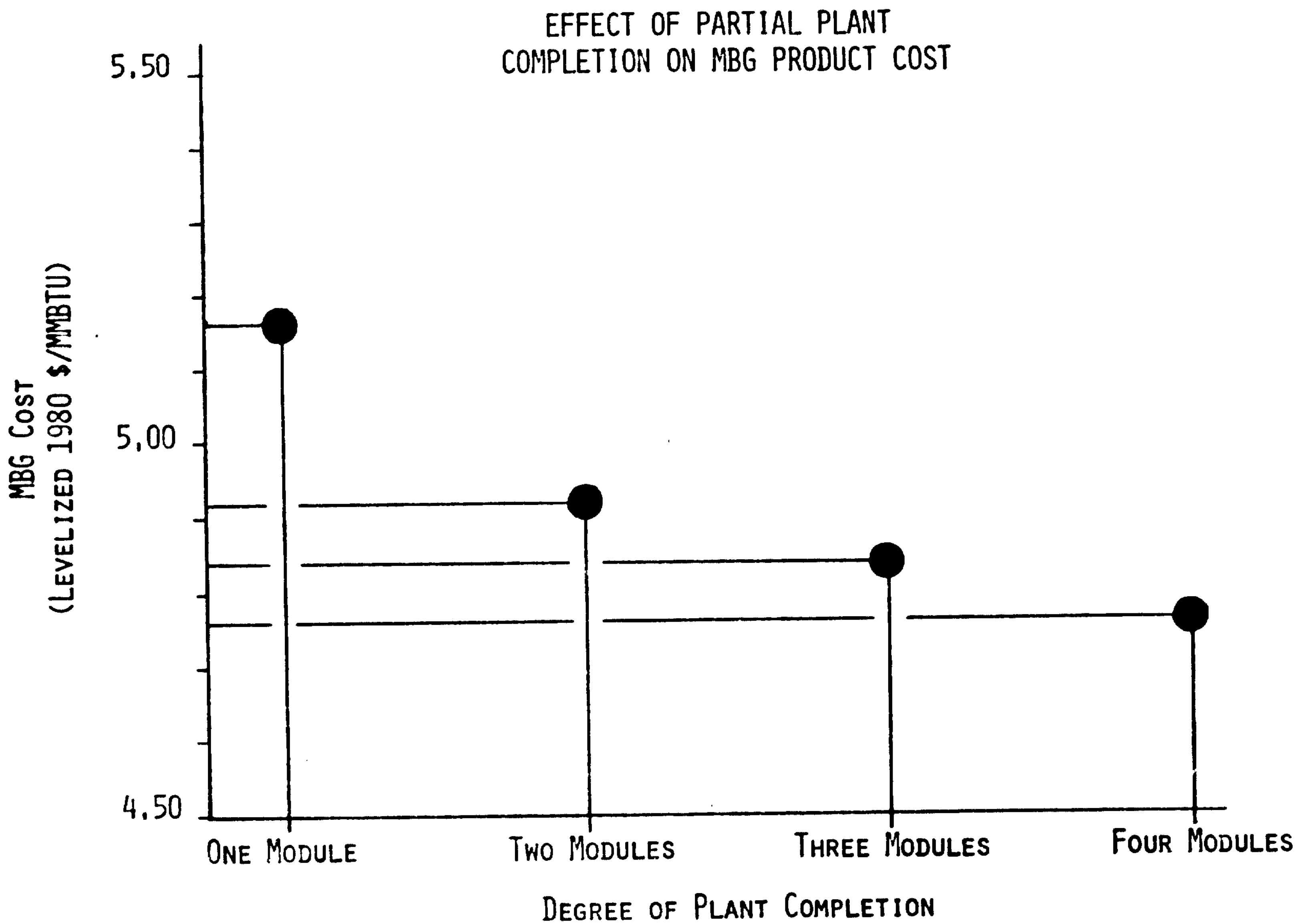
$$\Delta C / \Delta(OM) = \frac{6}{90} = .06667$$

EFFECT OF YEARLY O&M COSTS ON
COST OF MBG



EFFECT OF PARTIAL PLANT COMPLETION ON MBG PRODUCT COST

THE SENSITIVITY OF THE OVERALL MBG PRODUCT COST TO PARTIAL PLANT COMPLETION IS ANALYZED HERE. THE EFFECT OF COMPLETING ONLY ONE MODULE, INSTEAD OF THE ORIGINALLY SCHEDULED FOUR MODULES, IS TO RAISE THE COST OF THE MBG, ON A LEVELIZED $/MMBTU BASIS, FROM APPROXIMATELY $4.75 TO APPROXIMATELY $5.17.



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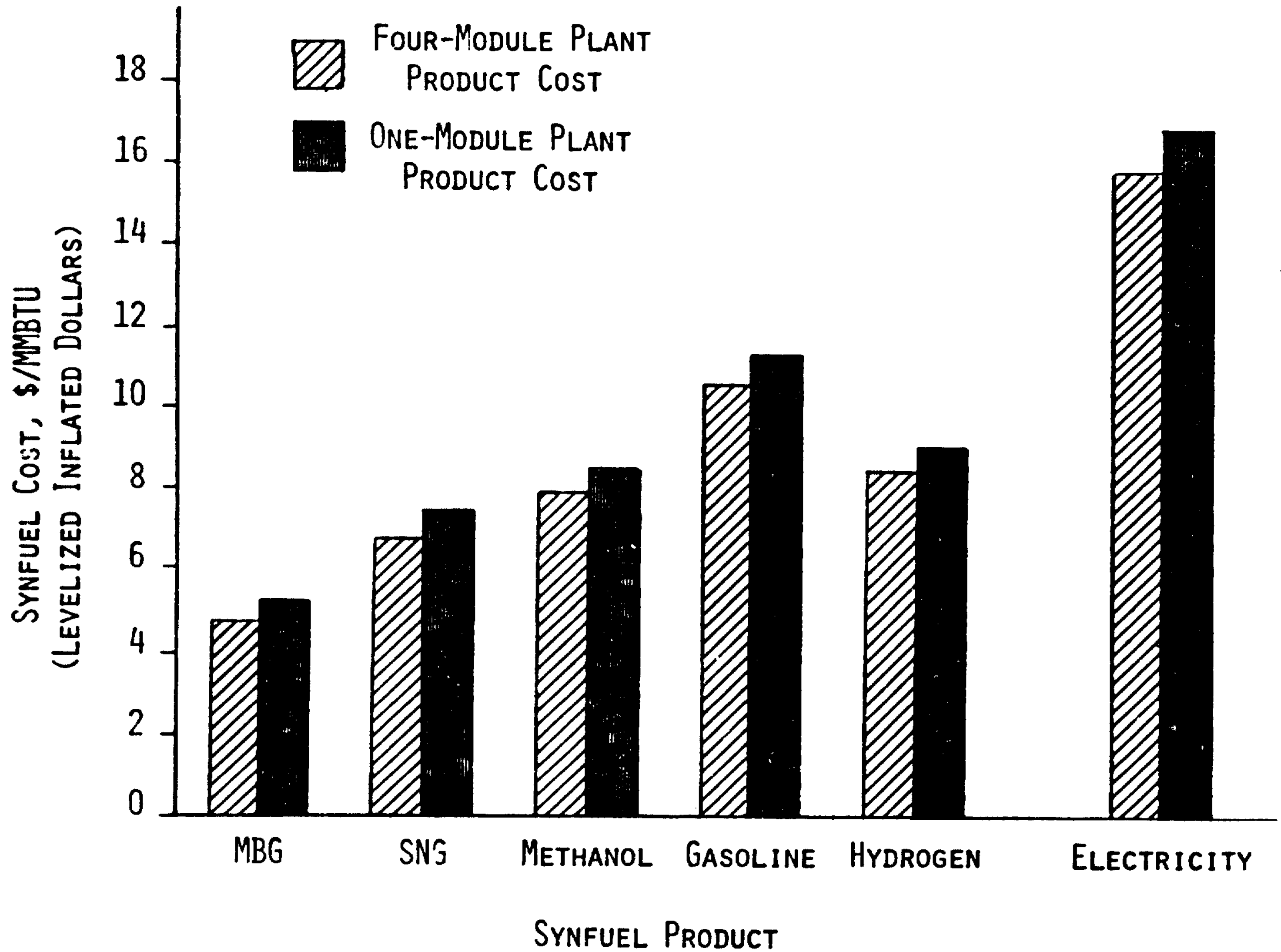
EFFECT OF PARTIAL PLANT COMPLETION ON SYNFUEL COST

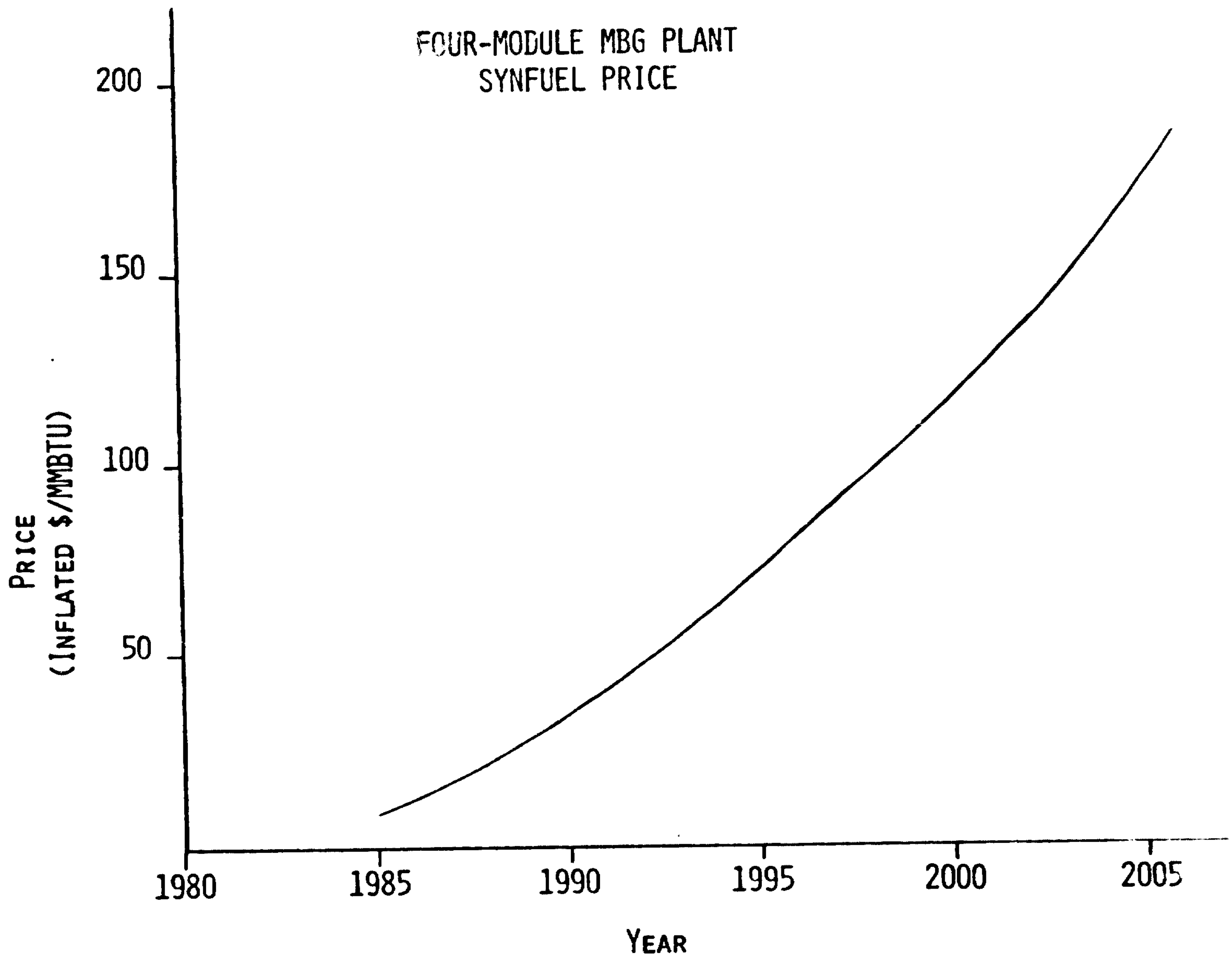
THE EFFECT OF COMPLETING ONLY ONE MODULE, INSTEAD OF THE ORIGINALLY SCHEDULED FOUR MODULES, FOR MBG AND THE ALTERNATE SYNFUEL PRODUCTS CONSIDERED IN THIS STUDY, IS SHOWN IN THIS FIGURE. ON A $/MMBTU BASIS, THE EFFECT IS APPROXIMATELY $1/MMBTU OR LESS LEVELIZED IN ALL CASES.

EFFECT OF PARTIAL PLANT
COMPLETION ON SYNFUEL COST



FOUR-MODULE MBG PLANT
SYNFUEL PRICE

THIS FIGURE ILLUSTRATES THE RAPID INCREASE IN THE MARKETABLE SELLING PRICE OF MBG IF: (1) IT IS ASSUMED TO SELL AT EXACTLY THE SAME PRICE (ON A $/MMBTU BASIS) AS NATURAL GAS; AND, (2) THE FUTURE PRICE INCREASES IN NATURAL GAS ARE BASED ON RECENT PROJECTIONS BY DATA RESOURCES, INC.


FOUR-MODULE MBG PLANT
SYNFUEL PRICE
200
150
100
50
PRICE
(INFLATED $/MMBTU)
1980
1985
1990
1995
2000
2005
YEAR

FOUR-MODULE MBG PLANT
SYNFUEL PRODUCTION COST

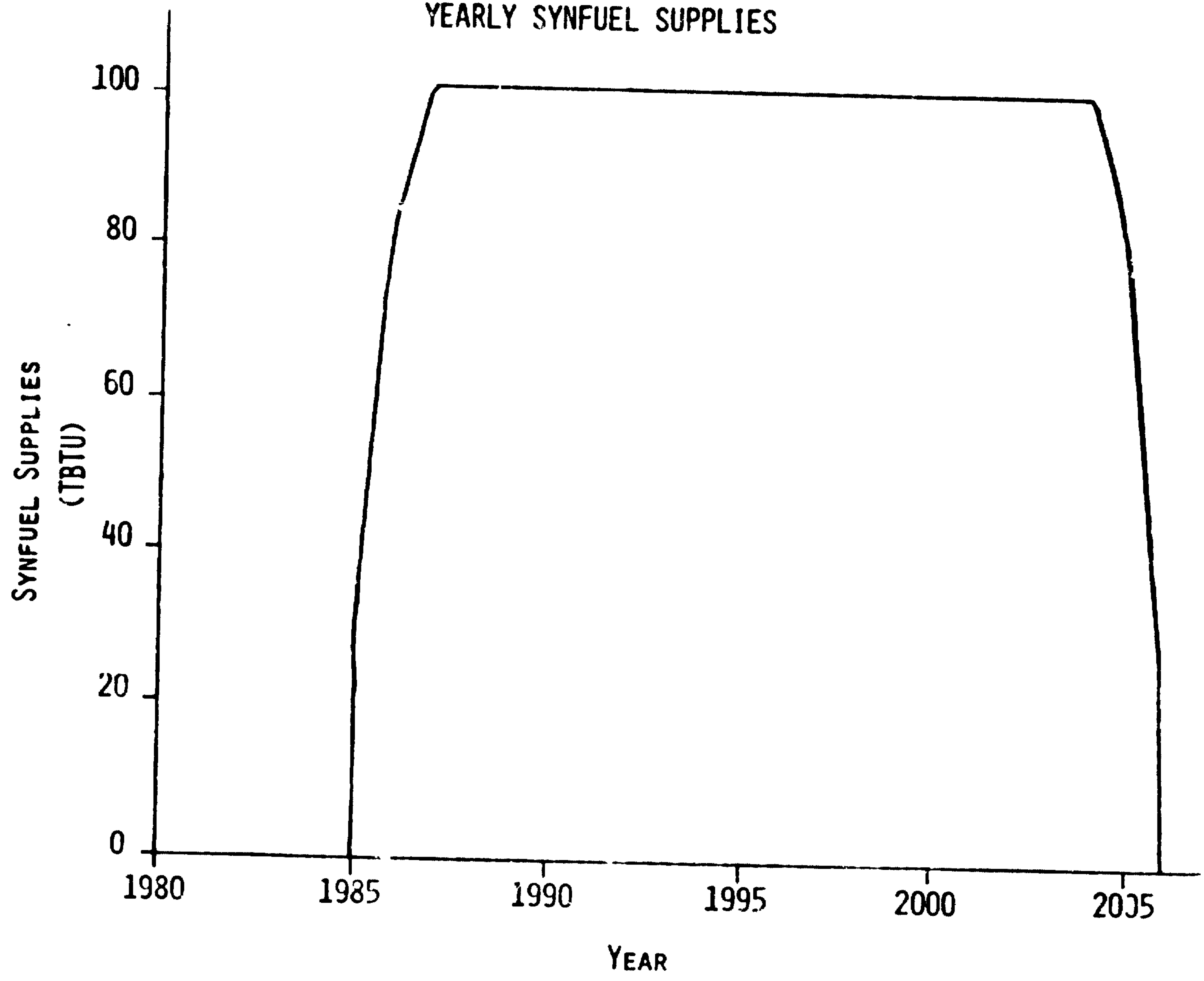
THE YEARLY ANNUAL COST OF PRODUCING MBG RISES FROM APPROXIMATELY 10 $/MMBTU (IN INFLATED DOLLARS) TO SLIGHTLY OVER 40 $/MMBTU DURING THE LIFETIME OF THE PLANT. THIS COST INCREASE IS CAUSED BY ESCALATION IN COAL COSTS AND OTHER O&M COSTS, SUCH AS IMPORTED ELECTRICITY.

FOUR-MODULE MBG PLANT
SYNFUEL PRODUCTION COST

FOUR-MODULE MBG PLANT
YEARLY SYNFUEL SUPPLIES

ASSUMING THAT THE MBG FROM THIS PLANT IS PRODUCED BY KOPPERS-TOTZEK GASIFIERS, THEN, AFTER ALL FOUR MODULES ARE OPERATING, THE YEARLY OUTPUT OF MBG, IN BILLIONS OF BTU, IS APPROXIMATELY 101 TRILLION BTU'S PER YEAR.

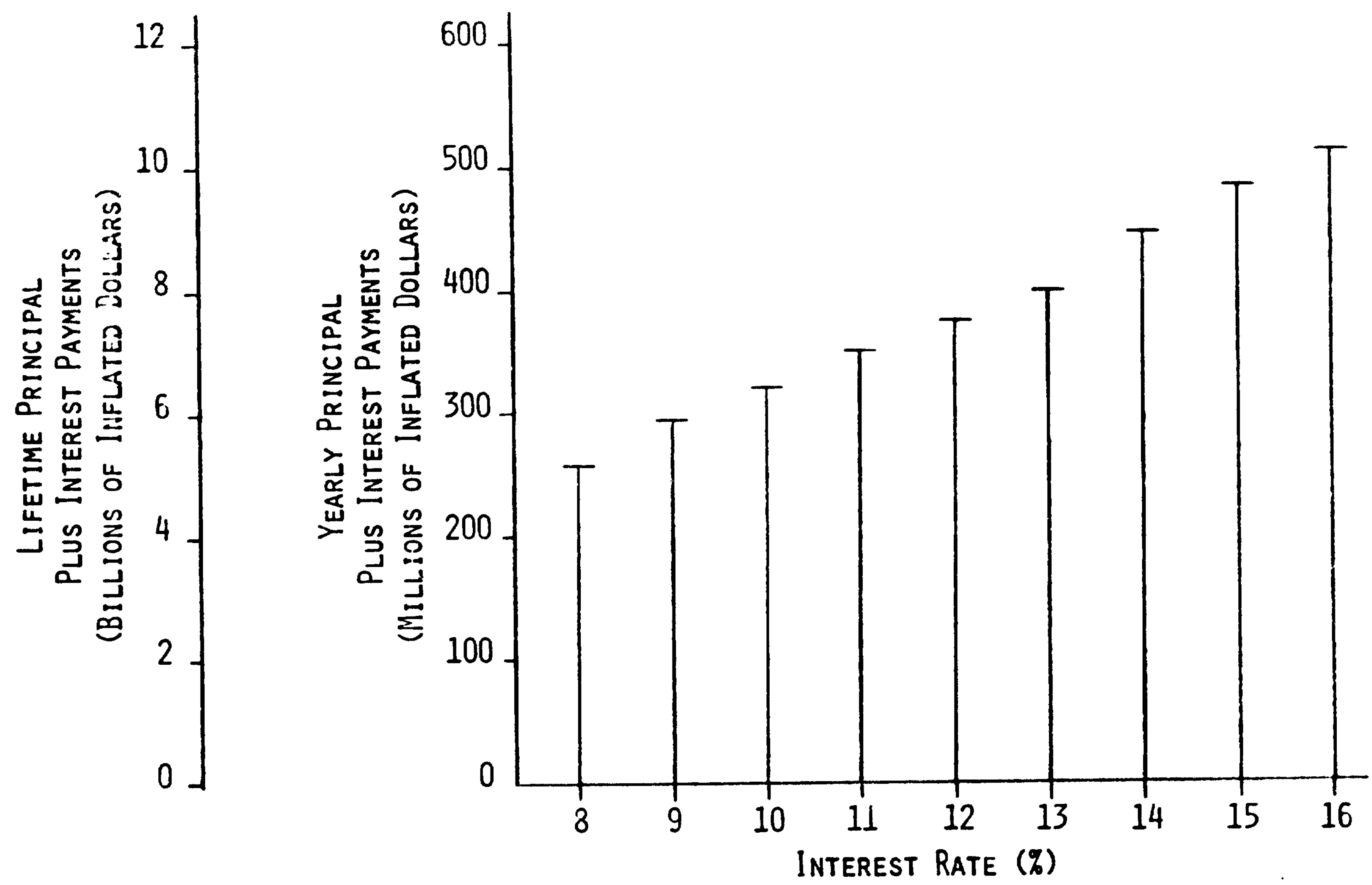
FOUR-MODULE MBG PLANT
YEARLY SYNFUEL SUPPLIES



SENSITIVITY OF LOAN PAYMENTS TO INTEREST RATES
FOUR-MODULE MBG PLANT

THIS FIGURE INDICATES THAT YEARLY DEBT REPAYMENTS INCREASE FROM 250 MILLION DOLLARS PER YEAR TO APPROXIMATELY 525 MILLION DOLLARS PER YEAR IF THE INTEREST RATES ON THE BORROWED MONEY INCREASE FROM 8% A YEAR TO 16% A YEAR.

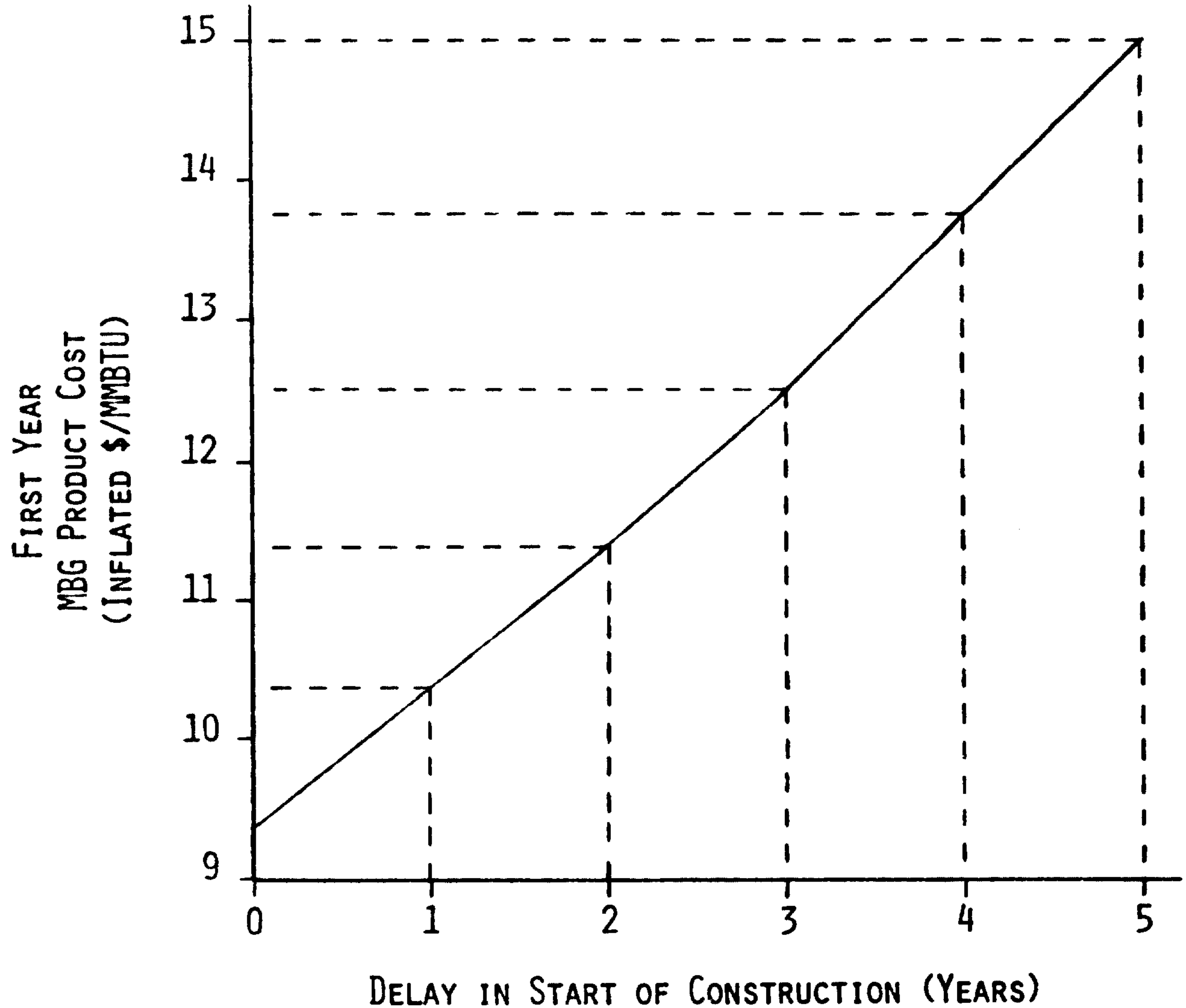
SENSITIVITY OF LOAN PAYMENTS TO INTEREST RATES
FOUR-MODULE MBG PLANT



SENSITIVITY OF MBG PRODUCT COST TO DELAYS IN START OF CONSTRUCTION FOR FOUR-MODULE FACILITY

ONE PARAMETER OF INTEREST IS THE "FIRST YEAR MBG PRODUCT COST" BECAUSE IT IS DESIRED THAT THIS COST OF PRODUCTION BE AT A LEVEL THAT WOULD ALLOW THE PRODUCT TO BE SOLD AT A MARKET PRICE AT WHICH A FINANCIAL LOSS WOULD NOT BE SUSTAINED. THIS FIGURE SHOWS THAT THE FIRST YEAR PRODUCT COST, IN INFLATED DOLLARS, RISES FROM APPROXIMATELY $9.30 PER MMBTU TO $15/MMBTU, IF THE INITIAL START OF PLANT CONSTRUCTION IS DELAYED FOR FIVE YEARS. THIS ASSUMES AN 8% ANNUAL INCREASE IN CONSTRUCTION COSTS.

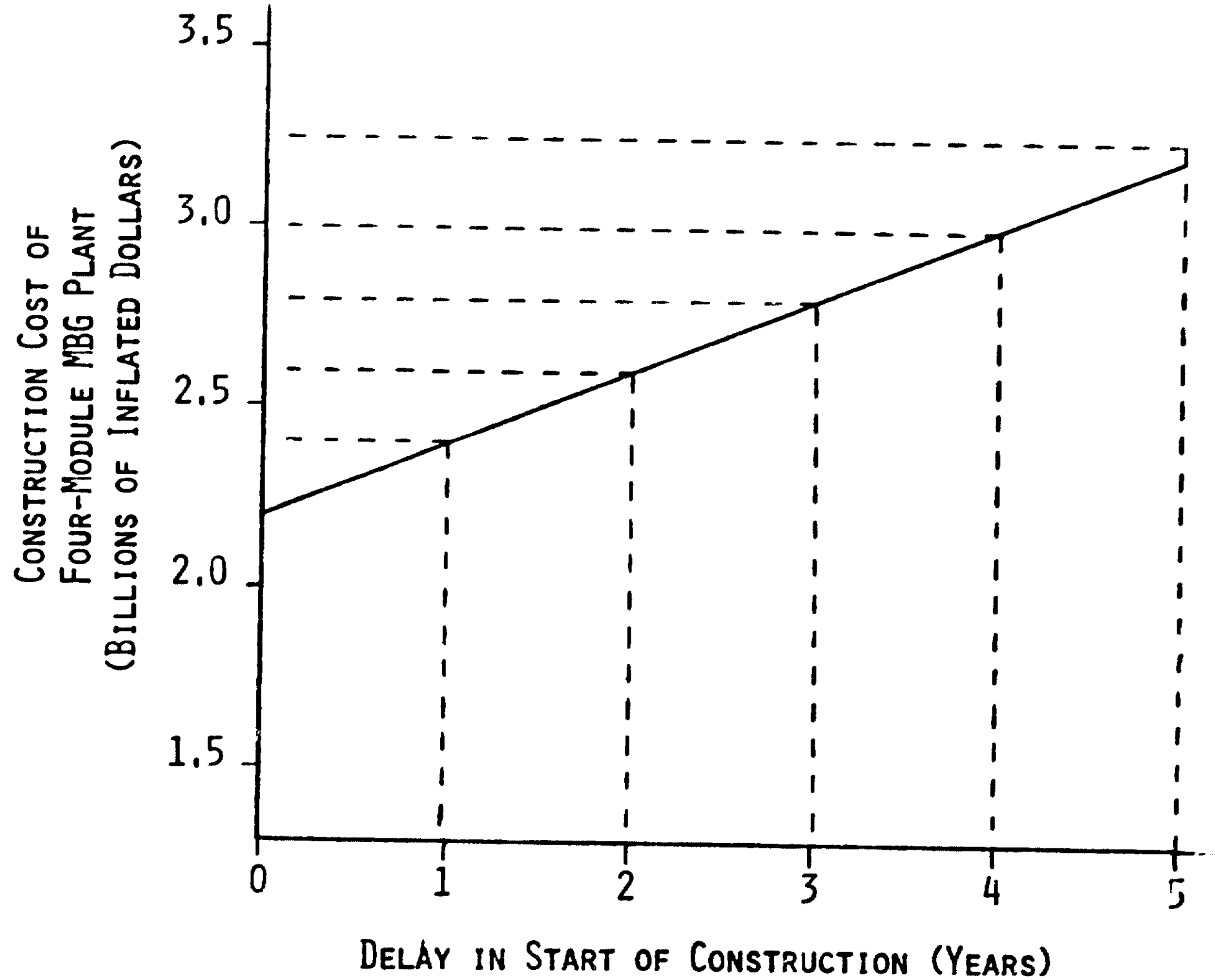
SENSITIVITY OF MBG PRODUCT COST
TO DELAYS IN START OF CONSTRUCTION
FOR FOUR-MODULE FACILITY



SENSITIVITY OF FOUR-MODULE MBG FACILITY TO DELAYS IN START OF CONSTRUCTION

THIS FIGURE ILLUSTRATES THAT THE CONSTRUCTION COST OF A FOUR-MODULE MBG FACILITY, IN INFLATED DOLLARS, INCREASES FROM APPROXIMATELY 2.2 BILLION DOLLARS TO 3.2 BILLION DOLLARS IF CONSTRUCTION IS DELAYED FOR FIVE YEARS. THIS ASSUMES AN 8% ANNUAL INCREASE IN CONSTRUCTION COSTS.

SENSITIVITY OF FOUR-MODULE MBG
FACILITY TO DELAYS IN START OF CONSTRUCTION



SENSITIVITY OF CUMULATIVE NET CASH FLOW TO OVERALL PROCESS EFFICIENCY

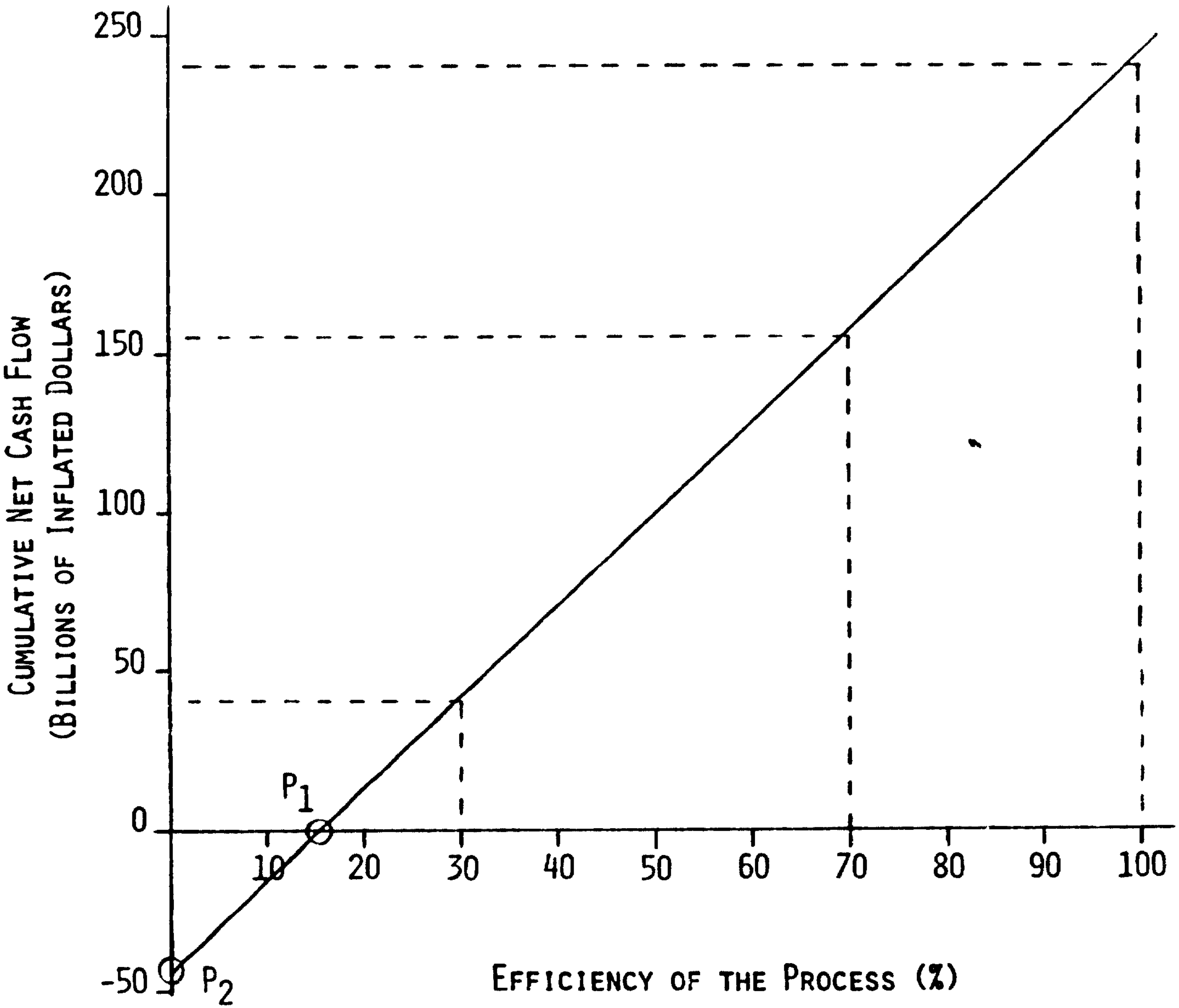
THIS FIGURE ILLUSTRATES SEVERAL IMPORTANT FEATURES ABOUT THE LIFE CYCLE ECONOMICS OF THE FOUR-MODULE MBG FACILITY. SOME OF THE MOST IMPORTANT OBSERVATIONS ARE SUMMARIZED BELOW:

(1) A DROP IN CONVERSION EFFICIENCY FROM 90% TO 70% RESULTS IN A LOSS OF APPROXIMATELY 75 BILLION DOLLARS OVER THE LIFETIME OF THE PLANT OR APPROXIMATELY 33% (75 BILLION/225 BILLION) OF THE "PROFIT" OF THE PLANT.

(2) SINCE THE MBG IS ASSUMED TO BE SOLD AT EXTREMELY HIGH PROJECTED NATURAL GAS PRICES (BASED ON PROJECTIONS BY DATA RESOURCES, INC.), THE CONVERSION EFFICIENCY AT WHICH THE LIFE CYCLE REVENUES EQUAL THE LIFE CYCLE COSTS (THE BREAK-EVEN POINT) IS VERY LOW, APPROXIMATELY 15% (SEE POINT P1 ON THE FIGURE).

(3) IF THE CONVERSION EFFICIENCY WAS ZERO, THEN THIS POINT GIVES THE LIFE CYCLE COSTS OF OPERATING THE PLANT. THIS IS POINT P2 ON THE FIGURE, AND WE SEE THAT THE LIFE CYCLE COSTS OF OPERATING THIS MBG FACILITY IS APPROXIMATELY 50 BILLION DOLLARS (IN INFLATED DOLLARS).

SENSITIVITY OF CUMULATIVE
NET CASH FLOW TO OVERALL
PROCESS EFFICIENCY



POTENTIAL COAL-DERIVED SYNFUEL PRODUCTS

THE SIX (6) PRODUCTS ON THIS CHART ARE THE ONES WHICH WERE ANALYZED IN THIS STUDY UTILIZING THE SYNFUEL ECONOMIC EVALUATION MODEL (SEEM).

POTENTIAL COAL-DERIVED SYNFUEL PRODUCTS

(1) Medium-BTU Gas (MBG)

(2) Synthetic Natural Gas (SNG)

(3) Methanol

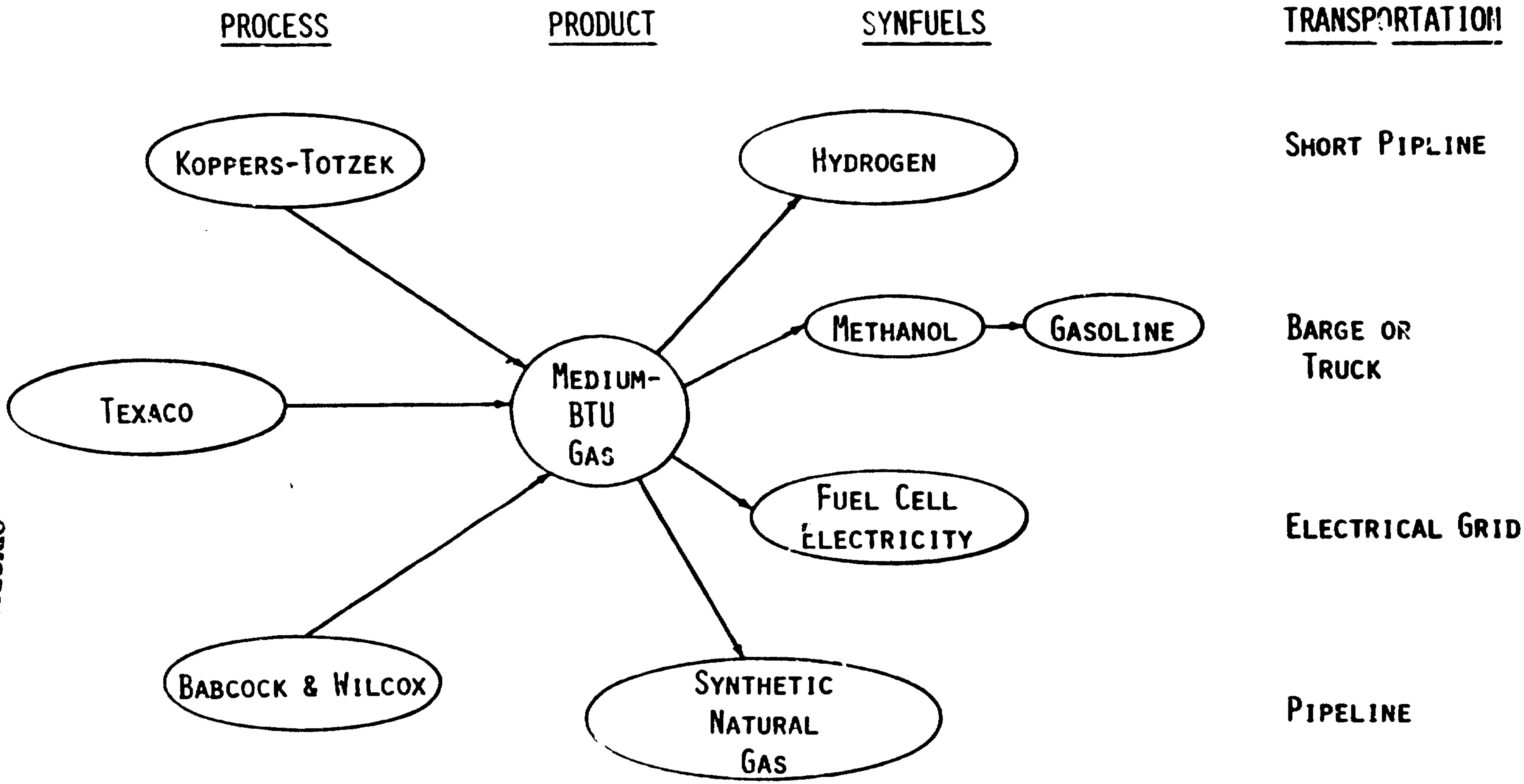
(4) Gasoline

(5) Hydrogen

(6) Fuel Cell Electricity

PROCESS - PRODUCT - SYNFUELS - TRANSPORTATION

THIS CHART ILLUSTRATES THAT DIFFERENT GASIFICATION PROCESSES, SUCH AS KOPPERS-TOTZEK, TEXACO, AND BABCOCK & WILCOX, CAN ALL BE UTILIZED TO PRODUCE MEDIUM-BTU GAS (MBG). THIS MBG CAN IN TURN BE CONVERTED INTO MANY OTHER USEFUL PRODUCTS, SUCH AS METHANOL, GASOLINE, ETC.


PROCESS
PRODUCT
SYNFUELS
TRANSPORTATION
KOPPERS-TOTZEK
TEXACO
BABCOCK & WILCOX
MEDIUM-BTU GAS
HYDROGEN
METHANOL
GASOLINE
FUEL CELL ELECTRICITY
SYNTHETIC NATURAL GAS
SHORT PIPLINE
BARGE OR TRUCK
ELECTRICAL GRID
PIPELINE

SYNFUELS SCENARIOS

THIS CHART ILLUSTRATES SOME OF THE POTENTIAL PRODUCTS WHICH THE VARIOUS MODULES OF THIS COAL GASIFICATION FACILITY COULD PRODUCE. ADDITIONALLY, POTENTIAL CUSTOMERS FOR THE MODULE OUTPUTS ARE SHOWN, AS WELL AS PRODUCT TRANSPORTATION MODES.

SYNFUELS SCENARIOS

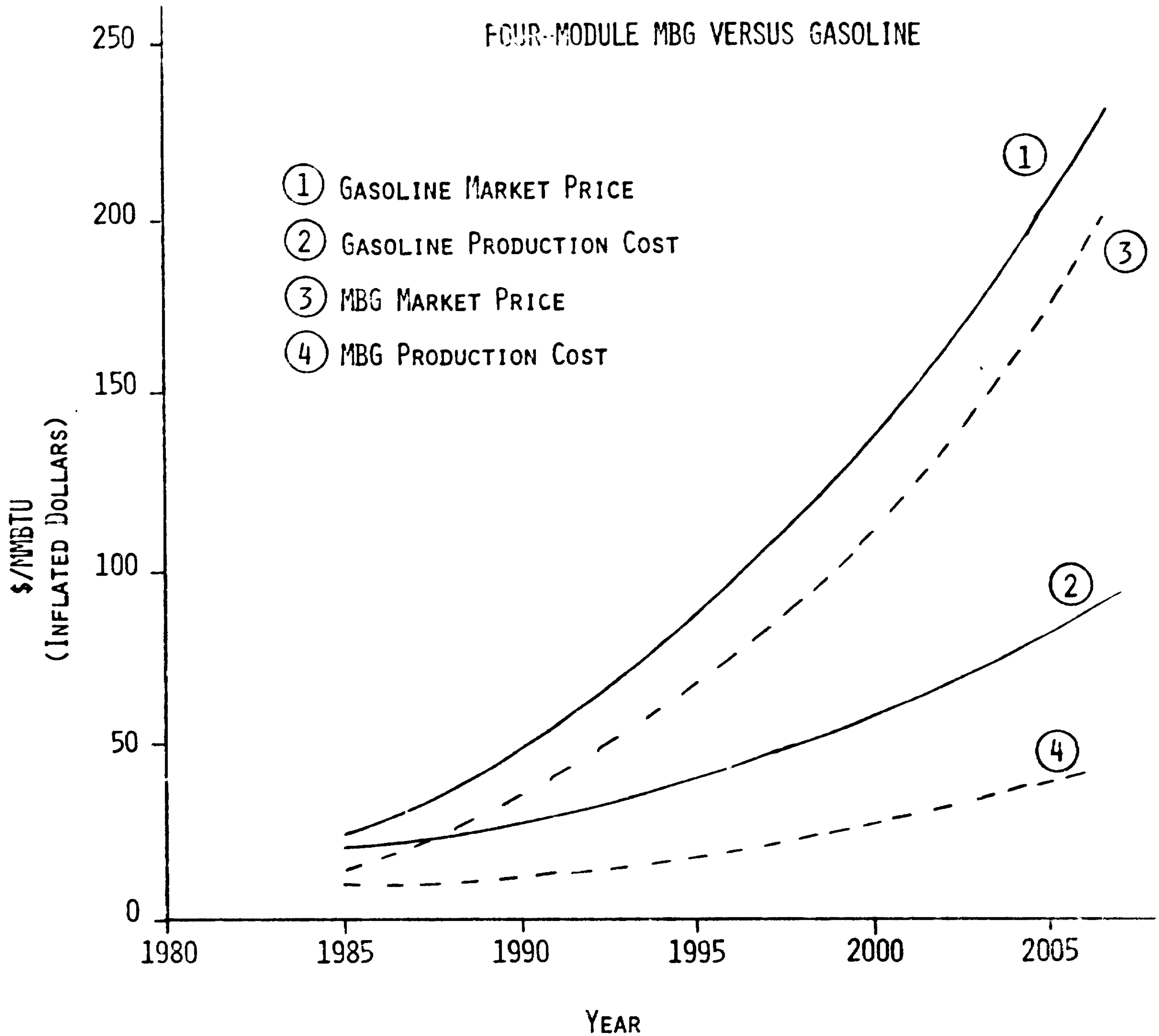
MODULE/PRODUCT	CUSTOMER	TRANSPORTATION
1. MBG 2. MBG 3. MBG 4. FUEL CELL ELECTRICITY	PIPELINE COMPANY CHEMICAL COMPANY NORTHERN ALA. INDUSTRIES TVA	SHORT PIPELINE SHORT PIPELINE PIPELINE ELECTRICAL GRID
1. MBG 2. MBG 3. SNG 4. SNG	NORTHERN ALA. INDUSTRIES " " " PIPELINE COMPANY " "	PIPELINE " SHORT PIPELINE " "
1. MBG 2. MBG 3. MBG 4. MBG	INDUSTRIES IN SOUTH CENTRAL TENN. & NORTHERN ALA. & NORTHERN ALA.	EXTENSIVE PIPELINES
1. METHANOL 2. METHANOL 3. GASOLINE 4. GASOLINE	INDUSTRIES " GASOLINE DISTRIBUTOR " "	BARGE OR TRUCK BARGE
1. MBG 2. MBG 3. HYDROGEN 4. HYDROGEN	INDUSTRIES " " "	PIPELINE " " "
1. FUEL CELL 2. " 3. " 4. "	TVA " " "	ELECTRICAL GRID
1. SNG 2. " 3. " 4. "	PIPELINE COMPANY " " " " " "	SHORT PIPELINE " " " " " "

FOUR-MODULE MBG VERSUS GASOLINE

THIS FIGURE ILLUSTRATES THAT FROM THE STANDPOINT OF "PROFIT", THAT IS, PRICE MINUS COST, MBG AND SYNTHETIC GASOLINE ARE APPROXIMATELY EQUIVALENT. THAT IS, THE DELTA DIFFERENCE, ON A $/MMBTU BASIS, BETWEEN THE MBG COST AND PRICE CURVES IS ABOUT THE SAME AS BETWEEN THE GASOLINE COST AND PRICE CURVES. HOWEVER, TWO CAVEATS SHOULD BE NOTED WHEN INTERPRETING THESE CURVES:

(1) MBG PIPELINE AND USER RETROFIT COSTS HAVE NOT BEEN CONSIDERED.

