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ECONOMIC ANALYSIS:
IMPACT OF CS/R PROCESS ON BENZENE MARKET

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FOREWORD

This report describes work performed between November 1980 and March 1981. This work was authorized as a subtask of UOP/SDC Task Order No. 19, sponsored by the United States Department of Energy (DOE) under Contract No. DE-AC01-78ET10159 (formerly ET-78-C-01-3117). The DOE program manager is Mr. Louis Jablansky. The UOP/SDC Gasification Program Manager is Mr. J. Cooper. The UOP/SDC Task Manager is Dr. J. Klein.

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ABSTRACT

Contract No. DE-AC01-78ET10159 (formerly ET-78-C-01-3117) between UOP/SDC and the United States Department of Energy (DOE) requires UOP/SDC to provide specific engineering and technical services to the DOE Office of Coal Processing in support of the Coal Gasification Program. This report covers an economic study on the projected price of benzene through the next decade based on market factors and production costs. The impact of the CS/R process on the benzene market was evaluated. In addition, the cost of gas from the CS/R process was determined as a function of the byproduct credit for benzene.

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SECTION 1 - INTRODUCTION

1.1 BACKGROUND

The Cities Service/Rockwell (CS/R) hydrogasification of coal process has been under development with Government assistance since 1977. Recent testing was performed with increased emphasis on achieving both repeatability and good material closures.¹ Based on these data, a preliminary conceptual design of a commercial plant is being prepared by the Lummus Company.¹ An economic study of the CS/R process has been prepared by UOP/SDC.³¹

Data from testing with the 3/4 ton/hour Engineering Test Unit have indicated that, in addition to SNG, carbon conversion to liquids of about 11% was achievable. The liquid product has been analyzed by RI and is reported to be approximately 98% benzene. The financial credit for this byproduct could result in a significant reduction in the cost of gas (COG) produced by the process.

At the request of DOE, a projection of the price of benzene to 1990 or beyond is given in this study. Other coal processes also yield benzene as a by-product. Use of the same price projection in economic studies of each process would ensure uniform estimates for any benzene credits. As part of this study, which concerns the CS/R process directly, a sample of the benzene collected by RI in one of its tests was analyzed and evaluated to determine the costs associated with purification to a chemical grade.

The effect of benzene on the CS/R process economics was also examined.

1.2 STUDY OBJECTIVES AND CONSTRAINTS

Following are the specific objectives and constraints of this study.

1.2.1 Objectives

- a. To determine the principal supply and demand factors in the marketing of benzene.

- b. To estimate the impact of these factors on the price of benzene.
- c. To conduct economic studies to determine the price of benzene.
- d. To analyze a sample of benzene from the CS/R process and estimate the costs of a full scale plant for upgrading the benzene to a commercial grade.
- e. To make a projection of the price of benzene to the year 1990.
- f. To estimate the net cost of gas from the CS/R process using the projected price of benzene as a basis for by-product credit.

1.2.2 Constraints

- a. To rely on chemical industry publications by market analysts to forecast events that will affect future benzene market conditions.
- b. To assume that the carbon conversion to benzene as well as other experimental conditions and data reported by RI in Reference 1 are achievable in the commercial plant.
- c. To use economic data from existing studies pertaining to the CS/R process.

1.3 APPROACH

A literature search was made to define and investigate benzene market price factors. Major manufacturing processes were identified and resulting production costs estimated based on projected raw materials and feedstock prices. To establish the demand, major uses of benzene were projected to the year 1990 using chemical industry economic predictions. The capacity of production facilities was then compared with the future demand for benzene.

A sample of the liquid from RI's test program was analyzed to determine the extent of upgrading needed to yield a salable, commercial grade benzene.

Results are presented as projections of the most likely benzene price. The effect of the price of benzene on the cost of gas produced was also developed.

SECTION 2 - BENZENE SUPPLY AND DEMAND FACTORS

2.1 GENERAL

The following section contains a discussion of the various factors that may be important in determining the future price of benzene.

Benzene is an aromatic organic compound with the chemical formula C_6H_6 . It is a colorless liquid with a normal boiling point of $80.1^\circ C$ and is insoluble in water. (The complete physical and chemical properties of benzene may be found in any handbook.) It is widely used as a chemical intermediate for the production of plastics such as polystyrene, nylon, and phenolics. Benzene is usually recovered from a mixture of aromatics called BTX (Benzene-Toluene-Xylene). A list of the major U.S. benzene manufacturers is given in Appendix A.