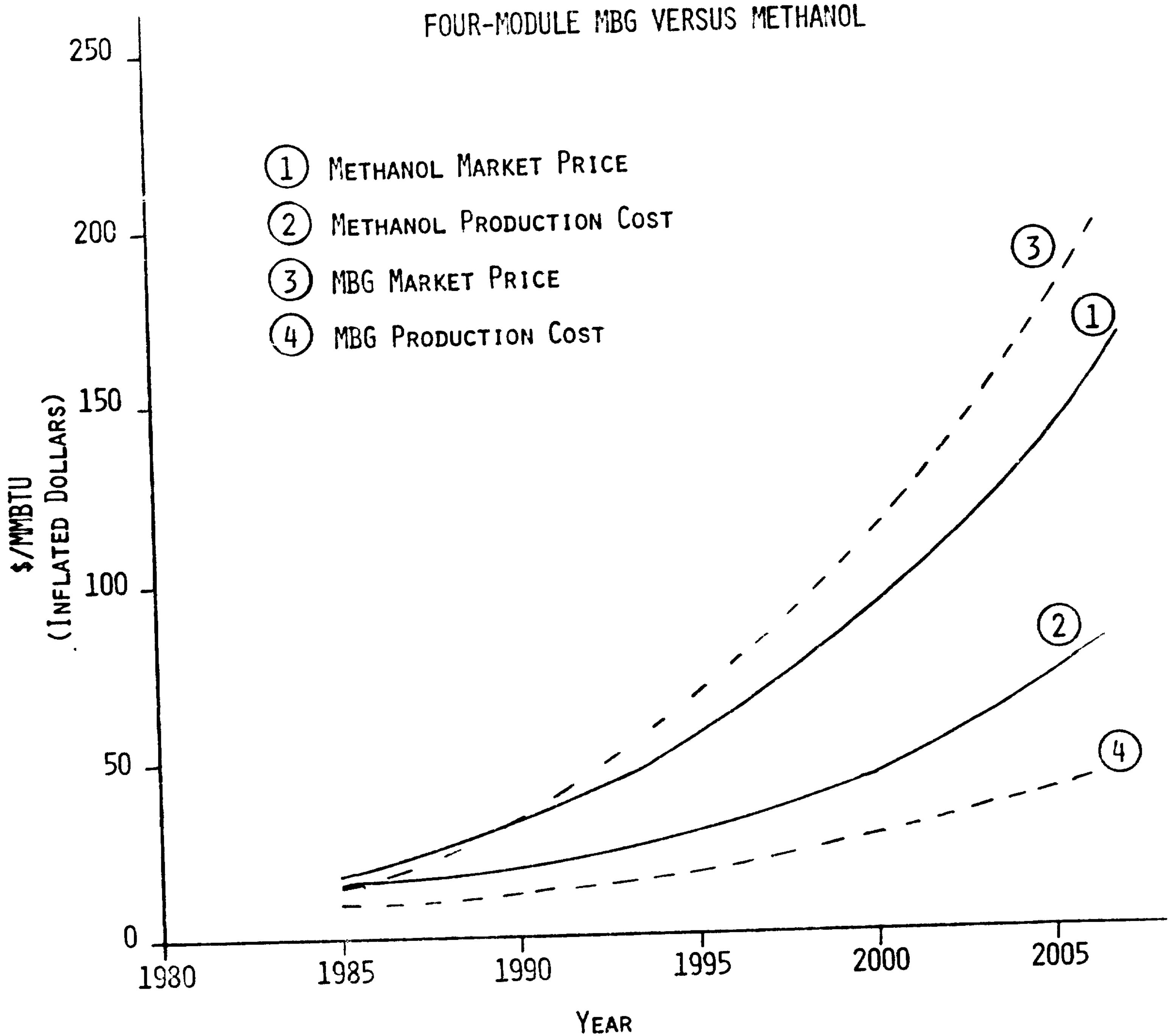
(2) THE QUANTITY OF BTU'S PRODUCED BY AN MBG PLANT IS MUCH HIGHER THAN THE QUANTITY PRODUCED BY A GASOLINE PLANT OF SIMILAR SIZE.



FOUR-MODULE MBG VERSUS GASOLINE
① GASOLINE MARKET PRICE
② GASOLINE PRODUCTION COST
③ MBG MARKET PRICE
④ MBG PRODUCTION COST
$/MMBTU
(INFLATED DOLLARS)
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
YEAR

FOUR-MODULE MBG VERSUS METHANOL

THIS CHART COMPARES THE RELATIVE ECONOMICS OF MBG AND METHANOL WHEN BOTH ARE PRODUCED BY A 20,000 TON PER DAY COAL CONVERSION FACILITY. IN THIS PARTICULAR CASE, THE METHANOL, ON A $/MMBTU BASIS, COSTS MORE TO PRODUCE THAN MBG WHILE IT SELLS FOR LESS.



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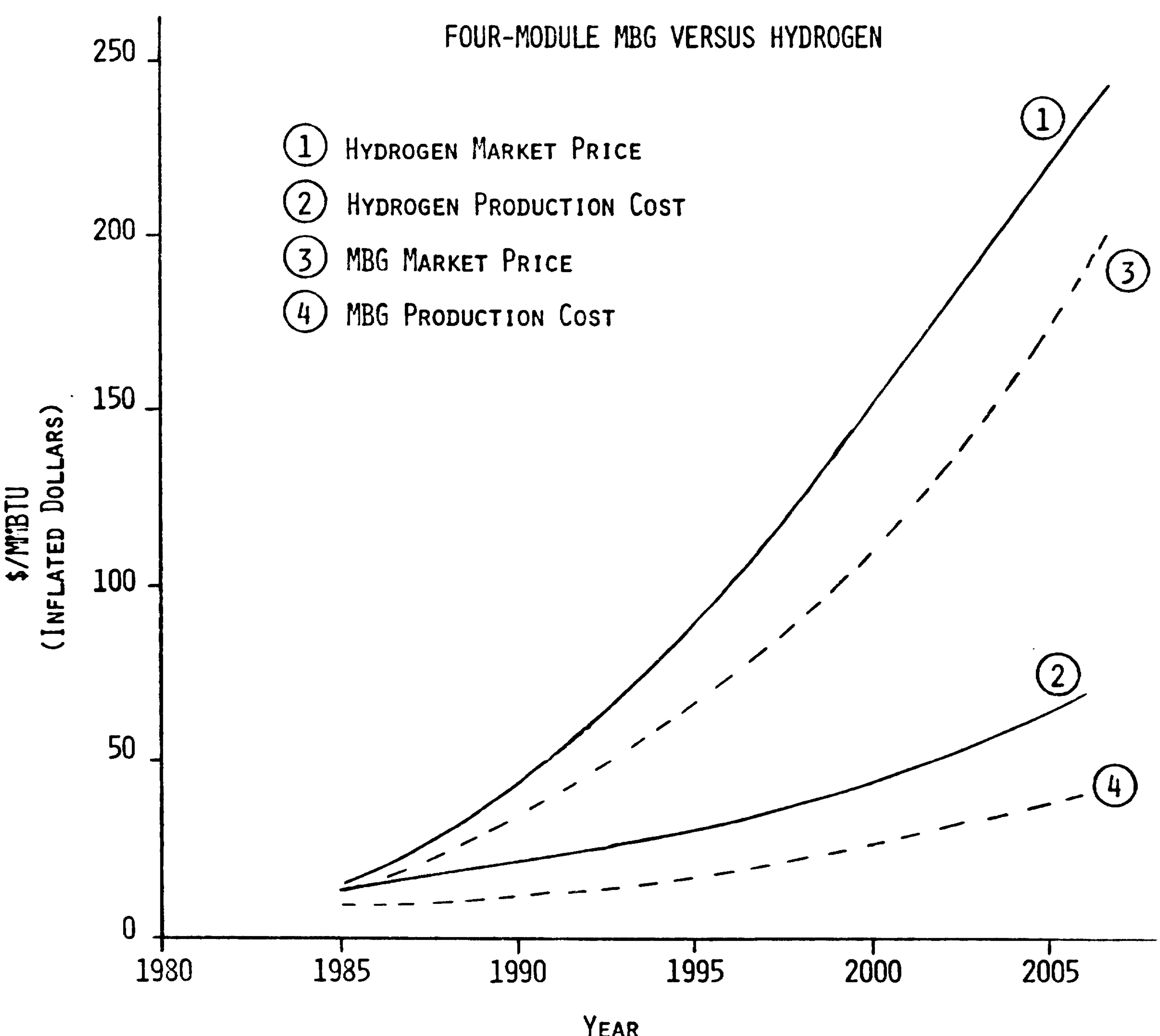
FOUR-MODULE MBG VERSUS HYDROGEN

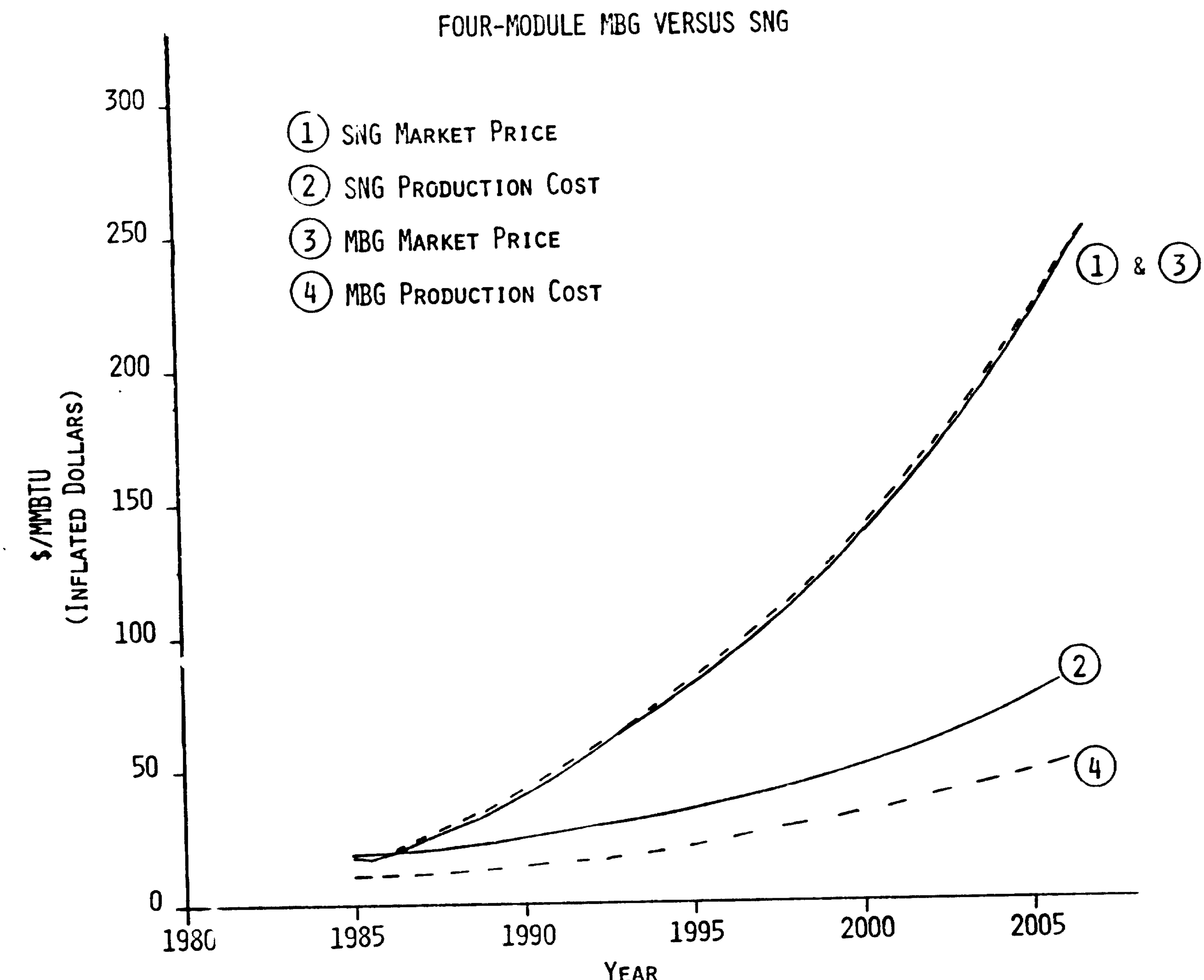
THIS FIGURE COMPARES THE RELATIVE ECONOMICS OF A 20,000 TON PER DAY MBG PLANT WITH A PLANT WHICH UTILIZES THE SAME AMOUNT OF COAL TO PRODUCE PURE HYDROGEN. IN THIS CASE, THE HYDROGEN COSTS MORE TO PRODUCE BUT IT IS ALSO ASSUMED TO SELL AT A PREMIUM TO NATURAL GAS BECAUSE IT IS A "CLEANER" FUEL, PRODUCING NO CO_2 DURING COMBUSTION AND ALSO BECAUSE IT COULD BE UTILIZED AS A CHEMICAL FEEDSTOCK WITHOUT FURTHER CHEMICAL DECOMPOSITION. THUS, THE RELATIVE ECONOMICS OF THE MBG AND HYDROGEN FACILITY APPEAR TO BE APPROXIMATELY EQUALLY ATTRACTIVE. (IT SHOULD BE NOTED THAT THE RELATIVE DEMAND FOR THESE PRODUCTS BY THE USER COMMUNITY IS NOT EXAMINED HERE.)



FOUR-MODULE MBG VERSUS HYDROGEN
1 Hydrogen Market Price
2 Hydrogen Production Cost
3 MBG Market Price
4 MBG Production Cost
$/MMBTU
(Inflated Dollars)
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
Year

FOUR-MODULE MBG VERSUS SNG

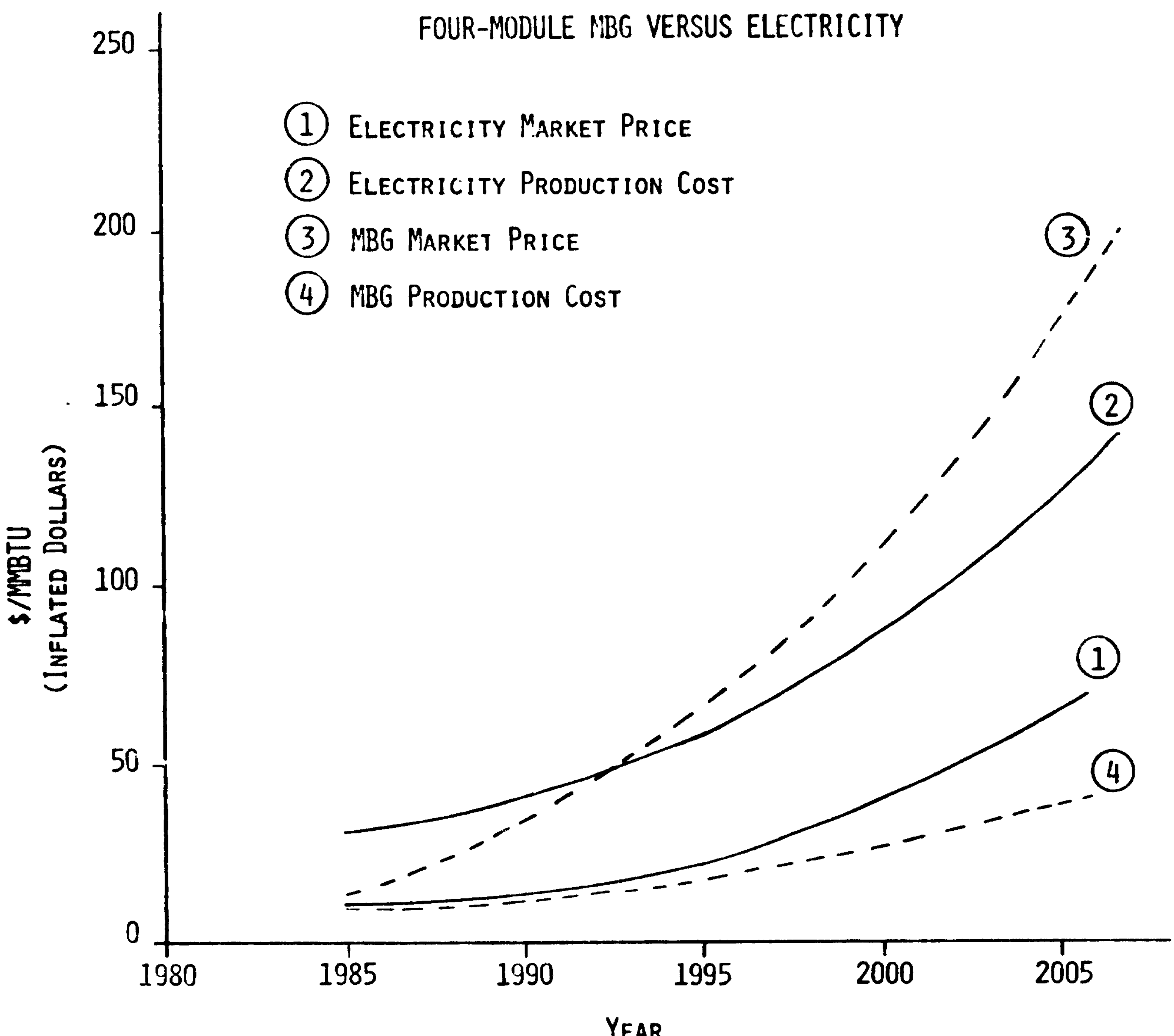
THIS FIGURE ILLUSTRATES THE RELATIVE ECONOMICS OF A FOUR-MODULE COAL CONVERSION FACILITY WHICH PRODUCES MEDIUM-BTU GAS VERSUS A FACILITY WHICH PRODUCES SUBSTITUTE NATURAL GAS (SNG). IT IS ASSUMED HERE THAT BOTH MBG AND SNG WILL SELL ON THE SAME \$/MMBTU BASIS AS NATURAL GAS. A COMPARISON OF CURVE 2 AND CURVE 4 SHOWS THAT SNG COSTS MORE THAN MBG TO PRODUCT ON A \$/MMBTU BASIS. HOWEVER, WHAT IS <u>NOT</u> SHOWN IN THE FIGURE IS THE FACT THAT THERE ARE VERY SMALL PIPELINE COSTS ASSOCIATED WITH DISTRIBUTING SNG INTO THE EXISTING PIPELINE SYSTEM AND, MORE IMPORTANTLY, THERE ARE <u>NO USER RETROFIT COSTS</u> WHEN SNG IS PRODUCED INSTEAD OF MBG. OF COURSE, THERE WOULD BE NO RETROFIT COSTS FOR ANY <u>NEW</u> INDUSTRIES THAT WERE BUILT SOLELY TO UTILIZE THE MBG FROM THIS PLANT.


FOUR-MODULE MBG VERSUS SNG
(1) SNG MARKET PRICE
(2) SNG PRODUCTION COST
(3) MBG MARKET PRICE
(4) MBG PRODUCTION COST
(1) & (3)
(2)
(4)
$/MMBTU
(INFLATED DOLLARS)
300
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
YEAR

FOUR-MODULE MBG VERSUS ELECTRICITY

THIS FIGURE EXAMINES THE RELATIVE ECONOMICS OF A FOUR-MODULE COAL CONVERSION FACILITY VERSUS A FACILITY WHICH UTILIZES COAL TO PRODUCE A GAS TO FEED TO FUEL CELLS, <u>LOCATED AT THE COAL CONVERSION FACILITY</u>, WHICH WOULD THEN PRODUCE ELECTRICITY TO INSERT IN THE TVA ELECTRICAL GRID NETWORK. THE WASTE HEAT FROM THESE FUEL CELLS, IN THIS EXAMPLE, HAS <u>NOT</u> BEEN UTILIZED IN ANY SORT OF COGENERATION MODE. ANOTHER VERY IMPORTANT ASSUMPTION IN THIS CASE IS THAT THE ELECTRICITY CAN BE SOLD <u>ONLY AT LOW PROJECTED RATES</u>. THESE RATES ARE ASSUMED TO INCREASE SLOWLY IN FUTURE YEARS.

GIVEN ALL OF THE ABOVE ASSUMPTIONS, THE RELATIVE ECONOMICS OF A FOUR-MODULE MBG PLANT VERSUS A FOUR-MODULE FUEL ELECTRICITY PLANT CAN BE SUMMARIZED AS FOLLOWS. THE MARKETABLE SELLING PRICE OF THE FUEL CELL ELECTRICITY IS ALWAYS <u>BELOW</u> ITS PRODUCTION COST, RESULTING IN A CLEARLY UNECONOMICAL SITUATION. ADDITIONALLY, THE FOUR-MODULE MBG FACILITY IS CLEARLY THE FACILITY OF CHOICE IN THIS SPECIFIC CASE.


FOUR-MODULE MBG VERSUS ELECTRICITY
1 ELECTRICITY MARKET PRICE
2 ELECTRICITY PRODUCTION COST
3 MBG MARKET PRICE
4 MBG PRODUCTION COST
$/MMBTU
(INFLATED DOLLARS)
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
YEAR

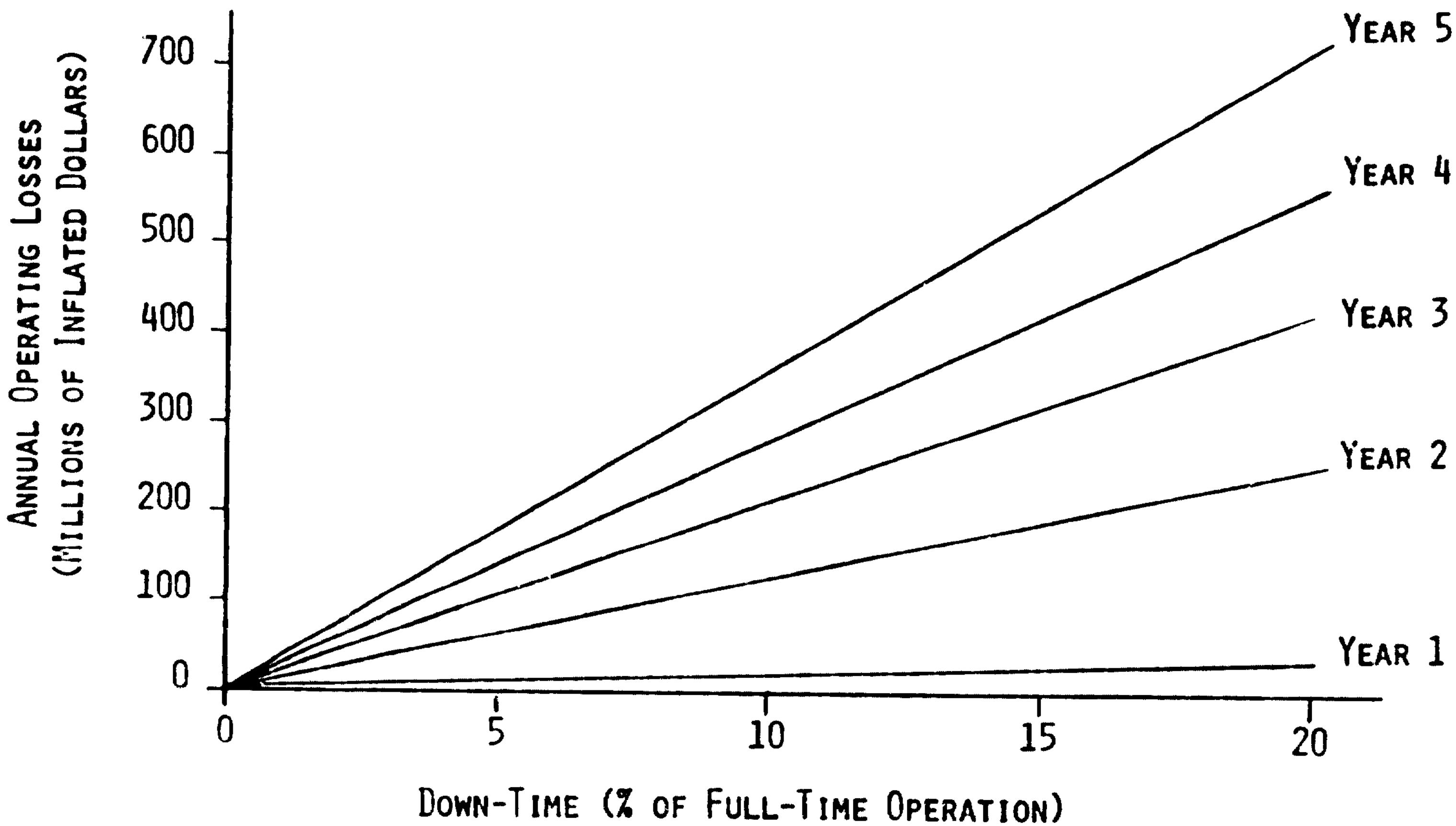
LOSS OF REVENUE INCURRED BECAUSE OF PLANT DOWN-TIME

- FOUR-MODULE MBG PLANT -

THIS FIGURE ILLUSTRATES THE IMPACT OF DOWN-TIME (LOSS OF MODULE PRODUCTION) DURING THE FIRST FIVE YEARS OF PLANT OPERATION. AN EXAMPLE OF THE INTERPRETATION OF THIS FIGURE IS AS FOLLOWS. IF THE DOWN-TIME (FOR ALL OPERATING MODULES) IS 20% PER YEAR, THEN AT THE END OF THE FIFTH YEAR (YEAR 5) OF OPERATION, THE PLANT IS LOSING APPROXIMATELY 750 MILLION DOLLARS PER YEAR IN POTENTIAL REVENUE. (THIS INCOME WOULD BE REALIZED IF ALL MODULES HAD BEEN OPERATING 100% OF THE TIME, INSTEAD OF BEING DOWN 20% OF THE TIME.)

LOSS OF REVENUE INCURRED BECAUSE OF
PLANT DOWN-TIME

- FOUR-MODULE MBG PLANT -



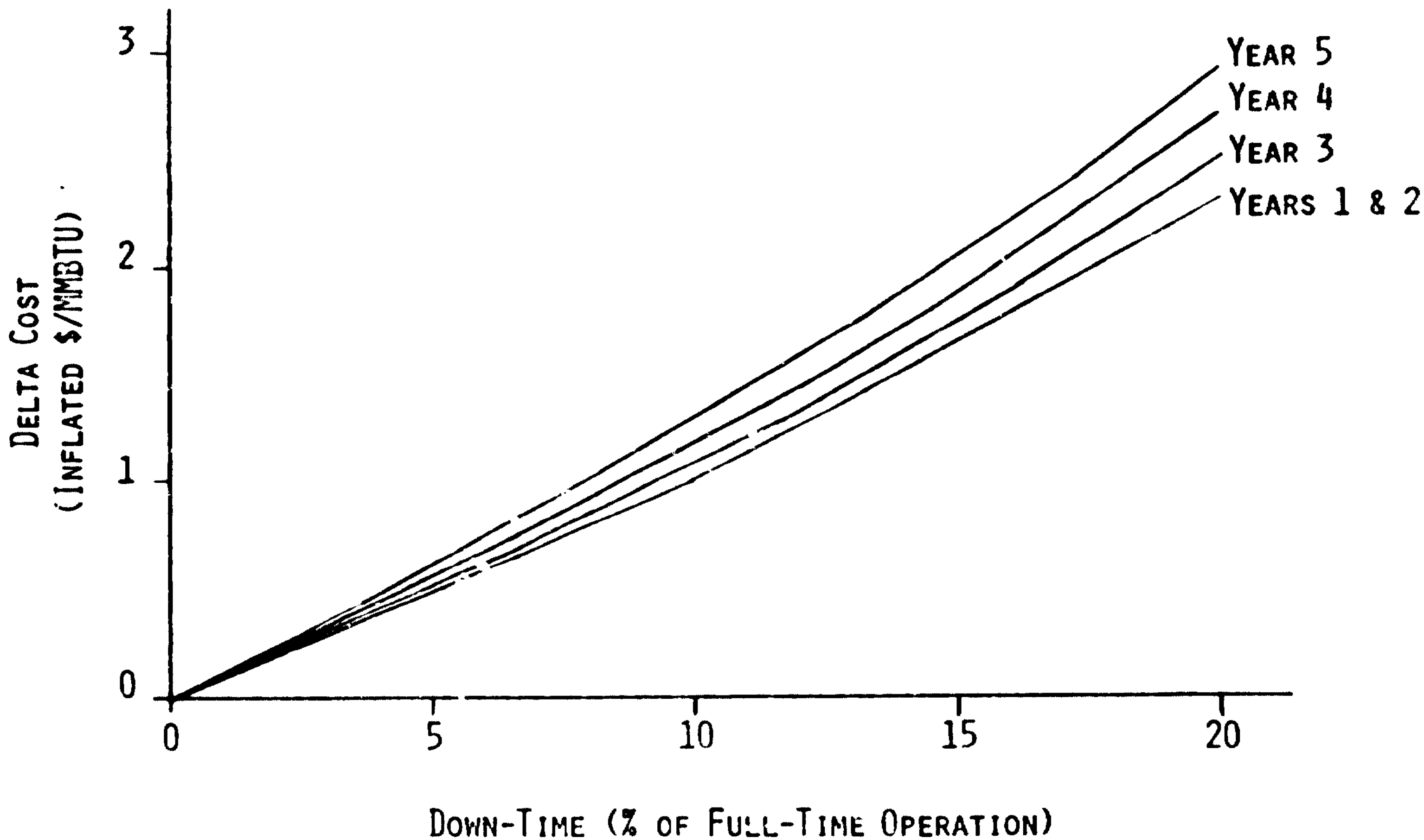
DELTA COST INCREASE IN MBG PRODUCT
BECAUSE OF PLANT DOWN-TIME

- FOUR-MODULE MBG PLANT -

THIS FIGURE SHOWS THE INCREMENTAL, OR DELTA, COST ADDED TO THE MBG PRODUCT COST BECAUSE THE PLANT IS NOT OPERATING AT 100% OF CAPACITY. FOR EXAMPLE, THE INCREMENTAL COST ADDED TO THE BASIC MBG PRODUCT COST, IF THE PLANT OPERATES WITH 20% DOWN-TIME (50% OF CAPACITY), IN THE FIFTH YEAR OF OPERATION IS APPROXIMATELY $3/MMBTU IN INFLATED DOLLARS.

DELTA COST INCREASE IN MBG PRODUCT
BECAUSE OF PLANT DOWN-TIME

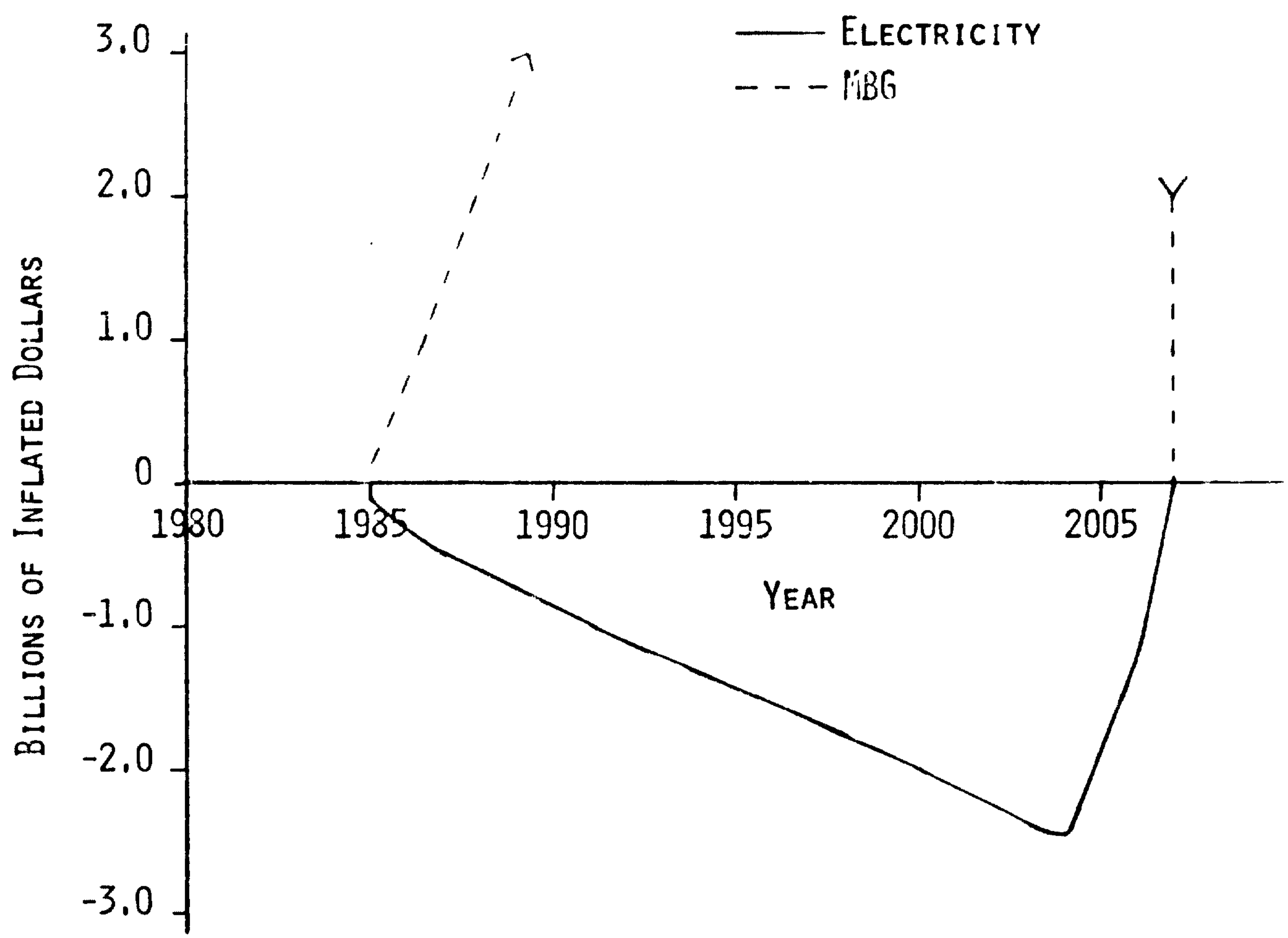
- FOUR-MODULE MBG PLANT -



NET CASH FLOW FOR FOUR-MODULE FUEL CELL PLANT

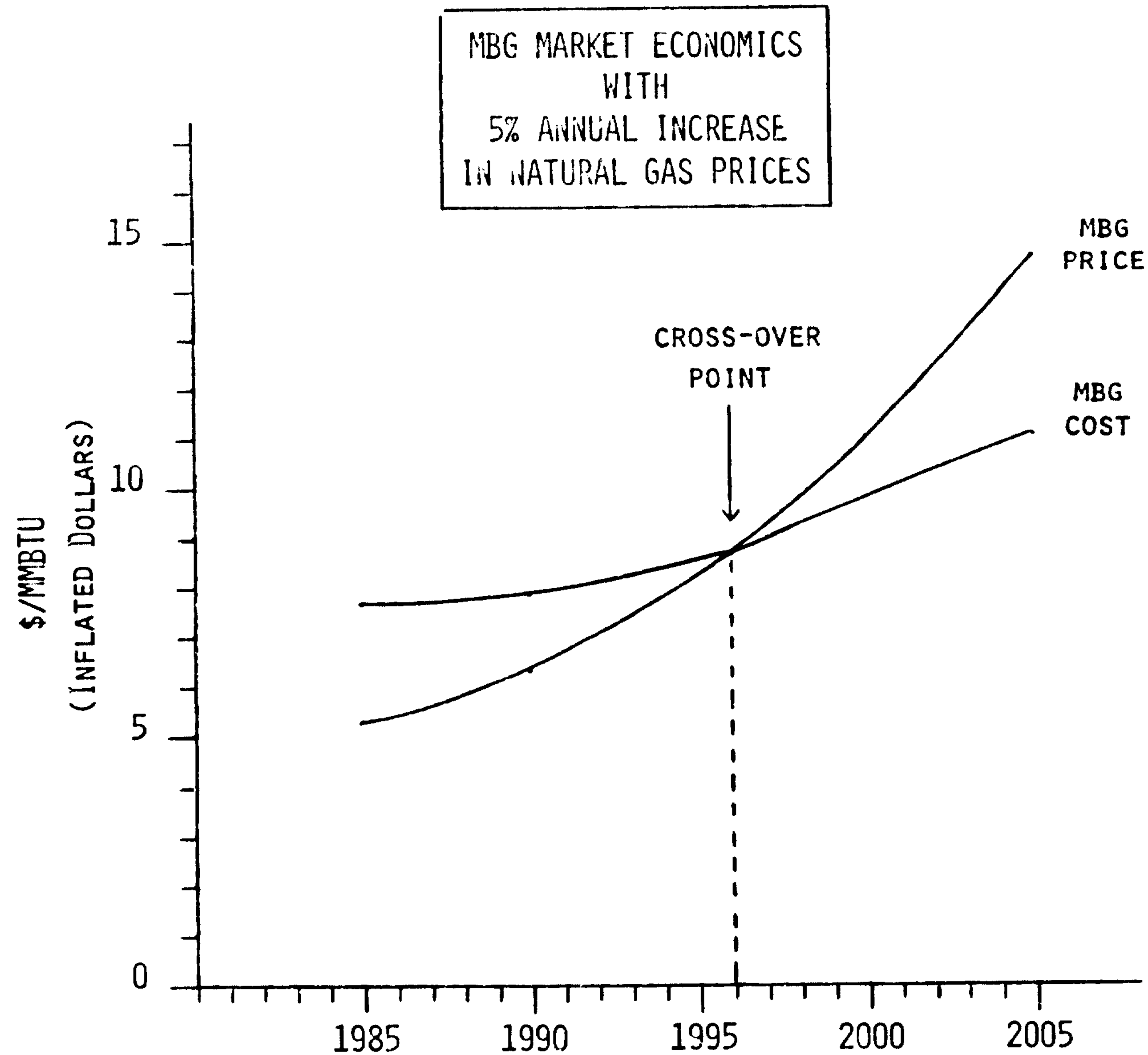
THIS FIGURE ILLUSTRATES THAT THE NET CASH FLOW (REVENUES MINUS COST) FOR CENTRAL-SITE FUEL CELL ELECTRICITY, USING COAL GAS AND SELLING THE ELECTRICITY AT PROJECTED TVA RATES, IS NEGATIVE FOR EVERY YEAR OF PLANT OPERATION. ON THE OTHER HAND, USING DRI PROJECTED NATURAL GAS PRICES, THE NET CASH FLOW FOR AN MBG PLANT OF THE SAME SIZE IS POSITIVE FOR EVERY YEAR OF OPERATION.

NET CASH FLOW FOR FOUR-MODULE FUEL CELL PLANT



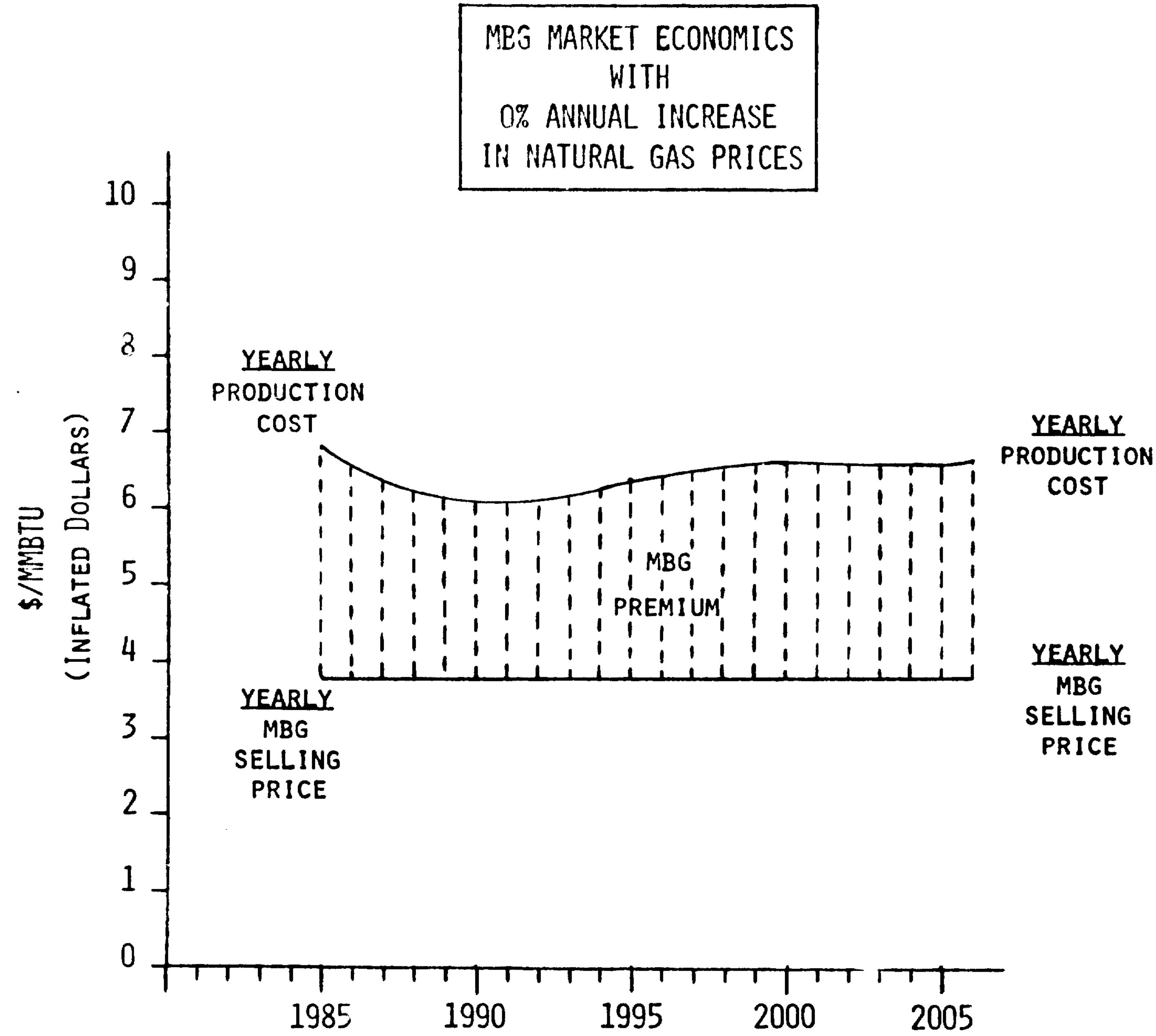
MBG MARKET ECONOMICS WITH
5% ANNUAL INCREASE IN NATURAL GAS PRICES

THIS FIGURE ILLUSTRATES THAT, GIVEN THE CURRENT HIGH PRICES OF NATURAL GAS AND DRI PROJECTED PRICE INCREASES, THEN, IF NATURAL GAS PRICES INCREASE AT 5% A YEAR COMPOUNDED, BY 1996 THE MBG PRODUCTION COST, ON A $/MMBTU BASIS, WILL EQUAL THE SELLING PRICE; I.E., BREAK-EVEN WILL HAVE OCCURRED.


MBG MARKET ECONOMICS
WITH
5% ANNUAL INCREASE
IN NATURAL GAS PRICES
MBG
PRICE
CROSS-OVER
POINT
MBG
COST
$/MMBTU
(INFLATED DOLLARS)
15
10
5
0
1985
1990
1995
2000
2005

MBG MARKET ECONOMICS WITH 0% ANNUAL INCREASE IN NATURAL GAS PRICES

THIS FIGURE ILLUSTRATES GRAPHICALLY THE IMPORTANCE OF MARKET PRICES OF COMPETING FUELS, IN THIS CASE NATURAL GAS, ON THE ECONOMICS OF A SYNFUELS PLANT. GIVEN THE OBVIOUSLY THEORETICAL SCENARIO WHERE NATURAL GAS PRICES DO NOT INCREASE IN THE FUTURE, EVEN IN INFLATED TERMS, THEN THE YEARLY MBG PRODUCT COST IS ALWAYS HIGHER THAN ITS SELLING PRICE, AND THE MBG MUST BE SOLD AT PREMIUM PRICES OF UP TO $2.50/MMBTU OVER THE PRICE OF NATURAL GAS (IN 1980 DOLLARS), JUST FOR THE MBG PLANT TO BREAK EVEN.

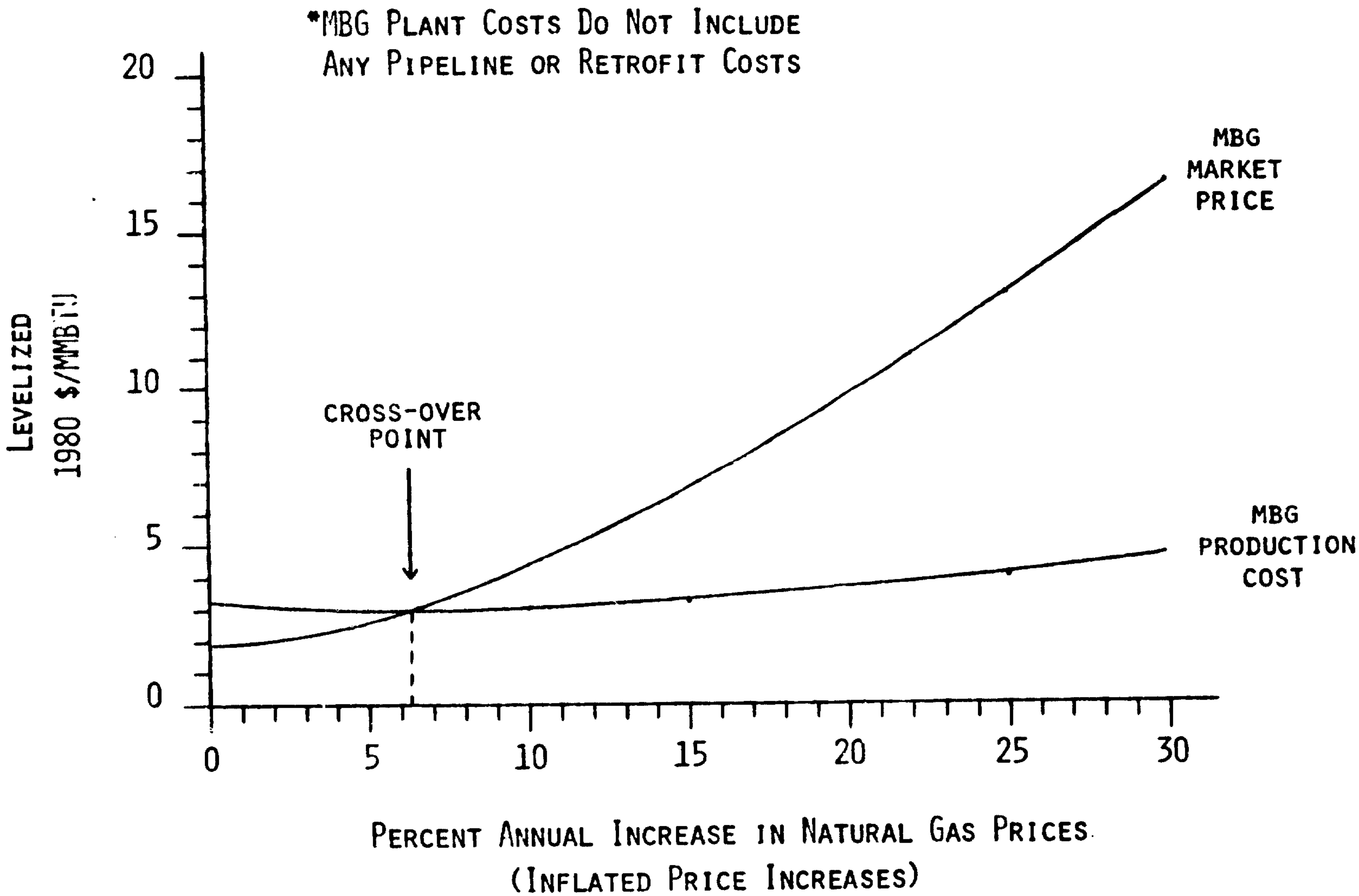


MBG MARKET ECONOMICS
WITH
0% ANNUAL INCREASE
IN NATURAL GAS PRICES
$/MMBTU
(INFLATED DOLLARS)
10
9
8
7
6
5
4
3
2
1
0
YEARLY
PRODUCTION
COST
MBG
PREMIUM
YEARLY
MBG
SELLING
PRICE
1985
1990
1995
2000
2005

SENSITIVITY OF MBG
TO ANNUAL INCREASES IN NATURAL GAS PRICES

THIS FIGURE ILLUSTRATES THAT, GIVEN THE CURRENT HIGH PRICES OF NATURAL GAS AS A BASE, THESE NATURAL GAS PRICES NEED INCREASE AT AN ANNUAL COMPOUNDED RATE OF ABOUT 6.5% FOR OUR MBG PLANT TO BREAK EVEN AFTER 20 YEARS OF OPERATION. (IT SHOULD BE NOTED THAT UNDER SUCH CIRCUMSTANCES, THE PLANT WOULD SUFFER HUGE OPERATING LOSSES DURING ITS EARLY YEARS OF OPERATION.)

SENSITIVITY OF MBG TO ANNUAL INCREASES IN NATURAL GAS PRICES



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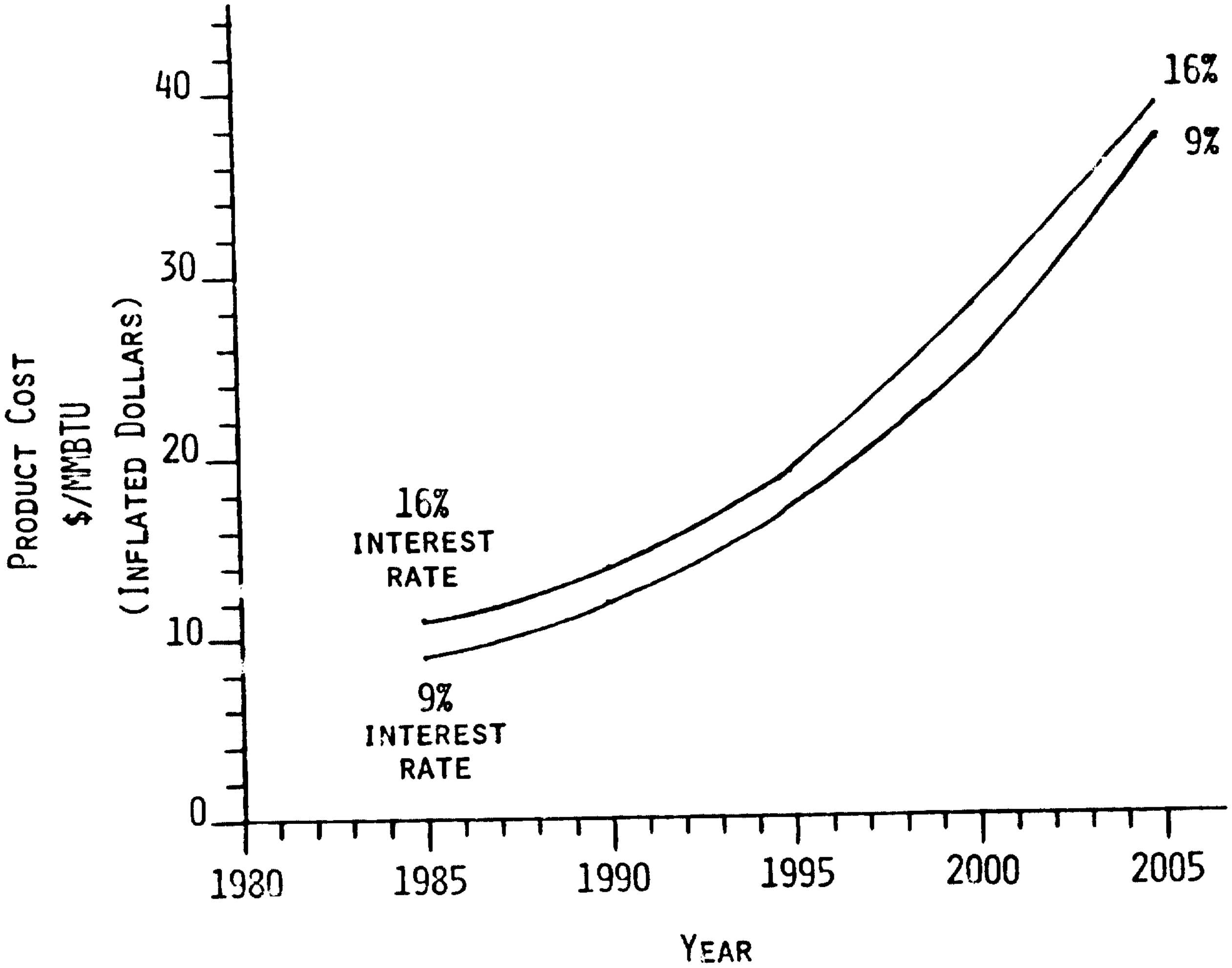
SENSITIVITY OF MBG PRODUCT COST TO THE COST OF CAPITAL

THIS FIGURE SHOWS THAT, OVER THE LIFETIME OF THE PLANT, THE MBG PRODUCT COST IS RELATIVELY INSENSITIVE TO WHETHER THE INTEREST RATE ON BORROWED CAPITAL IS 9% OR 16%. THE REASON FOR THIS INSENSITIVITY IS THAT INTEREST PAYMENTS ARE ONLY A SMALL FRACTION OF THE TOTAL PRODUCT COST. THE MAJOR ON-GOING CONTRIBUTORS TO PRODUCT COST ARE COAL COSTS AND O&M CCSTS.

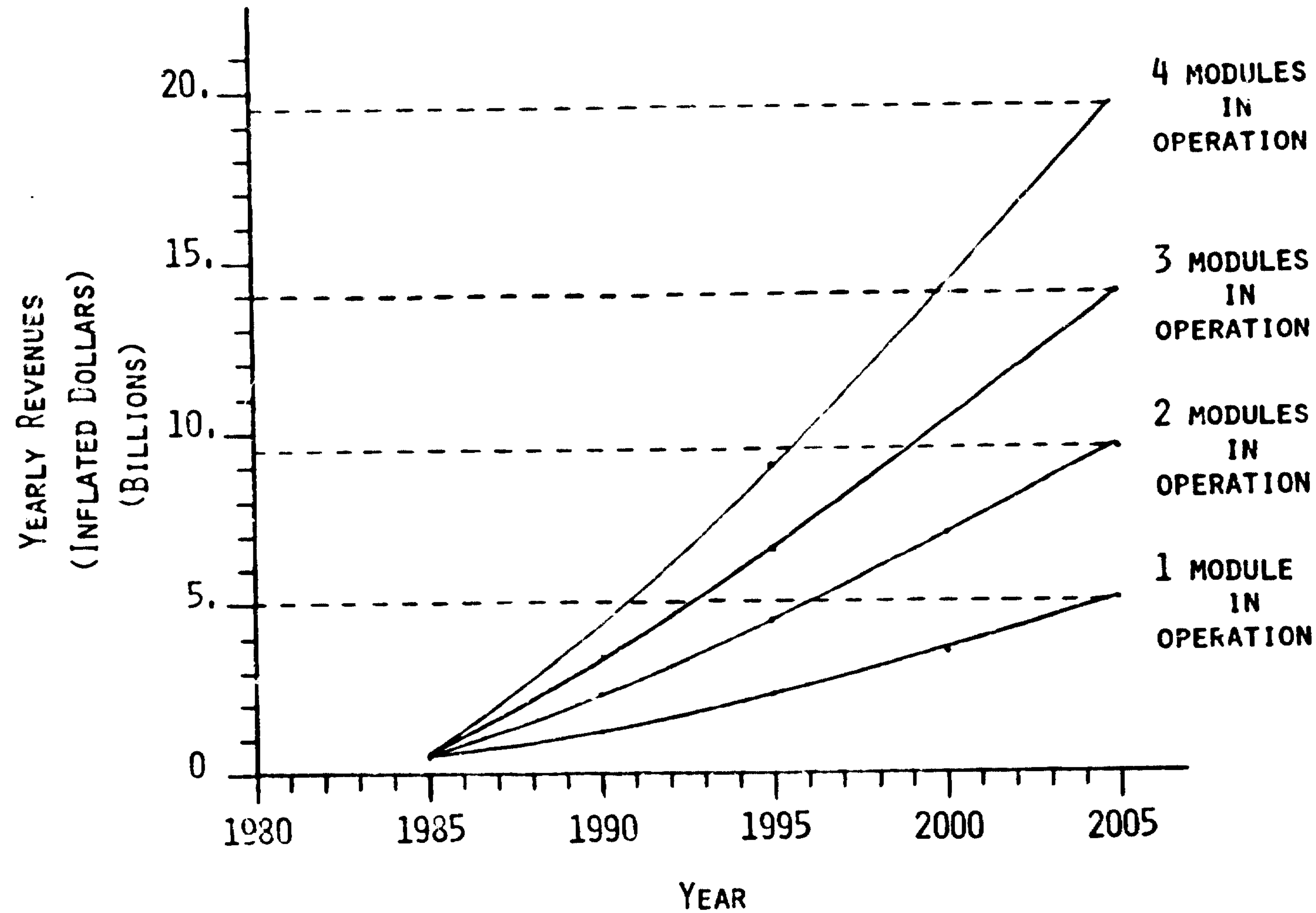
SENSITIVITY OF MBG PRODUCT COST
TO THE COST OF CAPITAL



SENSITIVITY OF MBG YEARLY REVENUES TO PARTIAL PLANT COMPLETION

THIS FIGURE ILLUSTRATES THE IMPACT ON THE MAGNITUDE OF YEARLY REVENUE IF PLANT CONSTRUCTION IS STOPPED AFTER EITHER 1, 2, 3 OR 4 MODULES HAVE BEEN COMPLETED.

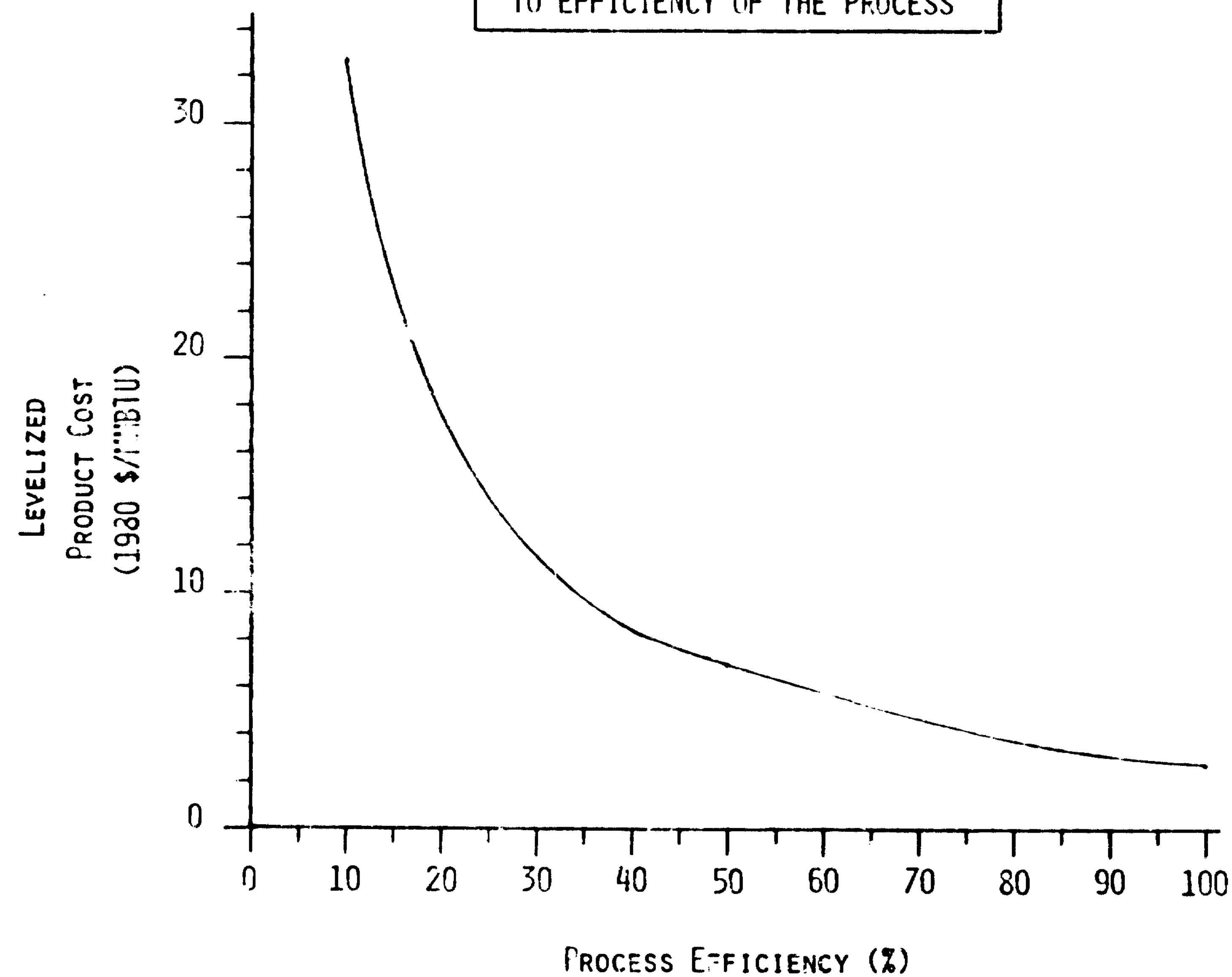
SENSITIVITY OF MBG YEARLY REVENUES TO PARTIAL PLANT COMPLETION



SENSITIVITY OF MBG PRODUCT COST
TO EFFICIENCY OF THE PROCESS

THIS FIGURE SHOWS THAT THE MBG PRODUCT COST GOES UP EXPONENTIALLY IF OVERALL MBG CONVERSION EFFICIENCY (FROM THE RAW COAL) DROPS BELOW APPROXIMATELY 50%.

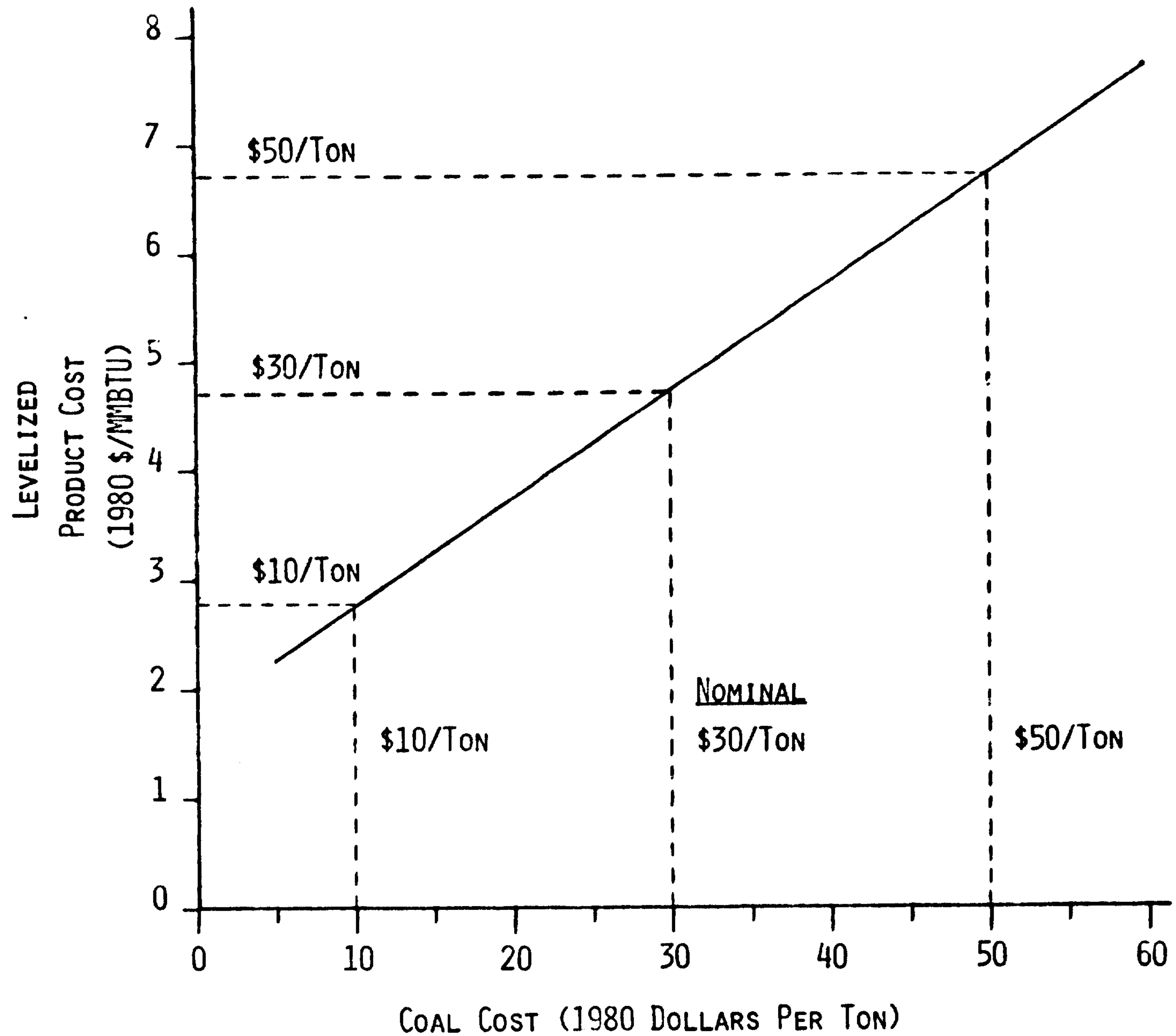
SENSITIVITY OF MBG PRODUCT COST TO EFFICIENCY OF THE PROCESS



SENSITIVITY OF MBG PRODUCT COST
TO COAL COST ESTIMATES

THIS FIGURE SHOWS THE SENSITIVITY OF THE MBG PRODUCT COST, IN LEVELIZED 1980 \$/MMBTU, TO VARIATIONS IN THE COST OF COAL FROM \$10/TON TO \$50/TON.

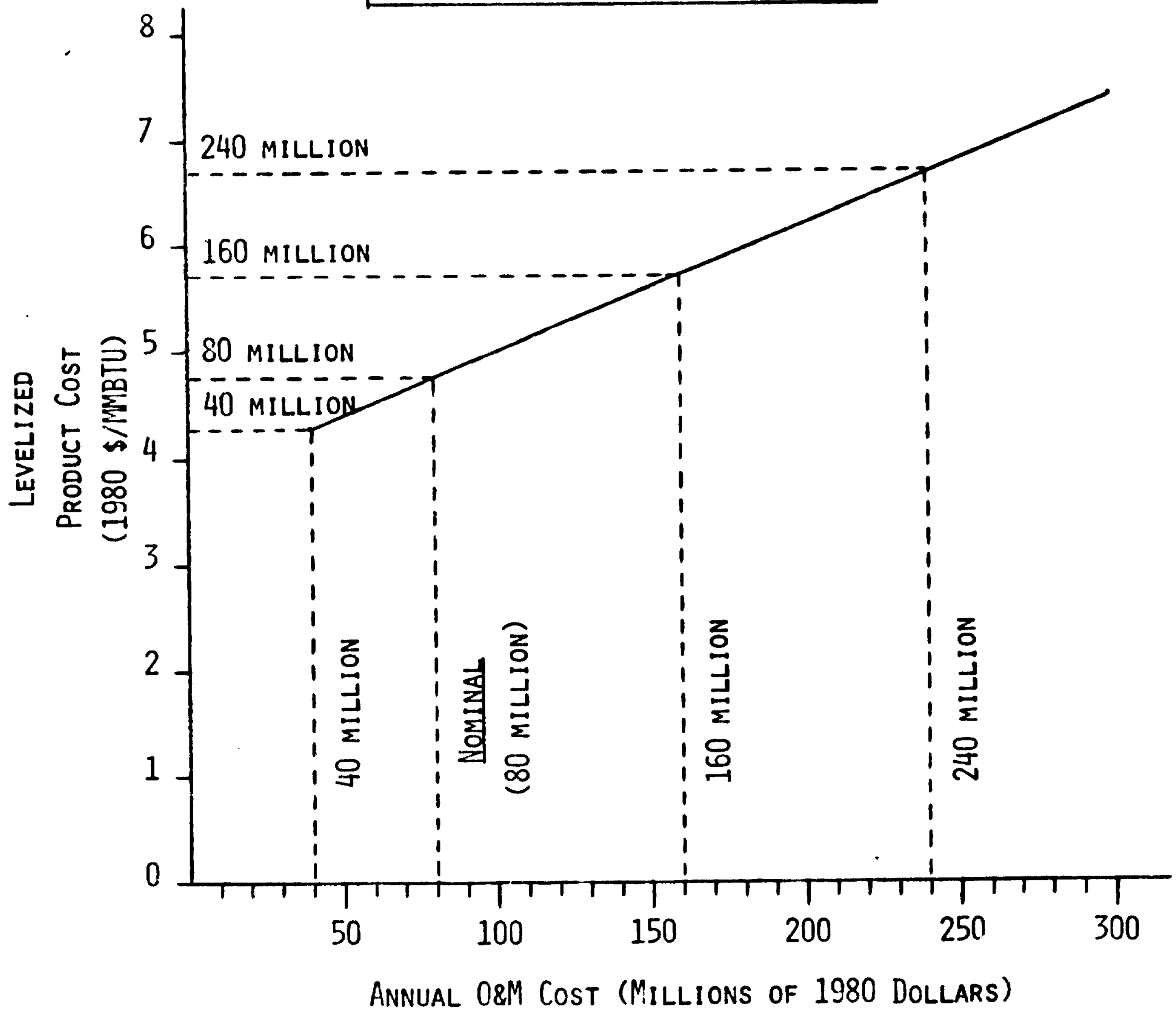
SENSITIVITY OF MBG PRODUCT COST TO COAL COST ESTIMATES



SENSITIVITY OF MBG PRODUCT COST TO O&M COST ESTIMATES

THIS FIGURE SHOWS THE SENSITIVITY OF THE MBG PRODUCT COST, IN LEVELIZED 1980 DOLLARS, TO VARIATION IN INITIAL OPERATIONAL COSTS OF FROM 50% (40 MILLION/160 MILLION) TO 300% (240 MILLION/80 MILLION) OF THE NOMINAL 80 MILLION DOLLAR OPERATING COST OF THE PLANT.

SENSITIVITY OF MBG PRODUCT COST
TO O&M COST ESTIMATES



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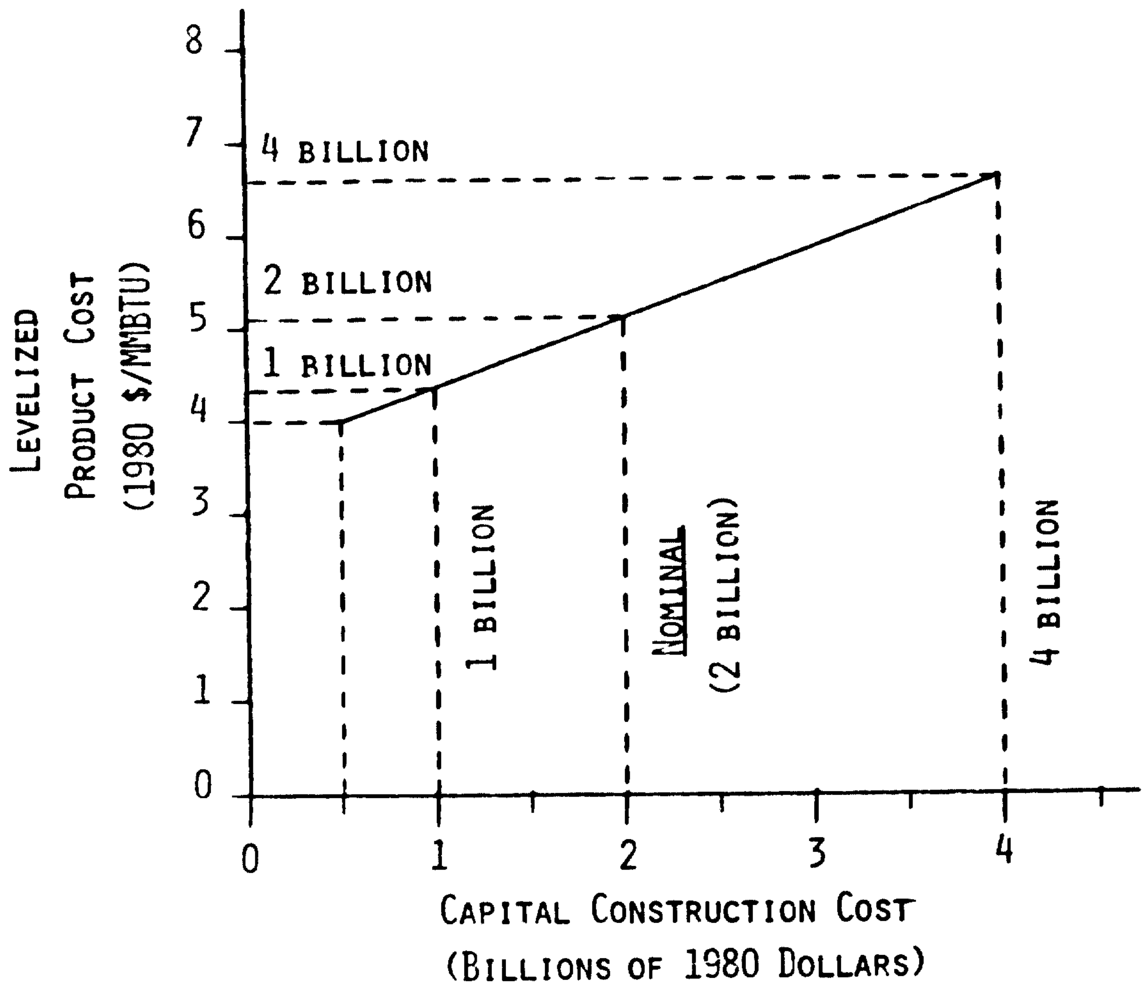
SENSITIVITY OF MBG PRODUCT COST TO
CONSTRUCTION COST ESTIMATES

THIS FIGURE SHOWS THAT, OVER THE LIFETIME OF THE PLANT, THE MBG PRODUCT COST IS RELATIVELY INSENSITIVE TO A VARIATION IN INITIAL CAPITAL COST ESTIMATES OF FROM 50% (1 BILLION/2 BILLION) TO 200% (4 BILLION/2 BILLION) OF THE NOMINAL $2 BILLION COST OF THE PLANT. THE VARIATION IN LEVELIZED 1980 $/MMBTU IS ONLY FROM $4.25 TO $6.5 PER MILLION BTU.

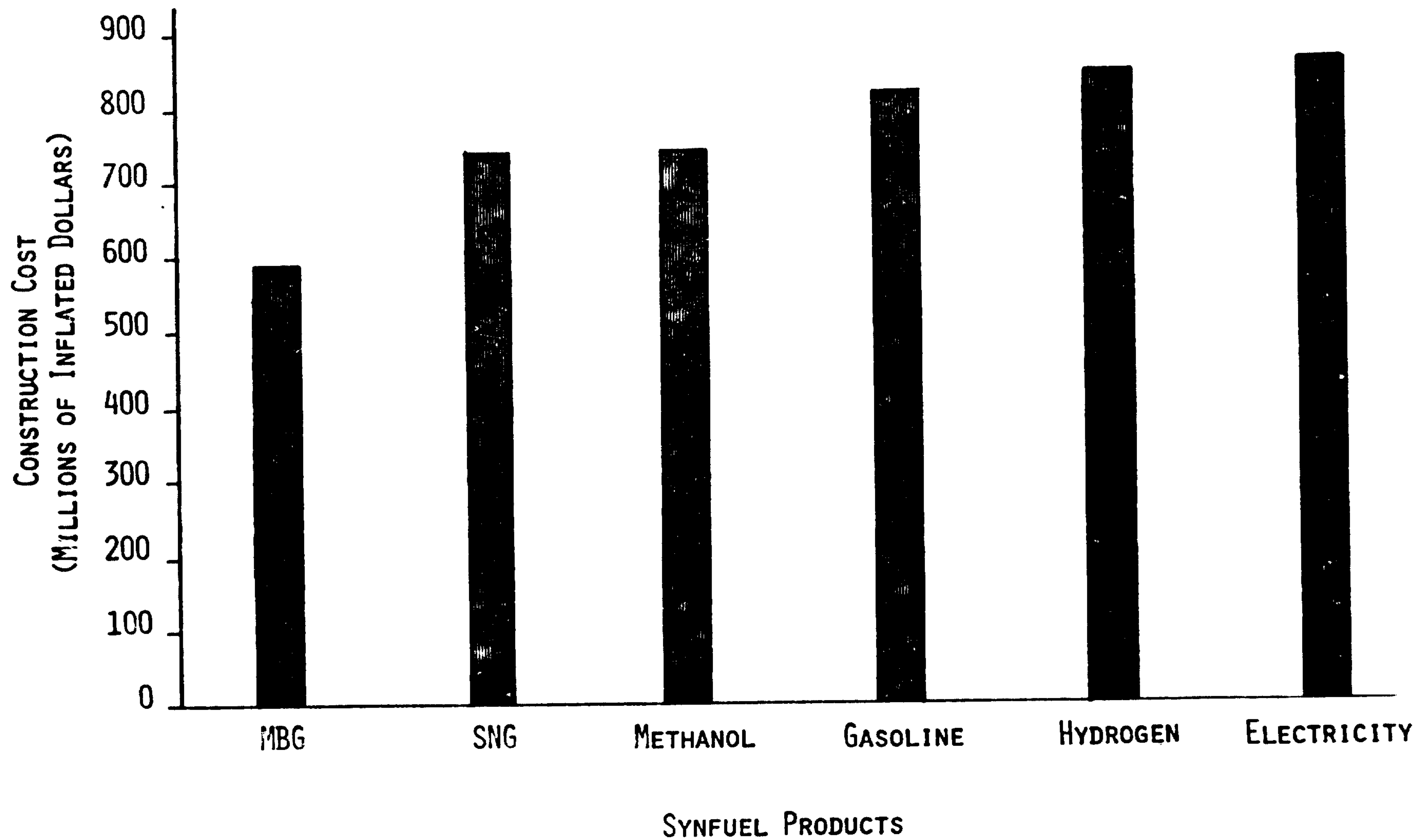
SENSITIVITY OF MBG PRODUCT COST TO CONSTRUCTION COST ESTIMATES



ONE-MODULE SYNFUEL FACILITIES COST

THIS FIGURE SHOWS THAT THE INFLATED COST OF THE FIRST MODULE OF THE FOUR-MODULE FACILITY RANGES FROM APPROXIMATELY 600 MILLION DOLLARS TO 850 MILLION DOLLARS, ASSUMING THE SAME NOMINAL SCHEDULE, IF THE CHOICE OF MBG AND ALTERNATE PRODUCTS SHOWN IS EXAMINED. IT SHOULD BE NOTED THAT THE ALTERNATIVE PRODUCTS ARE ASSUMED TO BE PRODUCED BY "ADDING ON" TO THE ORIGINAL MBG MODULE. THEREFORE, THE MBG MODULE IS THE LOWEST COST MODULE IN THIS SITUATION.

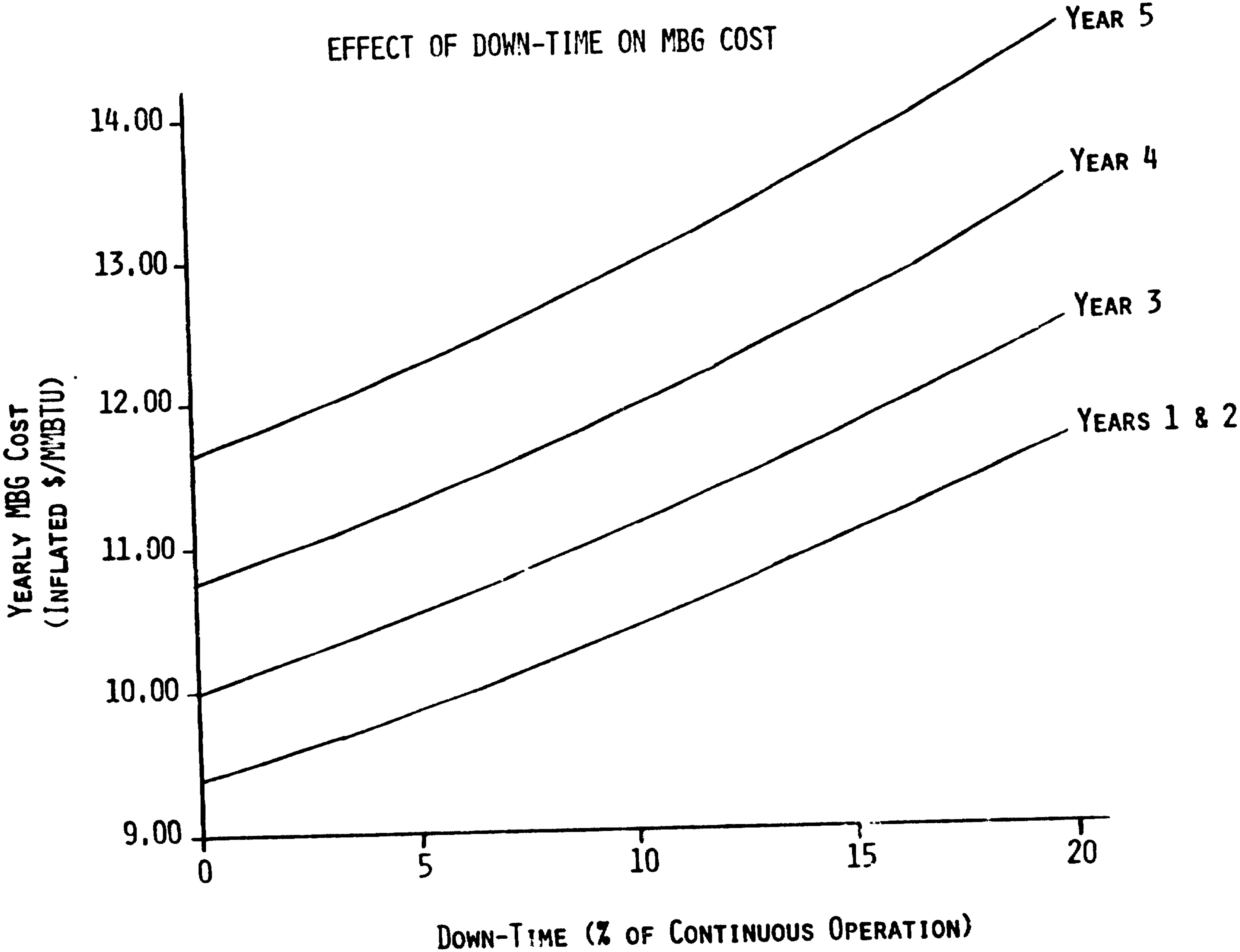
ONE-MODULE SYNFUEL FACILITIES COST



EFFECT OF DOWN-TIME ON MBG COST

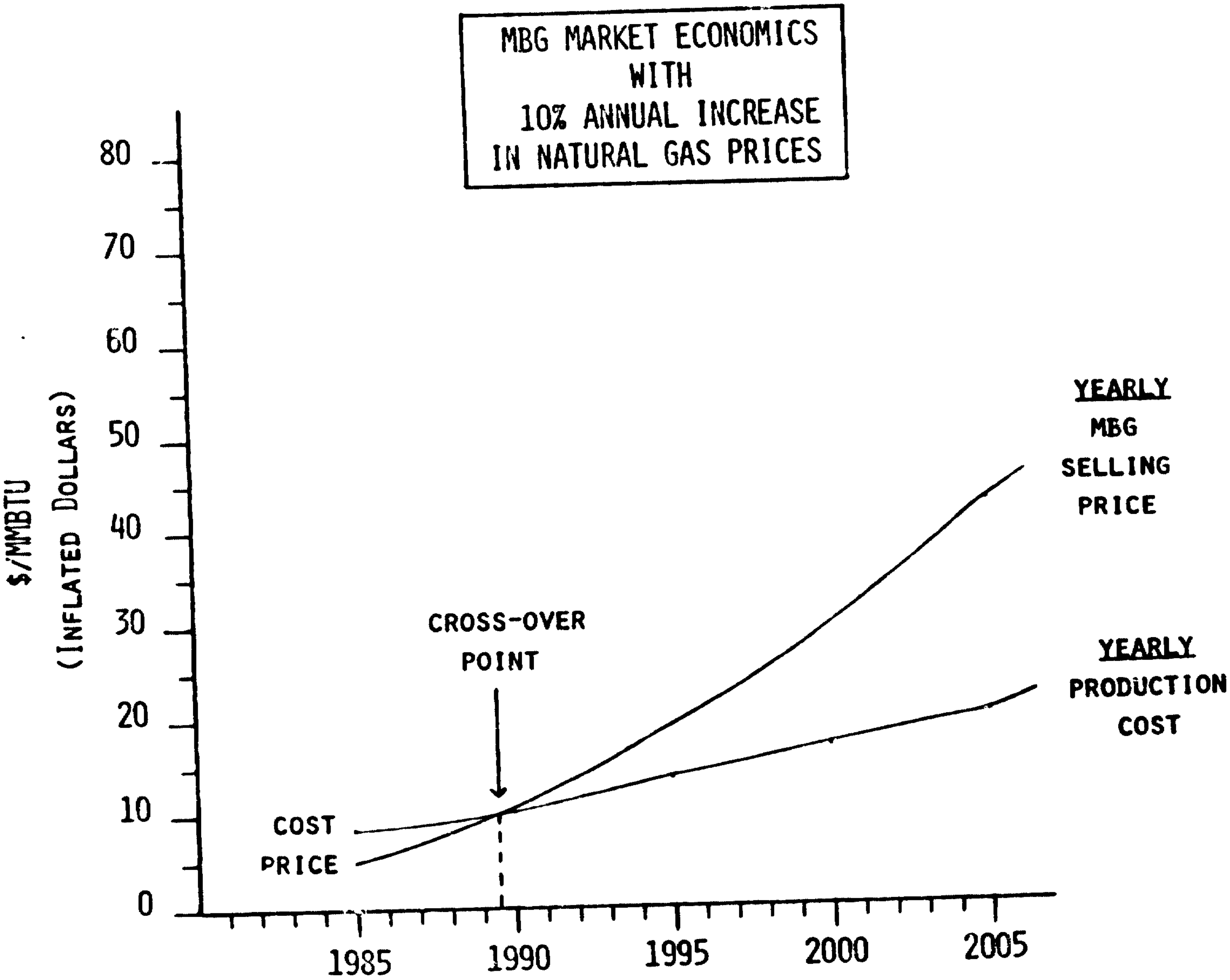
THIS FIGURE SHOWS THAT DOWN-TIME (LOSS OF MODULE PRODUCTION) CAN SIGNIFICANTLY IMPACT THE COST OF PRODUCTION OF MBG. FOR EXAMPLE, WITH A 20% DOWN-TIME RATE, BY THE END OF THE FIFTH YEAR OF PLANT OPERATION, THE MBG IS SELLING AT A PRODUCT COST OF OVER $16/MMBTU (IN INFLATED DOLLARS), VERSUS A PRODUCT OF APPROXIMATELY $11.75/MMBTU WITH 0% DOWN-TIME.

EFFECT OF DOWN-TIME ON MBG COST



MBG MARKET ECONOMICS WITH 10% ANNUAL INCREASE IN NATURAL GAS PRICES

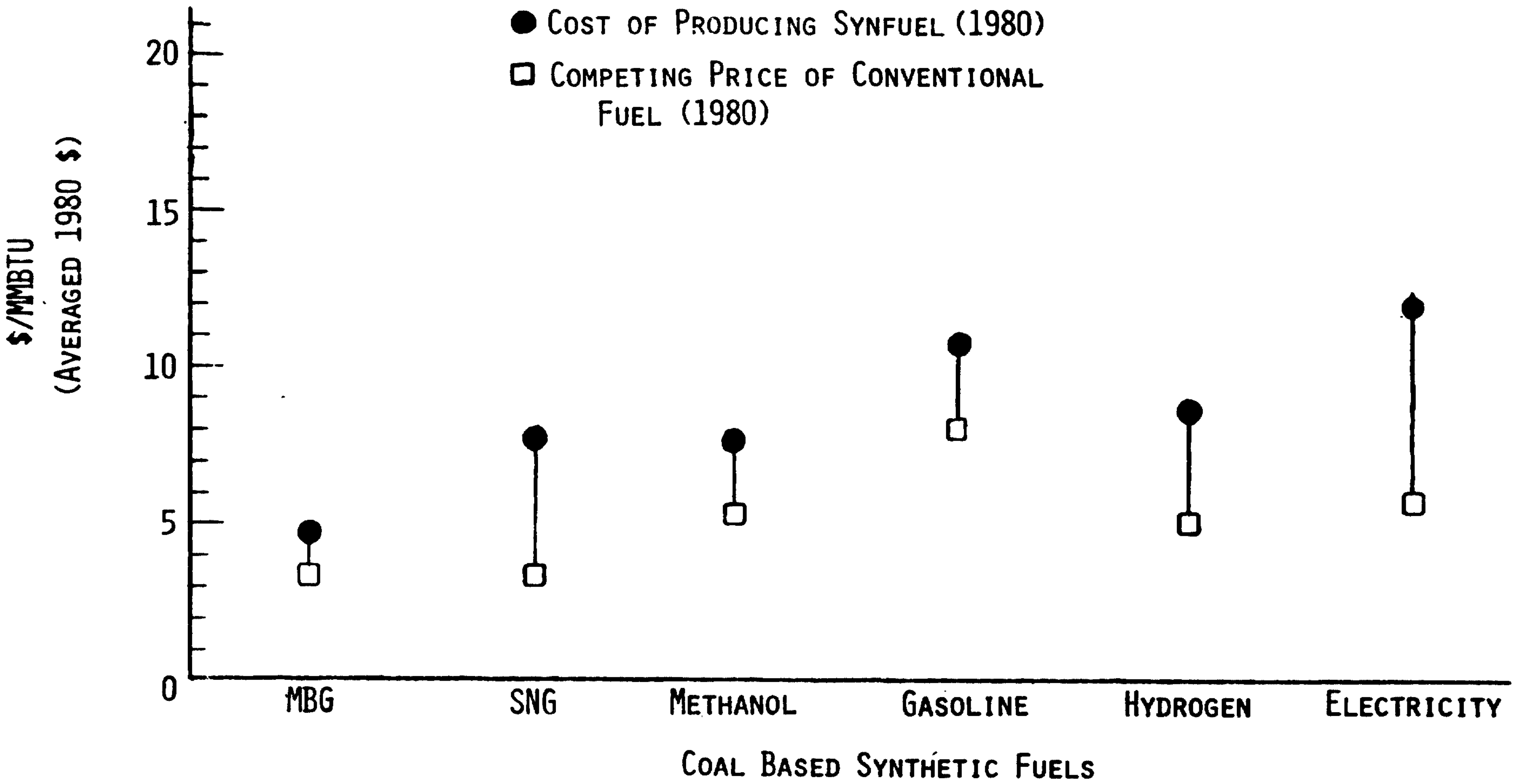
THIS FIGURE ILLUSTRATES THAT WITH 10% ANNUAL COMPOUNDED PRICE INCREASES IN NATURAL GAS, BREAK-EVEN WILL OCCUR IN 1990. IT TURNS OUT THAT, IN THIS CASE, BREAK-EVEN OCCURS EARLY ENOUGH IN THE MBG PLANT'S LIFE THAT IT MAKES MONEY BY THE END OF ITS 20-YEAR LIFE.


MBG MARKET ECONOMICS
WITH
10% ANNUAL INCREASE
IN NATURAL GAS PRICES
$/MMBTU
(INFLATED DOLLARS)
80
70
60
50
40
30
20
10
0
CROSS-OVER
POINT
COST
PRICE
YEARLY
MBG
SELLING
PRICE
YEARLY
PRODUCTION
COST
1985
1990
1995
2000
2005

SYNFUEL COST VERSUS PRICES
(1980 DOLLARS)

THIS CHART ILLUSTRATES THAT IF A FOUR-MODULE SYNFUELS PLANT WERE OPERATING TODAY (1980), THEN THE COST OF PRODUCING ITS PRODUCTS WOULD BE HIGHER THAN THE PRICE OF COMPETING FOSSIL FUELS.

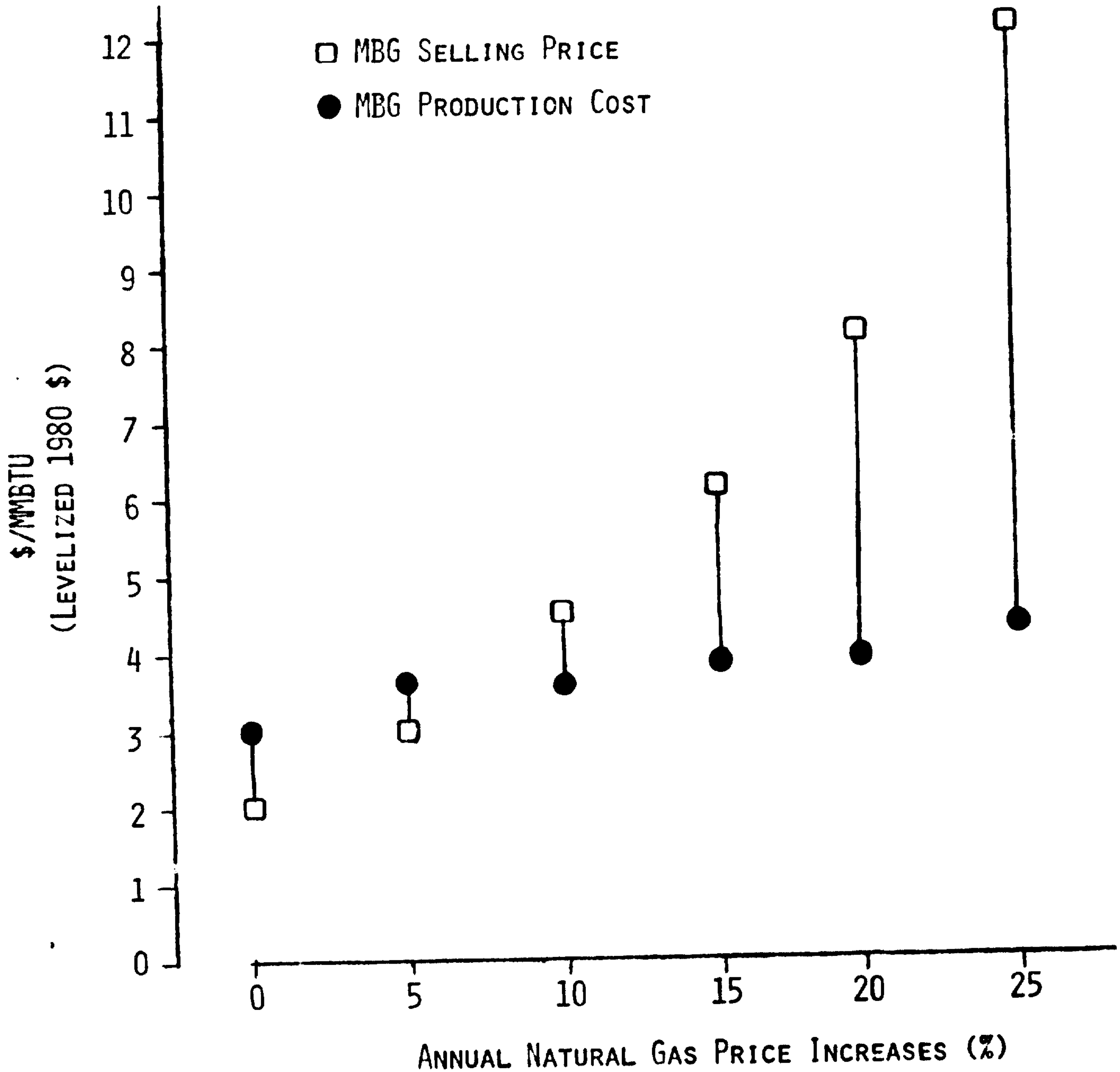
SYNFUEL COST VS. PRICES (1980 DOLLARS)



MBG SENSITIVITY TO NATURAL GAS PRICES

THIS FIGURE SHOWS THAT, IN LEVELIZED ECONOMIC VALUES, THE SELLING PRICE OF MBG EVENTUALLY EXCEEDS ITS PRODUCTION COST IF NATURAL GAS PRICES INCREASE AT A HIGH ENOUGH RATE OVER THE LIFE CYCLE OF THE MBG PLANT.

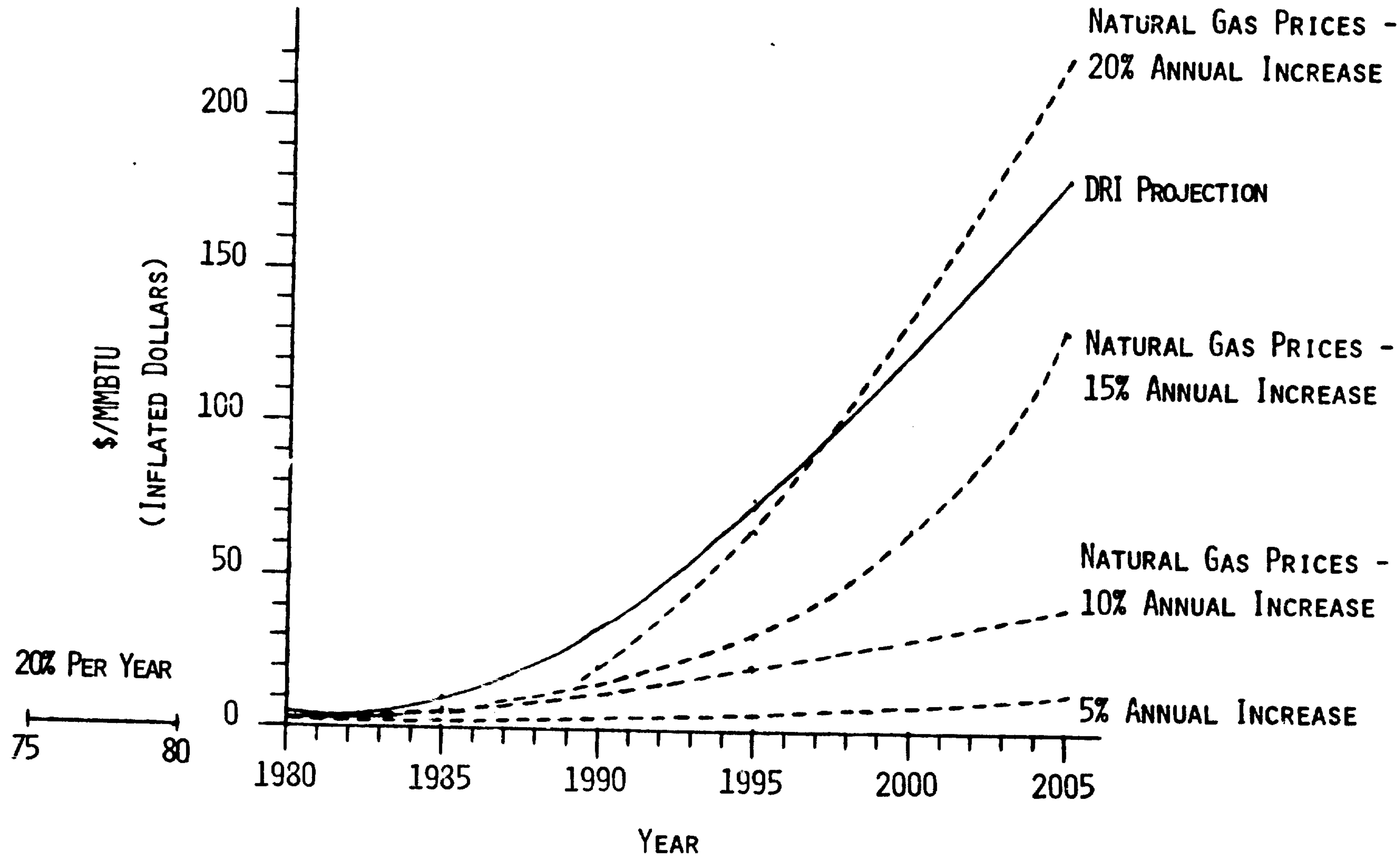
MBG SENSITIVITY TO NATURAL GAS PRICES



PROJECTED NATURAL GAS PRICES
ASSUMING VARIOUS ESCALATION RATES

THIS FIGURE SHOWS THAT THE ESCALATION RATES, DERIVED FROM DATA RESOURCES, INC. (DRI) PROJECTIONS, FOR NATURAL GAS PRICES ARE EQUIVALENT TO UNIFORM ANNUAL NATURAL GAS PRICES INCREASES OF ABOUT 17% (BETWEEN 15% AND 20% ON THE CHART). THESE DRI PROJECTIONS ARE THE BASIS FOR THE MBG SELLING PRICES THAT ARE UTILIZED IN THE BASE CASE IN THE COMPUTER MODEL.