2.2 BENZENE SUPPLY

Benzene is manufactured (or recovered) by the following processes:

a. Extraction from Petroleum Refinery Process Streams

More than 50% of crude petroleum is converted into gasoline during conventional refining operations. An initial distillate cut of light gasoline is used directly in the final gasoline pool, and the heavier distillates (light naphtha) are reformed in a catalytic process. The reformat, which is rich in aromatics and BTX, may be processed to remove benzene for sale. One of these processes, which was developed by Shell Oil and is licensed by UOP, involves a liquid-liquid extraction; it is called Sulfolane®. Other processes based on extraction distillation or selective absorption are also used to recover the benzene from reformat.

b. Hydrodealkylation of Toluene

Distillation of reformat or extraction of benzene results in a bottoms stream consisting principally of toluene (C_7H_8). Toluene can be readily

converted to benzene by the catalytic addition of hydrogen. Benzene and methane are produced.

c. Coking of Coal

Many metallurgical processes require firing with coke, which is a relatively pure form of carbon. This coke is produced by heating the coal in an oven in the absence of air. The volatiles that are driven off are condensed, yielding liquids and coal tar. The liquids are then fractionated, yielding benzene. Approximately 15 pounds of benzene can be recovered per ton of coal processed.

d. Pyrolysis of Heavy Feedstocks

In the past, most ethylene has been obtained from the pyrolysis of natural gas liquids (NGL) and light naphtha. These feedstocks have become more costly because of decreasing availability. Consequently, manufacturers are using heavier feedstocks. One byproduct of pyrolysis of the heavier feedstocks is pyrolysis gasoline containing aromatics from which benzene can be recovered by extraction and distillation.

e. Byproduct from Synfuel Production

Many new processes for making gas and liquids from coal also produce a liquid stream with a substantial benzene content. At present, such processes are not commercial sources of benzene, but, if they achieve commercial use, significant amounts of benzene may eventually become available from them.

Figure 2.1 shows the trends in future manufacturing sources of benzene derived from industry predictions. Table 2.1 is taken from this figure to illustrate future benzene production trends. The actual demand for benzene is expected to increase by approximately 66% over the next decade. Thus, even though a manufacturing source may show a decreasing percentage of the total market, new production facilities might still be required to meet the overall demand.

Figure 2.1 Benzene Manufacturing Processes (US)

Table 2.1: Benzene Production Sources			
Benzene Production Sources:	% of Total Manufacture		
	1980	1985	1990
Reformate	45	38	33
Hydrodealkylation	27	25	22
Pyrolysis	23	30	32
Coal (All Processes)	5	7	13

The percentage of benzene from reformate will decline as the amount of petroleum processed remains approximately constant while the demand for benzene continues to increase. Production of benzene from shale oil is assumed to parallel that from petroleum as shale oil itself replaces petroleum imports. It should also be noted that shale oil may have more recoverable aromatics than petroleum does.

Historically, about 30% of total installed benzene capacity has been from hydrodealkylation facilities. These facilities are brought into operation only when the economics are favorable, i.e., toluene cost is \$0.25 to .50 per gallon less than benzene. These facilities are expected to provide even less benzene as production of the lower-priced benzene from pyrolysis increases.

Benzene from pyrolysis should grow fairly rapidly through the decade as the demand for ethylene increases. The ethylene feedstock will use increasingly heavier petroleum fractions, resulting in more byproduct gasoline and aromatics. Historically, about 50% of the benzene available in pyrolysis gasoline has been recovered for sale.⁵

Commercial synfuel facilities co-producing benzene from coal may be a significant market factor in 1990s.

As presently conceived, few synthetic fuel processes result in marketable benzene. SRC-I was discussed in Reference 2, in which a possible recovery of 2.3% by weight of coal feed as benzene is claimed. The coking process results

in recovery of about 0.73% of coal feed as benzene. Exxon predicts synfuel coal use at 160 MMt/yr in 1990,³⁴ and the Institute of Gas Technology (IGT) predicts about 120 MMt/yr in 1992.³ Applying the lower, reasonable factor of 0.73% coal conversion to benzene and using the IGT prediction for 1990 instead of 1992, approximately 240 MMgal/yr of benzene may be expected to be produced from this source. This is about 10% of the total demand predicted for 1990. Reference 15 predicted "300 MMgal/yr of benzene (nearly 10%...)," which is in approximate agreement. Reference 5 (and present observation of the synfuel plans) indicates no significant amounts of benzene can be expected from synfuel programs before 1985. Reference 13 predicts 100 MMgal/yr from coal synfuels in 1985, which is also consistent (although on the high side) with the projected demand in 1990.

The CS/R process at a commercial level producing 250 billion Btu of SNG is projected to yield recoverable benzene at about 5% of the coal feed. This would correspond to about 3% of the total benzene demand in 1990 and is believed consistent with the assumed amounts available from coal synfuel programs. It should be noted that construction of a large number of CS/R plants would result in a surplus of benzene, which in turn would tend to depress the value of this byproduct.