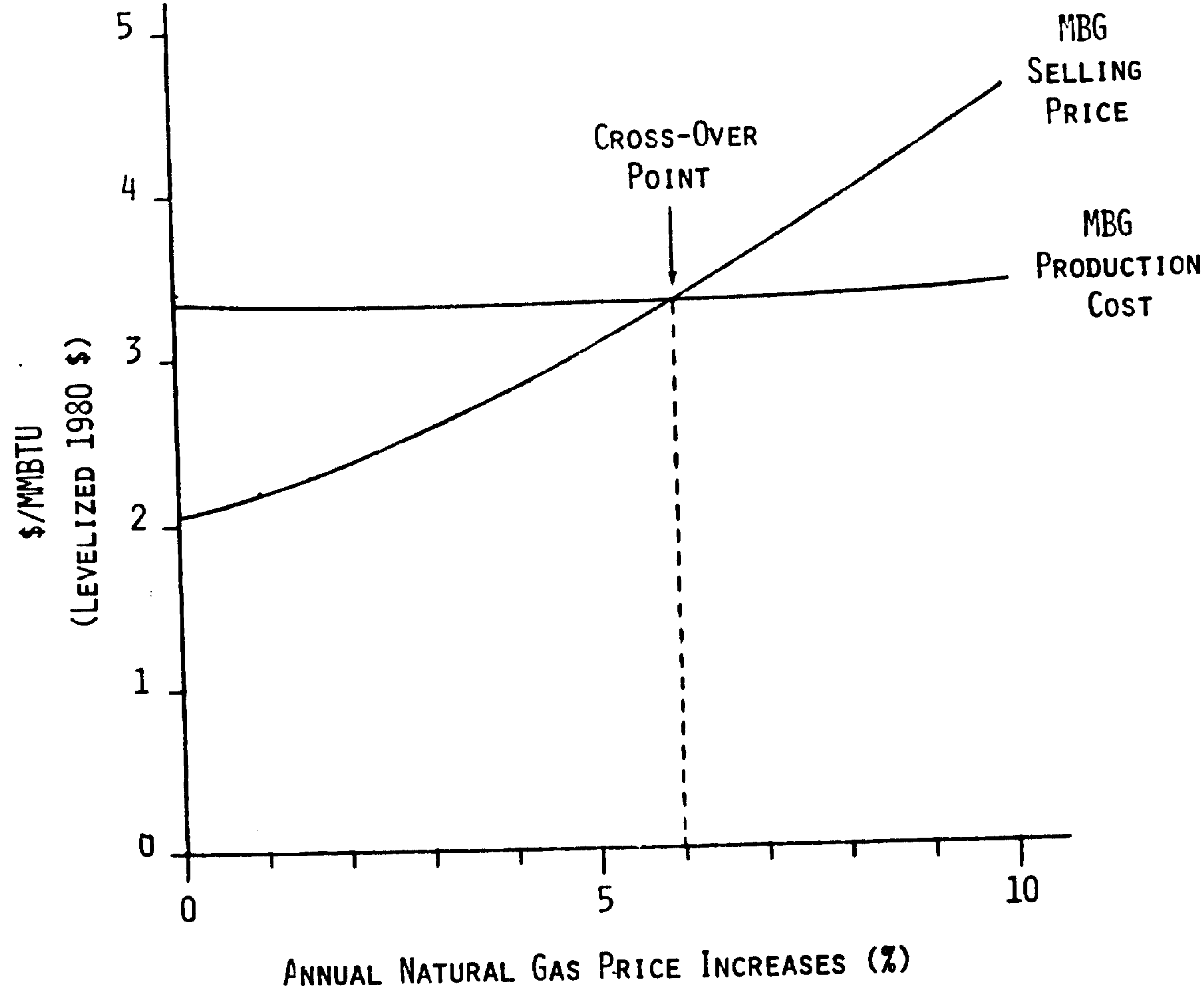
PROJECTED NATURAL GAS PRICES
ASSUMING
VARIOUS ESCALATION RATES



MBG SENSITIVITY TO ANNUAL INCREASES IN NATURAL GAS PRICES

THIS FIGURE SHOWS THAT THE CROSS-OVER POINT, IN LEVELIZED ECONOMIC TERMS, OCCURS WHEN NATURAL GAS PRICE INCREASES EXCEED APPROXIMATELY 6% PER YEAR (COMPOUNDED). AT THE CROSS-OVER POINT, THE LIFE CYCLE COSTS OF PRODUCING THE MBG EQUAL THE LIFE CYCLE REVENUE PRODUCED FROM SELLING THE MBG.

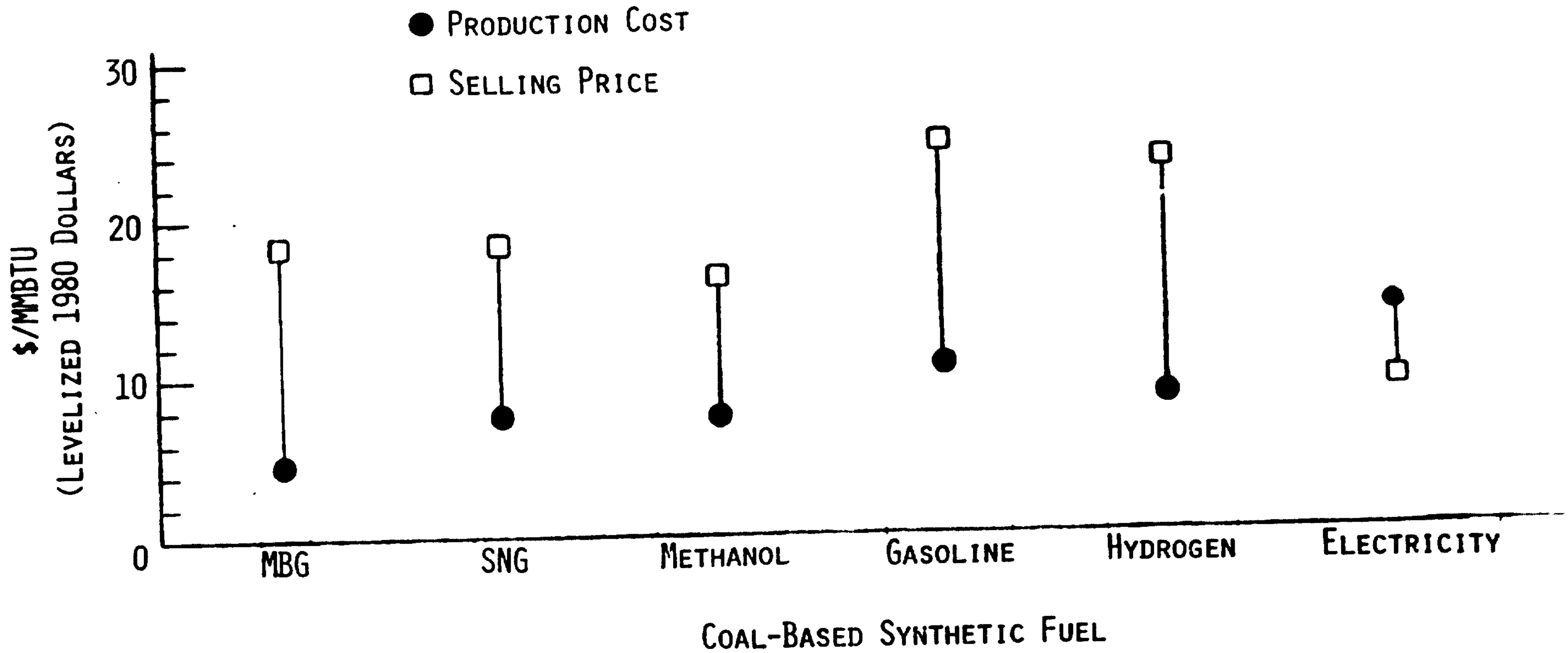
MBG SENSITIVITY TO ANNUAL INCREASES IN NATURAL GAS PRICES



SYNFUELS COSTS VERSUS PRICES

AT THE DRI ESCALATION RATES ASSUMED IN THIS STUDY, IT CAN BE SEEN THAT IN LEVELIZED ECONOMIC TERMS, THE LIFE CYCLE COSTS OF PRODUCING THE VARIOUS SYNFUEL PRODUCTS WILL BE LESS THAN THE LIFE CYCLE SELLING PRICE OF THE MBG, EXCEPT FOR FUEL CELL ELECTRICITY PRODUCED AT THE CENTRAL SITE.

SYNFUELS COSTS VS. PRICES



ANNUAL SYNFUEL PRODUCTION COSTS & PRICES
OF COMPETING FUELS

(INFLATED $/MMBTU, DRI PROJECTIONS)

THIS CHART ILLUSTRATES TWO IMPORTANT POINTS. FIRST, FUTURE SELLING PRICES OF MBG, WHICH ARE BASED ON DRI PROJECTIONS FOR NATURAL GAS PRICES, ARE EXTREMELY HIGH, RANGING FROM $9.91 IN 1985 TO $184.83 IN 2006. THIS MAKES MBG LOOK EXTREMELY ATTRACTIVE AND PROBABLY OVERSTATES ITS ATTRACTIVENESS. SECONDLY, ELECTRICITY PRICES ARE ASSUMED TO ESCALATE MUCH MORE SLOWLY, THUS STRONGLY AFFECTING THE SELLING PRICE OF FUEL CELL ELECTRICITY AND MAKING CENTRAL-SITE GENERATION OF FUEL CELL ELECTRICITY UTILIZING COAL APPEAR TO BE UNECONOMICAL.

ANNUAL SYNFUEL PRODUCTION COSTS & PRICES OF COMPETING FUELS
(INFLATED $/MMBTU, DRI PROJECTIONS)

	MBG		SNG		METHANOL		GASOLINE		HYDROGEN		ELECTRICITY	
YEAR	Cost	Price	Cost	Price	Cost	Price	Cost	Price	Cost	Price	Cost	Price
1985	9.38	9.91	15.40	9.91	15.34	17.43	20.80	26.72	16.74	12.80	21.46	11.04
1986	9.37	12.35	15.59	12.35	15.59	22.13	21.15	33.92	16.97	15.95	21.93	12.77
1987	10.01	15.75	16.66	15.75	16.67	21.09	22.59	32.32	18.09	20.35	23.44	14.21
1988	10.77	20.09	17.88	20.09	17.92	25.79	24.22	39.52	19.34	25.95	25.14	15.43
1989	11.65	25.89	19.26	25.89	19.32	29.39	26.05	45.04	20.76	33.45	27.04	16.98
1990	12.52	33.71	20.67	33.71	20.76	37.48	27.93	57.44	22.20	43.55	29.01	19.26
1991	13.44	43.19	22.17	43.19	22.29	41.66	29.93	63.84	23.74	55.80	31.11	21.26
1992	14.45	49.11	23.81	49.11	23.97	47.50	32.13	72.80	25.42	63.45	33.41	23.09
1993	15.56	55.72	25.61	55.72	25.81	49.54	34.54	75.92	27.27	72.00	35.95	25.03
1994	16.72	63.00	27.52	63.00	27.77	54.03	37.11	82.80	29.23	81.40	38.65	27.14
1995	18.01	71.01	29.63	71.01	29.93	58.88	39.92	90.24	31.39	91.75	41.61	29.42
1996	19.41	79.76	31.93	79.76	32.29	64.21	43.02	98.40	33.76	103.05	44.87	31.86
1997	20.90	89.16	34.39	89.16	34.82	69.95	46.33	107.20	36.29	115.20	48.37	34.52
1998	22.51	99.00	37.07	99.00	37.57	76.26	49.93	116.88	39.03	127.90	52.17	37.46
1999	24.23	109.17	39.95	109.17	40.54	83.10	52.82	127.36	42.00	141.05	56.31	40.57
2000	26.09	119.66	43.07	119.66	43.76	90.62	58.04	138.88	45.20	154.60	60.78	44.01
2001	28.09	130.03	46.44	130.02	47.23	98.76	62.59	151.36	48.66	168.20	65.61	47.67
2002	30.19	140.60	50.02	140.60	50.93	107.64	67.45	164.96	52.34	181.65	70.79	51.73
2003	32.48	150.85	53.94	150.85	54.99	117.35	72.77	179.84	56.37	194.90	76.48	56.06
2004	34.90	161.46	58.10	161.46	59.30	127.89	78.42	196.00	60.65	208.60	82.53	60.77
2005	37.33	172.72	62.41	172.72	63.79	139.37	84.34	213.60	65.11	223.15	88.93	65.88
2006	40.37	184.83	67.68	184.83	69.24	151.95	91.54	232.88	70.59	238.80	96.63	71.37

ANNUAL OPERATION & MAINTENANCE COST FOR VARIOUS FOUR-MODULE PLANTS

(MILLIONS OF INFLATED DOLLARS)

THIS TABLE SHOWS THAT O&M COSTS, EXCLUDING COAL COSTS, ARE LOWEST FOR THE MBG FACILITY AND HIGHEST FOR THE FUEL CELL ELECTRICITY FACILITY.

ANNUAL OPERATION & MAINTENANCE COST
FOR VARIOUS FOUR-MODULE PLANTS
(Millions of Inflated Dollars)

YEAR	MBG	SNG	METHANOL	GASOLINE	HYDROGEN	ELECTRICITY
1985	35.4	73.2	85.4	88.5	75.2	111.0
1986	117.0	241.9	282.3	292.5	248.6	367.0
1987	171.2	354.0	413.0	428.0	363.8	537.0
1988	188.8	390.3	455.5	472.0	401.2	592.2
1989	207.2	428.4	500.0	518.0	440.3	649.9
1990	228.0	471.4	550.1	570.0	484.5	715.1
1991	251.2	519.4	606.0	628.0	533.8	787.9
1992	276.0	570.6	665.9	690.0	586.5	865.7
1993	304.0	628.5	733.4	670.0	646.0	953.5
1994	334.4	691.4	806.7	836.0	710.6	1,048.9
1995	367.2	759.2	885.9	918.0	780.3	1,151.7
1996	404.0	835.3	974.7	1,010.0	858.5	1,267.2
1997	444.8	919.6	1,073.1	1,112.0	945.2	1,395.1
1998	488.8	1,010.6	1,179.2	1,222.0	1,038.7	1,533.1
1999	538.4	1,113.1	1,298.9	1,346.0	1,144.1	1,688.7
2000	592.0	1,224.0	1,428.2	1,480.0	1,258.0	1,855.8
2001	651.2	1,346.4	1,571.0	1,628.0	1,383.8	2,042.5
2002	716.0	1,480.3	1,727.4	1,790.0	1,521.5	2,245.7
2003	788.0	1,629.2	1,901.1	1,970.0	1,674.5	2,471.6
2004	866.4	1,791.3	2,090.2	2,166.0	1,841.1	2,717.5
2005	715.2	1,478.7	1,725.4	1,788.0	1,519.8	2,243.2
2006	262.2	542.1	632.6	655.5	557.2	822.4

ANNUAL SYNFUEL REVENUES FOR VARIOUS FOUR-MODULE FACILITIES

(BILLIONS OF INFLATED DOLLARS)

THIS TABLE SHOWS THAT MBG PRODUCES THE HIGHEST YEARLY REVENUE, OF THE PRODUCTS CONSIDERED. THIS IS A CONSEQUENCE OF THE FACT THAT MBG HAS A HIGH SELLING PRICE AND MORE MBG IS PRODUCED THAN ANY OTHER ALTERNATIVE PRODUCT.

ANNUAL SYNFUEL REVENUES FOR VARIOUS
FOUR-MODULE FACILITIES

(Billions of Inflated Dollars)

YEAR	MBG	SNG	METHANOL	GASOLINE	HYDROGEN	ELECTRICITY
1985	0.34	0.26	0.48	0.57	0.33	0.23
1986	1.29	0.98	1.37	1.63	1.25	0.76
1987	2.19	1.67	2.23	2.65	2.13	1.09
1988	2.82	2.16	2.54	3.02	2.74	1.21
1989	3.67	2.81	3.24	3.86	3.57	1.37
1990	4.70	3.60	3.61	4.29	4.58	1.51
1991	5.34	4.09	4.11	4.89	5.20	1.64
1992	6.06	4.64	4.29	5.10	5.90	1.78
1993	6.85	5.25	4.68	5.56	6.67	1.93
1994	7.73	5.91	5.10	6.06	7.52	2.09
1995	8.68	6.64	5.56	6.61	8.45	2.26
1996	9.70	7.42	6.06	7.20	4.45	2.45
1997	10.77	8.24	6.60	7.85	10.05	2.66
1998	11.88	9.09	7.19	8.55	11.57	2.88
1999	13.02	9.96	7.84	9.33	12.68	3.12
2000	14.16	10.84	8.55	10.17	13.79	3.38
2001	15.30	11.71	9.32	11.08	14.89	3.67
2002	16.41	12.56	10.16	12.08	15.98	3.98
2003	17.57	13.44	11.07	13.17	17.10	4.31
2004	18.79	14.38	12.07	14.35	18.30	4.67
2005	15.08	11.54	9.87	11.73	14.69	3.80
2006	5.38	4.12	3.58	4.26	5.24	1.37

ANNUAL COST FOR VARIOUS FOUR-MODULE PLANTS

(BILLIONS OF INFLATED DOLLARS)

THIS TABLE SHOWS, FOR EXAMPLE, THAT MAXIMUM ANNUAL COSTS IN INFLATED DOLLARS FOR THE DIFFERENT FOUR-MODULE SYNFUELS PLANTS RANGE FROM 3.80 BILLION DOLLARS FOR MBG TO 5.86 BILLION DOLLARS FOR CENTRAL-SITE FUEL CELL ELECTRICITY GENERATION.

ANNUAL COST FOR VARIOUS FOUR-MODULE PLANTS
(Billions of Inflated Dollars)

YEAR	MBG	SNG	METHANOL	GASOLINE	HYDROGEN	ELECTRICITY
1985	0.26	0.32	0.33	0.35	0.34	0.38
1986	0.76	0.97	1.01	1.07	1.04	1.17
1987	1.09	1.39	1.44	1.52	1.48	1.66
1988	1.17	1.49	1.55	1.63	1.59	1.78
1989	1.27	1.60	1.67	1.75	1.70	1.92
1990	1.36	1.72	1.80	1.88	1.82	2.06
1991	1.46	1.85	1.93	2.01	1.95	2.21
1992	1.57	1.98	2.08	2.16	2.08	2.37
1993	1.69	2.13	2.23	2.32	2.24	2.55
1994	1.82	2.29	2.40	2.49	2.40	2.74
1995	1.96	2.47	2.59	2.68	2.57	2.95
1996	2.11	2.66	2.80	2.89	2.77	3.18
1997	2.27	2.86	3.01	3.11	2.98	3.43
1998	2.45	3.09	3.25	3.35	3.20	3.70
1999	2.64	3.33	3.51	3.62	3.44	4.00
2000	2.84	3.59	3.79	3.90	3.71	4.31
2001	3.06	3.87	4.09	4.20	3.99	4.66
2002	3.28	4.16	4.41	4.53	4.29	5.02
2003	3.53	4.49	4.76	4.89	4.62	5.43
2004	3.80	4.84	5.13	5.27	4.97	5.86
2005	3.05	3.90	4.14	4.25	4.00	4.73
2006	1.10	1.41	1.50	1.54	1.45	1.71

YEARLY REVENUE - MINUS - COST FOR VARIOUS FOUR-MODULE FACILITIES

(BILLIONS OF INFLATED DOLLARS)

THIS TABLE SHOWS THAT MAXIMUM REVENUES MINUS COSTS, EXCLUDING TAXES, RANGE FROM +15 BILLION DOLLARS (INFLATED) FOR MBG TO -1.18 BILLION DOLLARS FOR CENTRAL-SITE FUEL CELL ELECTRICITY.

YEARLY REVENUE - MINUS - COST FOR VARIOUS
FOUR-MODULE FACILITIES
(Billions of Inflated Dollars)

YEAR	MBG	SNG	METHANOL	GASOLINE	HYDROGEN	ELECTRICITY
1985	0.08	-0.06	0.15	0.22	-0.02	-0.15
1986	0.52	0.01	0.36	0.56	0.21	-0.41
1987	1.00	0.29	0.79	1.14	0.64	-0.57
1988	1.64	0.67	0.99	1.40	1.16	-0.58
1989	2.40	1.20	1.57	2.11	1.87	-0.55
1990	3.34	1.87	1.81	2.41	2.75	-0.55
1991	3.88	2.24	2.18	2.88	3.26	-0.57
1992	4.49	2.66	2.21	2.94	3.82	-0.59
1993	5.16	3.11	2.44	3.24	4.44	-0.62
1994	5.91	3.62	2.69	3.57	5.13	-0.66
1995	6.72	4.17	2.97	3.93	5.88	-0.69
1996	7.59	4.76	3.26	4.31	6.68	-0.73
1997	8.50	5.38	3.59	4.74	7.51	-0.77
1998	9.43	6.00	3.94	5.20	8.36	-0.82
1999	10.38	6.63	4.33	5.71	9.23	-0.87
2000	11.33	7.25	4.76	6.27	10.08	-0.93
2001	12.24	7.84	5.23	6.88	10.90	-0.99
2002	13.13	8.39	5.75	7.55	11.69	-1.05
2003	14.03	8.95	6.31	8.28	12.48	-1.11
2004	15.00	9.54	6.93	9.08	13.32	-1.18
2005	12.04	7.64	5.72	7.48	10.68	-0.93
2006	4.28	2.71	2.09	2.73	3.79	-0.34

SUMMARY OF TEST CASE OUTPUT FOR VARIOUS PRODUCTS (FOUR-MODULE FACILITIES)

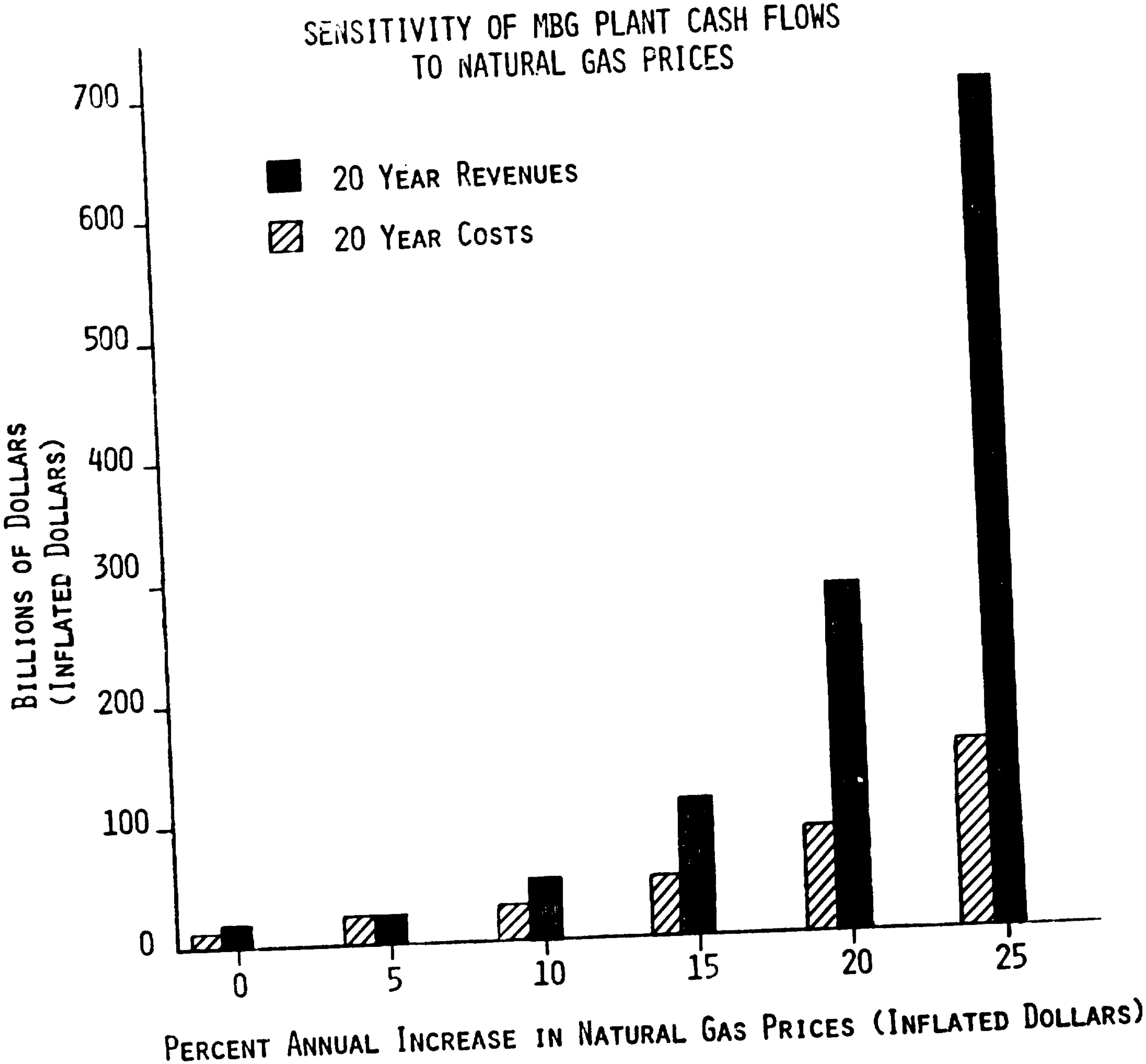
THIS TABLE ILLUSTRATES SOME OF THE CAPABILITIES OF THE SYNFUEL ECONOMIC EVALUATION MODEL TO PROVIDE QUANTITATIVE INFORMATION ON THE IMPORTANT ECONOMIC PARAMETERS OF COAL-BASED SYNTHETIC FUEL COMPLEXES.

SUMMARY OF TEST CASE OUTPUT FOR VARIOUS PRODUCTS
(FOUR-MODULE FACILITIES)

	MBG	SNG	METHANOL	GASOLINE	HYDROGEN	ELECTRICITY
TOTAL SYNFUELS PRODUCTION (Quadrillion BTU's)	2.18	1.67	1.73	1.34	1.64	1.43
TOTAL LIFETIME PLANT COST (Billions of Inflated $)	44.54	56.40	59.43	67.39	58.64	67.83
AVERAGE SYNFUELS COST ($/MMBTU)	20.47	33.87	34.33	45.70	35.76	47.80
TOTAL SYNFUELS REVENUES (Billions of Inflated $)	197.72	151.30	129.51	154.02	192.51	52.14
TOTAL SYNFUELS CASH FLOW (Billions of Inflated $)	153.18	94.90	70.08	92.63	133.87	-15.69
TOTAL PRESENT VALUE (Billions of Inflated $)	16.38	9.66	7.90	10.55	13.92	-2.26
LEVELIZED INFLATED COST (Billions of $)	0.8645	1.0946	1.1475	1.1914	1.1465	1.3119
LEVELIZED INFLATED REVENUE (Billions of $)	3.32	2.54	2.33	2.77	3.23	0.97
LEVELIZED INFLATED PRODUCT COST ($/MMBTU)	7.95	13.14	13.26	17.74	13.98	18.49
LEVELIZED INFLATED PRODUCT PRICE ($/MMBTU)	30.53	30.53	26.94	41.29	39.44	13.72
LEVELIZED 1980 COST (Millions of $)	518.28	655.65	687.98	714.25	687.38	786.53
LEVELIZED 1980 REVENUE (Billions of $)	1.99	1.52	1.40	1.66	1.94	0.58
LEVELIZED 1980 PRODUCT COST ($/MMBTU)	4.76	7.88	7.95	10.63	8.38	11.08
LEVELIZED 1980 PRODUCT PRICE ($/MMBTU)	18.30	18.30	16.15	24.75	23.65	8.23

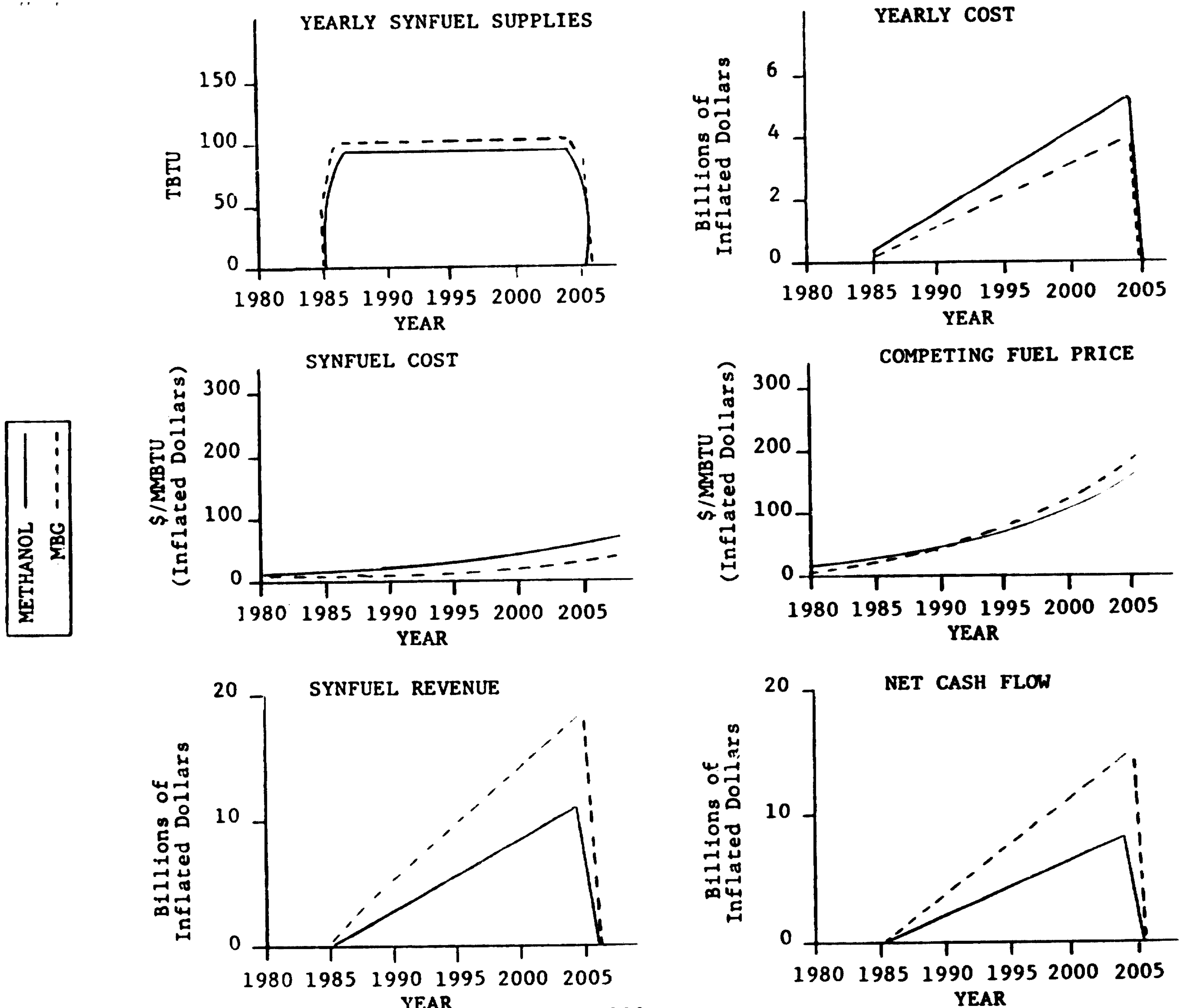
SENSITIVITY OF MBG PLANT CASH FLOWS TO NATURAL GAS PRICES

THIS CHART SHOWS THE EXTREME SENSITIVITY OF THE LIFE COST ECONOMICS OF THE MBG FACILITY TO THE PRICE OF THE NATURAL GAS WITH WHICH IT COMPETES. IT IS OBVIOUS THAT THE PROFITS OF THE PLANT WILL INCREASE IN A STRONGLY NON-LINEAR FASHION AS NATURAL GAS PRICES INCREASE.


SENSITIVITY OF MBG PLANT CASH FLOWS
TO NATURAL GAS PRICES
20 YEAR REVENUES
20 YEAR COSTS
BILLIONS OF DOLLARS
(INFLATED DOLLARS)
700
600
500
400
300
200
100
0
0
5
10
15
20
25
PERCENT ANNUAL INCREASE IN NATURAL GAS PRICES (INFLATED DOLLARS)

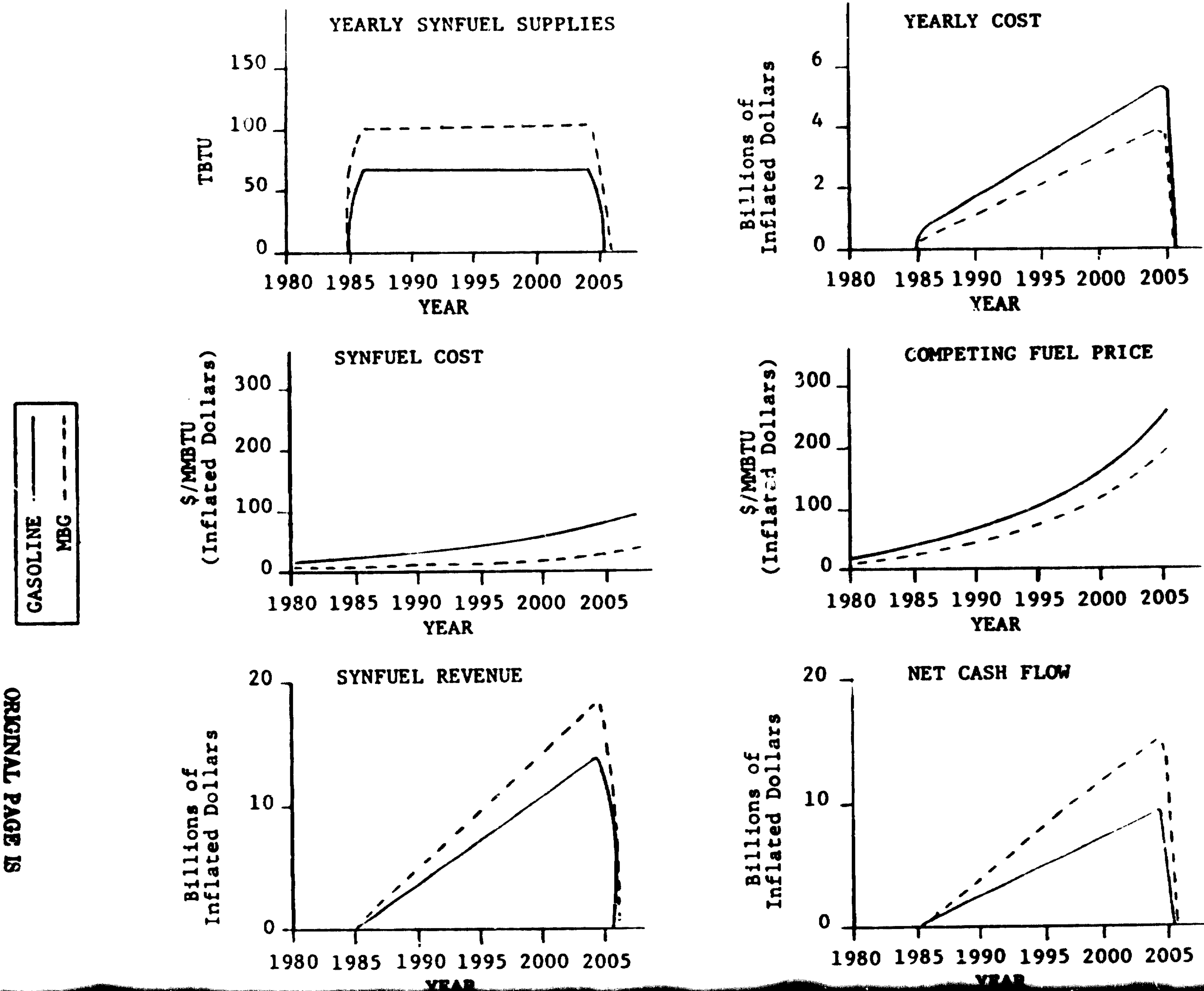
MBG VERSUS METHANOL

THIS PAGE PRESENT SEVERAL CHARTS WHICH ENABLE ONE TO PERFORM COMPARATIVE ECONOMIC EVALUATIONS OF ALTERNATIVE COAL-BASED SYNTHETIC FUEL COMPLEXES. THIS PARTICULAR COMPARISON IS BETWEEN MBG AND METHANOL.


YEARLY SYNFUEL SUPPLIES
TBTU
150
100
50
0
1980 1985 1990 1995 2000 2005
YEAR
YEARLY COST
Billions of Inflated Dollars
6
4
2
0
1980 1985 1990 1995 2000 2005
YEAR
SYNFUEL COST
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
COMPETING FUEL PRICE
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
SYNFUEL REVENUE
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005
YEAR
NET CASH FLOW
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005
YEAR
METHANOL
MBG

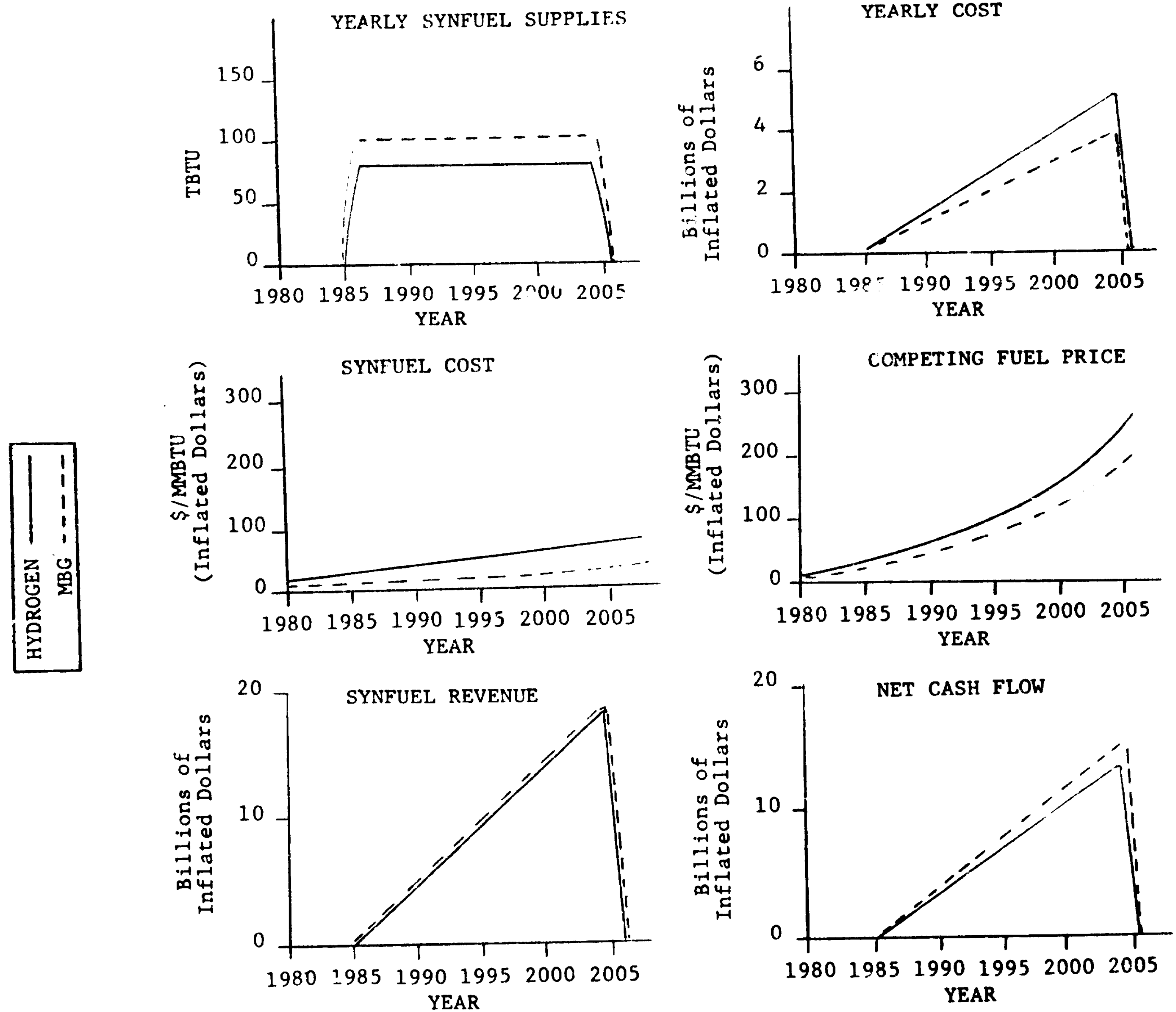
"MBG VERSUS GASOLINE"

THIS PAGE ILLUSTRATES THE RELATIVE ECONOMICS OF A COAL-BASED MBG FACILITY VERSUS A COAL-BASED SYNTHETIC GASOLINE FACILITY.


YEARLY SYNFUEL SUPPLIES
TBTU
150
100
50
0
1980 1985 1990 1995 2000 2005
YEAR
YEARLY COST
Billions of Inflated Dollars
6
4
2
0
1980 1985 1990 1995 2000 2005
YEAR
SYNFUEL COST
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
COMPETING FUEL PRICE
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
GASOLINE
MBG
SYNFUEL REVENUE
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005
NET CASH FLOW
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005

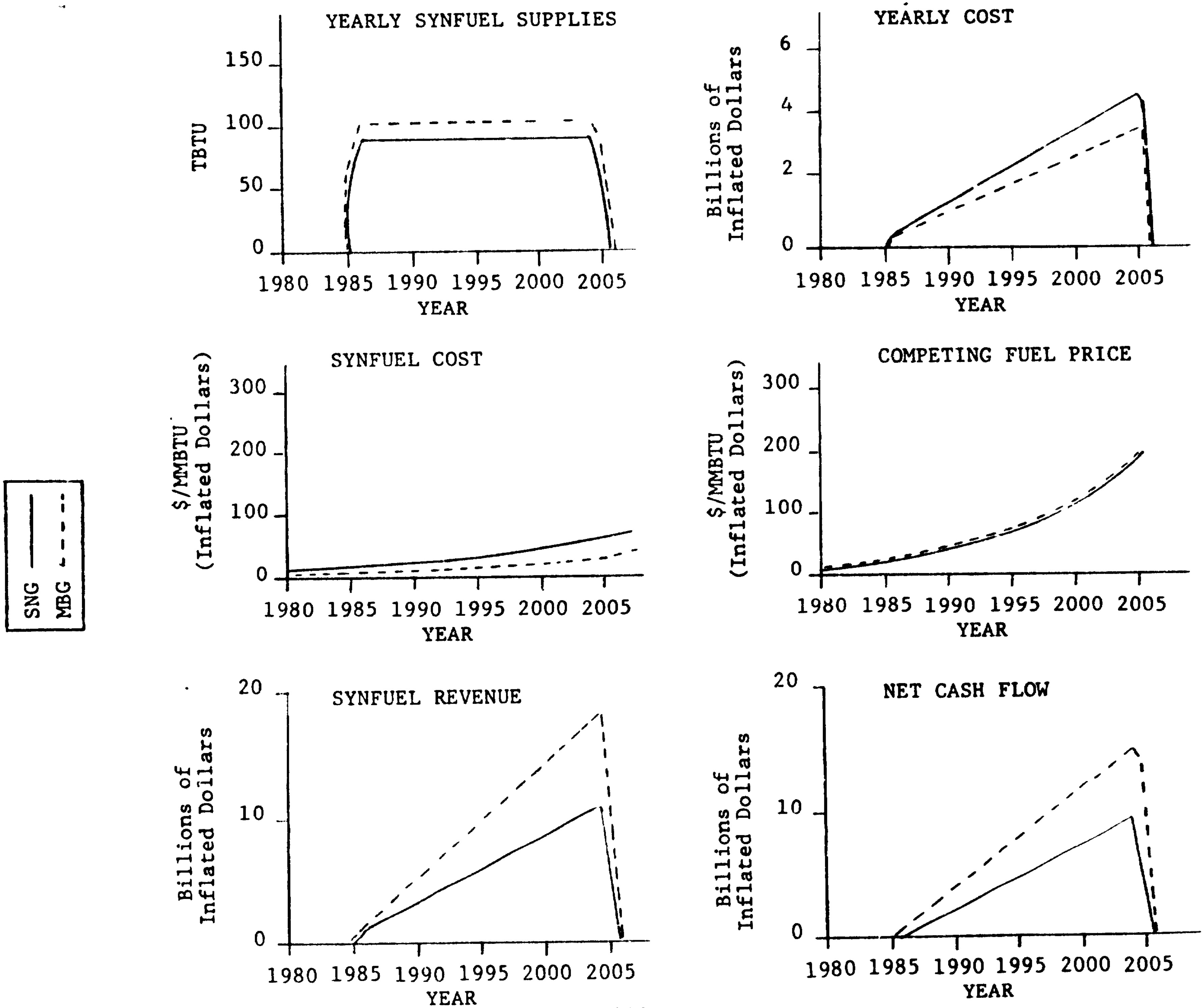
"MBG VERSUS HYDROGEN"

THIS PAGE ILLUSTRATES THE RELATIVE ECONOMICS OF A COAL-BASED MBG FACILITY VERSUS A COAL-BASED HYDROGEN FACILITY.


YEARLY SYNFUEL SUPPLIES
TBTU
150
100
50
0
1980 1985 1990 1995 2000 2005
YEAR
YEARLY COST
Billions of Inflated Dollars
6
4
2
0
1980 1985 1990 1995 2000 2005
YEAR
SYNFUEL COST
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
COMPETING FUEL PRICE
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
HYDROGEN
MBG
SYNFUEL REVENUE
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005
YEAR
NET CASH FLOW
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005
YEAR

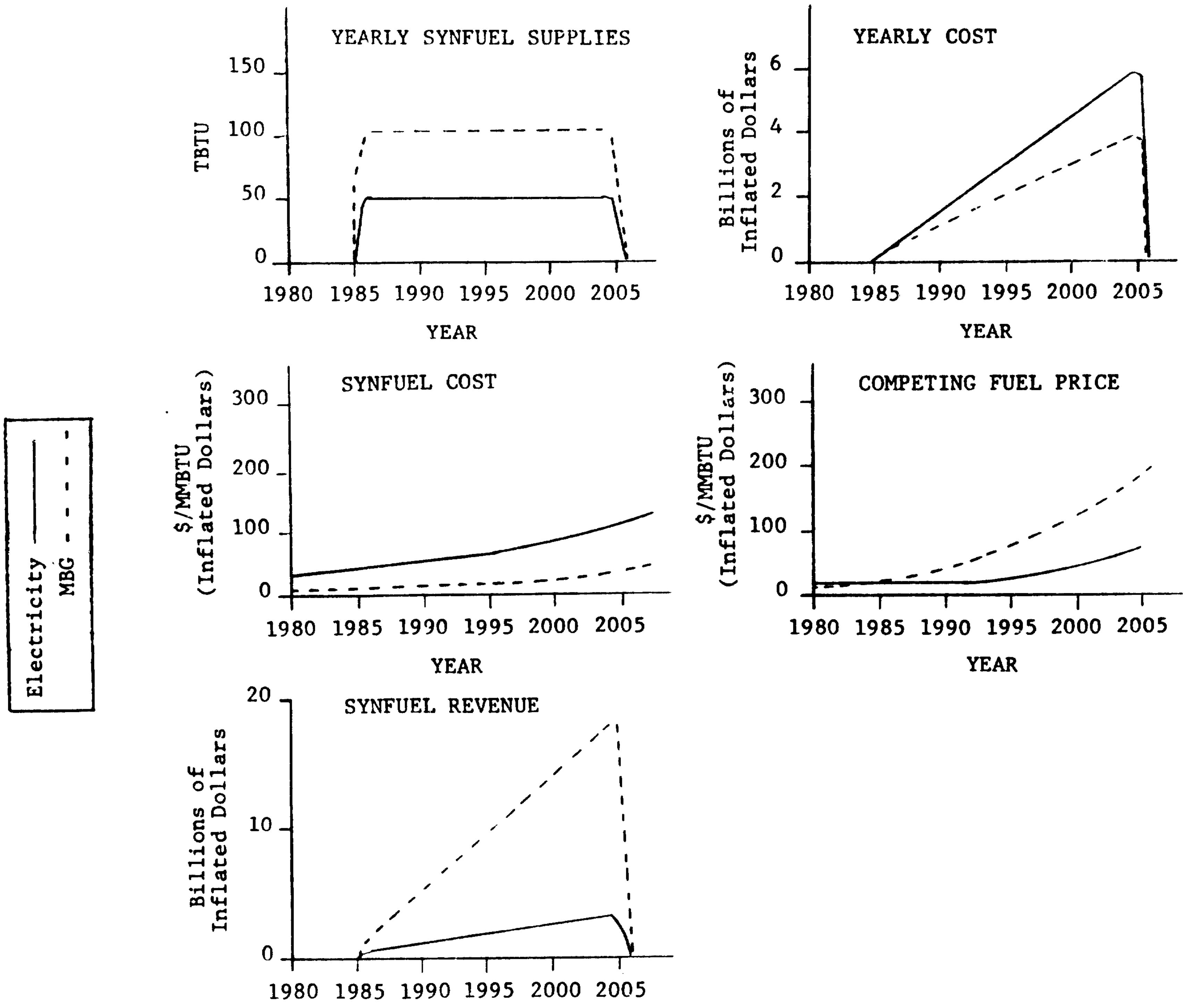
"MBG VERSUS SNG"

THIS PAGE ILLUSTRATES THE RELATIVE ECONOMICS OF A COAL-BASED MBG FACILITY VERSUS A SUBSTITUTE NATURAL GAS (SNG) FACILITY.


YEARLY SYNFUEL SUPPLIES
TBTU
0
50
100
150
1980 1985 1990 1995 2000 2005
YEAR
YEARLY COST
Billions of Inflated Dollars
0
2
4
6
1980 1985 1990 1995 2000 2005
YEAR
SYNFUEL COST
$/MMBTU (Inflated Dollars)
0
100
200
300
1980 1985 1990 1995 2000 2005
YEAR
COMPETING FUEL PRICE
$/MMBTU (Inflated Dollars)
0
100
200
300
1980 1985 1990 1995 2000 2005
YEAR
SNG
MBG
SYNFUEL REVENUE
Billions of Inflated Dollars
0
10
20
1980 1985 1990 1995 2000 2005
YEAR
NET CASH FLOW
Billions of Inflated Dollars
0
10
20
1980 1985 1990 1995 2000 2005
YEAR

"MBG VERSUS FUEL CELL ELECTRICITY"

THIS PAGE, AND THE NEXT PAGE, ILLUSTRATE THE RELATIVE ECONOMICS OF A COAL-BASED MBG FACILITY VERSUS A CENTRAL-SITE FUEL CELL FACILITY WHICH USES A COAL GAS IN ITS FUEL CELLS.


YEARLY SYNFUEL SUPPLIES
TBTU
150
100
50
0
1980 1985 1990 1995 2000 2005
YEAR
YEARLY COST
Billions of Inflated Dollars
6
4
2
0
1980 1985 1990 1995 2000 2005
YEAR
SYNFUEL COST
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
COMPETING FUEL PRICE
$/MMBTU (Inflated Dollars)
300
200
100
0
1980 1985 1990 1995 2000 2005
YEAR
Electricity
MBG
SYNFUEL REVENUE
Billions of Inflated Dollars
20
10
0
1980 1985 1990 1995 2000 2005
YEAR

ONE MODULE CONSTRUCTION COSTS

THIS TABLE SHOWS THAT IF THE BASIC MBG MODULE COSTS ABOUT 465 MILLION DOLLARS (1980 DOLLARS) THEN ALL OF THE ADD-ON UNITS TO MAKE THE OTHER PRODUCTS FALL WITHIN 209 MILLION DOLLARS OF THIS BASELINE COST. (I.E., 674 - 465 = 209 MILLION DOLLARS)

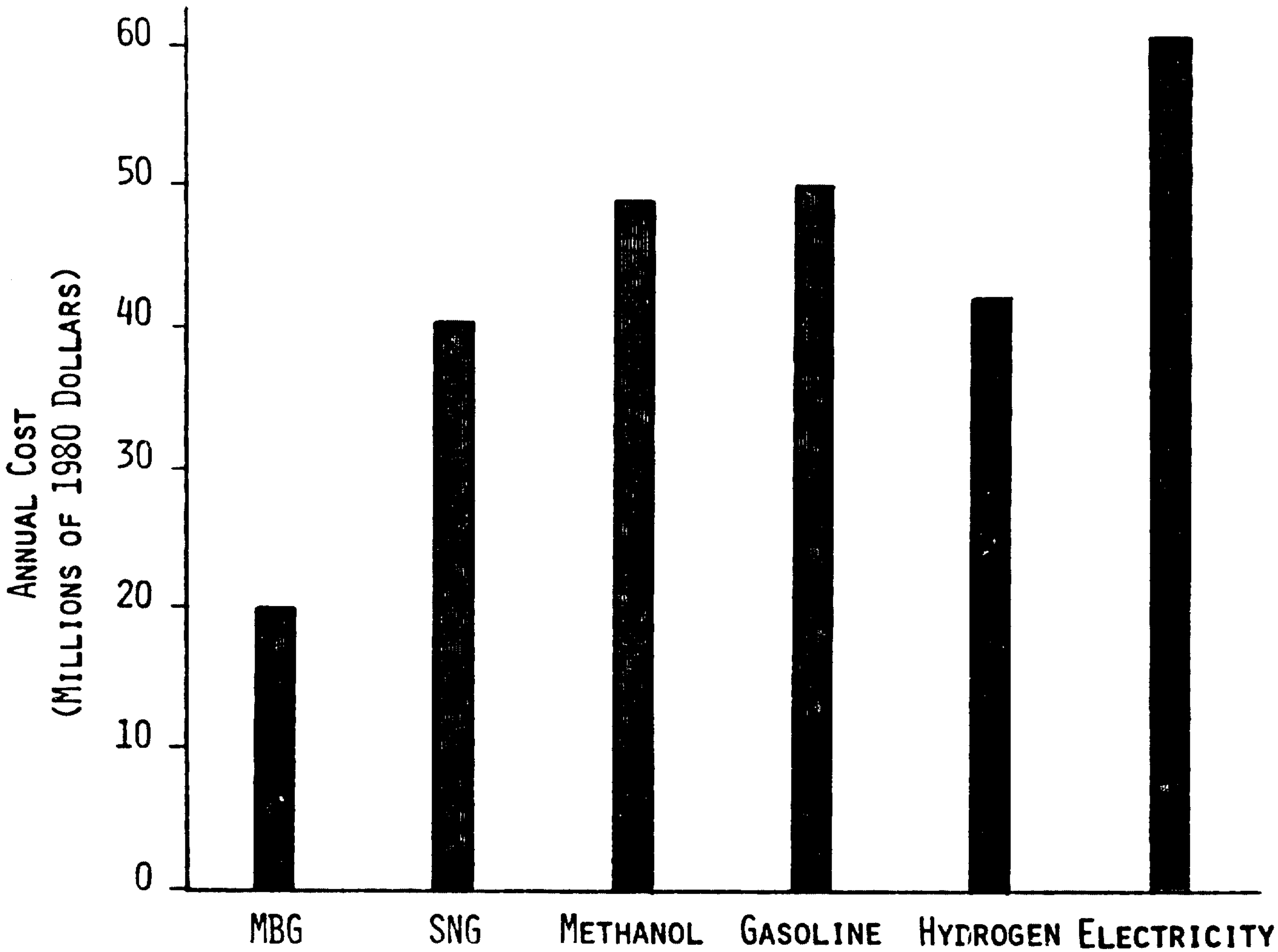
ONE MODULE CONSTRUCTION COSTS

Module Type	Construction Costs (1980 Dollars)
MBG	465,220,720.
SNG	580,720,720.
Methanol	577,720,720.
Gasoline	637,495,720.
Hydrogen	667,220,720.
Electricity	674,220,720.

ONE-MODULE FACILITIES
YEARLY OPERATION & MAINTENANCE COSTS

THIS CHART GIVES THE RELATIVE O & M COSTS OF ONE MODULE OF MBG VERSUS OTHER SYNFUEL PRODUCTS WHICH WOULD UTILIZE THE MBG OUTPUT OF THIS MODULE TO PRODUCE OTHER SYNFUELS

ONE-MODULE FACILITIES
YEARLY OPERATION & MAINTENANCE COSTS



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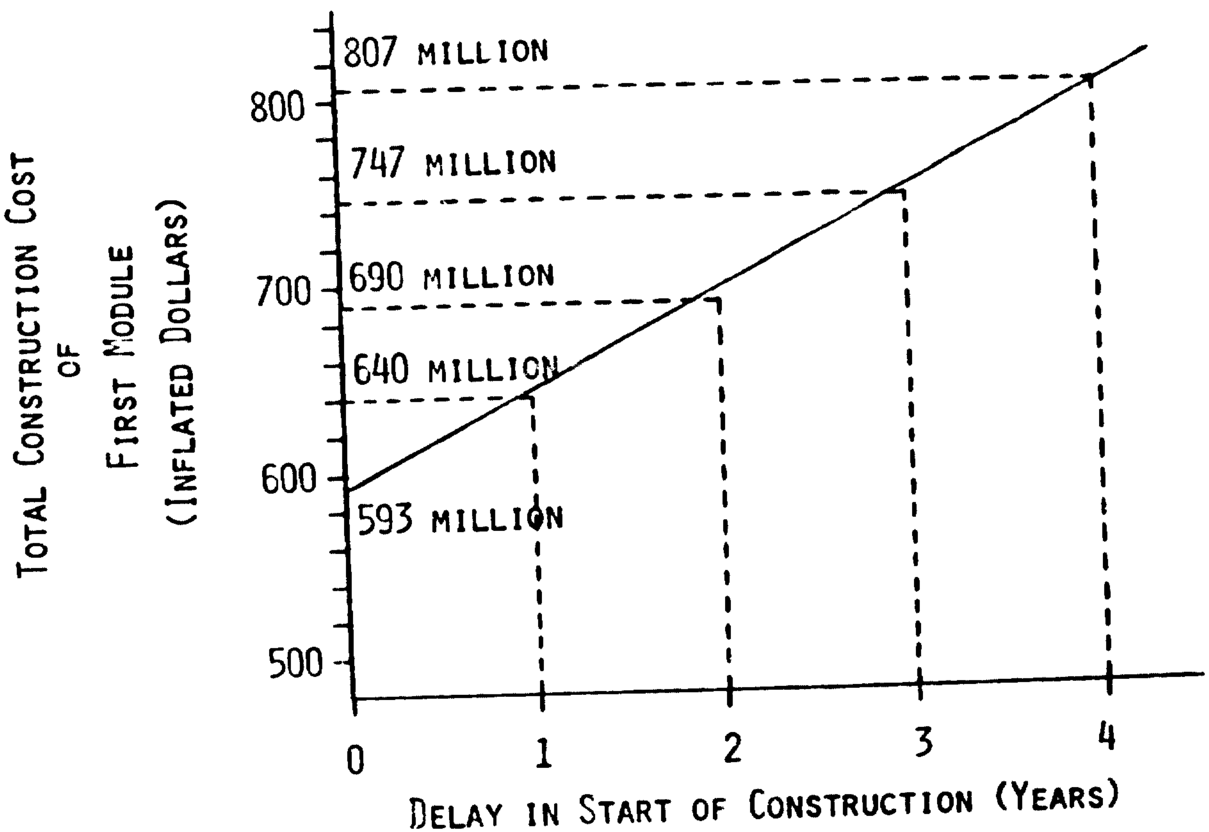
OF POOR QUALITY

SENSITIVITY OF THE FIRST MBG MODULE TO DELAYS IN START OF CONSTRUCTION

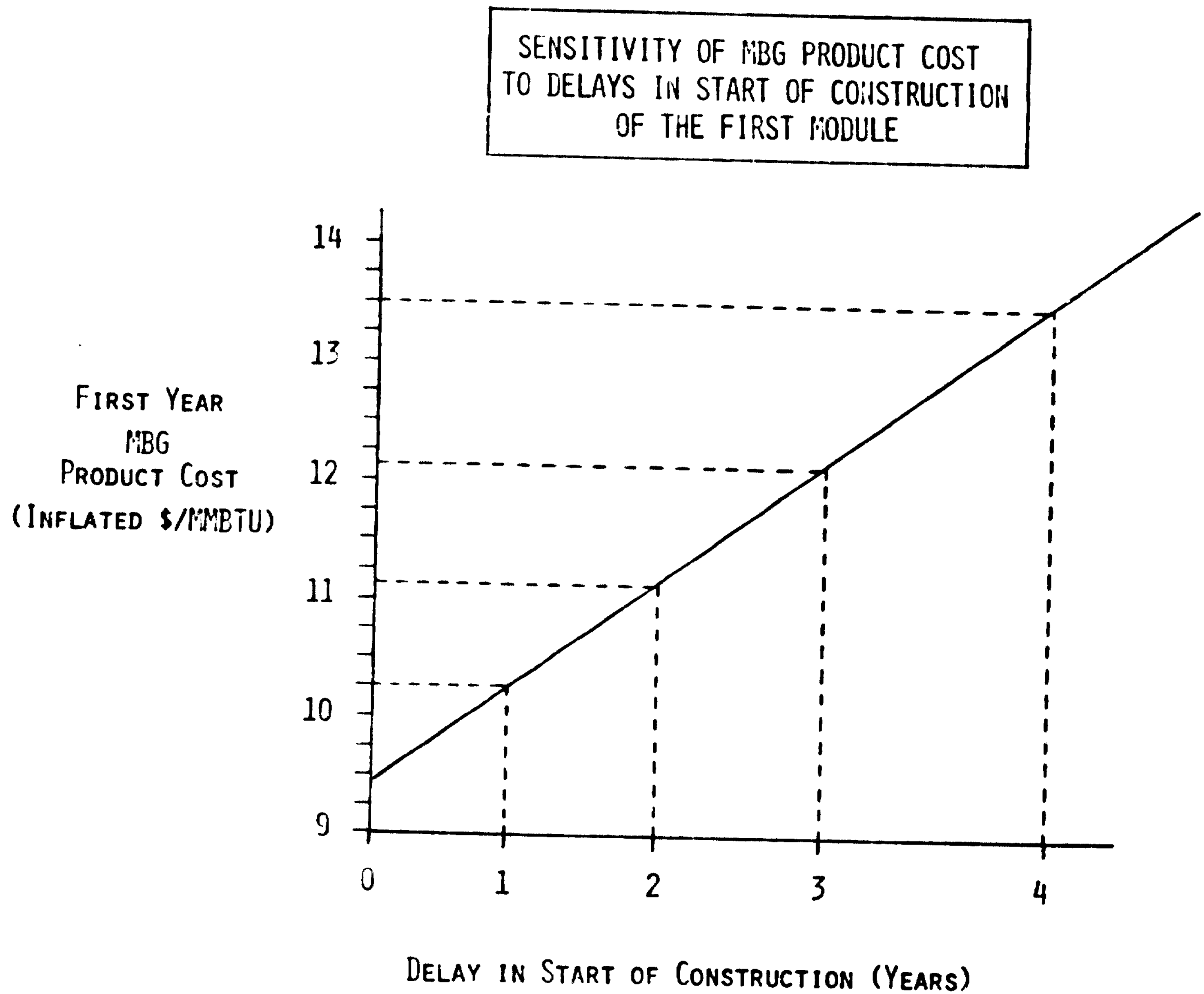
THIS FIGURE SHOWS THAT A FOUR-YEAR DELAY IN STARTING CONSTRUCTION OF THE FIRST MODULE WILL CAUSE THE CONSTRUCTION COST OF THIS MODULE, IN INFLATED DOLLARS, TO RISE FROM 593 MILLION DOLLARS TO 807 MILLION DOLLARS, AN INCREASE OF 214 MILLION DOLLARS. THIS INCREASE ASSUMES AN 8% A YEAR INCREASE IN CONSTRUCTION COSTS.

SENSITIVITY OF FIRST MBG MODULE
TO DELAYS IN START OF CONSTRUCTION



SENSITIVITY OF MBG PRODUCT COST
TO DELAYS IN START OF CONSTRUCTION
OF THE FIRST MODULE

THIS FIGURE SHOWS THAT A FOUR-YEAR DELAY IN STARTING CONSTRUCTION OF THE FIRST MODULE RESULTS IN THE FIRST YEAR COST OF PRODUCING THE MBG TO RISE FROM APPROXIMATELY $9.50/MMBTU TO $13.25/MMBTU, IN INFLATED DOLLARS.


SENSITIVITY OF MBG PRODUCT COST
TO DELAYS IN START OF CONSTRUCTION
OF THE FIRST MODULE
FIRST YEAR
MBG
PRODUCT COST
(INFLATED $/MMBTU)
14
13
12
11
10
9
0
1
2
3
4
DELAY IN START OF CONSTRUCTION (YEARS)

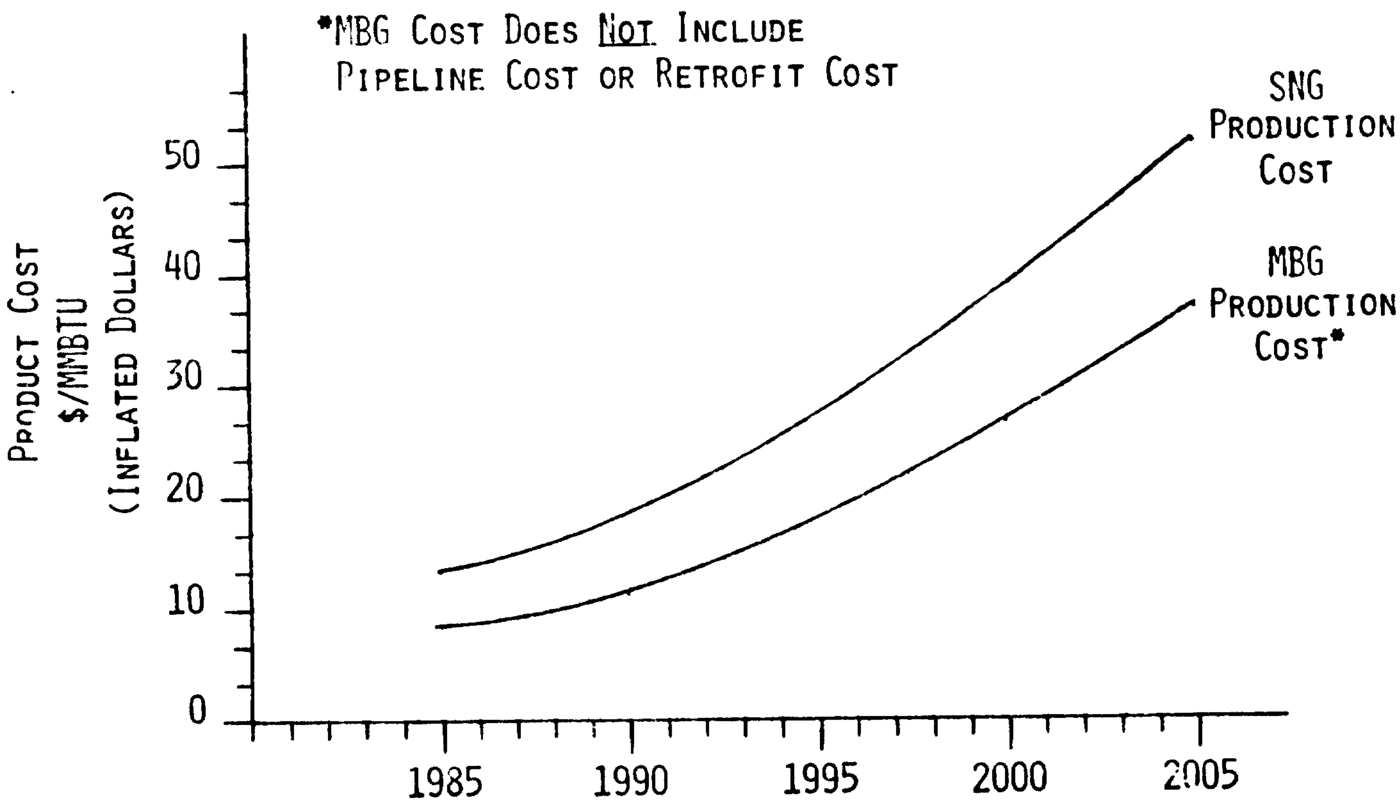
ONE MBG MODULE VERSUS ONE SNG MODULE

PRODUCT COST

THIS FIGURE SHOWS THAT, ON A $/MMBTU BASIS, THE COST OF PRODUCING SNG IS GREATER THAN THE COST OF PRODUCING MBG. HOWEVER, THIS FACT MUST BE ASSESSED IN PROPER PERSPECTIVE. A HUGE PIPELINE DISTRIBUTION SYSTEM IS ALREADY IN PLACE FOR TRANSPORTING NATURAL GAS. ALSO, THERE IS <u>NO</u> RETROFIT COST FOR THE END-USER OF SNG, IF HIS PLANT ALREADY USES NATURAL GAS.

ONE MBG MODULE
VERSUS
ONE SNG MODULE

PRODUCT COST

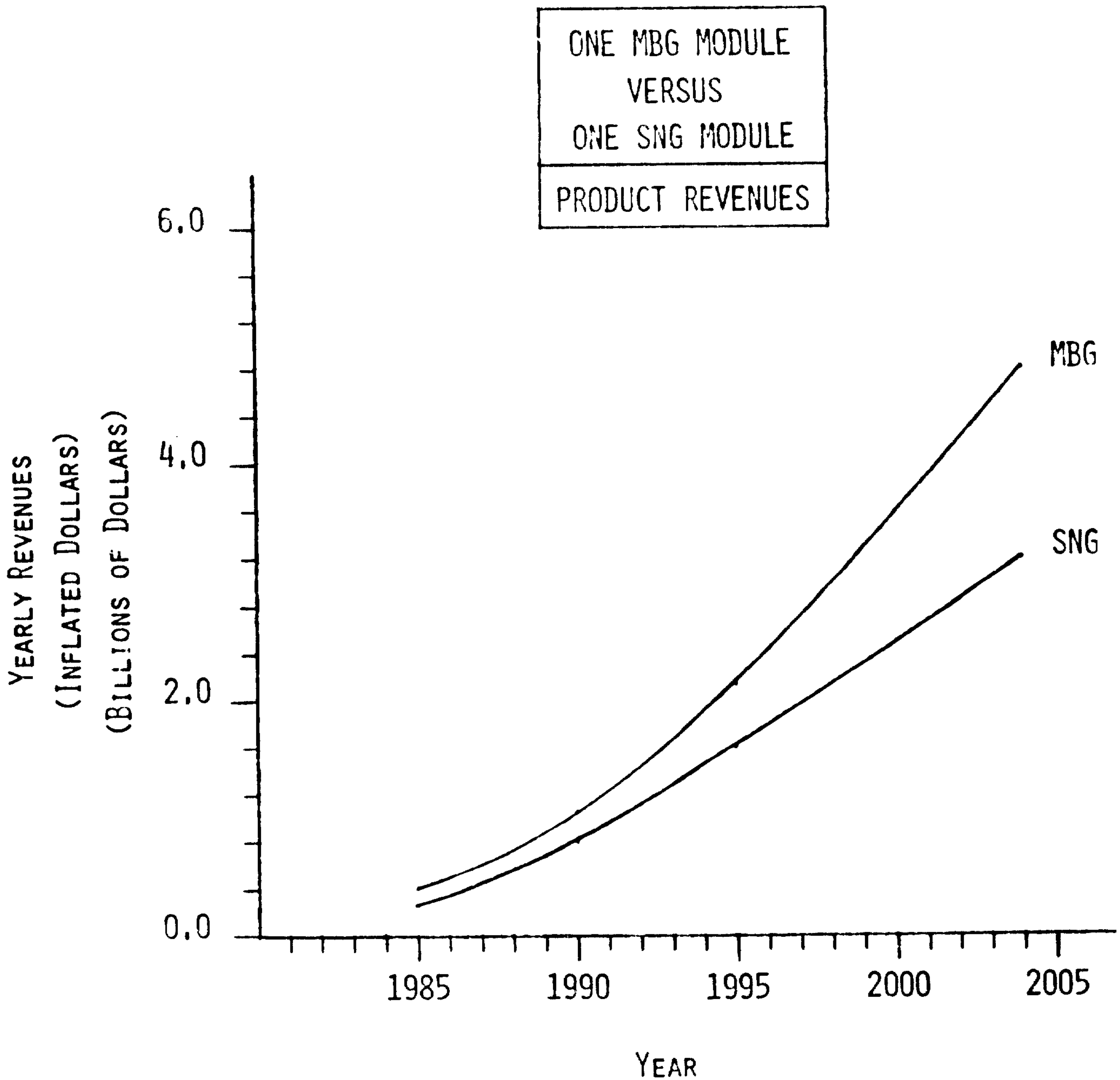


ORIGINAL PAGE IS OF POOR QUALITY

ONE MBG MODULE VERSUS ONE SNG MODULE

PRODUCT REVENUES

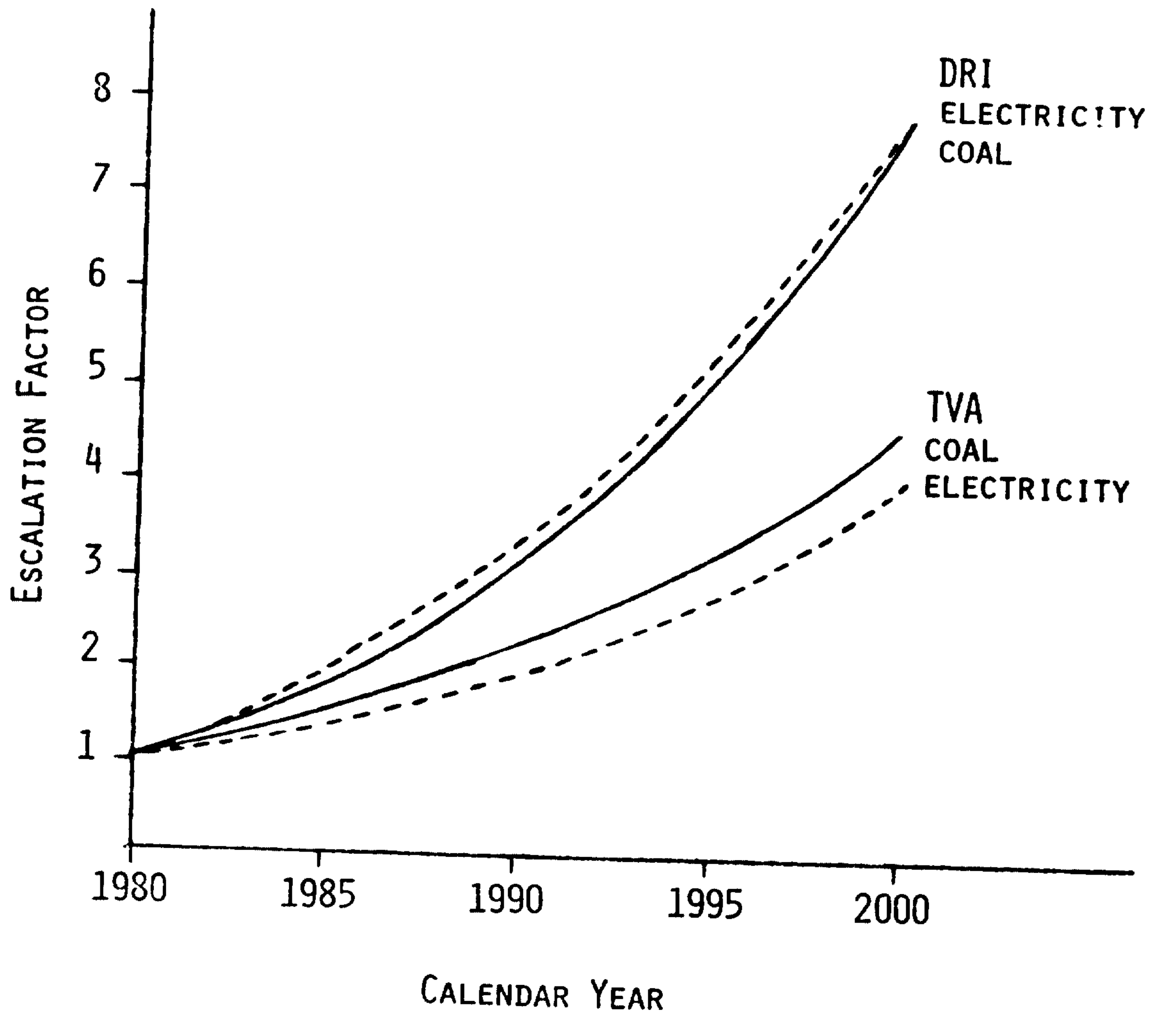
IF THE FIRST MODULE IS UTILIZED FOR SNG PRODUCTION, RATHER THAN MBG PRODUCTION, THEN THIS FIGURE SHOWS THAT THE YEARLY REVENUES GENERATED BY SELLING THE MBG WILL BE HIGHER THAN THOSE GENERATED BY SELLING THE SNG OUTPUT. THIS ASSUMES THAT BOTH MBG AND SNG ARE SOLD AT THE CURRENT YEAR MARKET PRICE OF NATURAL GAS.


ONE MBG MODULE
VERSUS
ONE SNG MODULE
PRODUCT REVENUES
YEARLY REVENUES
(INFLATED DOLLARS)
(BILLIONS OF DOLLARS)
6.0
4.0
2.0
0.0
MBG
SNG
1985
1990
1995
2000
2005
YEAR

ESCALATION FACTORS

USING DRI AND TVA ESCALATION RATES FOR ELECTRICITY AND COAL, THE PRICE INCREASES WILL AMOUNT TO FOUR TIMES THE PRICE FROM 1980 TO 2000 USING THE TVA RATES, AND ALMOST EIGHT TIMES USING THE DRI RATES. OBVIOUSLY, THESE ESCALATION RATES ARE VERY SIGNIFICANT AND WILL DETERMINE THE ECONOMIES OF SYNFUEL PRICES IN COMPETING WITH CONVENTIONAL FUELS. TDC USED THE DRI ESCALATIONS IN PERFORMING PRICE ANALYSIS OF FUELS.

ESCALATION FACTORS



PROJECT FUEL INCREASES

DATA RESOURCES, INC., (DRI) USES ECONOMETRIC MODELS TO PROJECT FUEL PRICE INCREASES. THE PERCENTAGE OF INCREASE AND THE CORRESPONDING FUEL PRICES ARE SHOWN FROM 1980 TO 2007 FOR COAL, NATURAL GAS, ELECTRICITY, GASOLINE, METHANOL, FUEL OIL, AND HYDROGEN.

CURRENT AND PROJECTED WHOLESALE
FUEL PRICES AND YEARLY PERCENTAGE INCREASES
(BEGINNING OF YEAR PRICES)

CALENDAR YEAR	80	81	82	83	84	85	86	87	88	89	90	91	92	93
COAL % INCREASE	[illegible]	16.1	13.1	11.7	11.1	10.9	10.9	10.7	10.5	10.0	9.8	10.2	10.2	10.0
$/MBTU	1.25	1.36	1.52	1.72	1.93	2.14	2.38	2.64	2.93	3.22	3.56	3.89	4.29	4.72
NATURAL GAS % INCREASE	18.5	20.8	16.1	15.6	15.5	24.6	27.9	27.4	28.9	30.2	28.1	11.7	11.5	11.1
$/MBTU	4.87	5.16	6.49	[illegible]	[illegible]	9.92	12.33	15.76	20.04	25.89	33.71	43.18	47.10	55.72
ELECTRICITY % INCREASE	10.7	16.7	11.5	11.1	9.9	11.2	9.8	9.2	9.1	9.0	8.9	8.5	9.6	8.4
$/MBTU	5.55	6.22	7.96	8.94	9.91	11.06	12.27	14.21	15.43	16.98	19.26	21.26	23.09	25.03
GASOHOL % INCREASE	[illegible]	10.6	19.7	12.5	17.2	27.1	9.8	6.0	14.1	27.5	11.2	9.1	9.0	9.0
$/MBTU	8.00	12.92	16.96	[illegible]	[illegible]	26.72	33.92	32.28	39.52	45.06	57.46	63.06	72.80	75.95
METHANOL % INCREASE	62.1	10.6	19.7	12.5	17.2	27.1	9.8	6.0	14.1	27.5	11.2	9.1	9.0	9.0
$/MBTU	[illegible]	8.56	11.01	13.21	14.86	17.61	22.33	24.30	25.76	29.39	37.48	41.67	45.47	49.51
FUEL OIL 2 % INCREASE	62.1	10.6	19.7	12.5	17.2	27.1	9.8	6.0	14.1	27.5	11.2	9.1	9.0	9.0
$/MBTU	[illegible]	8.66	11.29	13.51	15.20	17.81	22.64	24.86	26.35	30.07	38.34	42.61	46.51	50.70
HYDROGEN % INCREASE	18.5	20.1	16.1	[illegible]	15.5	24.6	27.9	27.4	28.9	30.2	28.1	11.7	11.5	11.1
$/MBTU	5.00	6.91	8.18	9.65	11.08	17.81	15.91	18.98	25.95	33.45	43.55	55.79	61.41	71.99

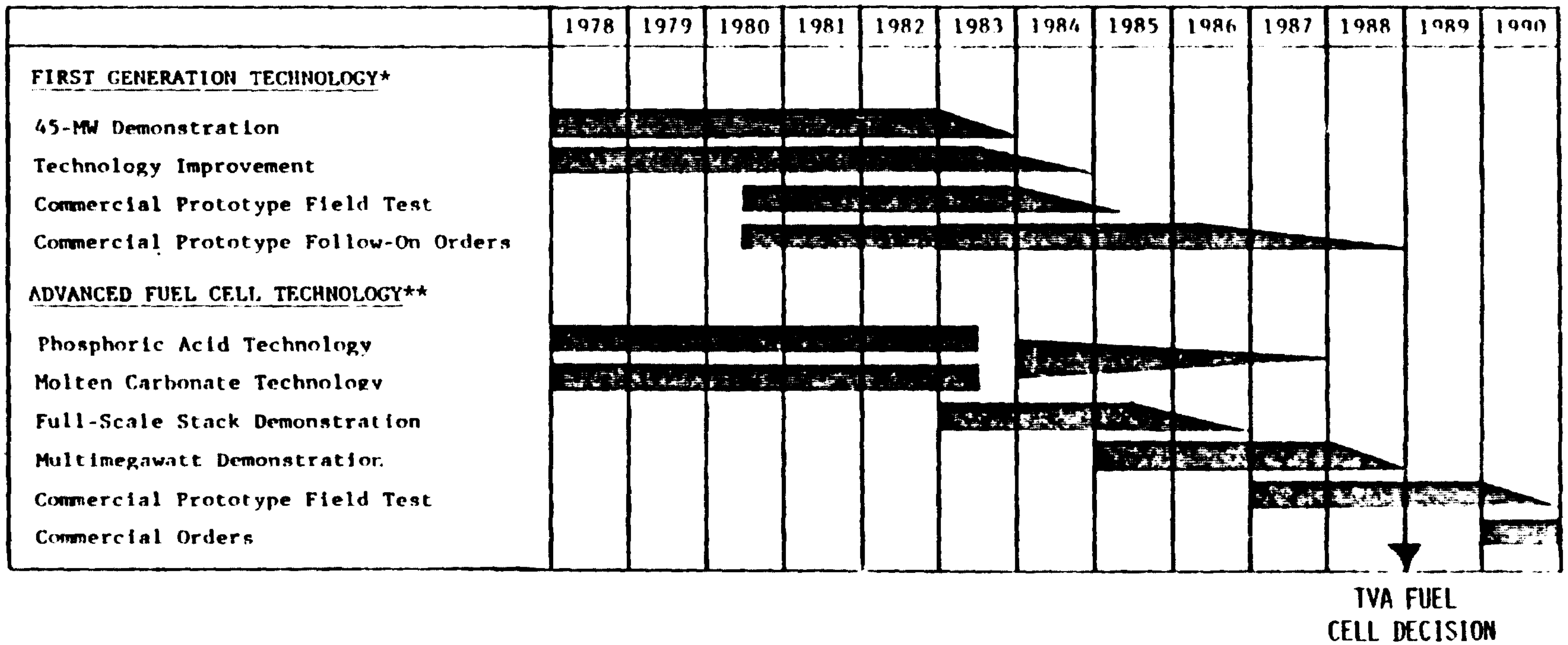
CALENDAR YEAR	94	95	96	97	98	99	00	01	02	03	04	05	06	07
COAL % INCREASE	9.8	9.6	9.4	9.2	9.0	8.8	8.6	8.4	8.2	8.0	7.8	7.8	7.8	7.8
$/MBTU	5.19	5.69	6.24	6.81	7.46	8.13	8.85	9.61	10.42	11.27	12.17	13.12	14.14	15.25
NATURAL GAS % INCREASE	12.7	12.3	11.8	11.0	10.1	9.6	8.8	8.0	7.3	7.0	7.0	7.0	7.0	7.0
$/MBTU	61.02	71.03	79.76	89.17	98.98	[illegible]	119.66	130.19	140.60	150.87	161.44	172.73	[illegible]	197.76
ELECTRICITY % INCREASE	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
$/MBTU	27.14	29.42	31.86	34.52	37.46	40.57	44.01	47.67	51.73	56.06	60.77	65.88	71.37	77.37
GASOHOL % INCREASE	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
$/MBTU	82.79	90.24	98.36	107.21	116.86	127.38	138.84	151.34	164.96	179.80	195.98	213.62	232.85	253.84
METHANOL % INCREASE	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
$/MBTU	53.96	58.82	64.11	69.88	76.17	83.03	90.50	98.65	107.53	117.20	127.75	139.25	151.78	165.78
FUEL OIL 2 % INCREASE	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
$/MBTU	55.26	60.21	65.65	71.56	78.00	85.02	92.67	101.01	110.11	120.07	130.83	142.59	[illegible]	169.41
HYDROGEN % INCREASE	12.7	12.3	11.8	11.0	10.1	9.6	8.8	8.0	7.1	7.0	7.0	7.0	7.0	7.0
$/MBTU	81.42	91.26	101.05	115.21	127.88	143.06	156.60	168.20	181.66	195.92	208.58	223.17	238.79	255.50

* DATA RESOURCES INC., U.S. LONG TERM REVIEW, SPRING 1980, AND WINTER 1979-1980

FUEL CELL DEVELOPMENT

FIRST GENERATION FUEL CELLS WILL BE COMMERCIALLY AVAILABLE (ACCORDING TO EPRI) DURING 1983. PHOSPHORIC ACID AND MOLTEN CARBONATE FUEL CELLS ARE CONSIDERED TO BE ADVANCED TECHNOLOGY AND WILL NOT BE AVAILABLE COMMERCIALLY UNTIL 1988 - 1989. THE ADVANCED TECHNOLOGY FUEL CELLS WILL REQUIRE FEWER BTU'S PER KWH OF ELECTRICITY GENERATED (7500 VERSUS 9300 BTU/KWH). A TVA DECISION ON USAGE OF THE PHOSPHORIC ACID OR MOLTEN CARBONATE COULD NOT BE MADE UNTIL 1988, ABOUT THE TIME MODULES 3 AND 4 WOULD BE COMING ON-LINE.

FUEL CELL DEVELOPMENT
(EPRI R & D STATUS REPORTS)



*9300 BTU/KWH

**7500 BTU/KWH; 0.78 VDC Individual Cells; Power Densities 150 W/Ft^2
40,000 Hours Demonstration

ELECTRICAL UTILITY LOAD DEFINITION

FUEL CELLS CAN OPERATE OVER A WIDE LOAD, THEREFORE CAN BE UTILIZED FOR BASE, PEAK, OR INTERMEDIATE ELECTRICAL LOADS. TDC ANALYZED FOUR MODULE PRODUCING MEDIUM-BTU GAS FOR FUEL CELLS OPERATING IN A BASE LOAD. THEREFORE, THE FUEL CELLS WOULD BE COMPETING ECONOMICALLY AGAINST TVA'S FOSSIL FUEL AND NUCLEAR POWER PLANTS.

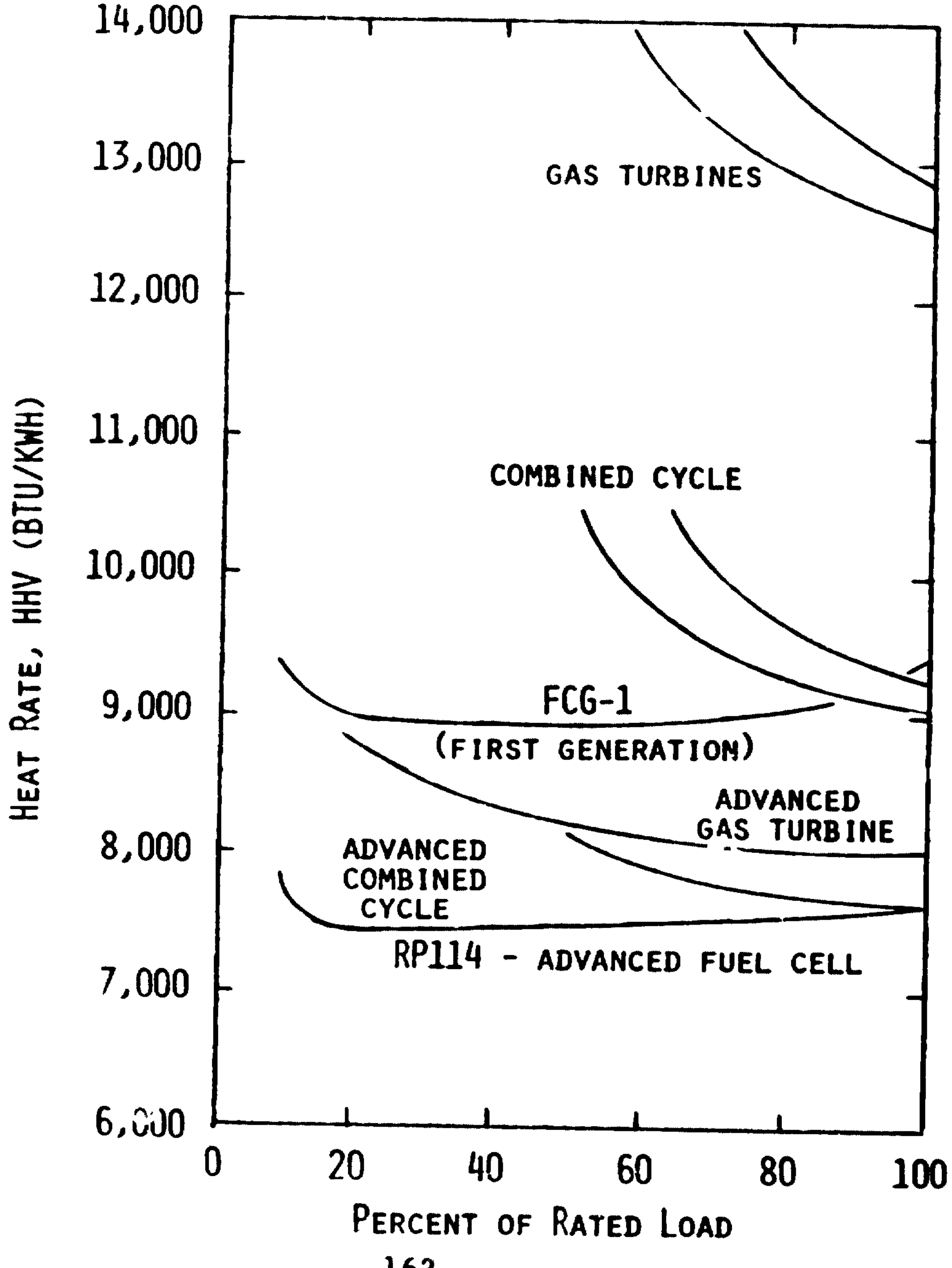
ELECTRICAL UTILITY LOAD DEFINITION

BASE LOAD	- 80% + UTILIZATION; > 8000 HOURS/YR; LARGE CAPITAL INVESTMENTS; LOW $/MBTU OPERATING AND CAPITAL RECOVERY COSTS; EFFICIENCIES 34 - 45%.
PEAK LOAD	- 15% UTILIZATION; LOW CAPITAL INVESTMENT; OPERATE 1500 HOURS/YR; HIGHER OPERATING COSTS; EFFICIENCIES 18 - 24%.
INTERMEDIATE LOAD	- 40% OF LESS UTILIZATION; OPERATE > 3500 HOURS/YR; TYPICALLY NATURAL GAS OF OIL FIRED; BASE AND PEAK LOAD PLANTS; EFFICIENCIES 24 - 34%.

TYPICAL UTILITY GENERATOR HEAT RATE CHARACTERISTICS

TVA IS CURRENTLY USING TURBINES FOR PEAK POWER GENERATION. THESE TURBINES OPERATE DURING JANUARY AND FEBRUARY WHEN HOME AND INDUSTRIAL HEATING REQUIREMENTS ARE HIGH. TVA IS CONSIDERING COMBINED-CYCLE UNITS FOR POWER GENERATION. AS THE FIGURE SHOWS, ADVANCED FUEL CELLS OPERATE OVER WIDE LOADS AND REQUIRE THE LESSER HEAT RATE FOR ELECTRICAL GENERATION.

TYPICAL UTILITY GENERATOR HEAT RATE CHARACTERISTICS



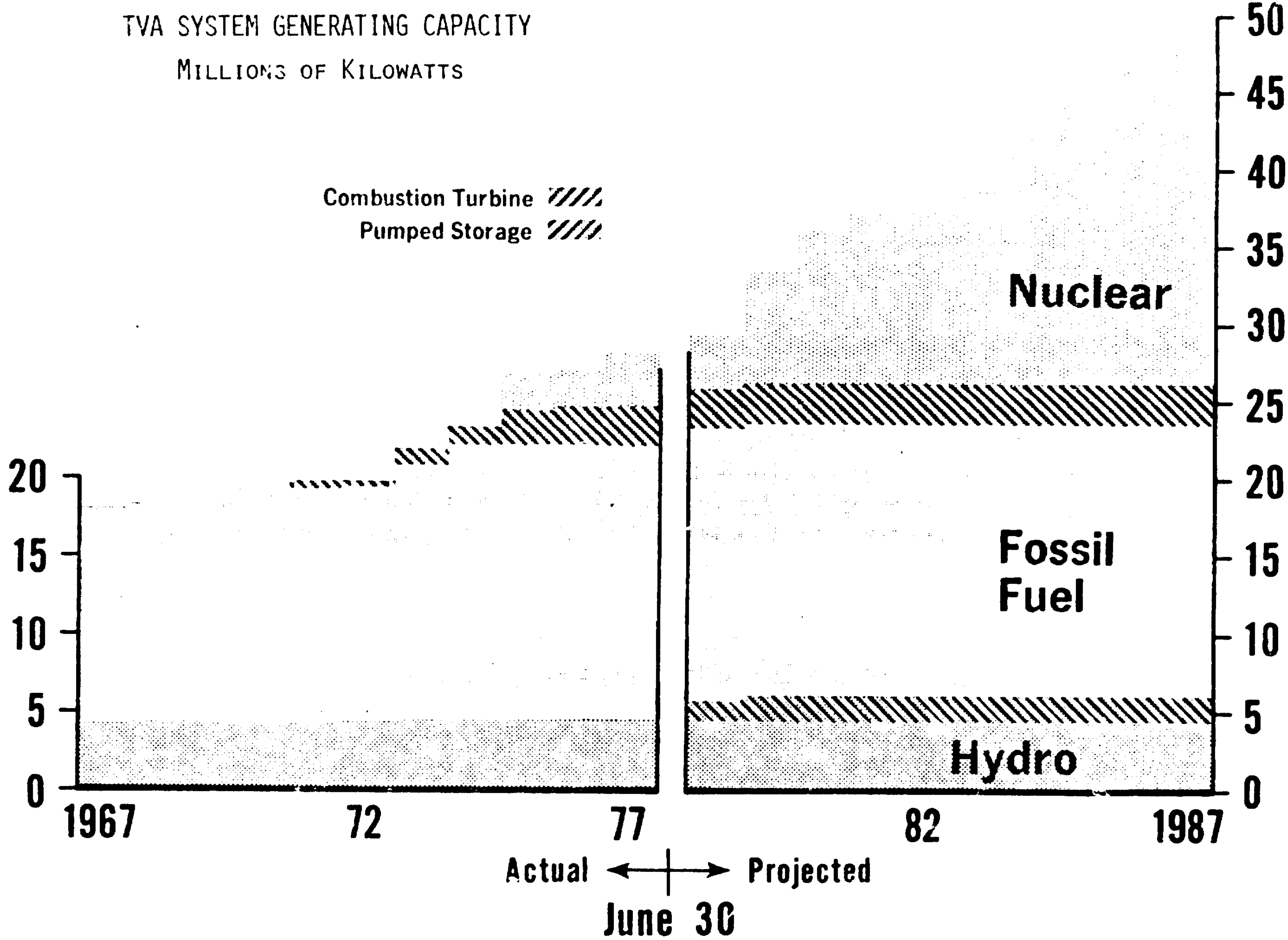
SOURCE: "AN ELECTRIC UTILITY FUEL CELL: DREAM OR REALITY?" A.P. FICKETT, AMERICAN POWER CONFERENCE, APRIL, 1975.