The production capacity for benzene in the United States has always been adequate, with demand running about 70% of nameplate capacity. Figure 2.2 shows some industry predictions and the continuation expected in the future. Towards the end of the decade, some hydrodealkylation capacity may be retired as its use becomes more infrequent and pyrolysis benzene production increases. "No shortage of benzene production capacity is anticipated since adequate extraction capacity either exists or is firmly planned to handle these (benzene) demands at least through the mid-1980's."⁷ Reference 15 similarly states "... unlikely...supply limitations... to 1990." None of the references reviewed in this study made mention of any possible shortage of capacity in the foreseeable future.

NOTE: NUMBERS ON CURVE REFER TO REFERENCES IN TEXT.

Figure 2.2 Benzene Supply and Demand

2.3 BENZENE DEMAND

Literature references predicting benzene demand were carefully compared. About 90% of the benzene consumed as a chemical intermediate can be assigned to four chemical derivative uses: styrene, cumene, cyclohexane, and aniline. At this time, there are no new processes for these uses that would materially alter the demand for benzene.⁷ Projected uses are shown in Figure 2.3. Predictions of overall benzene demand growth rates were shown in Figure 2.2. An average percentage growth rate of 4.2% for the decade was selected based on a demand of 2.9 billion gal/yr in 1990. (Private communications with DART Associates have indicated current lower growth demand estimates of 3.6% yr.) The 4.2% growth rate is plotted on Figure 2.2. New facilities projections utilizing benzene to 1988 are shown in Reference 20.

The previous discussion related to demand and production capacity for benzene as a chemical intermediate. At present, benzene is produced almost entirely from BTX feedstock by extraction and hydrodealkylation. However, BTX is also a valuable component in the gasoline pool as an octane booster, and thus there is a competing market for this benzene feedstock. In 1979, 90% of all aromatics was used in gasoline; the other 10% went to the petrochemical industry.⁷

The effect of this competition is reflected in the recent price history of benzene. Figure 2.4 shows a depressed market price from 1964 to 1973. The benzene price then tended to stabilize at 75-80¢ per gallon until 1979, when the price doubled, reaching \$1.65 per gallon by the end of 1980. At the same time, the demand for benzene for chemical uses was relatively slack.⁶

The above rise in price was caused principally by the increased use of BTX in the gasoline pool to boost octane. As the use of tetraethyl lead was phased out (because of EPA requirements), refineries were left with only BTX to obtain the (clear) high octane required for today's automobiles. This phenomenon has been discussed at length by industry economists (References 7, 11, 16, 28, 29, 30) and is reviewed here briefly as it pertains to the price prediction for benzene.

Figure 2.3 Benzene Demand (By Derivative)

Figure 2.4 Benzene Market Price

Gasoline consumption is predicted to follow the curve in Figure 2.5, which shows generally decreasing use through 1990. This is due to legislated mileage increases in future automobile production as well as to conservation. During this time period, however, consumption of unleaded gasoline will increase. (It should be noted that other economists have predicted a far lower percentage of leaded gasoline in 1985²⁹ and 1990.²⁵) Clear pool octane demand is shown increasing in Figure 2.6 as automobile engines require higher octane gasoline to increase mileage performance. Refineries are presently revamping their facilities to provide high octane clear gasoline while reducing the amount of low-value oil products. Use of new gasoline additives to boost clear octane rating will increase, since they are cheap enough to replace some of the BTX.²¹ One of these is Methyl-t-Butyl Ether (MTBE), which has been approved for use in gasoline in concentrations up to 7%;⁷ however, concentrations of only 3-4% are expected because of limitations in availability of the butylene feedstock required to produce this compound. A clearer picture of future total requirements for octane-improved gasoline is shown by expressing demand in terms of octane barrels, arrived at by multiplying the total demand curve of Figure 2.5 by the octane demand curve of Figure 2.6. The heavy curve in Figure 2.7 shows this octane barrel demand. The lighter curve in Figure 2.7, which shows U.S. octane barrel capacity, is taken from Reference 25. The surplus of octane barrel capacity shown after 1982 does not take into consideration octane booster additives, which would further add to the surplus. The same trend of surplus octane capacity in 1982 is shown in Reference 25.

The results of studying the future need for BTX (benzene feedstock) in gasoline leads one to predict a slowing of such use through the decade and a significant surplus by 1990.