TVA SYSTEM GENERATING CAPACITY

FOR FUEL CELLS TO BE VIABLE COMMERCIALLY, THEY MUST COMPETE WITH THE CURRENT AND PROJECTED TVA ELECTRICAL GENERATING CAPABILITY. TVA HAS SEVERAL NUCLEAR PLANTS COMING ON-LINE DURING THE 1980'S. THESE PLANTS WILL BE GENERATING AN INEXPENSIVE ELECTRICITY. TVA ELECTRICAL RATES DURING THE 1980'S ARE PROJECTED TO GROW BY PERCENTAGES RELATIVELY SMALL COMPARED TO PRETROLEUM PRODUCTS AND NATURAL GAS. THEREFORE, ECONOMICALLY, IT IS DIFFICULT FOR CENTRAL-SITE FUEL CELLS, OPERATING AT BASE LOADS, TO COMPETE WITH PROJECTED TVA ELECTRICAL RATES.

TVA SYSTEM GENERATING CAPACITY

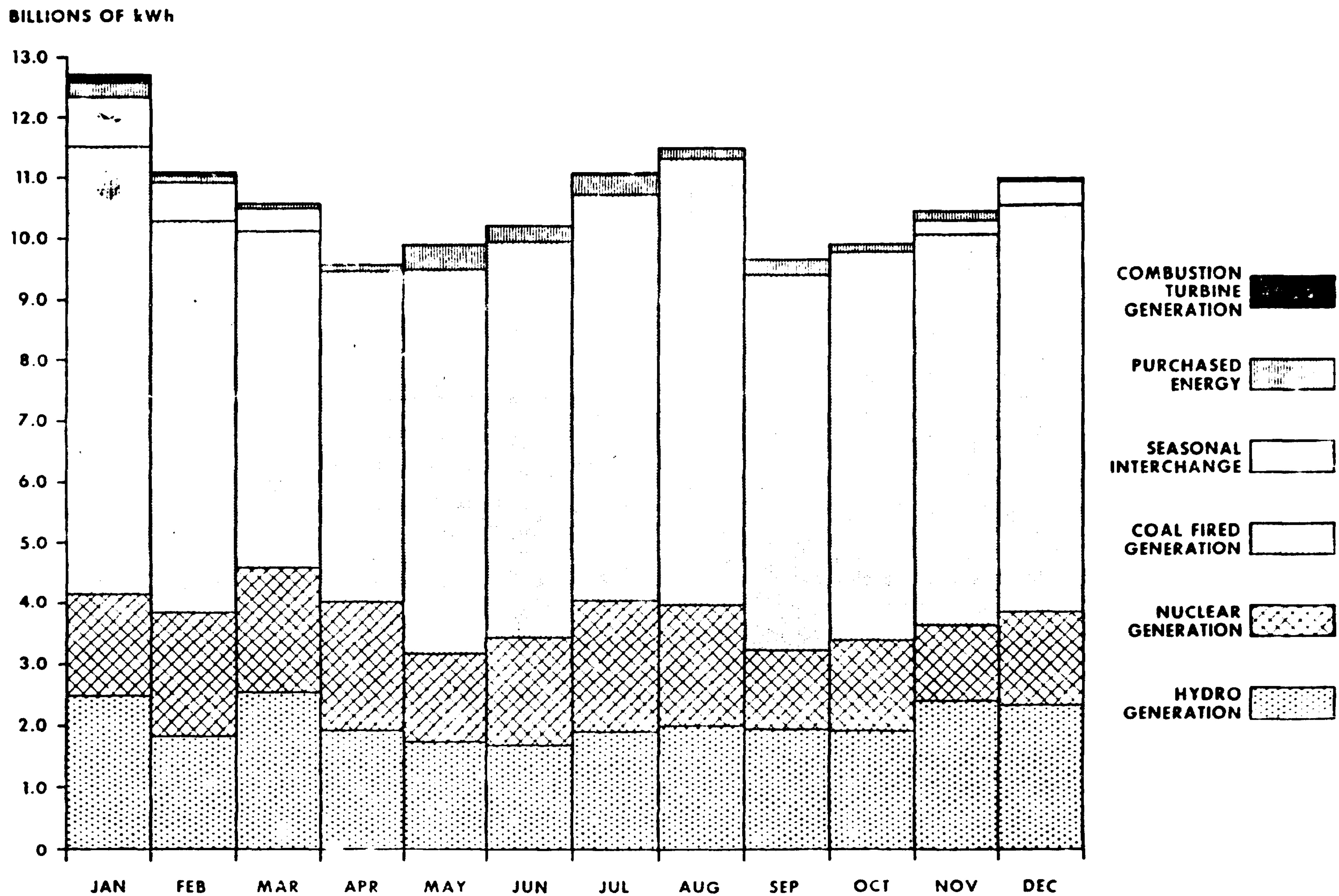
MILLIONS OF KILOWATTS



1979 TVA ELECTRICAL LOADS AND SUPPLY

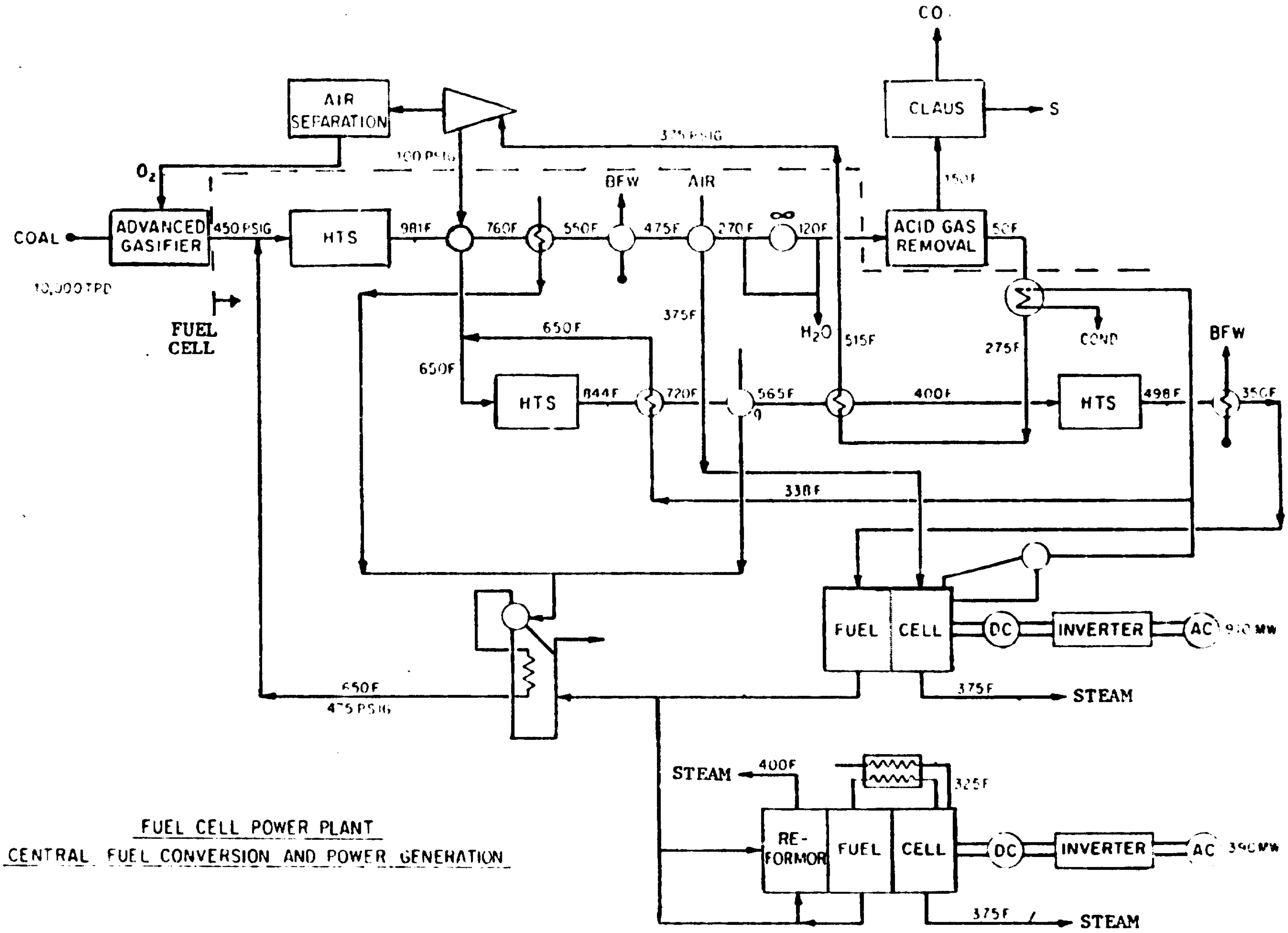
FUEL CELLS COULD BE UTILIZED FOR PEAK POWER LOAD REQUIREMENTS DURING THE MONTHS OF JANUARY AND FEBRUARY, JUNE AND JULY. CURRENTLY, TVA USES COMBUSTION TURBINE GENERATORS FUELED BY DIESEL OIL. IN 1979, APPROXIMATELY 1.8 TRILLION BTU'S OF FUEL WERE USED TO GENERATE PEAK ENERGY REQUIREMENTS. THE COMBUSTION TURBINES WERE USED AT APPROXIMATELY 2% OF THEIR OPERATING CAPACITY.

TVA LOADS & SUPPLY - 1979



FUEL CELL ACID TECHNOLOGY

A SCHEMATIC IS SHOWN USING A 10,000 TPD ADVANCED GASIFIER TO GENERATE FUEL FOR A CENTRAL FUEL CELL POWER GENERATION FACILITY. THE COAL GASIFICATION SYSTEM INCLUDES AN AIR SEPARATOR, ACID GAS REMOVAL, AND CLAUS SULPHUR AND CO_2 REMOVAL. THE FUEL CELL SCHEMATIC IS SECOND GENERATION ACID TECHNOLOGY BEING DEVELOPED BY EPRI.



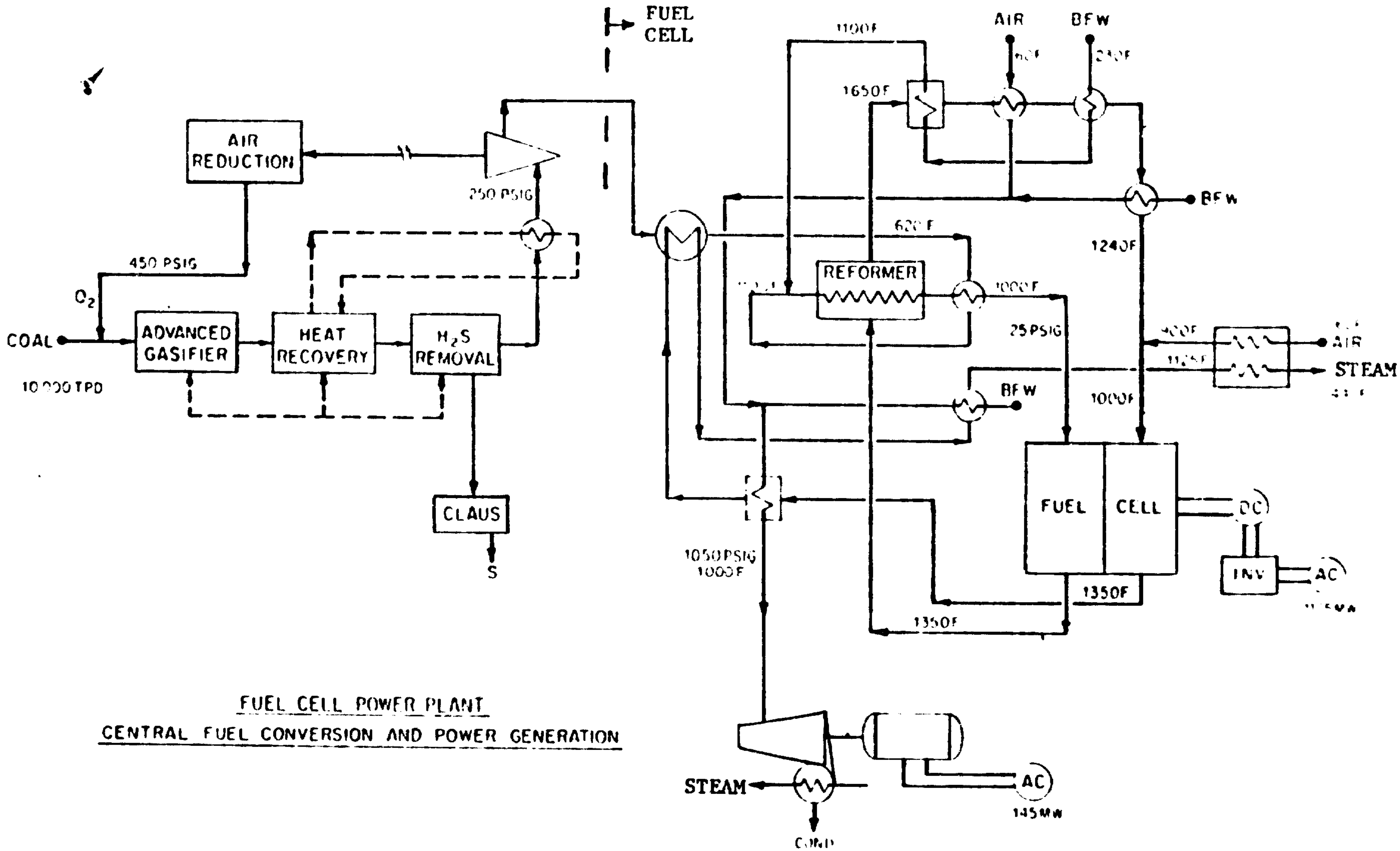
FUEL CELL POWER PLANT

CENTRAL FUEL CONVERSION AND POWER GENERATION

ACID TECHNOLOGY

MOLTEN CARBONATE FUEL CELL

THE SCHEMATIC SHOWS A 10,000 TPD ADVANCED GASIFIER GENERATING FUEL FOR A CENTRAL-SITE FUEL CELL BANK. THE COAL GASIFICATION SYSTEMS INCLUDE AN AIR REDUCTION, HEAT RECOVERY, AND SULPHUR REMOVAL. THE FUEL CELL SCHEMATIC IS A SECOND GENERATION MOLTEN CARBONATE TYPE BEING DEVELOPED BY EPRI.



FUEL CELL POWER PLANT

CENTRAL FUEL CONVERSION AND POWER GENERATION

FUEL CELL PARAMETERS

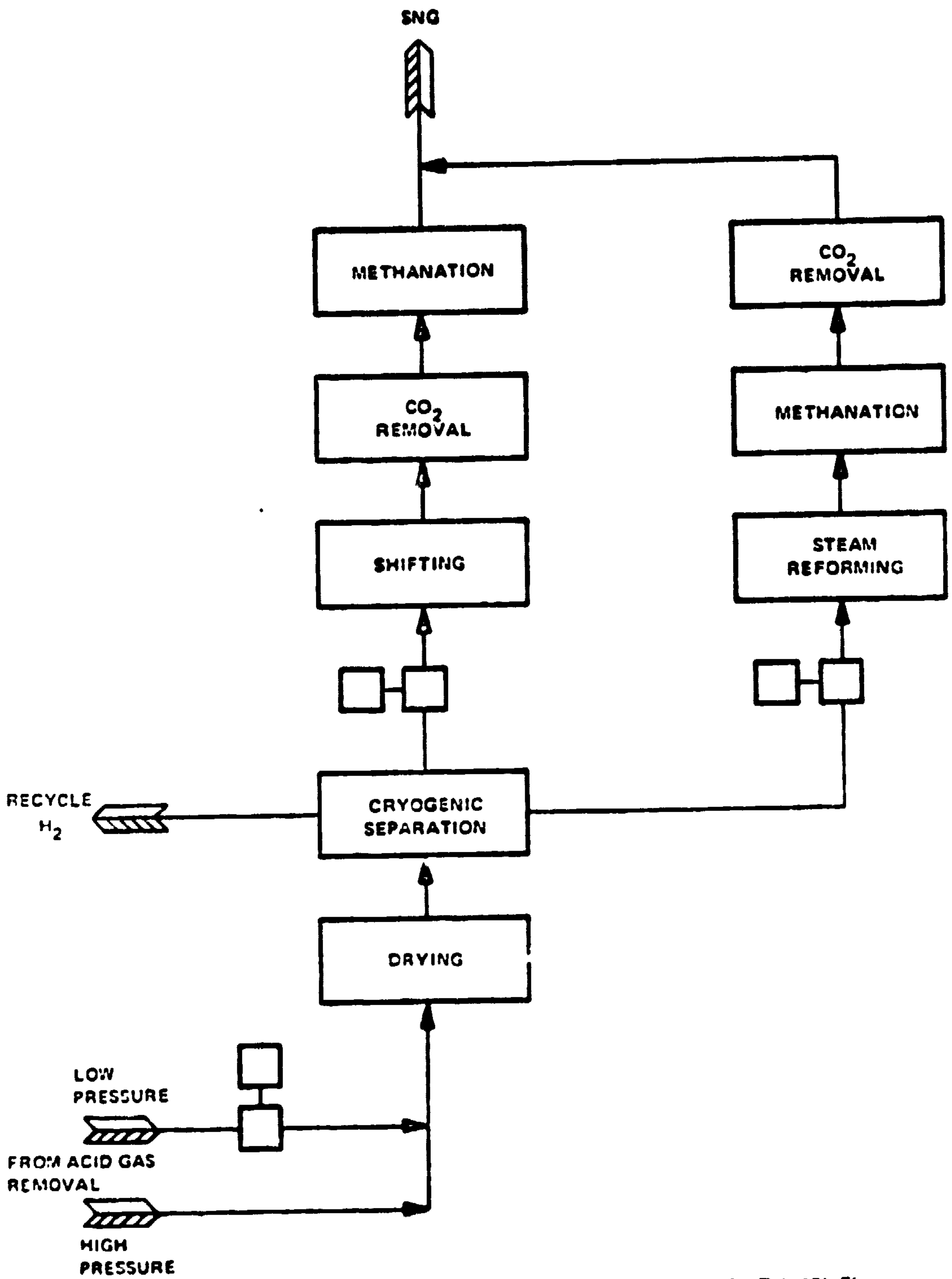
TDC DEVELOPED FUEL CELL COST PARAMETERS FOR TOTAL FACILITY COST AND ECONOMIC ANALYSIS. THE CENTRAL SITE 20,000 TPD COULD GENERATE APPROXIMATELY 2,600 MEGAWATTS OF ELECTRICITY, WHICH IS SIGNIFICANTLY LARGER THAN THE TYPICAL FOSSIL FUEL POWER PLANT. THE ESTIMATED CAPITAL INVESTMENT COST FOR THE MOLTEN CARBONATE FACILITY IS $745.1 (1980 $ MILLIONS) AND $836.4 MILLIONS FOR THE SECOND GENERATION ACID TECHNOLOGY. CAPITAL INVESTMENT ($/KW) IS 282 AND 322 FOR MOLTEN CARBONATE AND ACID FUEL CELLS RESPECTIVELY.

FUEL CELL PARAMETERS
($1980, MILLIONS)

SOURCE FUEL RATE	EPRI 250 BBTU/DAY MBG	
TYPE (CENTRAL BASE LOAD)	MOLTEN CARBONATE	ACID
CO SHIFT	----	22.10
REFORMING	93.70	----
HEAT EXCHANGER	63.70	74.40
AUX. BOILER	----	24.80
TURBO GENERATOR	60.10	----
CELL STACK & ANCILLARIES	527.60	645.20
FUEL CONDITIONING	----	70.00
TOTAL CAPITAL COST	745.10	836.40
YEARLY LABOR & MAINTENANCE (1%)	7.45	8.36
GENERATING, MW	2,640.00	2,600.00
$/KW	282.00	322.00
HEAT RATE (BTU/KWH)	7,720.00	7,840.00

SYNTHETIC NATURAL GAS (SNG) PRODUCTION SCHEMATIC

METHANATION OF MEDIUM-BTU GAS (MBG) INVOLVED DRYING THE MBG AFTER ACID GAS REMOVAL, AND SHIFTING AND METHANATING THE GAS. CARBON DIOXIDE (CO_2) AND HYDROGEN ARE REMOVED TO PROVIDE ESSENTIALLY PURE METHANE (CH_4). THE SCHEMATIC IS A TYPICAL METHANATION PROCESS OF A SYNTHESIS GAS AND IS STATE-OF-THE-ART.



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SNG PRODUCTION SCHEMATIC DIAGRAM

KOPPERS-TOTZEK MBG TO HYDROGEN

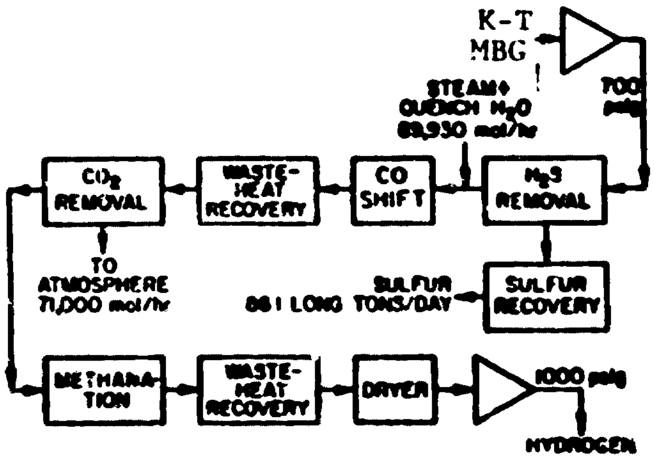
CONVERTING MEDIUM-BTU GAS FROM THE KOPPERS-TOTZEK PROCESS TO HYDROGEN IS SHOWN ON THE SCHEMATIC. SULPHUR AND CARBON MONOXIDE ARE REMOVED AND CARBON DIOXIDE IS SHIFTED. ESSENTIALLY PURE (99%) HYDROGEN IS GENERATED AT 1000 PSIG.

MOBIL METHANOL TO GASOLINE

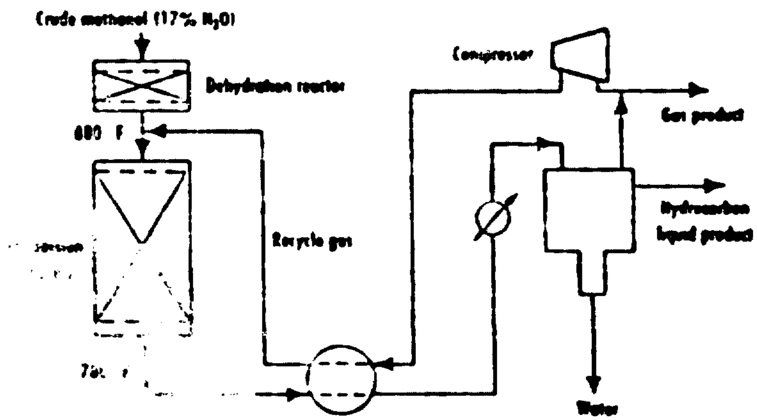
MOBIL OIL HAS DEVELOPED A PROCESS TO CONVERT METHANOL TO GASOLINE, CALLED THE MOBIL-M PROCESS. CRUDE METHANOL (17% WATER) IS CONVERTED TO PROCESSED HIGH-OCTANE GASOLINE.

SYNFUELS PROCESSES

KOPPERS-TOTZEK MBG TO HYDROGEN



MOBIL METHANOL TO GASOLINE



SYNFUELS PARAMETERS

1980 CAPITAL COST ESTIMATES FOR ADDING HYDROGEN AND SYNTHETIC NATURAL GAS (SNG) TO THE FOUR-MODULE MEDIUM-BTU GAS (MBG) FACILITY ARE ILLUSTRATED. THE MBG FUEL RATE IS ASSUMED TO BE 250 BBTU/DAY. THE SNG FACILITY CONTAINS A 35 MILE PIPELINE COST TO GADSDEN. IN BOTH CASES, IT IS ASSUMED THE YEARLY OPERATIONS AND MAINTENANCE COSTS ARE 1% OF THE CAPITAL INVESTMENT.

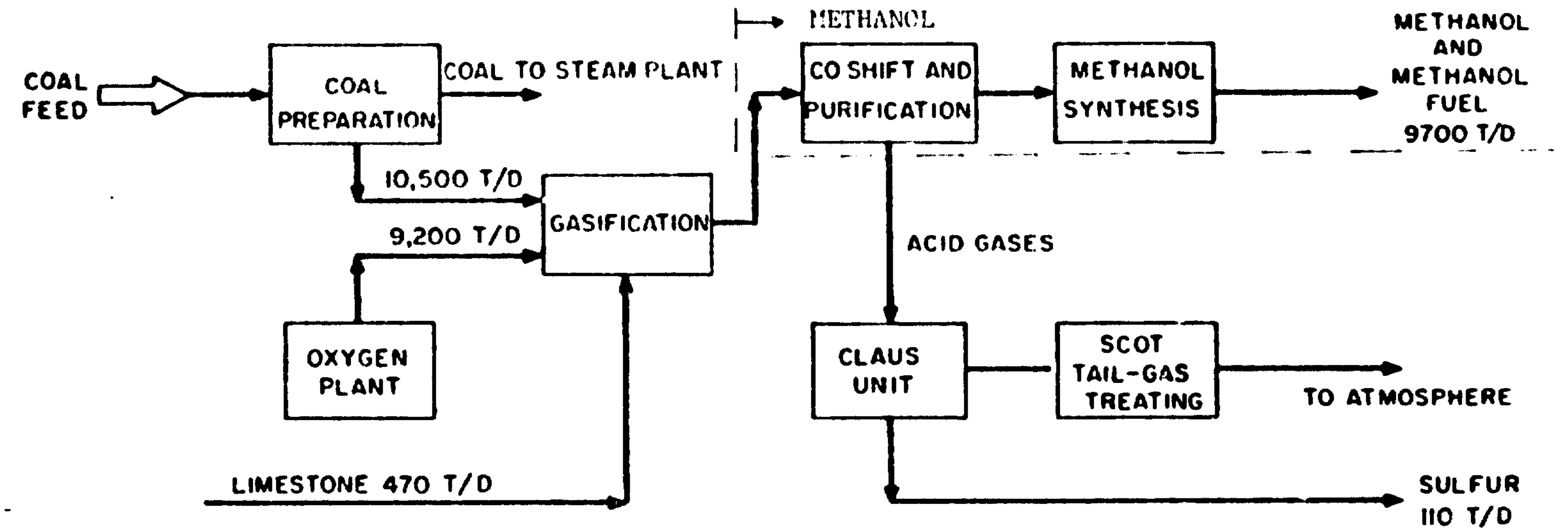
SYNFUELS PARAMETERS

PRODUCT	HYDROGEN	
SOURCE	KOPPERS-TOTZEK	
MBG FUEL RATE	250 BBTU/DAY	
SYNTHESIS GAS COMPRESSION	$10.50	
CO SHIFT	12.90	
CO_2 & H_2S REMOVAL	97.50	
METHANATION & DRYING	8.30	
PRODUCT COMPRESSION	8.00	
SULFUR RECOVERY	17.60	
TOTAL CAPITAL COST	$54.80	
YEARLY LABOR & MAINTENANCE	$ 0.54	

PRODUCT	SYNTHETIC NATURAL GAS	
SOURCE	PARSONS	
MBG FUEL RATE	250 BBTU/DAY	
SHIFT CONVERSION		$76.63
METHANATION		0.77
SNG TREATING		62.16
PIPELINE (GADSDEN)		12.96
TOTAL CAPITAL COST		$152.52
YEARLY LABOR & MAINT.		$ 1.52

COAL-TO-METHANOL FACILITY

A COAL-TO-METHANOL BADGER FACILITY DESIGN IS SHOWN FOR A 10,500 TPD COAL GASIFICATION FACILITY. THE METHANOL PROCESS INCLUDES CO SHIFT, PURIFICATION, AND METHANOL SYNTHESIS.



BLOCK FLOW DIAGRAM FOR ONE TRAIN OF BADGER COMMERCIAL COAL-TO-METHANOL PLANT.

METHANOL AND GASOLINE SYNFUEL PARAMETERS

METHANOL AND GASOLINE CAPITAL AND OPERATIONS AND MAINTENANCE (O&M) COST ESTIMATES ARE DEPICTED. THE ESTIMATES WERE DERIVED FROM BABCOCK AND WILCOX, MOBIL, AND ESCOE REPORTS. ONE PERCENT OF THE CAPITAL ESTIMATE COSTS ARE ESTIMATED TO BE O&M. THE COST ESTIMATES ARE BASED ON AN MBG FUEL RATE OF 250 BBTU/DAY.

SYNFUELS PARAMETERS

($1980, Millions)

Product	Methanol		Gasoline
Source	Babcock & Wilcox		Mobil & ESCOE
MBG Fuel Rate	250 BBTU/Day		250 BBTU/Day
Methanol Synthesis	$176.20	Reactor	$122.80
Synthesis Gas Compression	28.80	Conversion	79.90
Methanol Drying	16.70	Gas Plant	11.50
Methanol Purification	4.50	Pollution Systems	46.40
Product Storage	13.50	Compression	34.80
Total Capital Cost	$239.70	Storage	14.50
Yearly Labor & Maintenance	$ 2.39		$317.70
			$ 3.16

SYNFUEL ECONOMIC EVALUATION MODEL (SEEM)

- DETAILED PROGRAM DESCRIPTION -

SYNFUEL ECONOMIC EVALUATION MODEL

- DEFINITION OF PROGRAM VARIABLES -

SYNFUEL ECONOMIC EVALUATION PARAMETERS

INPUT VARIABLES

NCAS	Number of Cases to Be Run
FCM (I,J)	Fundamental Cost Matrix
SSM (I,J)	Synfuel Supply Matrix
CFF (I,J)	Competing Fuel Price Matrix
SPM (I.J)	Synfuel Price Matrix
SRM (I.J)	Synfuel Revenue Matrix
CFM (I)	Cash Flow Matrix
DCFM (I)	Discounted Cash Flow Matrix
PCT	Percent of Cost (Not Currently Exercised)
PCT1 (I)	Percent of Construction Cost for Module 1 Allotted to Year I
PCT2 (I)	" " " " " Module 2 " " Year I
PCT3 (I)	" " " " " Module 3 " " Year I
PCT4 (I)	" " " " " Module 4 " " Year I
PRSD1 (J.I)	Premium or Subsidy Factor for Cost in Year I for Product J
PSRD2 (J.I)	Premium or Subsidy Factor for Price in Year I for Product J
EP1	Efficiency of the Gasification Process for Module 1
EP2	" " " " " " Module 2
EP3	" " " " " " Module 3
EP4	" " " " " " Module 4

INPUT VARIABLES (CONTINUED)

JT1	DESIGNATION OF SYNFUEL PRODUCT FOR MATRIX POSITION, MODULE 1
JT2	" " " " " " " MODULE 2
JT3	" " " " " " " MODULE 3
JT4	" " " " " " " MODULE 4
IST1	START OF CONSTRUCTION FOR MODULE 1
IST2	" " " " MODULE 2
IST3	" " " " MODULE 3
IST4	" " " " MODULE 4
IOP1	START OF OPERATION FOR MODULE 1
IOP2	" " " " MODULE 2
IOP3	" " " " MODULE 3
IOP4	" " " " MODULE 4
1X1	SHUT-DOWN TIME OF MODULE 1 AT END OF LIFE
1X2	" " " " MODULE 2 " " " "
1X3	" " " " MODULE 3 " " " "
1X4	" " " " MODULE 4 " " " "
1YEAR	YEAR OF CURRENT ANALYSIS
1FLAG	FLAG TO EXECISE FUEL PRICE ESCALATION PARAMETERIZATION ROUTINE

XCC1	CONSTRUCTION COST FOR MODULE 1
XCC2	" " " MODULE 2
XCC3	" " " MODULE 3
XCC4	" " " MODULE 4
CC051	YEARLY COAL COST FOR MODULE 1
CC052	" " " " MODULE 2
CC053	" " " " MODULE 3
CC054	" " " " MODULE 4
XC051	YEARLY TRANSPORTATION COST FOR MODULE 1
XC052	" " " " MODULE 2
XC053	" " " " MODULE 3
XC054	" " " " MODULE 4
OC1	YEARLY OPERATION AND MAINTENANCE COST FOR MODULE 1
OC2	" " " " " " MODULE 2
OC3	" " " " " " MODULE 3
OC4	" " " " " " MODULE 4
PNG	CURRENT PRICE OF NATURAL GAS ($/MMBTU)
PFO	" " " FUEL OIL "

INPUT VARIABLES (CONTINUED)

PEL	CURRENT PRICE OF ELECTRICITY ($/MMBTU)
PGSL	" " " GASOLINE "
PMET	" " " METHANOL "
PHZ	" " " HYDROGEN "
RCO (I)	INFLATION FACTOR FOR COAL PRICE IN YEAR I
RNG (I)	" " " NATURAL GAS PRICE IN YEAR I
RFO (I)	" " " FUEL OIL PRICE IN YEAR I
REL (I)	" " " ELECTRICITY PRICE IN YEAR I
RGSL (I)	" " " GASOLINE PRICE IN YEAR I
RMET (I)	" " " METHANOL PRICE IN YEAR I
RHZ (I)	" " " HYDROGEN PRICE IN YEAR I
RCC1 (I)	INFLATION FACTOR FOR CONSTRUCTION COST OF MODULE 1 IN YEAR I
RCC2 (I)	" " " " " " MODULE 2 " YEAR I
RCC3 (I)	" " " " " " MODULE 3 " YEAR I
RCC4 (I)	" " " " " " MODULE 4 " YEAR I
ROM (I)	INFLATION FACTOR FOR OPERATION AND MAINTENANCE COST IN YEAR I
RXP (I)	INFLATION FACTOR FOR TRANSPORTATION COST IN YEAR I

INPUT VARIABLES (CONTINUED)

SUP1	YEARLY COAL INPUT IN BTU'S FOR MODULE 1
SUP2	" " " " " " MODULE 2
SUP3	" " " " " " MODULE 3
SUP4	" " " " " " MODULE 4
XR1	INTEREST RATE ON MONEY BORROWED FOR CONSTRUCTION OF MODULE 1
XR2	" " " " " " " " MODULE 2
XR3	" " " " " " " " MODULE 3
XR4	" " " " " " " " MODULE 4
D1	DISCOUNT INTEREST RATE
RINF	GENERAL PRICE INFLATION
ESRT	ESCALATION RATE OF COMPETING FUELS
BINF	BASIC UNDERLYING INFLATION RATE
CINF	CONSTRUCTION INFLATION RATE
COINF	COAL INFLATION RATE
OMINF	OPERATION AND MAINTENANCE INFLATION RATE
FINF	FACTOR OF GENERAL INFLATION DUE TO FUEL PRICE INCREASE

COMPUTATIONAL VARIABLES

ALL INPUT VARIABLES:

L	COUNTER TO EXERCISE PRICE THEN COST LOOPS
I	YEAR COUNTER (ROW)
J	PRODUCT DESIGNATOR (COLUMN)
AA	INFLATED CONSTRUCTION COST FOR MODULE 1 IN YEAR I
BB	" " " " MODULE 2 " YEAR I
CC	" " " " MODULE 3 " YEAR I
DD	" " " " MODULE 4 " YEAR I
SUM10	SUM OF CONSTRUCTION COSTS FOR N YEARS FOR MODULE 1
SUM11	" " " " " " " " MODULE 2
SUM12	" " " " " " " " MODULE 3
SUM13	" " " " " " " " MODULE 4
CC1	TOTAL ESCALATED CONSTRUCTION COSTS FOR MODULE 1
CC2	" " " " " MODULE 2
CC3	" " " " " MODULE 3
CC4	" " " " " MODULE 4

COMPUTATIONAL VARIABLES (CONTINUED)

SUM14	DESIGNATOR PORTION OF CONSTRUCTION COST TO BE CHARGED INTEREST, YEAR I, MODULE 1
SUM15	DESIGNATOR PORTION OF CONSTRUCTION COST TO BE CHARGED INTEREST, YEAR I, MODULE 2
SUM16	DESIGNATOR PORTION OF CONSTRUCTION COST TO BE CHARGED INTEREST, YEAR I, MODULE 3
SUM17	DESIGNATOR PORTION OF CONSTRUCTION COST TO BE CHARGED INTEREST, YEAR I, MODULE 4
DM1	VARIABLE USED FOR STORING CONSTRUCTION COST WITH INTEREST DURING CONSTRUCTION, MODULE 1
DM2	VARIABLE USED FOR STORING CONSTRUCTION COST WITH INTEREST DURING CONSTRUCTION, MODULE 2
DM3	VARIABLE USED FOR STORING CONSTRUCTION COST WITH INTEREST DURING CONSTRUCTION, MODULE 3
DM4	VARIABLE USED FOR STORING CONSTRUCTION COST WITH INTEREST DURING CONSTRUCTION, MODULE 4
SUM1	VARIABLE FOR COMPUTING TOTAL SYNFUELS COST

COMPUTATIONAL VARIABLES (CONTINUED)

XCRF1	CAPITAL RECOVERY FACTOR ON CONSTRUCTION COST FOR MODULE 1
XCRF2	" " " " " " " MODULE 2
XCRF3	" " " " " " " MODULE 3
XCRF4	" " " " " " " MODULE 4
CRF1	CAPITAL RECOVERY FACTOR MULTIPLIED BY COST FOR MODULE 1
CRF2.	" " " " " " " MODULE 2
CRF3	" " " " " " " MODULE 3
CRF4	" " " " " " " MODULE 4
SUM18	VARIABLE WHICH ADDS CONSTRUCTION COSTS FOR DESIGNATED YEARS, MODULE 1
SUM19	VARIABLE WHICH ADDS CONSTRUCTION COSTS FOR DESIGNATED YEARS, MODULE 2
SUM20	VARIABLE WHICH ADDS CONSTRUCTION COSTS FOR DESIGNATED YEARS, MODULE 3
SUM21	VARIABLE WHICH ADDS CONSTRUCTION COSTS FOR DESIGNATED YEARS, MODULE 4

C-3

COMPUTATIONAL VARIABLES (CONTINUED)

X1	VARIABLE FOR COMPUTING OPERATING COST OF APPROPRIATE YEARS, MODULE 1
X2	VARIABLE FOR COMPUTING OPERATING COST OF APPROPRIATE YEARS, MODULE 2
X3	VARIABLE FOR COMPUTING OPERATING COST OF APPROPRIATE YEARS, MODULE 3
X4	VARIABLE FOR COMPUTING OPERATING COST OF APPROPRIATE YEARS, MODULE 4
Y1	VARIABLE FOR STORING COAL COST OF APPROPRIATE YEARS, MODULE 1
Y2	" " " " " " " " MODULE 2
Y3	" " " " " " " " MODULE 3
Y4	" " " " " " " " MODULE 4
Z1	VARIABLE FOR STORING TRANSPORTATION COST OF APPROPRIATE YEARS, MODULE 1
Z2	VARIABLE FOR STORING TRANSPORTATION COST OF APPROPRIATE YEARS, MODULE 2
Z3	VARIABLE FOR STORING TRANSPORTATION COST OF APPROPRIATE YEARS, MODULE 3
Z4	VARIABLE FOR STORING TRANSPORTATION COST OF APPROPRIATE YEARS, MODULE 4

COMPUTATIONAL VARIABLES (CONTINUED)

CPCST (JT1,I)	COMPUTED COST OF MODULE 1 FOR YEAR I
CPCST (JT2,I)	" " " MODULE 2 " YEAR I
CPCST (JT3,I)	" " " MODULE 3 " YEAR I
CPCST (JT4,I)	" " " MODULE 4 " YEAR I
SUM1	VARIABLE FOR ADDING TOTAL ANNUAL COST
T1	VARIABLE FOR COMPUTING & STORING SYNFUEL SUPPLY FOR MODULE 1
T2	" " " " " " " " MODULE 2
T3	" " " " " " " " MODULE 3
T4	" " " " " " " " MODULE 4
SUM6	VARIABLE FOR COMPUTING TOTAL SYNFUEL SUPPLIES
SUM3	VARIABLE FOR COMPUTING TOTAL SYNFUEL REVENUES
SUM8	VARIABLE FOR COMPUTING LEVELIZED REVENUE STREAM
XPU	VARIABLE SET TO ANNUAL EQUIVALENT FACTOR FOR LEVELIZED STREAM
YTOT	TOTAL SYNFUEL SUPPLIED FOR FOUR MODULES
DPM1	VARIABLE SET TO LEVELIZED PRODUCT PRICE IN $/MMBTU
FACT1	DISCOUNTING FACTOR
FACT2	PORTION OF NUMERATOR IN UNIFORM PAYMENT FACTOR
SAVE (I)	UNINFLATED REVENUE STREAM (DISCOUNTED)

COMPUTATIONAL VARIABLES (CONTINUED)

SUM9	VARIABLE FOR SUMMING UNINFLATED REVENUE STREAM
UPF1	NUMERATOR IN UNIFORM PAYMENT FACTOR
UPF2	DENOMINATOR IN UNIFORM PAYMENT FACTOR
UPF	UNIFORM PAYMENT FACTOR
AP	LEVELIZED UNINFLATED ANNUAL PAYMENT
DPM2	LEVELIZED COST OF PRODUCT IN $/MMBTU
TEMP1	VARIABLE FOR COMPUTING CASH FLOW FOR YEAR I
SUM4	VARIABLE FOR SUMMING CASH FLOW
SCOST	SYNFUELS COST ON A $/MMBTU BASIS
SUM5	VARIABLE FOR SUMMING DISCOUNTED CASH FLOW

OUTPUT VARIABLES

FCM (I,J)	FUNDAMENTAL COST MATRIX
SUM1	TOTAL SYNFUELS COST
SSM (I,J)	SYNFUEL SUPPLY MATRIX
SUM6	TOTAL SYNFUEL SUPPLIES
SCOST	SYNFUELS COST ON A $/MMBTU BASIS
CFP (I,J)	COMPETING FUEL PRICE MATRIX
SPM (I,J)	SYNFUEL PRICE MATRIX
SRM (I,J)	SYNFUEL REVENUE MATRIX
SUM3	TOTAL SYNFUELS REVENUES
CFM (I)	CASH FLOW MATRIX
SUM4	TOTAL SYNFUELS CASH FLOW
DCFM (I)	DISCOUNTED CASH FLOW MATRIX
SUM5	TOTAL PRESENT VALUE
SUM8	LEVELIZED INFLATED REVENUE
DPM1	INFLATED $/MMBTU
AP	LEVELIZED 1980 REVENUE
DPM2	LEVELIZED 1980 $/MMBTU

SYNFUEL ECONOMIC EVALUATION MODEL

- SAMPLE PROGRAM OUTPUT -

FUNDAMENTAL COST MATRIX

TIME	MOD1 COST	MOD2 COST	MOD3 COST	MOD4 COST	O&M COST	COAL COST	XPORT COST	ANNUAL COST
.100000+001	.450000+008	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.200000+001	.143750+009	.450000+008	.000000	.000000	.000000	.000000	.000000	.000000
.300000+001	.237600+009	.143750+009	.450000+008	.000000	.000000	.000000	.000000	.000000
.400000+001	.226000+009	.237600+009	.143750+009	.450000+008	.000000	.000000	.000000	.000000
.500000+001	.000000	.228000+009	.237600+009	.143750+009	.175000+009	.507600+008	.700000+007	.299699+009
.600000+001	.000000	.000000	.228000+009	.237600+009	.402000+009	.110880+009	.160800+008	.662839+009
.700000+001	.000000	.000000	.000000	.228000+009	.693000+009	.179280+009	.277200+008	.110082+010
.800000+001	.000000	.000000	.000000	.000000	.106400+010	.257760+009	.425600+008	.163208+010
.900000+001	.000000	.000000	.000000	.000000	.122400+010	.279360+009	.489600+008	.182008+010
.100000+002	.000000	.000000	.000000	.000000	.140800+010	.300960+009	.563200+008	.203304+010
.110000+002	.000000	.000000	.000000	.000000	.161600+010	.325440+009	.646400+008	.227384+010
.120000+002	.000000	.000000	.000000	.000000	.186000+010	.351360+009	.744000+008	.255352+010
.130000+002	.000000	.000000	.000000	.000000	.214000+010	.380169+009	.856000+008	.287352+010
.140000+002	.000000	.000000	.000000	.000000	.246000+010	.410400+009	.984000+008	.323656+010
.150000+002	.000000	.000000	.000000	.000000	.283200+010	.443520+009	.113280+009	.365656+010
.160000+002	.000000	.000000	.000000	.000000	.325600+010	.478080+009	.130240+009	.413208+010
.170000+002	.000000	.000000	.000000	.000000	.374400+010	.511200+009	.149760+009	.467272+010
.180000+002	.000000	.000000	.000000	.000000	.430400+010	.547200+009	.172160+009	.529112+010
.190000+002	.000000	.000000	.000000	.000000	.495200+010	.586080+009	.198080+009	.600392+010
.200000+002	.000000	.000000	.000000	.000000	.569200+010	.626400+009	.227680+009	.681384+010
.210000+002	.000000	.000000	.000000	.000000	.654800+010	.671040+009	.261920+009	.774872+010
.220000+002	.000000	.000000	.000000	.000000	.752800+010	.717120+009	.301120+009	.681400+010
.2[illegible]0000+002	.000000	.000000	.000000	.000000	.565600+010	.767520+009	.346240+009	.100375+011

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COMPETING FUEL PRICE MATRIX

TIME	NG PRICE	FO PRICE	GSL PRICE	MET PRICE	H2 PRICE	EL PRICE
.100000+001	.400000+001	.400000+001	.800000+001	.897000+001	.500000+001	.100000+002
.200000+001	.460000+001	.460000+001	.920000+001	.103155+002	.575000+001	.115000+002
.300000+001	.528000+001	.528000+001	.105600+002	.118404+002	.660000+001	.132000+002
.400000+001	.608000+001	.608000+001	.121600+002	.136344+002	.760000+001	.152000+002
.500000+001	.700000+001	.700000+001	.140000+002	.156975+002	.875000+001	.175000+002
.600000+001	.804000+001	.804000+001	.160800+002	.180297+002	.100500+002	.201000+002
.700000+001	.924000+001	.924000+001	.184800+002	.207207+002	.115500+002	.231000+002
.800000+001	.106400+002	.106400+002	.212800+002	.238602+002	.133000+002	.266000+002
.900000+001	.122400+002	.122400+002	.244800+002	.274482+002	.153000+002	.306000+002
.100000+002	.140800+002	.140800+002	.281600+002	.315744+002	.176000+002	.352000+002
.110000+002	.161600+002	.161600+002	.323200+002	.362358+002	.202000+002	.404000+002
.120000+002	.186000+002	.186000+002	.372000+002	.417105+002	.232500+002	.465000+002
.130000+002	.214000+002	.214000+002	.428000+002	.479895+002	.267500+002	.535000+002
.140000+002	.246000+002	.246000+002	.492000+002	.551655+002	.307500+002	.615000+002
.150000+002	.283200+002	.283200+002	.566400+002	.635076+002	.354000+002	.708000+002
.160000+002	.325600+002	.325600+002	.651200+002	.730158+002	.407000+002	.814000+002
.170000+002	.374400+002	.374400+002	.748800+002	.839592+002	.468000+002	.936000+002
.180000+002	.430400+002	.430400+002	.860800+002	.965172+002	.538000+002	.107600+003
.190000+002	.495200+002	.495200+002	.990400+002	.111349+003	.619000+002	.123800+003
.200000+002	.569200+002	.569200+002	.113840+003	.127643+003	.711500+002	.142300+003
.210000+002	.654800+002	.654800+002	.130960+003	.146839+003	.818500+002	.163700+003
.220000+002	.752800+002	.752800+002	.150560+003	.168815+003	.941000+002	.188200+003
.230000+002	.665600+002	.865600+002	.173120+003	.194111+003	.108200+003	.216400+003
.240000+002	.995600+002	.995600+002	.199120+003	.223263+003	.124450+003	.248900+003
.250000+002	.114480+003	.114480+003	.228960+003	.256721+003	.143100+003	.28[illegible]+003

SYNFUEL SUPPLY MATRIX

TIME	MBG QUAN	SNG QUAN	SGSL QUAN	SMET QUAN	SH2 QUAN	SEL QUAN	SFO QUAN	ANNUAL QUAN
.100000+001	.000000	.000000	.000000	.000000	.000000	.000000	.100000	.000000
.200000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.300000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.400000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.500000+001	.000000	.000000	.000000	.216810+008	.000000	.000000	.000000	.216810+008
.600000+001	.000000	.000000	.000000	.433620+008	.000000	.000000	.000000	.433620+008
.700000+001	.000000	.000000	.000000	.650430+008	.000000	.000000	.000000	.650430+008
.800000+001	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.900000+001	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.100000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.110000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.120000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.130000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.140000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.150000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.160000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.170000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.180000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.190000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.200000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.210000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.220000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.230000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.240000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008
.250000+002	.000000	.000000	.000000	.867240+008	.000000	.000000	.000000	.867240+008

SYNFUEL PRICE MATRIX

TIME	MBG PRICE	SNG PRICE	SGSL PRICE	SMFT PRICE	SH2 PRICE	SEL PRICE	SFO PRICE
.100000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.200000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.300000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.400000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.500000+001	.000000	.000000	.000000	.138231+002	.000000	.000000	.000000
.600000+001	.000000	.000000	.000000	.152952+002	.000000	.000000	.000000
.700000+001	.000000	.000000	.000000	.169245+002	.000000	.000000	.000000
.800000+001	.000000	.000000	.000000	.188192+002	.000000	.000000	.000000
.900000+001	.000000	.000000	.000000	.209870+002	.000000	.000000	.000000
.100000+002	.000000	.000000	.000000	.234426+002	.000000	.000000	.000000
.110000+002	.000000	.000000	.000000	.262192+002	.000000	.000000	.000000
.120000+002	.000000	.000000	.000000	.294442+002	.000000	.000000	.000000
.130000+002	.000000	.000000	.000000	.331341+002	.000000	.000000	.000000
.140000+002	.000000	.000000	.000000	.373232+002	.000000	.000000	.000000
.150000+002	.000000	.000000	.000000	.421632+002	.000000	.000000	.000000
.160000+002	.000000	.000000	.000000	.476463+002	.000000	.000000	.000000
.170000+002	.000000	.000000	.000000	.538803+002	.000000	.000000	.000000
.180000+002	.000000	.000000	.000000	.610110+002	.000000	.000000	.000000
.190000+002	.000000	.000000	.000000	.692392+002	.000000	.000000	.000000
.200000+002	.000000	.000000	.000000	.785692+002	.000000	.000000	.000000
.210000+002	.000000	.000000	.000000	.893492+002	.000000	.000000	.000000
.220000+002	.000000	.000000	.000000	.101633+003	.000000	.000000	.000000
.230000+002	.000000	.000000	.000000	.115741+003	.000000	.000000	.000000
.240000+002	.000000	.000000	.000000	.131962+003	.000000	.000000	.000000
.250000+002	.000000	.000000	.000000	.150518+003	.000000	.000000	.000000

SYNFUEL REVENUE MATRIX

TIME	MRG REV	SNG REV	SGSL REV	SMET REV	SH2 REV	SIL REV	SFO REV	ANNUAL REV
.100000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.200000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.300000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.400000+001	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
.500000+001	.000000	.000000	.000000	.299699+009	.000000	.000000	.000000	.299699+009
.600000+001	.000000	.000000	.000000	.662839+009	.000000	.000000	.000000	.662839+009
.700000+001	.000000	.000000	.000000	.110082+010	.000000	.000000	.000000	.110082+010
.800000+001	.000000	.000000	.000000	.163208+010	.000000	.000000	.000000	.163208+010
.900000+001	.000000	.000000	.000000	.182008+010	.000000	.000000	.000000	.182008+010
.100000+002	.000000	.000000	.000000	.203304+010	.000000	.000000	.000000	.203304+010
.110000+002	.000000	.000000	.000000	.227384+010	.000000	.000000	.000000	.227384+010
.120000+002	.000000	.000000	.000000	.255352+010	.000000	.000000	.000000	.255352+010
.130000+002	.000000	.000000	.000000	.287352+010	.000000	.000000	.000000	.287352+010
.140000+002	.000000	.000000	.000000	.323656+010	.000000	.000000	.000000	.323656+010
.150000+002	.000000	.000000	.000000	.365656+010	.000000	.000000	.000000	.365656+010
.160000+002	.000000	.000000	.000000	.413208+010	.000000	.000000	.000000	.413208+010
.170000+002	.000000	.000000	.000000	.467272+010	.000000	.000000	.000000	.467272+010
.180000+002	.000000	.000000	.000000	.529112+010	.000000	.000000	.000000	.529112+010
.190000+002	.000000	.000000	.000000	.603392+010	.000000	.000000	.000000	.603392+010
.200000+002	.000000	.000000	.000000	.681384+010	.000000	.000000	.000000	.681384+010
.210000+002	.000000	.000000	.000000	.774872+010	.000000	.000000	.000000	.774872+010
.220000+002	.000000	.000000	.000000	.881403+010	.000000	.000000	.000000	.881403+010
.230000+002	.000000	.000000	.000000	.100375+011	.000000	.000000	.000000	.100375+011
.240000+002	.000000	.000000	.000000	.114442+011	.000000	.000000	.000000	.114442+011
.250000+002	.000000	.000000	.000000	.130535+011	.000000	.000000	.000000	.130535+011

LEVELIZED INFLATED REVENUE = .127059+010

INFLATED $/MMBTU = .146510+002

LEVELIZED 1980 REVENUE = .613812+000

1980 $/MMBTU = .707776+001

TASK 2

INDUSTRY ENERGY REQUIREMENTS

TASK 2. INDUSTRY ENERGY REQUIREMENTS

DURING THIS THREE MANWEEK TASK, TDC DETERMINED NATURAL GAS CURTAILMENTS IN NORTHERN ALABAMA AND SOUTH CENTAL TENNESSEE, PERFORMED A SYNFUEL MARKET ASSESSMENT, DETERMINED CURRENT AND PROJECTED INDUSTRIAL GROWTH, AND ANALYZED AN INTEGRATED INDUSTRIAL CO-GENERATION PARK.

TASK 2 - INDUSTRY ENERGY REQUIREMENTS

- Fuel Curtailments
- Synfuel Market Assessment
- Industrial Growth
- Co-Generation

INDUSTRY ENERGY REQUIREMENTS

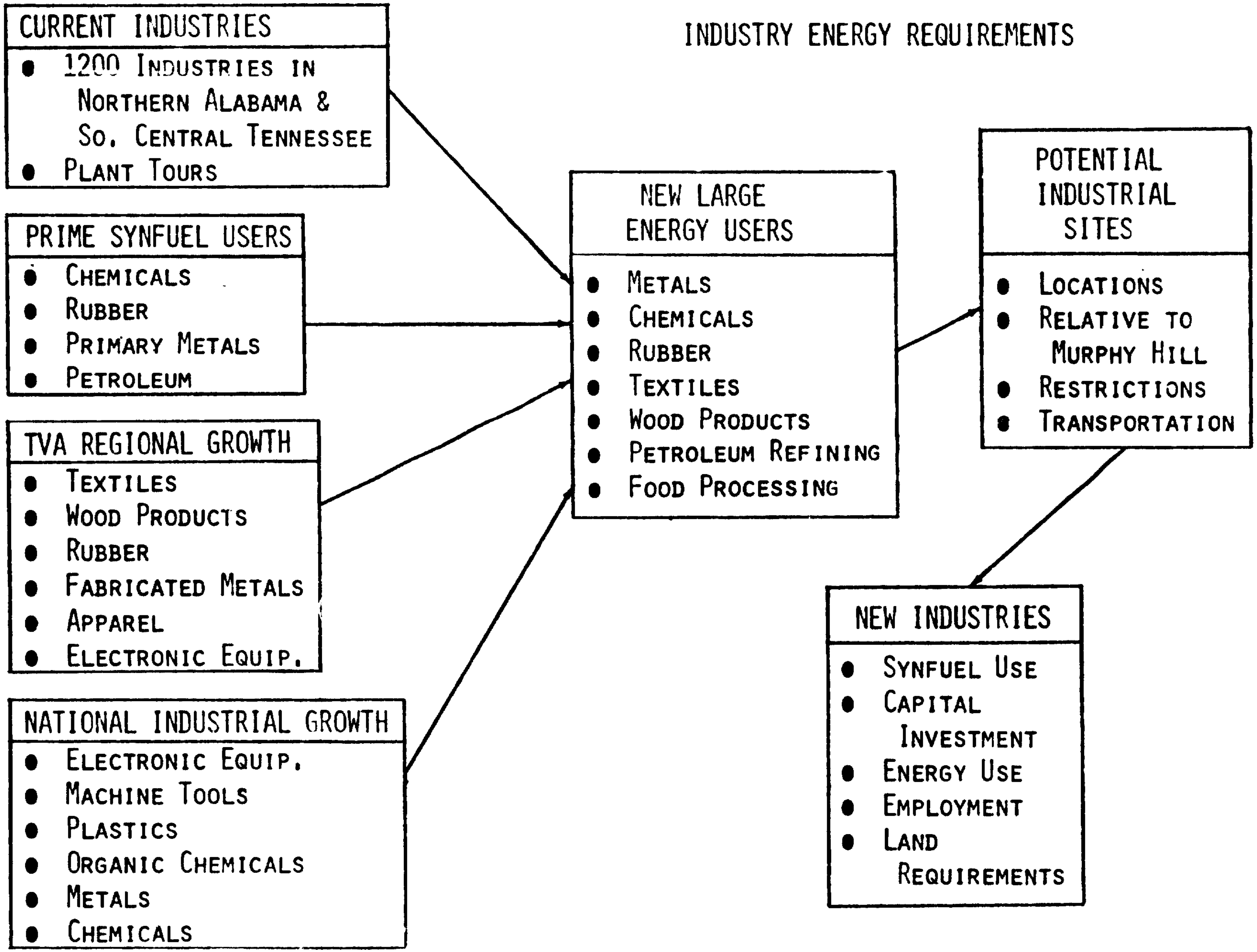
In previous NASA/MSFC contracts, TDC established an industrial data base containing industry energy requirements, manufacturing processes, and number of employees for 1,200 businesses in Northern Alabama and South Central Tennessee. The current TDC contract emphasized new industry moving into the TVA region because of the coal conversion facilities' significant energy availability. TDC also determined the prime industrial synfuel users, in order of highest priority and primary synfuel utilization, to be:

1. Chemical (Feedstock)
2. Rubber (Thermal)
3. Primary Metals (Thermal)
4. Petroleum (Thermal and Feedstock)

In 1978 and 1979, textiles, wood products, rubber, fabricated metals, apparel, and electronic equipment industries grew the most in the TVA area. Only wood products and rubber industries are large energy and synfuel users.

Nationally, electronic equipment, machine tools, plastics, chemicals, and metals industries grew the most. Chemicals and metals industries utilize the most energy. TDC analyzed potential industrial sites for new large energy users relative to the Murphy Hill site. Estimates were made on synfuel utilization, capital investment, energy use, employment and land requirements.

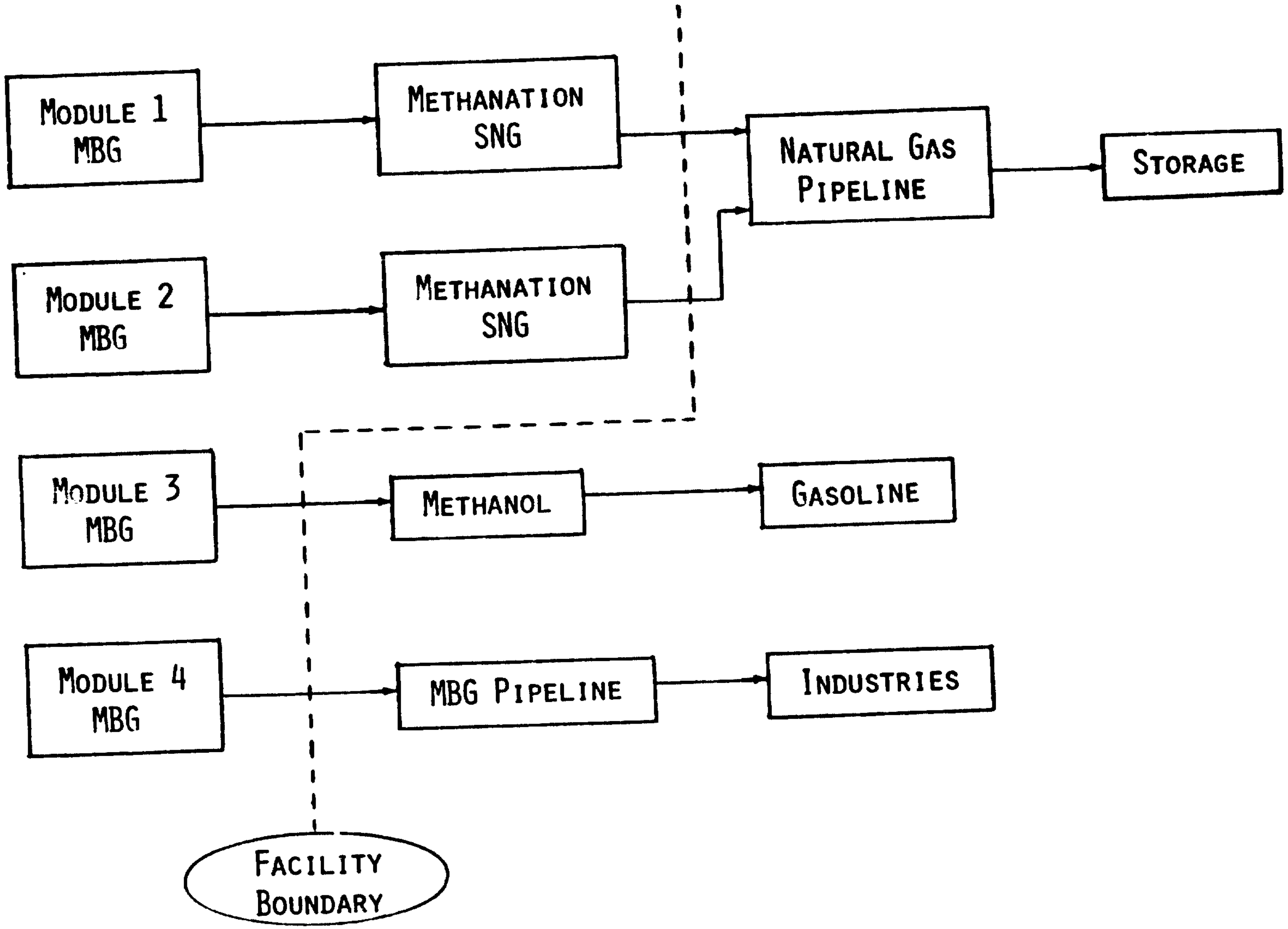
INDUSTRY ENERGY REQUIREMENTS



TVA COAL CONVERSION FACILITY
MODULE SYNFUELS PRODUCTS

THE ILLUSTRATION SHOWS THE FOUR-MODULE COAL CONVERSION FACILITY PRODUCING MBG. THE FIRST TWO MODULES USE METHANATION UNITS TO GENERATE SYNTHETIC NATURAL GAS (SNG) WHICH COULD BE SOLD DIRECTLY TO DISTRIBUTORS OF NATURAL GAS. MODULE 3 COULD SELL MBG OVER THE FACILITY BOUNDARY TO A CHEMICAL FIRM WHICH WOULD CONVERT THE MBG TO METHANOL AND THEN GASOLINE. THE FOURTH MODULE COULD GENERATE MBG FOR PIPELINE TRANSPORTATION TO INDUSTRIES IN NORTHER ALABAMA. THIS STUDY ALSO ANALYZED AN ALTERNATIVE TO THE FOURTH MODULE; THAT IS, AN INTEGRATED CO-GENERATION INDUSTRIAL PARK USING MBG AND/OR METHANOL AS FUEL AND FEEDSTOCKS.

TVA COAL CONVERSION FACILITY
MODULE SYNFUELS PRODUCTS



SYNFUELS MARKET POTENTIAL

A MARKET ASSESSMENT OF THE SIX SYNFUELS WAS MADE FOR UTILIZATION IN NORTHERN ALABAMA. THE SUPPLY OF FOUR MODULES PRODUCING THE SYNFUEL IS COMPARTED TO 1980 AND 1990 ESTIMATED MARKET DEMANDS. AS CAN BE SEEN, SYNTHETIC NATURAL GAS AND GASOLINE WOULD NOT CREATE AN OVER-SUPPLY SITUATION. CURRENTLY, A SMALL OR NON-EXISTENT MARKET EXISTS FOR METHANOL AND HYDROGEN. MARKETS COULD BE DEVELOPED FOR METHANOL AND HYDROGEN BY INDUSTRIES LOCATING IN NORTHERN ALABAMA AND USING THE SYNFUELS FOR FUEL OR FEEDSTOCKS. THE CONCLUSION WHICH CAN BE DRAWN FROM THE CHART IS THAT THE 20,000 TPD COAL CONVERSION FACILITY WILL SATURATE THE NORTHERN ALABAMA MARKET, AND A DIVERSITY OF PRODUCTS WHICH CAN BE EXPORTED (I.E., SNG, ELECTRICITY, GASOLINE) SHOULD BE CONSIDERED.

SYNFUELS MARKET POTENTIAL

	MBG	METHANOL	SNG	ELECTRICITY	HYDROGEN	GASOLINE
POTENTIAL CUSTOMERS	CHEMICALS RUBBER METALS PETROLEUM	INDUSTRIAL FUEL GASOLINE BLENDING PEAK POWER SHAVING	WIDE INDUSTRIAL USE	WIDE INDUSTRIAL USE	AMMONIA GLASS METHANOL (+CO) HYDROTREATING METALS PETROLEUM REFINING	FUEL
AMOUNT YEARLY PRODUCED* (4 MOD; TBTU/YR)	110.44	86.74	83.42	71.02	82.16	67.31
1980 NORTH ALA. MARKET (TBTU/YR) (EXCLUDES BIRMINGHAM)	27.0	NONE	124.8	56.6 (INCLUDES RESIDENTIAL)	7.5	139.2
1990 NORTH ALA. MARKET (TBTU/YR)	40.0	>50.0	184.7	83.6	11.8	145.9
1980/1990** PRICE ($/MBTU)	4.80/30.45	7.50/35.73	7.80/30.45	14.85/21.88	8.20/38.06	10.80/31.87
COMMENTS	TVA PLANS TO SELL 3/4 OF OUTPUT DIRECTLY TO PIPELINE/ CHEMICAL COMPANIES	COULD CONVINCE SEVERAL LARGE INDUSTRIES TO CONVERT TO METHANOL AS FUEL	EFFICIENCY OF SNG PRODUCTION APPEARS HIGH COMPARED TO MBG	FUEL CELL ELECTRICITY NOT ECONOMICALLY COMPETITIVE WITH FOSSIL & NUCLEAR ELECTRICITY	HYDROGEN PRICES A STRONG FUNCTION OF QUANTITY SOLD PER DAY	GASOLINE DEMAND IS EXPECTED TO REMAIN FLAT OR DECREASE

*90% OPERATIONS; 20,000 TPD; 24,050,000 BTU/TON
**1980 PRODUCTION COSTS EQUALS PRICE; 1990 COMPETING FUEL ESCALATION PRICE

MAJOR INDUSTRIAL GROWTH IN TVA REGION

DURING 1978 AND 1979, ABOUT 180 NEW INDUSTRIES LOCATED IN THE TVA REGION. OVER 200 EXISTING INDUSTRIES EXPANDED THEIR FACILITIES. EMPLOYMENT INCREASED BY OVER 20,000 EACH YEAR. INDUSTRIES RANKED BY GROWTH ARE ILLUSTRATED. THE MAJOR INDUSTRIAL GROWTH IS NOT FROM LARGE ENERGY USERS.

MAJOR INDUSTRIAL GROWTH IN TVA REGION

	1978	1979
New Plants	171	181
Expansions	254	281
KW Demand	277,905	469,505
Investment	$915,027,000	$2,100,260,000
Employment	21,637	28,400

Industries Ranked By Growth

1. Instrumentation
2. Machinery
3. Electronic Machinery
4. Apparel
5. Textile Mills
6. Furniture Manufacturing
7. Primary Metals*
8. Fabricated Metals
9. Paper*
10. Food
11. Rubber*
12. Stone & Clay
13. Chemicals*

NORTH ALABAMA INDUSTRIAL SYNFUELS SELECTION

PAST TDC STUDIES CONCLUDED THAT THE METALS, CHEMICALS, WOOD, RUBBER, AND PETROLEUM INDUSTRIES WOULD HAVE A PROPENSITY TO USE SYNFUELS OR LARGE AMOUNTS OF ENERGY. THE TVA AREA HAS RESOURCES OF WATER, POWER, WOOD, LAND, AND INEXPENSIVE LABOR. CURRENTLY, THERE ARE NO PETROLEUM REFINERIES IN NORTHERN ALABAMA; THEREFORE, A REFINERY WOULD BE A PRIME NEW INDUSTRY. WITH THE TENNESSEE-TOMBIGBEE CANAL, ALUMNA AND CRUDE COULD BE SHIPPED FROM THE GULF TO NORTHERN ALABAMA. NEW INDUSTRIES WOULD LOCATE NEAR THE MURPHY HILL SITE TO AVOID TRANSPORTING SYNFUELS LONG DISTANCES. NEW INDUSTRIES LOCATING IN NORTHERN ALABAMA COULD BE INTEGRATED WITH EXISTING INDUSTRIES AND UTILIZE FUEL CELLS AND CO-GENERATION OF ENERGY.

NORTH ALABAMA INDUSTRIAL SYNFUELS SELECTION

- PRIME SYNFUELS INDUSTRIES - METALS, CHEMICALS, WOOD, RUBBER, PETROLEUM
- MAJOR REGIONAL RESOURCES - WATER, POWER, WOOD, LAND, LABOR
- NO PETROLEUM REFINERY IN NORTHERN ALABAMA
- ACCESS TO NORTHERN ALABAMA THROUGH TENN-TOMBIGBEE FROM GULF (CRUDE & ALUMNA)
- EMPHASIZE NEW INDUSTRIES LOCATING NEAR MURPHY HILL
- DEMONSTRATE NEW ENERGY TECHNOLOGY SUCH AS FUEL CELLS AND CO-GENERATION
- INTEGRATE WITH EXISTING INDUSTRY SUCH AS ALUMINUM, RUBBER, CHEMICALS, WOOD

INDUSTRIAL SITE SELECTION

New industrial sites should be selected for proximity to Murphy Hill with adequate land, on the main channel of the Tennessee River, and be environmentally acceptable. Four sites were selected considering the above criteria. Three of the sites are owned by TVA, the fourth (the Revere Site at Goose Pond) could be shared.

INDUSTRIAL SITE SELECTION

- Proximity to Murphy Hill
- Land Availability (> 200 Acres)
- On Main Channel of River
- Environmentally Acceptable
- No Large Industrial Restrictions

Preliminary Sites

Name	Proximity	Approximate Acres	Current Owner	Channel Miles from Murphy Hill
Connors Island	Guntersville	600	TVA	12
Finley Island	Decatur	6,000	TVA	62
Courtland	Courtland	3,000	TVA	82
Goose Pond	Scottsboro	300	Revere	11

INTEGRATED NORTHERN ALABAMA CO-GENERATION INDUSTRIAL PARK

COMBINING SYNFUEL INDUSTRY TYPES, NORTHERN ALABAMA CHARACTERISTICS, CO-GENERATION, AND FUEL CELLS, THE SCHEMATIC SHOWS AN INTEGRATED INDUSTRIAL PARK POSSIBLY LOCATING CLOSE TO MURPHY HILL. THE ALUMINUM PLANT COULD BE AT REVERE OR THE PAPER MILL WOULD BE AT COURTLAND. THE PETROLEUM AND PETROCHEMICAL PLANT WOULD BE NEW: VCM IS VINYL CHLORIDE MONOMER, WHICH IS USED TO MAKE PLASTICS, AND STYRENE IS USED IN MAKING TIRE CORD. ALUMNA AND CRUDE COULD BE SHIPPED IN VIA THE TENNESSEE-TOMBIGBEE WATERWAY.

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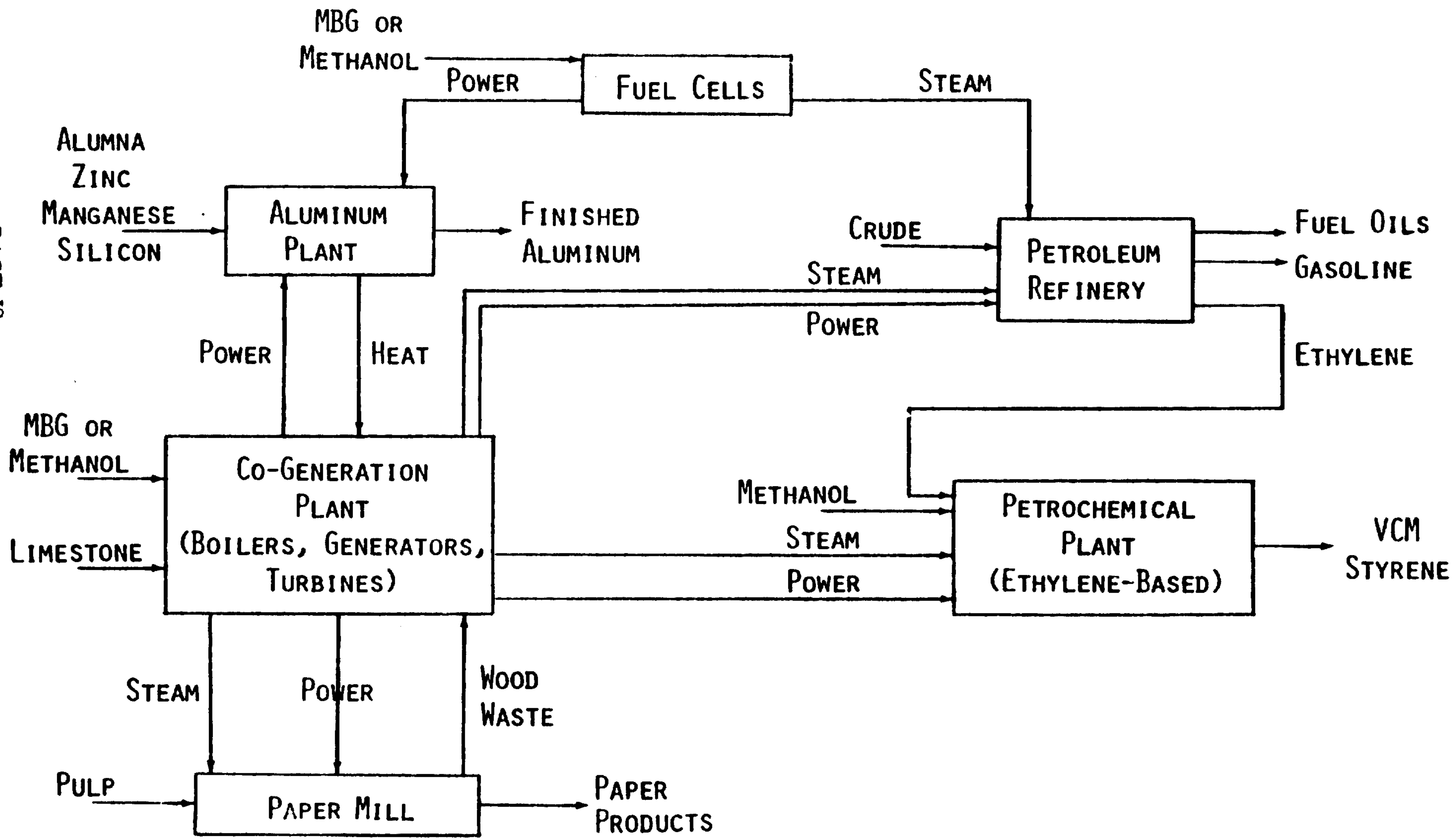
INTEGRATED NORTHERN ALABAMA
CO-GENERATION INDUSTRIAL PARK



CO-GENERATION INDUSTRIAL PARK
ESTIMATED PARAMETERS

ESTIMATES WERE MADE OF FUEL REQUIREMENTS, ELECTRICITY NEEDS, CAPITAL INVESTMENT, AND NUMBER OF EMPLOYEES THE INDUSTRIAL PARK WOULD REQUIRE. FUEL CELLS AND THE CO-GENERATION PLANT WOULD GENERATE ELECTRICITY AND STEAM. METHANOL AND/OR MBG WOULD BE IMPORTED FROM THE COAL GASIFICATION SITE.

CO-GENERATION INDUSTRIAL PARK ESTIMATED PARAMETERS

Element	Fuel Reqs. (TBTU/Yr)	Electricity (TBTU/Yr)	1980 Capital Investment ($ Million)	Number of Employees
Paper Mill	2.5	0.9	350	800
Aluminum	3.0	6.0	400	1,500
Petroleum Refinery	2.5*	0.3	80	600
Petrochemical	1.5*	2.0	110	300
Co-Generation Plant Plus Methanol Reqs.	50.0**	--	400	200
Fuel Cells	10.0**	--	100	150
TOTALS	60.0 (EXCLUDES INDUSTRIES)	9.2	1,440	3,550

*Does Not Include Crude and Methanol Feedstocks

**Co-Generation Plant and Fuel Cells Generate Electricity and Steam; Methanol Imported

TASK 3

CUSTOMER GAS CONSTITUENT REQUIREMENTS

CUSTOMER GAS CONSTITUENT REQUIREMENTS

TDC ANALYZED NATURAL GAS MONTHLY DEMAND SCHEDULES AND QUANTITY OF FUELS PURCHASED BY NORTHERN ALABAMA INDUSTRIES. THIS WAS REPORTED SEPARATELY UNDER A MEMO ENTITLED "NATURAL GAS DEMAND IN NORTHERN ALABAMA". A BRIEF MEDIUM-BTU GAS APPLICATION AND INDUSTRY RETROFIT ASSESSMENT WAS MADE. EIGHT LARGE INDUSTRIES IN NORTHERN ALABAMA WERE VISITED AND FUEL REQUIREMENTS WERE DETERMINED.

STUDY CONCLUSIONS AND RECOMMENDATIONS ARE MADE FOLLOWING THE TASK OUTPUTS.

CUSTOMER GAS CONSTITUENT REQUIREMENTS

TASK 3

- CUSTOMER GAS CONSTITUENT REQUIREMENTS
  - DEMAND SCHEDULES
  - QUANTITY OF FUELS PURCHASED
  - MEDIUM-BTU GAS APPLICATION
  - NORTHERN ALABAMA LARGE ENERGY USER PLANT TOURS
  - RETROFIT ASSESSMENT
- CONCLUSIONS AND RECOMMENDATIONS

INDUSTRY ENERGY CURTAILMENTS

NATURAL GAS CURTAILMENTS DURING 1977 AND 1978 WERE COMPILED BY TDC FOR MAJOR ENERGY CONSUMING INDUSTRIES IN NORTHERN ALABAMA. TO AVOID RELEASING PROPRIETARY INFORMATION, THE INDUSTRIES WERE GROUPED BY STANDARD INDUSTRIALIZATION CODE (SIC) ON A TWO-DIGIT LEVEL. THE LISTED SIC CODES ARE THE GROUPS THE NATURAL GAS CURTAILMENTS WERE AMALGAMATED INTO.

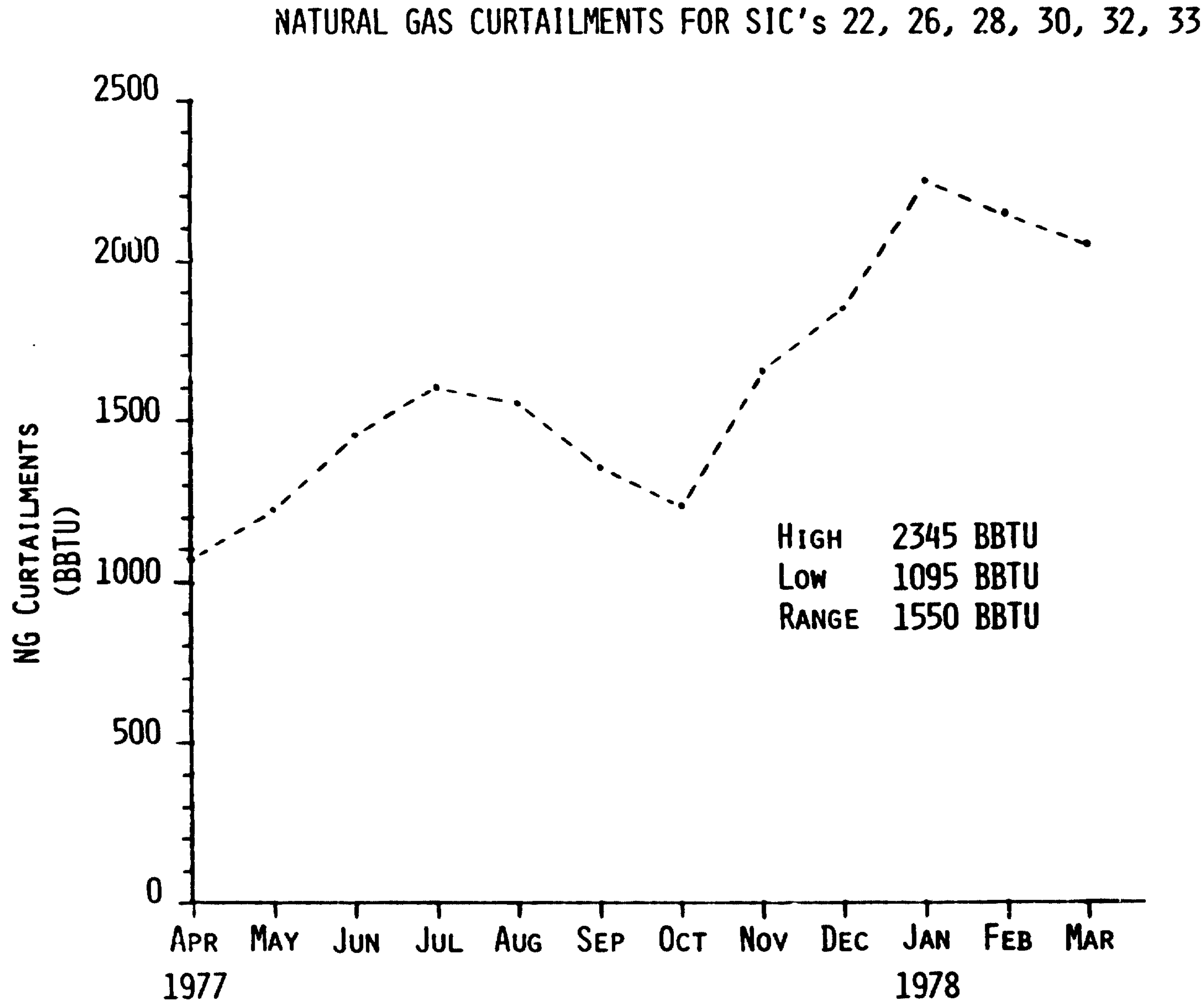
INDUSTRY ENERGY CURTAILMENTS

STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODES

SIC	Two-Digit Industry Title
22	Textile Mill Products
26	Paper and Allied Products
28	Chemicals and Allied Products
30	Rubber and Leather Products
32	Stone, Clay, Glass and Concrete Products
33	Primary Metals Industries

NATURAL GAS CURTAILMENTS

GROUPING ALL THE NORTHERN ALABAMA INDUSTRIES TOGETHER, NATURAL GAS CURTAILMENTS RANGED FROM A LOW OF 1,095 BILLION BTU (BBTU) PER MONTH DURING APRIL OF 1977, TO A HIGH OF 2,345 BBTU DURING JANUARY OF 1978. PEAK CURTAILMENTS OCCURRED DURING THE SUMMER AND WINTER MONTHS WHEN RESIDENTS HAVE PRIORITY OVER INDUSTRIES ON ENERGY SUPPLIES.



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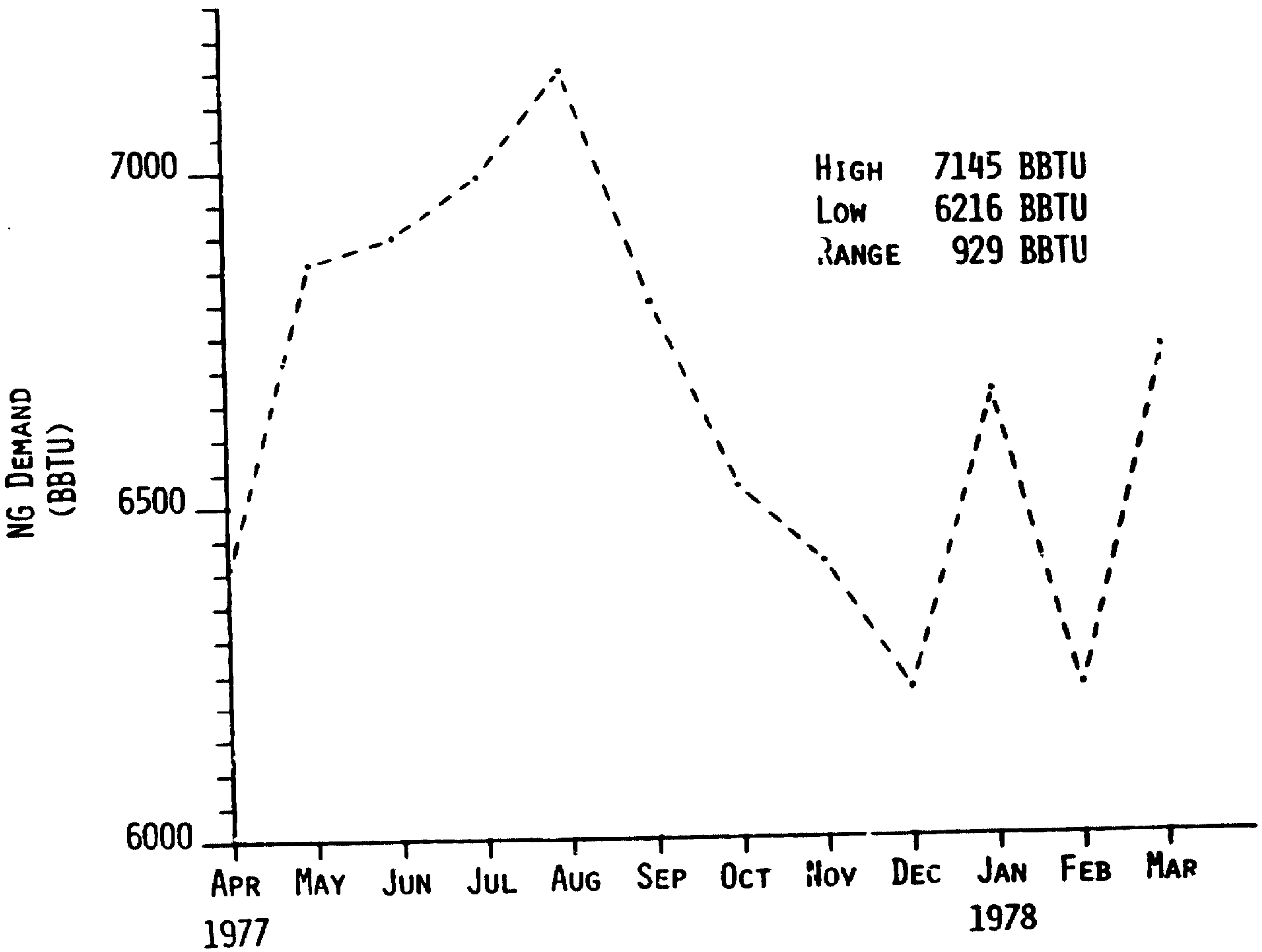
INDUSTRIAL NATURAL GAS DEMAND

NORTHERN ALABAMA INDUSTRIAL NATURAL GAS DEMAND (INCLUDES FUEL OIL USEAGE DURING NATURAL GAS CURTAILMENT) IS SHOWN TO PEAK DURING THE SUMMER AND WINTER MONTHS. THE VARIATION IN DEMANDS IS OVER 900 BBTU PER MONTH.

MONTHLY VARIATION OF INDUSTRIAL NATURAL GAS DEMAND
SIC CODES 22, 26, 28, 30, 32, 33



NORTHERN ALABAMA INDUSTRY SURVEY

EIGHT LARGE ENERGY CONSUMING INDUSTRIES WERE SURVEYED AND VISITED DURING JUNE, 1980, BY REPRESENTATIVES FROM NASA, TDC, AND UAH. RESULTS OF THE SURVEY SHOW THAT THE INDUSTRIES SURVEYED PREFERRED NATURAL GAS BECAUSE OF RETROFIT AND HEATING REQUIREMENTS. MONSANTO COULD USE HYDROGEN, BUT NOT IN THE AMOUNT THAT WOULD BE SIGNIFICANT. REYNOLDS METALS COULD BE A LARGE USER OF SYNTHETIC NATURAL GAS BY THE LATE 1980'S, AND COULD POSSIBLY USE MBG.

NORTHERN ALABAMA INDUSTRY SURVEY

PLANT	PRODUCT	ESTIMATED ENERGY USEAGE			OTHER (TBTU/YR)	ESTIMATED SYNFUEL UTILIZATION (TBTU/YR)	DEMAND SCHEDULE & VARIANCE	COMMENTS
		NATURAL GAS (TBTU/YR)	FUEL* OIL (TBTU/YR)	ELECTRICAL (TBTU/YR)				
FRUEHAUF	ALUMINUM EXTRUSIONS	0.6	0.2 #2	N/A	PROPANE	1.0 SNG	24 HOURS/DAY 5-6 DAYS/WK	NO FIRM NATURAL GAS CONTRACT, DIRECT FIRE FURNACES
AMOCO	TEREPHTLAIC ACID	4.4	0.2 #6	2.4	BUTANE	8.0 SNG OR MBG	24 HOURS/DAY 7 DAYS/WK SMALL VARIANCE 50% CAPACITY	CO-GENERATION INTEREST, NO FEEDSTOCK REQS.
FORD	ALUMINUM CASTINGS	0.04	--	0.006	--	--	24 HOURS/DAY 7 DAYS/WK SMALL VARIANCE	UNCERTAIN IF PLANT WILL STAY IN PRODUCTION, PREFERS ELECTRICITY
MONSANTO	ACYLIC, SYNTHETIC WOOL, POLYESTER, COKE	1.8	--	0.52	1.1 HYDROGEN LARGE COAL USER	2.0 H_2 OR MBG	24 HOURS/DAY 7 DAYS/WK SMALL VARIANCE	CO-GENERATION, STEAM TURBINES, & HYDROGEN PRODUCTION STUDIES
REYNOLDS	ALUMINUM BARS & SHEETS	6.9	0.587 (INCLUDES DIESEL, LUBE, & KEROSENE)	12.6	0.32 COAL	30.0 SNG OR MBG	24 HOURS/DAY 7 DAYS/WK ± 50% VARIANCE	MBG RETROFIT, FUEL CELL, MHD STUDIES DC POWER NEED
GOODYEAR (GADSDEN)	TIRES & TUBES	1.3	0.38 #6	N/A	--	1.5 SNG	24 HOURS/DAY 5-6 DAY WEEK	NO SYNFUEL UTILIZATION STUDIES UNDERWAY
REPUBLIC STEEL	STEEL PLATES & SHEETS	6.0	0.2 #2	N/A	1.8 COAL	6.0 SNG OR 3.0 MBG	24 HOURS/DAY 5-6 DAY WEEK ± 50% VARIANCE	CO-GENERATION, COAL GASIFICATION STUDIES PERFORMED: USE LOW BTU BLAST FURNACE GAS
GOODYEAR (DECATUR)	TIRE CORD & FABRIC	0.5	0.05 #2	N/A	PROPANE	0.5 SNG	24 HOURS/DAY 6 DAYS/WK	GAS REQUIREMENTS SENSITIVE TO BTU CONTENT

*RECENT NATURAL GAS CURTAILMENTS SMALL; USUALLY UTILIZE FUEL OIL WHEN NATURAL GAS CURTAILED

CUSTOMER GAS CONSTITUENT CONCERNS

FROM THE SURVEYED EIGHT COMPANIES, ALL EXPRESSED CONCERN ABOUT RETROFIT COSTS. SULFUR CONTENT, COMBUSTION PRODUCTS, AND SAFETY ARE ALSO CONCERNS OF SOME OF THE INDUSTRIES.

CUSTOMER GAS CONSTITUENT CONCERNS*

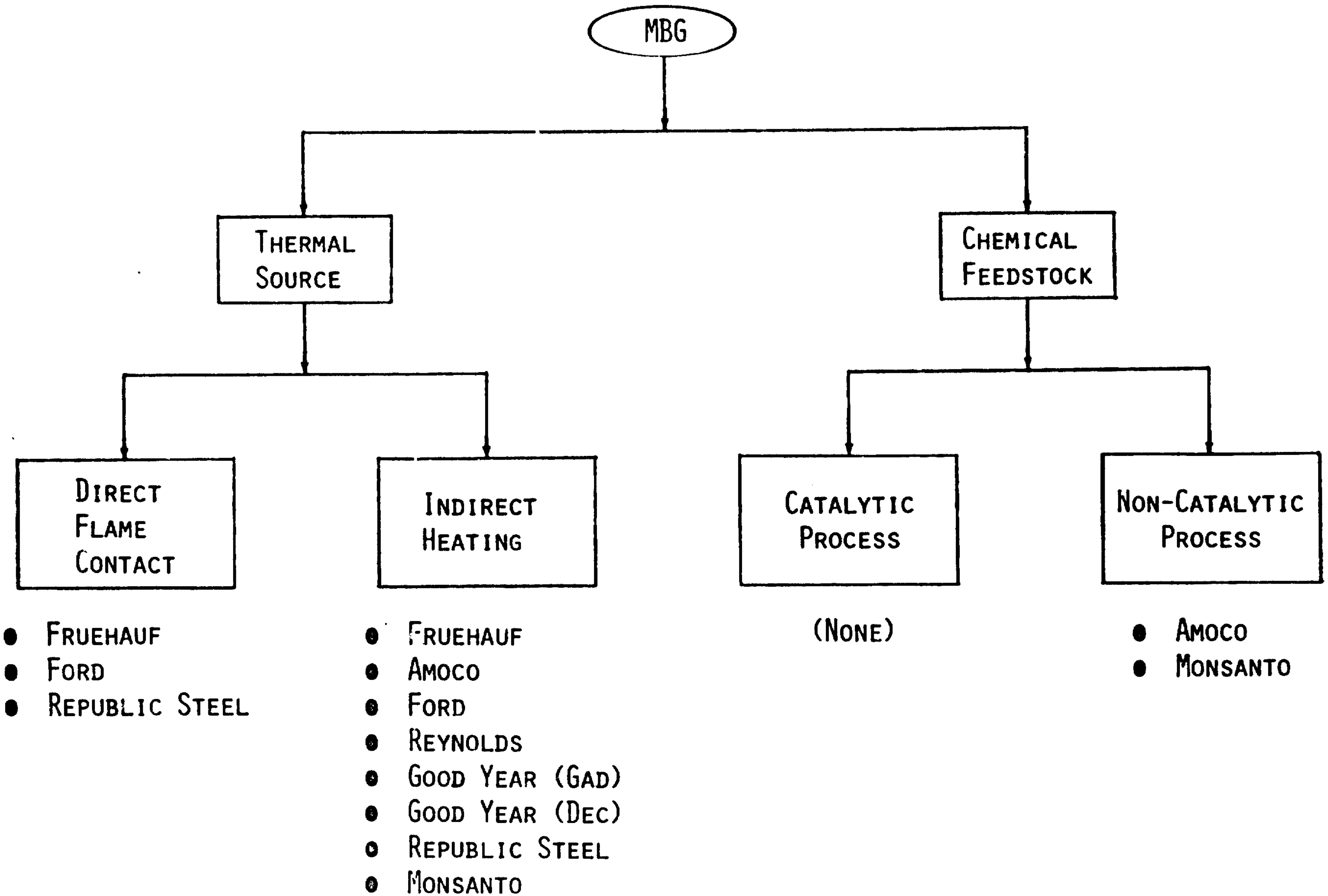
	Plant Name	Retrofit	Sulfur Content	Combustion Products	Safety
1.	Fruehauf	X	X	X	X
2.	Amoco	X			
3.	Ford	X	X	X	
4.	Reynolds	X			
5.	Good Year (GAD)	X			
6.	Good Year (DEC)	X		X	
7.	Republic Steel	X	X	X	X
8.	Monsanto	X	X		

*This excludes the cost of buying the MBG, and the cost of retrofitting customer plants to the MBG.

POTENTIAL CUSTOMER UTILIZATION OF MBG

MEDIUM-BTU GAS (MBG) CAN BE USED AS A THERMAL SOURCE OR FEEDSTOCK. ALL THE SURVEYED INDUSTRIES COULD USE MBG IN INDIRECT HEATING. ONLY AMOCO AND MONSANTO COULD USE MBG AS A FEEDSTOCK.

POTENTIAL CUSTOMER UTILIZATION OF MBG



INDUSTRIAL GAS CONSTITUENTS

Commercial-grade industrial gas constituents are shown for a variety of gases. Koppers-Totzek (K-T) MBG is also shown for reference. Methane (or natural gas) has an energy content around 1000 BTU/Ft^3 compared to the K-T MBG of 300 BTU/Ft^3.

INDUSTRIAL GAS CONSTITUENTS

- Commercial Grade -

Constituents	Hydrogen	Carbon Monoxide	Carbon Dioxide	Nitrogen	Oxygen	Methane	Koppers-Totzek
CO_2	--	2000 ppm	99.5%	0.002%	10 ppm	0.70%	9.3%
O_2	20 ppm	0.4%	0.086%	0.02%	99.6%	0.1%	--
N_2	5 ppm	0.8%	0.342%	99.9%	0.5%	0.47%	1.0%
H_2	99.95%	0.7%	--	--	--	--	34.3%
H_2O	--	--	0.072%	0.001%	10 ppm	--	1.9%
CO	--	98.0%	--	--	--	--	53.0%
CH_4	--	--	--	--	--	93.63%	0.5%

KOPPERS-TOTZEK MEDIUM-BTU GAS (MBG) INDUSTRIAL APPLICATION

FLAME TEMPERATURES FOR MBG AND NATURAL GAS ARE ABOUT THE SAME. THE BURNER NOZZLES OF BOILERS WILL HAVE TO BE MODIFIED SINCE THE STREAM VELOCITIES AND FUEL RICHNESS ARE DIFFERENT. USING MBG INSTEAD OF NATURAL GAS WILL PROBABLY CAUSE FLUES TO BE MODIFIED; PIPING, VALVES, AND CONTROLS WILL HAVE TO BE MODIFIED. EACH PLANT WILL HAVE TO BE ANALYZED FOR RETROFIT OF MBG SINCE BOILERS, BURNERS, AND PIPING ARE UNIQUE.