2.4 IMPORTS AND EXPORTS OF BENZENE

The import/export market in benzene constituted 3 to 6% of the total benzene demand in the U.S. from 1973-1977.³⁵ This trend is expected to continue to 1985, when about 5% is predicted.^{17,32,35} Reference 15 predicts 1985 and 1990 imports at 5% and 9% percent respectively of total U.S. demand. The

GASOLINE PREDICTIONS

Figure 2.5 Motor Gasoline Demand

Figure 2.6 Gasoline Octane Demand

Figure 2.7 Octane Barrel Supply/Demand

predicted increase in imports is not explained. European overcapacity has been projected for the 80s in Reference 18. An in-depth discussion of the European benzene market is found in Reference 19. The Middle East venture into the chemical benzene and derivative market will provide only 100 MMgal/yr, which is not considered enough to significantly disturb world markets.

For this study, imports of benzene were assumed not to be an important factor in the future price of benzene.

2.5 ENVIRONMENTAL AND HEALTH ASPECTS

Benzene has been known to cause cancer in both animals and humans²² and thus has been regulated at not more than 10 ppm in the working environment. Recently, OSHA attempted to enforce a 1 ppm limit with prohibited skin contact, but the court disallowed this lower limit on the basis that improved safety had not been proved.⁸ Other studies by the EPA and the Rubber Manufacturing Association relating to amounts absorbed through the skin have proved to be inconclusive in defining benzene health hazards. At this time, no additional regulations are under consideration; however, if additional safety motivated regulations (such as a limitation of 1 ppm in work atmospheres) were imposed, it would require large expenditures on the part of benzene producers and processors.⁹ Since benzene is a basic chemical with no known less toxic replacement, it is likely that such action would result in higher prices being charged.¹¹ Such additional manufacturing costs would be common to the industry and were not considered in this economic study.

2.6 BENZENE MARKETING

The marketing aspects of benzene were briefly investigated. For this study it was assumed that the gas producing facility would provide the required benzene upgrading processes, since existing processors would not be geared to handle this relatively new material. The location of the facility may increase the delivered cost of the benzene product. If the facility were located near a western coal mine, for example, substantial transportation charges would be

incurred in shipping benzene to such points of use as the East or the Gulf region of Texas. The cost for transport from Cheyenne, Wyoming to Houston, Texas in tank cars is about 20¢/gallon (Santa Fe Railroad estimates - private communication). Costs associated with marketing have not been charged in this study but could amount to 20 cents per gallon. It is assumed that some (or all) of this cost would have to be absorbed by the seller to make the benzene competitive. Marketing of benzene is discussed in detail in References 10 and 23.

SECTION 3 - BENZENE SAMPLE ANALYSIS

A sample of the liquid product collected by RI during Test No. 318-067 was sent to UOP Research Laboratories for both analysis and estimate of necessary purification processes.

Details of the exact method of collection and analysis used by RI are given in Appendix B. The sample was obtained by adsorption on a carbon bed and recovered by steam stripping (82% by weight recovery). RI's analysis showed that it contained 98.8% benzene, 1.1% toluene, 0.08% thiophene, and small quantities of other hydrocarbons. The UOP laboratory essentially confirmed this analysis. The UOP /Research Laboratories' report is reproduced in Appendix C.

Both Rockwell's and UOP's laboratory analyses show unacceptably high concentrations of thiophene in the sample. UOP's analysis also indicated trace quantities of olefin. Both UOP and Rockwell conducted their analyses on samples that had been subjected to extensive laboratory scale processing in the course of their collection as discrete samples. That processing included passing the raw product gas through a cold trap held at an unspecified temperature. No analysis of cold trap liquids was presented and no sample of cold trap liquids was submitted for analysis. Processing analogous to that conducted in the laboratory in the course of collecting a sample is unlikely to be used in a commercial scale plant. No sample was submitted that represented a specific stream that might be available for processing to recover commercial grade benzene in the full scale plant. The processing scheme needed for recovery and purification of the benzene byproduct would depend very much upon the techniques used for isolation of the byproduct stream in the commercial plant.

Costs for benzene recovery and purification are greatly affected by the concentration and nature of contaminants. Contaminants indicated, specifically thiophene, are not normally present in schemes now used for commercial production of benzene. Background data needed to specify the purification scheme in this particular case are not readily available. Fractionation is one possibility, but a benzene-thiophene system may demonstrate significant departures

from ideality. Estimating benzene losses in a fractionation scheme is difficult at this point. Benzene losses could be minor, or they could be intolerable, accompanied by a high energy consumption. Hydrotreating would be a reasonable alternative, but this scheme would also result in significant benzene losses. Further study would be required to determine the loss in yield using either scheme.

Conventional processing schemes for benzene recovery and purification may not work for the raw material expected to be available in a commercial scale Rockwell hydrogasification plant. Contaminants and their concentrations normally dealt with in conventional benzene recovery and purification schemes may be radically different from those one would expect to encounter in a coal gasification plant based on the CS/R process.

The benzene from the CS/R process could be sold as a gasoline additive. Purification may be expensive and involve some product loss. Capital costs associated with the purification process are believed to be a relatively small portion of the total outlay (less than 2%) and would not greatly affect the price of the byproduct benzene. More specific data on the potential contaminants (cyclopentane, cyclohexane, phenol, naphthalene, methylnaphthalene, propylbenzene, thiophene, and sulfur-containing compounds) in the gas and liquid streams must be made available to develop a realistic system for upgrading the benzene and for further economic analysis.

SECTION 4 - RAW MATERIALS FOR BENZENE MANUFACTURE

As noted in Section 2.4, the processes for manufacture (or recovery) of benzene include the following: Sulfolane® extraction of reformate, hydrodealkylation of toluene, extraction from ethylene production pyrolysis processes, and coking or recovery from various synfuels processes using coal.

The first three processes, which use raw material from petroleum sources, now produce 95% of the U.S. benzene supply. This percentage is expected to drop to 85% percent in 1990. The rest of the production of benzene in 1990 will come from processes using coal as a feedstock.

Any projection of petroleum prices is admittedly speculative and assumes no prolonged crisis or interruption in imported supplies. The latest DOE forecasts²⁷ already seem out-of-date. For instance, a low-end price for 1990 is \$27/bbl in 1979 dollars. The predicted top end price of \$44/bbl in 1979 dollars has been extended to \$50/bbl (1980 dollars) and used in this study for the 1990 price. A discussion of world oil prices is beyond the scope of this study; however, it is noted that the ability of importing countries to pay and the price-deflating influence of synfuels development are expected to keep oil prices within reason. (Capricious pricing would have effects far beyond raising benzene prices, since it would adversely affect gross national product and, hence, benzene demand as well.)

The domestic and world market price of coal is projected to rise as the value of petroleum increases. At any given time, the price of coal to the user depends principally upon its rank, its characteristics (heating value, sulfur content, ash characteristics), and the transportation costs to point of use. For this study, the cost of coal in 1980 dollars was assumed to be \$30/ton in 1980 and to escalate to \$50/ton in 1990. This escalation does not seem excessive in view of the increased demand for coal and the environmental and safety issues being considered today. An estimate of the price of coal in 1990 is needed for cost-of-gas calculations; however, in these, the cost of coal is presented parametrically.

The price of BTX, the major feedstock for benzene production, depends on the value of benzene and toluene in gasoline, as explained in Section 2.3. This value derives from their ability to boost the clear octane rating of gasoline. The dollar value of octane is obtained from the wholesale price of clear gasoline as a function of octane rating. The value of benzene and toluene as blend agents can then be derived from the price of gasoline as shown in Table 4.1.

The price of gasoline (and benzene feedstock) is assumed in this study to escalate with the price of oil. This correlation was close from 1950 to 1970, after which gasoline prices rose more rapidly than the price of oil. The average price of oil in recent years was affected by government regulations, but the price of gasoline is again expected to be proportional to that of oil now that the price of oil has been decontrolled.

Table 4.1
Cost of Feedstock for Benzene Production
(Based on Value in Gasoline)

	OCTANE RATING ⁽¹⁾	WHOLESALE COST ⁽¹⁾ \$/GALLON	VALUE IN GASOLINE \$/GALLON	COST AS HDA FEEDSTOCK \$/gallon
BENZENE	97		1.13	
TOLUENE	104		1.21	1.44 ⁽²⁾
REGULAR GASOLINE	86 (CLEAR)	1.00		
PREMIUM GASOLINE	92 (CLEAR)	1.07		

(1) JANUARY 1981, OIL DAILY

(2) 1.19 GALLONS TOLUENE YIELDS 1 GALLON OF BENZENE

SECTION 5 - ECONOMIC ANALYSIS CALCULATIONS

5.1 GENERAL

The assumption made in calculating the benzene price is that the cost of production sets a price floor over the long term. The production cost is defined to include all of costs that can be specifically assigned to the production of benzene, including raw material costs, labor and other operating costs, taxes, insurance, and cost of capital. Costs of transportation, marketing, and distribution of the product are omitted. The production cost may thus be considered to represent the value of the product at the exit of the production facility.

In engineering practice, the production cost is frequently referred to as the product price, meaning the hypothetical price sufficient for the recovery of all of the costs of production, including capital recovery and return on investment. This terminology is used here. When using the results, it is desirable to recognize the distinction between the production cost and the actual selling price of a product. In the economy, selling prices are determined by a combination of production costs, marketplace forces, and government regulations. Such selling prices may bear little relationship to calculated production costs.