KOPPERS-TOTZEK MEDIUM-BTU GAS (MBG) INDUSTRIAL APPLICATION

- Flame Temperature of $3600^{o}F$ Is About Same for MBG and Natural Gas
- Burner Flame Length to Nozzle Diameter Ratio for MBG Is About 1/3 of Natural Gas
- Natural Gas Burner Nozzles Will Have to Be Modified for MBG Stream Velocities and Fuel Richness to Prevent Flashback
- Steam Boiler Useage of MBG Will Cause Flue Gas Volume and Steam from Hydrogen Problems
- MBG Piping, Valves, and Controls Will Have to Be Retrofitted
- MBG Ignitability in General Is No Problem
- Each Plant Useage of MBG Will Be Unique and Retrofit Studies Will Have to Be Performed

I. PRINCIPAL CONSTITUENTS
OF
CURRENT INDUSTRIAL FUELS

GASEOUS FUELS

NATURAL GAS, IN NORMAL USAGE, IS CONSTRUED TO BE A NATURALLY OCCURRING MIXTURE OF HYDROCARBONS AND NON-HYDROCARBONS ASSOCIATED WITH PETROLIFEROUS GEOLOGIC FORMATIONS. IT CONSISTS PRIMARILY OF METHANE (CH_4) WITH MINOR AMOUNTS OF ETHANE (C_2H_6) AND OTHER HEAVIER HYDROCARBONS AND CERTAIN NON-COMBUSTIBLES SUCH AS CARBON DIOXIDE, NITROGEN, AND HELIUM. NATURAL GAS AS SUPPLIED BY THE UTILITY COMPANIES USUALLY CONTAINS FROM 80 TO 95 PERCENT METHANE, WITH ETHANE, PROPANE, AND NITROGEN MAKING UP THE REMAINDER. THE HEATING VALUE OF SUCH GASES RANGES FROM 900 TO 1200 BTU/CU.FT., WITH THE SPECIFIC GRAVITY (AIR = 1.0) VARYING FROM 0.58 TO 0.79.

ALTHOUGH THERE IS NO SINGLE COMPOSITION THAT MAY BE TERMED THE "TYPICAL" NATURAL GAS, THE NEXT TABLE SHOWS ANALYSES OF NATURAL GAS AS DISTRIBUTED IN A NUMBER OF CITIES IN THE UNITED STATES.

ANALYSES OF NATURAL GAS*

City	Methane	Ethane	Propane	Butanes	Pentanes	Hexanes Plus	CO_2	N_2	Misc.	Heating Value, BTU/cu. Ft.	Specific Gravity
Baltimore, MD	94.40	3.40	0.60	0.50	0.00	0.00	0.60		...	1051	0.590
Birmingham, AL	93.14	2.50	.67	.32	.12	.05	1.06	2.14	...	1024	.590
Boston, MA	93.51	3.82	.93	.28	.07	.06	0.94	0.39	...	1057	.604
Columbus, Ohio	93.54	3.58	0.66	.22	.06	.03	.85	1.11	...	1028	.597
Dallas, Texas	86.30	7.25	2.78	.48	.07	.02	.63	2.47	...	1093	.651
Houston, Texas	92.50	4.80	2.00	.30	...	...	.27	0.13	...	1031	.623
Kansas City, MO	72.79	6.42	2.91	.50	.06	Trace	.22	17.10	...	945	.695
Los Angeles, CA	86.50	8.00	1.90	.30	.10	.10	.50	2.60	...	1084	.638
Milwaukee, WI	89.01	5.19	1.89	.66	.44	.02	.00	2.73	.06 He	1051	.627
New York, NY	94.52	3.29	0.73	.26	.10	.09	.70	0.31	...	1049	.595
Phoenix, AZ	87.37	8.11	2.26	.13	.00	.00	.61	1.37	...	1071	.633
Salt Lake City, UT	91.17	5.29	1.69	.55	.16	.03	.29	0.82	...	1082	.614
San Francisco, CA	88.69	7.01	1.93	.28	.03	.00	.62	1.43	.01 He	1086	.625
Washington, D.C.	95.15	2.84	0.63	.24	.05	.05	.62	0.42	...	1042	.586

*Source: Ref. 1

IMPU IES IN RAW NATURAL

ANALYSIS OF A SAMPLE OF NATURAL GAS*

COMPONENT	MOLE %
METHANE	76.2
ETHANE	6.4
PROPANE	3.8
n-BUTANE	1.3
ISOBUTANE	0.8
n-PENTANE	0.3
ISOPENTANE	0.3
CYCLOPENTANE	0.1
HEXANE + HYDROCARBONS	0.3
NITROGEN	9.8
OXYGEN	TRACE
ARGON	TRACE
HYDROGEN	0.0
HYDROGEN SULFIDE	0.0
CARBON DIOXIDE	0.2
HELIUM	0.45

* PANHANDLE NATURAL GAS FIELD (TEXAS).

*Source: Ref. 1

CARBON COMPOSITION OF CRUDE PETROLEUM

FUEL TYPE	NUMBER OF CARBON ATOMS IN THE FUEL
GAS	C_1-C_4
GASOLINE	C_5-C_{12}
KEROSENE	C_{10}-C_{16}
FUEL OIL	C_{15}-C_{22}
LUBRICATING OIL	C_{19}-C_{35}
RESIDUE	C_{36}-C_{90}

*Source: Ref. 2

	McComb, Mississippi		Southwest Texas		East Texas	Wyoming (Sour)	New Mexico	N. Kenai Penin., Alaska	San Ardo, California	Opelousas, Louisiana		Velma, Oklahoma
Gravity, °API	40.7		36.5		39.1	17.9	37.5	25.9	13.3*	38.2		29.1
Distillation, °F:												
Type	D 86§	UOP 76§	D 86	UOP 76	D 86	D 86	D 86	D 86	UOP	D 86	UOP 76	D 86
IBP (initial boiling point)	152	152	158	158	125	306	118	160	IBP 180 0.3†	127	127	115
5% over	192	192	208	208	191	408	162	196	180–300 1.6†	206	206	224
10	221	224	244	244	211	476	224	220	300–550 16.1†	256	256	382
30	314	341	461	461	355	633	354	514	550–650 10.6†	438	438	659
50	504	506	700	770	539	675	530	660	650–900 17.3†	545	575	712
70	655	703	760+	1075	702	710	626	690	900–1000 6.0†	672	720	748
90	760+	977	...	...	760	732‡	728	710‡	1000+ 48.1†	760+	905	748+
EP (end point)	...	1062	...	...	760+	732+	734+	710+	....	...	978	
% recovered	98.5	95.5	98.5	90.5	97.0	89.0	94.0	40.0	....	98.5	96.0	95.5
% bottoms	...	4.5	...	9.5	...	...	...	...	....	...	4.0	
% coke, wt	1.6	...	1.8	...	2.8	11.0	5.6	...	....	0.7		
% recovered												
At 400°F	37.0	...	32.0	...	31.5	4.5	35.0	...	1.9*	26.5		22.5
525°F	53.0	...	48.0	...	54.0	15.0	55.0	...	17.9*	46.0		43.5
572°F	60.0	...	54.0	...	...	20.0	...	...	....	54.0		50.0
Total sulfur, wt %	0.07		0.15		0.2	3.33	1.0	1.096	1.93*	0.08		1.14
Reid vapor pressure, psi	4.6		3.4		...	0.2	8.8	4.2	...	8.4		1.0
Pour point, °F	60		30		55	−5	25	...	...	40		< −30
Bottom sediment and water, vol %	0.10		0.10		0.1	0.3	0.3	2.5	...	0.15		0.2
Conradson carbon residue, wt %	0.79		1.74		...	...	...	...	...	0.52		
Salt (as NaCl) lb/1,000 bbl	4		< 0.5		31	0.6	14.0	76.0	...	5.0		78.0
Gasoline, vol %	35.5		32.0		29.0	6.3	37.8	14.1	1.9	26.1		22.3
Kerosine, vol %	18.1		12.1		10.1	9.1	...	18.0	16.1	18.9		17.3
Diesel fuel, vol %	14.6		38.0		13.8	14.0	...	18.4	10.6	22.9		8.5
Gas oil, vol %	28.1		12.6		...	30.7	41.2	22.3	23.3	27.9		31.9
Asphalt (bottoms), vol %	3.7		5.3		(47.1)	39.9	20.8	25.7	48.1	4.1		20.0
Metals (in gas oils), ppm:												
Nickel	0.06		...		...	...	...		0.15	...		
Vanadium	0.08		...		...	...	...	...	< 0.1			

*Calculated.
†% over in indicated boiling range.
‡Cracked at 80% over.
§ Designates data from Method of Test D 86, Committee D-2 on Petroleum Products and Lubricants, ASTM.
§ Designates data from UOP Laboratory Test Methods for Petroleum and Its Products, No. 76, Universal Oil Products Company.

Source: Ref. 1

ANALYSES OF WORLD CRUDE OILS

Source: Ref. 1

	Arabian	Minas, Central Sumatra, Topped		Putomayo Colombia		Gulf Nigeria	
Gravity, °API	30.0	35.3		35.0		34.7	
Distilation, °F:							
Type	D 86	D 86*	UOP 76	°F	Vol.%	°F	Vol%
IBP (initial boiling point)	77	173	594	IBP 400	34.1	IBP 140	6.3
5%	160	216	662	400-500	9.3	140-170	1.8
10	231	246	699	500-650	20.3	170-310	16.8
20	287	295	750	650-750	9.0	310-520	26.5
30	···	341	792	750-900	11.4	520-680	19.3
50	330	427	890	900+	17.2	680+	30.9
70	435	497	1042	···	···	···	···
90	452	575	Cracked	···	···	···	···
95	526	519	···	···	···	···	···
EP (end Point)	526	639	1042+	···	···	···	···
% recovered		99.0	72.5	101.3		101.6	
% residue	···	1.0	27.5	···		···	
Total sulfur, wt %	3.05	0.2		0.49		0.16	
Reid vapor pressure, psig	3.8						
Pour point, °F	-33	0		45		20	
Gasoline, vol %	29.1	11		34.1		24.9	
Kerosine, vol %	16.0	16		9.3		26.5	
Gas oils, vol %	12.5	14		40.7		19.3	
Residuum, vol %	42.4	59		17.2		30.9	
Metals in gas oils, ppm:							
Vanadium	0	···		25		0.7	
Nickel	0	···		11		5.1	
Iron	3						
Salt, lb/1,000 bbl	12	···		Trace		5	

	Zulia, Venezuela		Iran		Kuwait	
Gravity, °API	25.2		36.6		31.5	
Distilation, °F:						
Type	Hempel	Vol.%	Hempel			
IBP (initial boiling point)	IBP 122	0.1	IBP 122	1.5	IBP 122	
5%	122-167	1.2	122-167	2.8	122-167	[illegible]
10	167-212	2.3	167-212	4.5	167-212	[illegible]
20	212-257	3.7	212-257	6.3	212-257	[illegible]
30	257-302	3.9		7.1	257-302	[illegible]
50	302-347	4.1	302-347	5.6	302-347	[illegible]
70	347-392	3.6	347-392	5.4	347-392	[illegible]
90	392-437	3.4	392-437	5.4	392-437	[illegible]
95	437-482	4.7	437-482	5.5	437-482	[illegible]
EP (end Point)	482-527	6.0	482-527	7.4	482-527	[illegible]
	527-583	2.2	527-583	2.6	527-583	[illegible]
	583-633	5.1	583-633	6.6	583-633	[illegible]
	633-687	4.9	633-687	5.6	633-687	[illegible]
	687-738	5.2	687-738	5.1	687-738	[illegible]
	738-790	7.3	738-790	5.9	738-790	[illegible]
% recovered	57.7		77.3			
% residue	42.1		22.5		34.8	
Total sulfur, wt %	1.69		1.12		2.62	
Reid vapor pressure, psig						
Pour point, °F	5		5		5	
Gasoline, vol %	18.9		32.2		25.5	
Kerosine, vol %	14.1		18.3		13.7	
Gas oils, vol %						
Residuum, vol %						
Metals in gas oils, ppm:						
Vanadium						
Nickel						
Iron						
Salt, lb/1,000 bbl						

TYPICAL ULTIMATE ANALYSES OF PETROLEUM FUELS

Composition, %	No. 1 fuel oil (41.5° A.P.I.)	No. 2 fuel oil (33° A.P.I.)	No. 4 fuel oil (23.2° A.P.I.)	Low sulfur, No. 6 F.O. (12.6° A.P.I.)	High sulfur, No. 6 (15.5° A.P.I.)
Carbon	86.4	87.3	86.47	87.26	84.67
Hydrogen . . .	13.6	12.6	11.65	10.49	11.02
Oxygen	0.01	0.04	0.27	0.64	0.38
Nitrogen . . .	0.003	0.006	0.24	0.28	0.18
Sulfur	0.09	0.22	1.35	0.84	3.97
Ash	<0.01	<0.01	0.02	0.04	0.02
C/H Ratio . .	6.35	6.93	7.42	8.31	7.62

Source: Ref. 1

A.S.T.M. Detailed Requirements for Fuel Oils

Fuel oil grade	Description and requirements for use	Flash point, F (C)	Pour point, F (C)	Water and sediment, vol %	Carbon residue on 10% bottoms, %	Ash, wt %	Distillation temperature, F (C): 10% point	Distillation temperature, F (C): 90% point		Saybolt viscosity, sec: Universal at 100 F (38 C)		Saybolt viscosity, sec: Furol at 122 F (50 C)		Kinematic viscosity, centistokes: At 100 F (38 C)		Kinematic viscosity, centistokes: At 122 F (50 C)		Gravity, deg API	Copper strip corrosion
		Min	Max	Max	Max	Max	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
No. 1	A distillate oil intended for vaporizing pot type burners and other burners requiring this grade of fuel	100 or legal (38)	0	trace	0.15		420 (215)		550 (288)					1.4	2.2			35	No. 3
No. 2	A distillate oil for general purpose domestic heating for use in burners not requiring No. 1 fuel oil	100 or legal (38)	20 (−7)	0.10	0.35			540 (282)	640 (338)	32.6	37.93			2.0	3.6			30	
No. 4	Preheating not usually required for handling or burning	130 or legal (55)	20 (−7)	0.50		0.10				45	125			5.8	26.4				
No. 5 (light)	Preheating may be required depending on climate and equipment	130 or legal (55)		1.00		0.10				150	300			32	65				
No. 5 (heavy)	Preheating may be required for burning and, in cold climates, may be required for handling	130 or legal (55)		1.00		0.10				350	750	(23)	(40)	75	162	42	81		
No. 6	Preheating required for burning and handling	150 (65)		2.00						(900)	9000	45	300			92	638		

* A.S.T.M. Burner Fuel Specification D 396

Source: Ref. 1

II. IMPURITIES IN INDUSTRIAL NATURAL GAS AND FUEL OILS

CHEMICAL AND PHYSICAL PROPERTIES*

PETROLEUM FUELS CONSIST PRIMARILY OF PARAFFINS, ISOPARAFFINS, AROMATICS, AND NAPHTHENES, PLUS RELATED HYDROCARBON DERIVATIVES OF SULFUR, OXYGEN, AND NITROGEN THAT WERE NOT REMOVED BY REFINING. OLEFINS ARE ABSENT OR NEGLIGIBLE EXCEPT WHERE CREATED BY CRACKING OR OTHER SEVERE REFINING. VANADIUM AND NICKEL COMPOUNDS ARE LOW IN VOLATILITY AND DO NOT DISTILL INTO THE No. 1 AND No. 2 FUEL OIL FRACTIONS. VACUUM-TOWER DISTILLATES WITH A FINAL BOILING POINT EQUIVALENT TO 850 TO 1050^{O}F. AT ATMOSPHERIC PRESSURE ARE OCCASIONALLY AVAILABLE AS FUEL NOT CONFORMING WITH A.S.T.M. SPECIFICATIONS AND MAY CONTAIN 0.1 TO 0.5 P.P.M. VANADIUM AND NICKEL.

THE BLACK VISCOUS DISTILLATION-TOWER BOTTOMS (RESIDUUM) MAY BE TAKEN DIRECTLY FROM THE STILL AND BURNED AS INDUSTRIAL FUEL WITHOUT COOLING BELOW 450^{O}F., OR MAY BE BLENDED INTO THE RESIDUAL FUELS OF COMMERCE. DILUTED WITH 5 TO 20 PER CENT DISTILLATE THIS BECOMES No. 6 FUEL OIL, OR IT MAY BE CUT BACK WITH 20 TO 50 PER CENT DISTILLATE TO MAKE No. 4 AND 5 FUEL OILS FOR COMMERCIAL USE, AS IN SCHOOLS AND APARTMENT HOUSES. DISTILLATE-RESIDUAL BLENDS ARE ALSO USED AS DIESEL FUEL IN LARGE STATIONARY AND MARINE ENGINES. HOWEVER, DISTILLATES WITH INADEQUATE SOLVENT POWER WILL PRECIPITATE ASPHALTENES AND OTHER HIGH-MOLECULAR-WEIGHT COLLOIDS FROM "VISBROKEN" (SEVERELY HEATED) RESIDUALS. A BLOTTER TEST, A.S.T.M. D 2781, CAN BE USED TO DETECT SLUDGE IN PILOT BLENDS. CENTRIFUGE TESTS, FILTRATION TESTS, AND MICROSCOPIC EXAMINATION HAVE ALSO BEEN USED.

No. 6 FUEL OIL CONTAINS 10 TO 500 P.P.M. VANADIUM AND NICKEL IN COMPLEX ORGANIC MOLECULES, PRINCIPALLY PROPHYRINS, WHICH CANNOT ECONOMICALLY BE REFINED OUT OF THE OIL. SALT, SAND, RUST, AND DIRT MAY ALSO BE PRESENT, GIVING No. 6 A TYPICAL ASH CONTENT OF 0.01 TO 0.5 PER CENT BY WEIGHT.

*Source: Ref. 1

COMBUSTION DEPOSITS*

RESIDUAL FUELS COST LESS AND HAVE HIGHER HEAT CONTENT PER GALLON THAN DISTILLATE FUELS, BUT THEY USUALLY HAVE HIGHER SULFUR CONTENT PLUS SODIUM, VANADIUM, NICKEL AND OTHER ASH-FORMING INGREDIENTS. IN AND NEAR THE COMBUSTION ZONE, MOSTEN ASH CAN CAUSE CORROSION AND DEPOSITS; IN OTHER AREAS THAT ARE BELOW 350°F., WATER AND SULFUR COMPOUNDS CONDENSE INTO CORROSIVE ACID SOLUTIONS.

DURING COMBUSTION, THE ASH-FORMING MATERIALS ARE CONVERTED TO OXIDES WHICH INTERACT TO FORM A VARIETY OF CHEMICAL COMPOUNDS. IF THEY COOL AND SOLIDIFY BEFORE STRIKING A SOLID SURFACE, THE ASH PARTICLES ARE LIKELY TO PASS THROUGH THE EQUIPMENT. HOWEVER, PARTS OF A BOILER (OR GAS TURBINE OR DIESEL ENGINE) WHICH OPERATE AT THE ASH FUSION TEMPERATURE OR HIGHER MAY ACCUMULATE SLAG DEPOSITS AND BE SUBJECT TO CATASTROPHIC CORROSION. VANADIUM COMPOUNDS ARE PARTICULARLY CORROSIVE WHEN MOLTEN.

COMBUSTION AIR OFTEN CARRIES DUST THAT AFFECTS FURNACES. A CLASSICAL EXAMPLE IN LIMESTONE AREAS IS THE DIOPSITE FORMED IN THE FLAME BY LIMESTONE AND SILICA DUST, AND DEPOSITED ON REFRACTORIES AS A GLASS. SPALLING OCCURS WHEN THE FURNACE COOLS BECAUSE THE DIOPSITE AND REFRACTORY SHRINK AT DIFFERENT RATES.

ASHES ARE MIXTURES OF COMPOUNDS WITH DIFFERENT SINTERING AND SOFTENING TEMPERATURES, AND FUSION MAY OCCUR OVER A RANGE OF 200°F. BETWEEN THE INITIAL SINTERING AND FINAL COMPLETE LIQUEFACTION. FOR EXAMPLE, V_2O_5 MELTS AT 1243°F., BUT OIL ASH FUSION TEMPERATURES RANGE FROM BELOW 1000 TO OVER 2000°F., DEPENDING ON THE RELATIVE CONCENTRATIONS OF FLUXES (PRINCIPALLY SODIUM) AND REFRACTORY COMPOUNDS (SUCH AS SILICA, MAGNESIA, AND ALUMINA). AS A GENERAL RULE, VANADIUM CORROSION USUALLY OCCURS AT TEMPERATURES ABOVE 1250°F., AND SULFIDATION (ATTACK OF NICKEL ALLOYS BY SULFATES) ABOVE 1650°F.

MAGNESIA, EPSOM SALTS, AND OTHER INEXPENSIVE MAGNESIUM COMPOUNDS ARE ADDED AT MG/V WEIGHT RATIOS OF 3 TO 1 OR 3.5 TO 1 TO PREVENT CORROSION AND DEPOSITION BY RAISING THE ASH FUSION TEMPERATURE. THERE IS DISAGREEMENT OVER THE VALUE OF ALUMINA AS A COADDITIVE TO OVERCOME THE SLIGHT TENDENCY OF MAGNESIA TO FORM DEPOSITS. CALCIUM COMPOUNDS HAVE BEEN WIDELY TESTED BUT ARE NOW CONSIDERED UNDESIRABLE BECAUSE THEY FORM HARD, ADHERENT, INSOLUBLE DEPOSITS. MANGANESE COMPOUNDS AND, TO A LESSER EXTENT, LEAD AND COPPER COMPOUNDS ARE BEING USED AS COMBUSTION CATALYSTS TO REDUCE SOOT AND SMOKE FORMATION. ASIDE FROM ADDITIVES DESIGNED TO MODIFY THE ASH OR COMBUSTION PERFORMANCE, THERE ARE MANY PROPRIETARY ADDITIVES SOLD TO BENEFIT THE FUEL HANDLING SYSTEM. THESE MAY CONTAIN SOLVENTS OR DISPERSANTS TO COMBAT SLUDGE DEPOSITS, EMULSIFIERS OR DEEMULSIFIERS FOR WATER IN THE FUEL, CORROSION INHIBITORS, AND OTHER SPECIFIC FUNCTIONAL INGREDIENTS. FUEL SUPPLIERS SHOULD BE CONSULTED FOR POSSIBLE ADVERSE REACTIONS BETWEEN THE ADDITIVE AND FUEL, AND CLAIMS FOR THE ADDITIVE SHOULD BE EVALUATED CAUTIOUSLY, BUT THEIR POTENTIAL USEFULNESS FOR SPECIFIC PERFORMANCE PROBLEMS SHOULD NOT BE OVERLOOKED.

*Source: Ref. 1

TYPICAL SLAG FROM BOILER FIRED WITH NO. 6 FUEL OIL*

	OIL ASH, %	SUPERHEATER DEPOSIT, %
SiO_2	1.7	7.0
Al_2O_3	0.3	4.1
Fe_2O_3	3.8	5.8
CaO	1.7	4.5
MgO	1.1	2.5
NiO	1.9	1.1
V_2O_5	7.9	0.9
Na_2O	31.3	23.7
SO_3	42.3	46.4

* FROM MCILROY, HOLLER, AND LEE, A.S.M. E., PAPER NO. 52-A-160

FUEL CHARACTERISTICS*

FUELS USED IN INDUSTRIAL ENGINES OF THE INTERNAL-COMBUSTION TYPE ARE USUALLY DERIVATIVES OF PETROLEUM, OR ELSE NATURAL OR MANUFACTURED GASES. ALCOHOLS AND MIXTURES OF GASOLINE AND ALCOHOL OR BENZOL CAN ALSO BE USED. A GAS ENGINE WILL OPERATE SATISFACTORILY ON ANY GAS WHICH IS FREE OF DUST, NON-CORROSIVE (I.E., LESS THAN 60 GRAINS H_2S PER 100 CU. FT.), DOES NOT DETONATE, DOES NOT PREIGNITE DURING COMPRESSION STROKE, AND PRODUCES ENOUGH HEAT ON BURNING TO DEVELOP POWER.

IN GENERAL THE FUEL MUST HAVE A HEAT CAPACITY OF OVER 600 BTU/CU. FT. GASOLINE ENGINES REQUIRE IN ADDITION THAT THE FUEL WILL VAPORIZE IN THE CARBURETOR. DIESELS WILL BURN ANY FUEL THAT CAN BE INJECTED, PROVIDED THAT IT WILL BURN UNDER CONTROLLED CONDITIONS, POSSESSES SUFFICIENT LUBRICITY TO LUBRICATE THE INJECTION PLUNGERS, WILL SUPPLY ENOUGH HEAT, AND IS GRIT-FREE, CONTAINING LESS THAN 3 PER CENT SULFUR, 70 P.P.M. VANADIUM, AND 125 P.P.M. VANADIUM PENTOXIDE. MOST DIESEL ENGINES USE EITHER NO. 2 OR NO. 5 FUEL OILS. THE LATTER MUST BE HEATED TO A VISCOSITY OF 50 TO 70 S.S.U. (250°F. APPROXIMATELY) FOR PROPER INJECTOR LUBRICATION AND INJECTION CHARACTERISTICS.

GASEOUS FUELS CONTAINING FRACTIONS WHOSE IGNITION TEMPERATURE IS LOWER THAN THAT OF METHANE MAY REQUIRE THE USE OF LOW-COMPRESSION HEADS AND A RESULTING DERATING OF THE GAS ENGINE.

THE METHOD OF REPORTING FUEL CONSUMPTION VARIES AMONG THE DIFFERENT INDUSTRIES AND ALSO AMONG COUNTRIES. TRADE ASSOCIATIONS USUALLY HAVE RECOMMENDED PROCEDURES. THUS THE DIESEL ENGINE MANUFACTURERS ASSOCIATION (UNITED STATES) CALCULATES EFFICIENCIES BASED ON THE LOWER HEATING VALUE (LHV) FOR GAS FUELS AND THE HIGHER HEATING VALUE FOR OIL FUELS. IT IS GENERAL PRACTICE TO REPORT GAS-ENGINE PERFORMANCE IN TERMS OF BTU/HP.-HR. (LHV) AND OIL-ENGINE PERFORMANCE IN TERMS OF POUNDS OF FUEL CONSUMED PER HORSEPOWER-HOUR. FOR ELECTRIC POWER PLANTS, FUEL CONSUMPTION IS REPORTED IN TERMS OF KILOWATTS. THE AUXILIARIES INCLUDED WITH ENGINE-EFFICIENCY CALCULATIONS VARY WITH INDUSTRY PRACTICE.

*Source: Ref. 1

III. COMPARISON OF COAL-BASED SYNTHETIC FUEL GASES WITH NATURAL GAS

1. BURNER COMPARISONS

RETROFIT OF INDUSTRIAL BURNERS*

COMBUSTION TRIALS WERE COMPLETED WITH THE FOURTH BURNER (HIGH-FORWARD-MOMENTUM) AND THE FIFTH BURNER (FLAT-FLAME). EXPERIMENTS HAVE BEGUN WITH THE SIXTH BURNER (HIGH-EXCESS-AIR). THE HIGH-FORWARD-MOMENTUM BURNER COULD BE OPERATED WITH A STABLE FLAME USING ALL THREE OF THE SUBSTITUTE FUEL GASES, KOPPERS-TOTZEK OXYGEN (KTO), WELLMAN-GALUSHA AIR (WGA) AND WINKLER AIR (WA). KTO PERFORMED SLIGHTLY BETTER THAN NATURAL GAS IN TERMS OF THERMAL EFFICIENCY WHILE WGA AND WA DID NOT PERFORM AS WELL AS NATURAL GAS.

THE FLAT-FLAME BURNER COULD NOT BE OPERATED WITH A FLAT-FLAME USING ANY OF THE SUBSTITUTE FUELS. SUBSEQUENT EXPERIMENTS FOUND THAT MODIFYING THE AIR INLET AND DOWNRATING THE BURNER FROM 3 MILLION BTU/HR TO 2 MILLION BTU/HR COULD ACHIEVE A FLAT-FLAME WITH KTO FUEL GAS. MUCH MORE SERIOUS DOWNRATING WOULD BE NECESSARY FOR THE LOW-BTU WELLMAN-GALUSHA AIR AND WINKLER AIR FUEL GASES ON THIS PARTICULAR BURNER.

*Source: Ref. 3

ABSTRACT*

DATA WERE GATHERED TO DETERMINE THE PERFORMANCE OF A HIGH-FORWARD-MOMENTUM BURNER WHEN RETROFIT WITH THREE LOW-TO-MEDIUM-BTU GASES. THE BURNER WAS FIRED ON THE IGT PILOT-SCALE TEST FURNACE WITH A LOAD SIMULATING ONE ZONE OF A CONTINUOUS REFRACTORY KILN OR ONE INSTANT DURING THE HEAT-UP OF A BATCH KILN. THE LOW-AND MEDIUM-BTU GASES SIMULATED FOR THESE COMBUSTION TRIALS WERE KOPPERS-TOTZEK OXYGEN, WELLMAN-GALUSHA AIR, AND WINKLER AIR FUEL GASES. ALL OF THE SUBSTITUTE FUELS EXHIBITED STABLE FLAMES WHEN DIRECTLY RETROFIT ON THE BURNER. KOPPERS-TOTZEK OXYGEN GAVE A THERMAL EFFICIENCY SLIGHTLY GREATER THAN THAT FOR NATURAL GAS, BUT WELLMAN-GALUSHA AND WINKLER AIR FUEL GASES EACH HAD LOWER EFFICIENCIES. KOPPERS-TOTZEK OXYGEN AND WELLMAN-GALUSHA AIR FUEL GASES HAD FLAME LENGTHS LONGER THAN THAT FOR NATURAL GAS, WHEREAS WINKLER AIR FUEL GAS HAD A FLAME LENGTH COMPARABLE TO THE NATURAL GAS FLAME.

*Source: Ref. 4

APPROACH*

COMBUSTION DATA WAS GATHERED FOR EIGHT TYPES OF INDUSTRIAL BURNERS WITH THREE LOW-BTU GASES IN ORDER TO EVALUATE THE MAGNITUDE OF THE RETROFIT PROBLEM. THE THREE GASES ARE KOPPERS-TOTZEK OXYGEN, WELLMAN-GALUSHA AIR, AND WINKLER AIR. THE EIGHT TYPES OF BURNERS ARE FORWARD FLOW, KILN, NOZZLE MIX, HIGH FORWARD MOMENTUM, FLAT FLAME, HIGH EXCESS AIR, PREMIX TUNNEL, AND BOILER BURNER. THE FIRING LEVEL AND LOAD CONFIGURATION ON THE IGT PILOT-SCALE FURNACE WILL BE ADJUSTED TO SIMULATE A FURNACE ON WHICH EACH BURNER IS TYPICALLY FOUND. THE FOLLOWING DATA WILL THEN BE COLLECTED:

- RATE OF GAS AND AIR FLOW INTO THE BURNER
- COMBUSTION AIR PREHEAT TEMPERATURE
- VELOCITY OF FUEL AND AIR AT BURNER OUTLET
- FLUE-GAS TEMPERATURE
- VOLUME OF FLUE GASES
- FLUE-GAS SPECIES CONCENTRATIONS
- HEAT ABSORPTION PROFILE
- RESONANCE NOISE LEVEL
- FLAME LENGTH MEASUREMENTS AND PHOTOGRAPHIC DOCUMENTATION OF THE FLAME
- FLAME-WIDTH MEASUREMENTS
- FURNACE EFFICIENCY
- RADIANT HEAT FLUX FROM THE FLAME
- RADIANT HEAT FLUX ACROSS THE FURNACE
- POST FLAME EMISSIVITY
- AVERAGE FLAME TEMPERATURE AT SIX AXIAL AND TEN RADIAL POSITIONS ALONG THE FURNACE CENTER LINE
- FLOW DIRECTION PROFILE

THIS REPORT PRESENTS THE RESULTS OF COMBUSTION TRIALS USING A NORTH AMERICAN MANUFACTURING CO. TEMPEST BURNER, WHICH IS REPRESENTATIVE OF THE HIGH-FORWARD-MOMENTUM (HFM) BURNER TYPE. THE BURNER SIZE AND FIRING RATE WERE CHOSEN TO SIMULATE THE FIRING DENSITY (BTU/CF-HR) IN A REFRACTORY KILN.

*Source: Ref. 4

NOMINAL CHARACTERISTICS OF KOPPERS-TOTZEK MEDIUM BTU GAS*

Fuel	CO	H_2	CO_2	CH_4	N_2	H_2O	Heating Value, BTU/SCF	Adiabatic Flame Temp,* °F	Specific Gravity
Koppers-Totzek Oxygen	53.0	34.3	9.3	0.5	1.0	1.9	287	3570	0.68

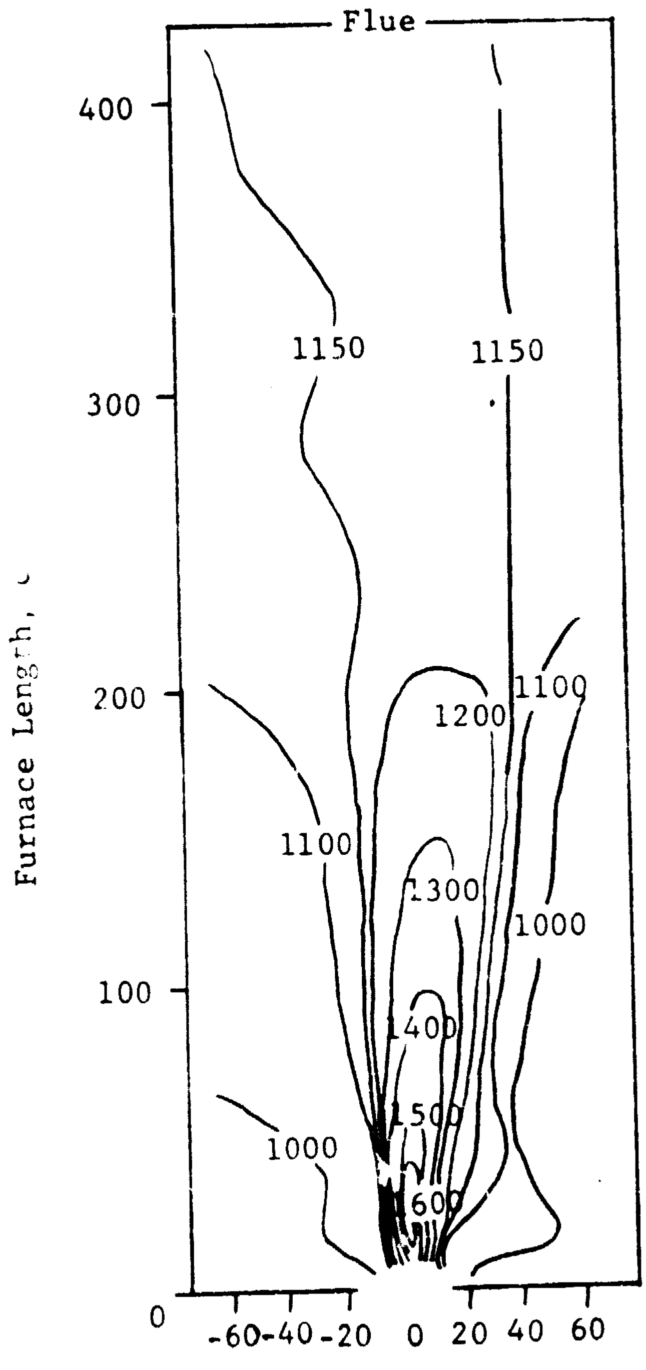
*Source: Ref. 4

FURNACE AND HIGH-FORWARD-MOMENTUM BURNER OPERATION CONDITIONS*

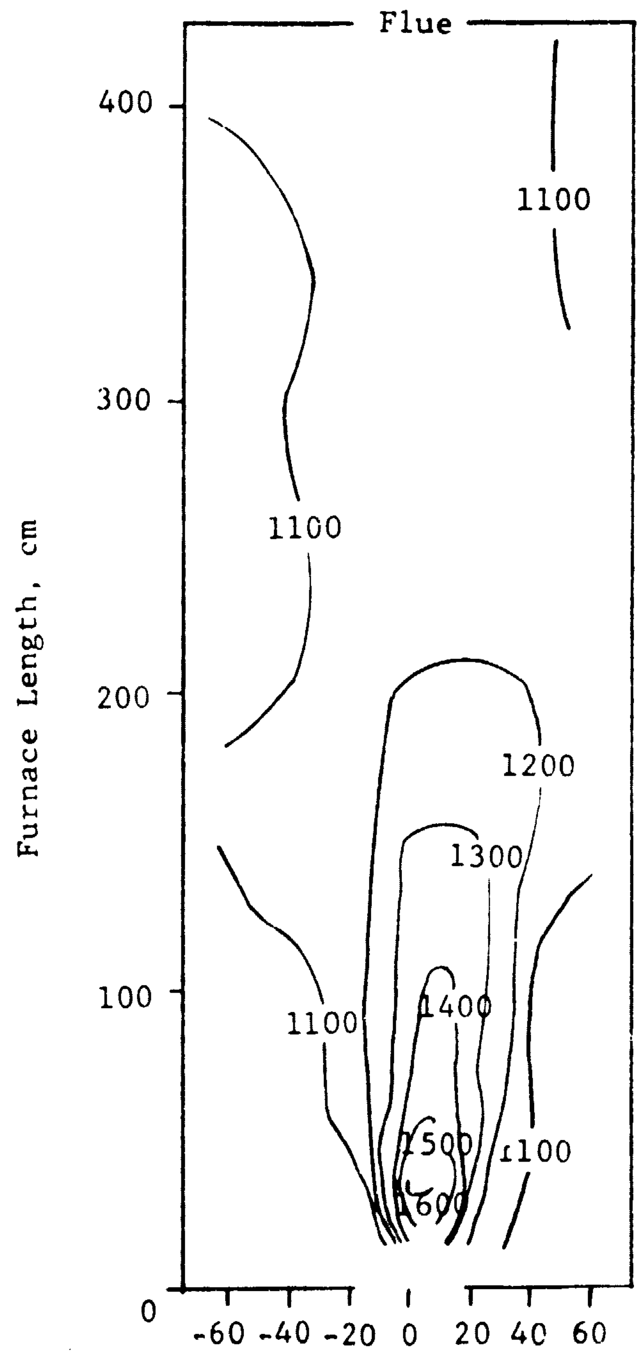
									Flue Gas Analysis				
Fuel Type	Fuel[a] Flow, SCF/HR	Air[b] Flow, SCF/HR	Fuel[c] Velocity, ft/s	Air Velocity, ft/s	Flue Gas Temperature, °F	Volume Flow Flue Gas SCF/HR	Flame Length, cm	Thermal[d] Efficiency, %	NO_x ppm	CO ppm	CO_2 %,	O_2 Dry Basis	N_2
Natural Gas	2,900	30,670	231	200	2069	33,540	66	34.0	49	20	10.8	1.9	87
Koppers-Totzek Oxygen	10,550	24,350	838	158	2139	30,330	111	35.5	25	35	23.9	1 9	74

*Source: Ref. 4

TEMPERATURE PROFILES (^{o}C) FOR NATURAL GAS ON THE HIGH-MOMENTUM BURNER

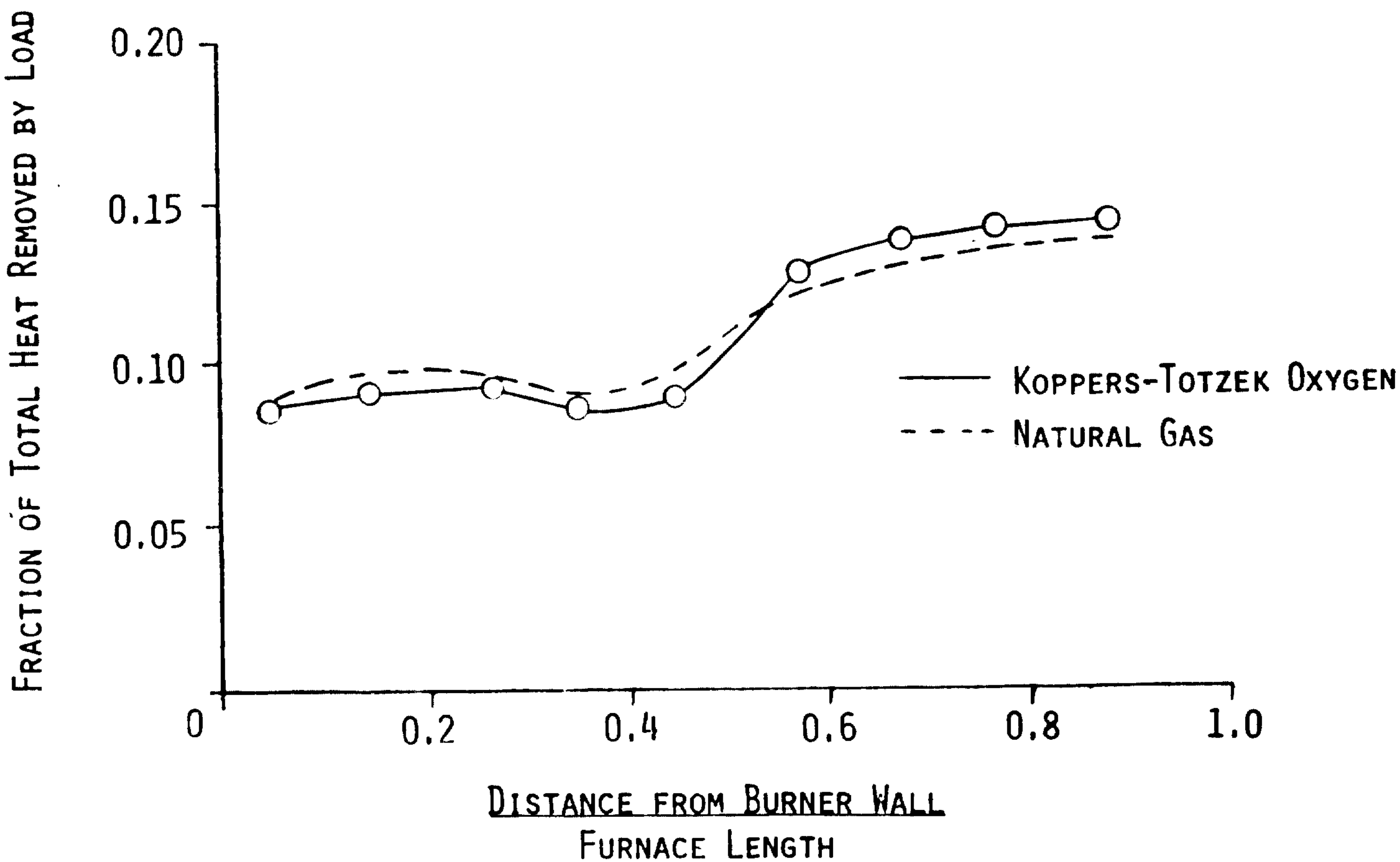


TEMPERATURE PROFILE (^{o}C) FOR KOPPERS-TOTZEK OXYGEN FUEL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER



Source: Ref. 4

HEAT-ABSORPTION PROFILES FOR KOPPERS-TOTZEK OXYGEN AND NATURAL GAS ON THE HIGH-FORWARD-MOMENTUM BURNER



Source: Ref. 4

KOPPERS-TOTZEK OXYGEN FUEL GAS RETROFIT CONCLUSIONS*

KTO WILL GIVE FEW PROBLEMS WHEN RETROFITTED TO THIS BURNER IF THE EXTENDED FLAME LENGTH (111 CM VS. 66 CM) IS ACCEPTABLE. THIS WILL PROBABLY BE THE CASE FOR MANY APPLICATIONS OF THIS BURNER. THE THERMAL EFFICIENCY, FLAME TEMPERATURES, AND HEAT ABSORPTION PROFILE ARE ALL SIMILAR TO THOSE MEASURED FOR NATURAL GAS.

*Source: Ref. 4

GAS CONSTITUENT REQUIREMENTS

- DATA SEARCH -

- A PRELIMINARY SURVEY OF INDUSTRIAL PROCESSES INDICATED THAT:
  - PLANT-SPECIFIC DATA IS ABSENT.
  - APPARENTLY SIMILAR PROCESSING ROUTES MAY USE DIFFERENT MIXES OF FUEL EVEN THOUGH THE TOTAL ENERGY CONSUMED IS THE SAME.
  - DIFFERENT COMPANIES OPERATING APPARENTLY IDENTICAL SYSTEMS FREQUENTLY CONSUME DIFFERENT AMOUNTS OF ENERGY BECAUSE OF PLANT AGE, DEGREE OF MAINTENANCE, ETC.
  - PROCESS ENERGY DIFFERENCES MAY ARISE BECAUSE OF DIFFERENT WAYS OF UTILIZING THERMAL BY-PRODUCTS SUCH AS WASTE STEAM, FLAMMABLE BY-PRODUCT GASES, ETC.

2. IMPURITIES IN MEDIUM-BTU GAS

NONHYDROCARBON IMPURITIES IN COAL GASES*

TYPE OF IMPURITY	TYPICAL CONCENTRATION, PERCENT BY VOLUME
HYDROGEN SULFIDE	0.3-3.0
CARBON DISULFIDE	0.016
CARBON OXYSULFIDE	0.009
THIOPHENE	0.010
MEREAPTANS	0.003
AMMONIA	1.1
HYDROGEN CYANIDE	0.10-0.25
PYRIDINE BASES	0.004
NITRIC OXIDE	0.0001
CARBON DIOXIDE	1.5-2.0

*Source: Ref. 5

CONCLUSIONS

THE COAL CONVERSION FACILITY UNDER DESIGN CONSIDERATION WILL PRODUCE AN AMOUNT OF ENERGY WHICH WOULD SATURATE THE NORTHERN ALABAMA REQUIREMENTS. THEREFORE, DIVERSIFICATION OR EXPORTATION OF PRODUCTS IS NECESSARY. SYNTHETIC NATURAL GAS (SNG) OR GASOLINE WOULD BE PRIME PRODUCTS SINCE THE INFRASTRUCTURE EXISTS FOR DISTRIBUTION. METHANOL COULD BE DEVELOPED INTO A FUEL OR FEEDSTOCK. ESCALATION OF CONVENTIONAL FUELS (PARTICULARLY NATURAL GAS) SHOULD PROVIDE COMPETITIVE ECONOMICS FOR SYNFUELS DURING THE 1980'S.

AN ALTERNATE TO RETROFITTING SEVERAL LARGE INDUSTRIES FOR MBG WOULD BE AN INDUSTRIAL PARK DEMONSTRATING FUEL CELLS AND CO-GENERATION. A FEW LARGE COMPANIES OR FUEL DISTRIBUTORS WILL USE THE MAJORITY (IF NOT ALL) THE SYNFUELS PRODUCTS FROM THE COAL CONVERSION FACILITY.

CONCLUSIONS

- Coal Conversion Plant Produces Amount of Energy Which Would Saturate Northern Alabama Requirements; Therefore, Exportation Is Required
- Prime Synfuels for Current Market Could Be SNG and Gasoline Because of Existing Distribution System; Methanol Could Be Developed into Prime Fuel
- Escalation of Competing Conventional Fuels Prices Should Provide Synfuel Competitive Economics in Future
- Attractive Alternate to Retrofitting Existing Industries for MBG (Small Market) Would Be New Industries in Co-Generation Industrial Park and/or Producing SNG and Methanol
- A Few Large Industries or Fuel Distributors Will Utilize Major [illegible] (If Not All) of Synfuels Under Long-Term Contracts

RECOMMENDATIONS

NASA/MSFC SHOULD CONTINUE TO DEVELOP AND EXPAND THE CAPABILITIES TO PERFORM SYSTEM ENGINEERING STUDIES TO OPTIMIZE DESIGNS OF COAL CONVERSION FACILITIES FOR PRODUCTION OF ALTERNATE FUELS. ENERGY SYSTEMS SHOULD ALSO BE ANALYZED FOR USE OF CO-GENERATION TECHNIQUES AND DEMONSTRATION OF FUEL CELLS. COMPETING FUEL PRICES SHOULD BE BETTER UNDERSTOOD SINCE COMMERCIALIZATION OF SYNFUELS WILL BE DRIVEN BY COST AND PRICE. THE SYNFUELS ECONOMIC EVALUATION MODEL (SEEM) SHOULD BE EXPANDED FOR EXTENSIVE COST AND ECONOMIC ANALYSIS. METHANOL IS CURRENTLY NOT BEING EXTENSIVELY USED IN NORTHERN ALABAMA; IT SHOULD BE INVESTIGATED FOR USE AS A FEEDSTOCK OR FUEL.

RECOMMENDATIONS

- Continue Coal Conversion System Engineering Studies for Production of SNG, Gasoline, Methanol, Electricity, and MBG
- Analyze Co-Generation and Fuel Cell Industrial Parks
- Competing Fuel Price Escalation Will Make or Break Economics of Coal Conversion Facility; Therefore, Better Understanding of Price Escalations Is Necessary
- Synfuels Economic Evaluation Model (SEEM) Should Be Enhanced and Utilized to Support Engineering and Product Market Assessment of Coal Conversion Facility
- Investigate Utilization of Methanol as Fuel and Feedstock

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