The effect of benzene quantity and value on the cost of gas (COG) of the CS/R process was calculated using the computer program PRP, which was originally written at the Oak Ridge National Laboratory for the economic evaluation of processes for the production of synthetic fuels.

5.2 Calculation of Benzene Production Price

The benzene production price (cost) was calculated as the sum of the costs of chemicals, utilities, labor, maintenance, and insurance and taxes (all based on current experience) plus capital cost plus feedstock costs. Capital costs were estimated using the method developed by C. F. Braun Company³⁹ for DOE for uniform gas costing of coal processes:

$$\text{Avg cost of capital} = \frac{0.05 (C-W) + .005 (p + 48/52(1-d)r) (C - .025(C-W))}{G}$$

where

- C = total capital
- W = working capital
- p = $d i + (1-d)r$ (return on rate base)
- G = cost basis, gallons/yr - 80% operating time
- i = interest on debt, 9%/yr
- d = debt fraction, 0.4
- r = return on equity, 15%/yr

5.3 COST OF GAS CALCULATIONS

5.3.1 General

The COG was calculated by two methods, Discounted Cash Flow Method (DCFM) and Utility Financing Method (UFM), for comparison with Reference 31.

In the DCFM, for a fixed rate of return on investment (ROI), the sum of the present worths of the cash flows for each year of the project life is set to zero. The cash flows in the investment years less the cash flow during the operations years will equal zero only for one specific cost of gas, which is the average cost of gas over the plant life. The plant financing is made up entirely of equity at 12% ROI.

The UFM also presents average lifetime energy cost. In this method,

$$\text{COG} = (N + .12C + .02W)/G$$

where COG = cost of gas (\$/MMBtu)

N = net operating cost (\$MM/yr)

C = total capital (\$MM)

W = working capital and land (\$MM)

G = annual product gas rate (Trillion Btu/yr)

COGs calculated by these methods are widely different. For instance, for the base case in 1990 with low benzene production, the COG is \$6.70 per MMBtu by the DCFM and \$4.75 per MMBtu by the UFM. Both methods ignore the importance of inflation in evaluating the financial worth of a project.

The treatment of income taxes and tax credits and cash flow in the first years of a project is important to its commercial success. When these factors are explicitly considered, the COG may differ significantly from that calculated by the above methods. A method of rectifying these deficiencies is to provide an annual DCFM solution that shows the effects of inflation, income tax credits, and variable amounts of debt financing in order to calculate ROI or product price. Reference 37 discusses the importance of considering inflation in such calculations. Results of such calculations have been included for comparison.

5.3.2 Description of Computer Program

The computer program PRP was written at Oak Ridge National Laboratory for the economic evaluation of processes for the production of synthetic fuels. PRP calculates the production cost of the main product of a process plant when the capital investments, operating expenses, interest rates, byproduct prices, and other related information are supplied by the user. PRP can be used in a parametric mode in which the cost of the feedstock (e.g., coal) and the rate of return on equity are varied automatically over any desired range of values. The program is especially useful in the evaluation of synthetic fuel projects because of the marked influence of feedstock price and unusual types of financing on the cost of the product.

The PRP program affords flexibility in the handling of investments, capital structures, operating expenses, and taxes. Provision is made for Federal income taxes, state income taxes, state revenue taxes, and local property taxes. The calculation of Federal income taxes provides for investment tax credit, tax-loss carry-forward calculations, several methods of calculating depreciation allowances, and various other options. Investment, expenses, and onstream efficiency (plant operating factor) can be provided year by year for the entire life

of the project. Several options are provided for the calculation of interest during construction. The program is general in application and its use is not restricted to any particular industry.

An optional feature of the program is the ability to calculate the after-tax rate of return on equity when the product is sold at a specified price. This feature is useful in industries in which the product is sold within an existing price structure. In this case, the usual object of evaluation is to determine whether the project will provide an adequate rate of return on investment.

A typical computer printout is shown in Appendix D.

SECTION 6 - PROJECTED PRICE OF BENZENE TO 1990

Factors that may affect benzene prices, already discussed, are briefly summarized here. The demand will continue to be approximately 70% of industry production capacity. Demand for BTX (benzene feedstock) in gasoline will decline through the decade because of the following: (1) total gasoline demand will decrease; (2) refineries are increasing production of high octane clear gasoline; and (3) new facilities producing gasoline additives for enhancing octane of clear gasoline will be onstream. The advent of synfuel benzene, increased benzene from pyrolysis, and relatively flat petroleum processing will tend to increase benzene supplies over demand, for which reason benzene production by the more expensive hydrodealkylation method can be expected to decrease. Environmental factors, if proving benzene toxicity, will result in price increases reflecting the safety precautions and are not significant for this study. A qualitative summary of these factors is shown in Table 6.1.

The price history of benzene was shown in Figure 2.4 (page 2-9). From 1950 to 1973 the price was essentially constant. The price rose to about 75 cents per gallon and stayed at this level from 1974 to 1979. This rise was caused by an oil shortage and price hikes. In 1979, a major factor in the doubled price was the competition for use of BTX (benzene feedstock) in gasoline. This condition is expected to be alleviated by 1982, and thereafter there should be a surplus of BTX.

Also shown plotted in Figure 2.4 are two industry estimates of future benzene price. Reference 33 is based on inflation of about 9%/yr. It is not known if Reference 36 used an inflation factor.

This study bases the benzene price prediction on the production cost. Inflation has been ruled out for consideration in this study because it is a constant all-pervasive factor. An attempt was made to correlate benzene price with Gross National Product without success.

Table 6.1: Qualitative Effects of Some Benzene Price Determinants

<u>Item</u>	<u>Effect on Price through Decade</u>	<u>Remarks</u>
Manuf. Process	Decrease	Byproduct benzene from pyrolysis to increase
Demand	None	Nominal increase of 4.2%; no direct effect
Production Capacity	None	Present relation to demand assumed
Gasoline Competition	Decrease	Gasoline consumption decreasing; BTX replaced or increased reforming severity for high octane
Imports/exports	None	Minor in quantity
Environmental	Increase	Costs will cover safety measures
Raw Materials	Increase	Both oil and coal will increase in real cost

Benzene is now produced almost entirely by two processes: Sulfolane® recovery from BTX, and hydrodealkylation of toluene. The Sulfolane® BTX extraction process and hydrodealkylation were selected for costing. The Sulfolane® process with variations may be applied to either petroleum reformat or to pyrolysis byproducts. Reference 33 shows a slightly higher production cost for benzene from pyrolysis (6% higher) but Reference 17 indicates the same production price for both feedstocks. Processes other than the Sulfolane® may be more economical, depending on the composition of the BTX stream. For example, the Litol® process licensed by Air Products and Chemicals, Inc. may be more suitable for the recovery of benzene, especially from coal processes. Reference 40 reports operating costs of the Litol® process of 15 cents per gallon of benzene, which is about the same as for the Sulfolane® process. However, the capital and operating costs of the process are overshadowed by feed costs and constitute only 10% of the benzene price.

The 1980 production costs of benzene by the Sulfolane® and hydrodealkylation processes were derived from actual production figures. Capital costs were obtained by application of Equation (1), Section 5.2. Feedstock costs are shown in Figure 6.1. Benzene production prices for 1980 are shown in Table 6.2.

Benzene price projections to 1990 are shown in Figure 6.2. Production prices in 1980 were projected at a 5.2%/yr escalation rate over the decade in real oil price (and benzene-feedstock price). The 1980 price of benzene feedstock was used as a base for the escalation. (Although that price is believed to be artificially high and subject to a drop after 1982, when gasoline demands will be satisfied, the present data do not justify reducing it. If it were reduced, the projected price of benzene would of course be lower.) The assumption is made that the necessary new construction of production facilities can be accomplished with no real escalation of costs (escalation only at general rate of inflation). The initial price bulge to 1982, leveling off to the higher priced limit, represents the increasing competition for feedstock with gasoline, which should disappear by 1984 if not earlier. The predicted decrease in benzene production by hydrodealkylation and increase by pyrolysis near 1990 tends to put its market price closer to the lower limit; but history and inherent uncertainties in prediction make the hydrodealkylation production price more probable.

1980 DOLLARS
NO INFLATION

• BASED ON VALUE IN GASOLINE
AS OCTANE IMPROVER

Figure 6.1 Feedstock Costs

Table 6.2: Benzene Production Cost--1980

	Sulfolane®	Hydrodealkylation
Benzene production, bbls/day	3,000	2,500
Feed	Raffinate	Toluene
Capital cost	\$10.77 MM	\$14.43 MM
<u>Cost per Gallon (\$/gallon)</u>		
Chemicals	.0008	(.0140)
Catalyst	-	.0020
Hydrogen	-	.0510
Vent gas	-	(.0670)
Utilities	.0696	.0130
Electric (\$10/MMBtu)	.0025	.0100
Fuel (\$5/MMBtu)	.0322	.0105
Steam (\$6/Mlb)	.0343	(.0411)
Cooling Water (\$.10/1,000 gal)	.0006	.0336
Labor	.0076	.0143
Maint. (3-1/2% investment)	.0136	.0220
Ins. and taxes (2% total)	.0078	.0126
*Capital costs	.0450	.0711
<hr/>		
Total	.144	.119
Feedstock	1.130	1.440
Production Cost	1.274	1.559

*Including depreciation, ROI, taxes, interest.

1980 DOLLARS
NO INFLATION

Figure 6.2 Projected Price of Benzene

Thus the price in 1990 is predicted to be between \$2.02 to \$2.51 per gallon, with a probable price of \$2.51 per gallon (in 1980 dollars).

Any price projection is necessarily limited by the exclusion of unforeseen events. Such events might include inordinate rise in oil prices, loss of facilities from natural calamities (e.g., hurricane in the Gulf area), new technological processes, gasoline requirements for large quantities of BTX, and radical changes in GNP or currency.

SECTION 7 - COST OF GAS

The effect of benzene price (byproduct credit) on COG was investigated using the PRP computer program with inputs per Reference 31 and as shown in Table 7.1.

Figures 7.1 and 7.2 show the COG vs. the benzene price credit for UFM and DCFM financing and for both base case yield (5.8% carbon conversion to benzene) and high yield (11%.4) cases.

The effect on COG of applying the predicted benzene price credit is tabulated in Table 7.2. This table was made by entering Figures 7.1 and 7.2 with benzene price projections from Figure 6.3 and proceeding as shown on Figure 7.1. Gas is more costly for DCFM financing because of the high equity position (100% equity). For the UFM base case, the purified benzene reduces the COG by about 6% more than the gasoline value in 1990. A similar trend can be seen for the DCFM base case COG.

In the high yield case, the COG is more sensitive to benzene price, as can be seen from the relative slopes of Figures 7.1 and 7.2. The high yield case shows a change of \$1/MMBtu in COG for an 80 cent change in cost of one gallon of benzene, whereas, for the base case, the benzene price must change by about \$1.80 for a \$1/MMBtu change in COG. Using UFM calculations, the price differential between purified benzene and benzene gasoline value is about 12% in 1990.

Several computer runs were made to illustrate the effects of inflation and tax credits on COG, which are not readily apparent. A typical case is shown in Fig. 7.3. The rate of inflation has a large effect on COG. Tax credits have little effect for first estimates.

Table 7.1 - Input Assumptions (PRP)
(page 1 of 2)

I. Common Economic Data Inputs

Federal Income Tax Rate	.48
Federal Investment Tax Credit	.10
State Income Tax Rate	.03
Local Property Tax	.02
Property Insurance Rate	.01
Income Tax Credit	10%
Inflation Rate	9%

	<u>UFM</u>	<u>DCFM</u>
Debt Fraction of Capital	.75	0%
Equity Fraction of Capital	.25	100%
Annual Interest on Debt	.09	.09
Project Life (years)	20	25
Rate of Return on Equity	.15	.12
Depreciation Life (years)	16	20
Depreciation Method	SYD ¹	SL ²
Project Life (years)	20	25

1. Sum of years digits
2. Straight line

Table 7.1 - Input Assumptions (PRP)
(page 2 of 2)

Process Costs	Capital Cost \$ Millions 1981	O&M Cost \$ Millions 1981	Feedstock Cost \$ Millions 1981	Working Capital \$ Millions 1981
*High Yield CS/R	1745.9	114.9	161.8	55.8
*Base Case CS/R	1520.1	86	144	39
<u>Process Materials</u>				
	<u>Feedstock</u>	<u>SNG</u>	<u>Outputs</u>	
<u>CS/R Process</u>	Coal T/D	Billion Btu/D	Benzene B/D	Sulfur LT/D
				Ammonia ST/D
High Yield Case	19780	250	6800	637
Base Case	17643	250	3035	568
Value	\$25/Ton	Variable	\$.9 to \$4/gal	\$40/LT
				\$120/Ton

*High yield and base cases refer to carbon conversions to Benzene from the CS/R process of 11.4% and 5.8% respectively.

NO INFLATION, NO TAX CREDIT
1979 DOLLARS

(ECONOMIC PARAMETERS FROM REF. 31)

Figure 7.1 Cost of Gas vs. Benzene Byproduct Credit
CS/R Process—Base Case (5.8 % Carbon Conversion to Benzene)

**NO INFLATION, NO TAX CREDIT
1979 DOLLARS *
(ECONOMIC PARAMETERS FROM REF. 31)**

Figure 7.2 Cost of Gas vs. Benzene Byproduct Credit
CS/R Process—High Yield Case (11.4% Carbon Conversion to Benzene)

* BENZENE PRICES IN 1980 DOLLARS
(GIVES RESULTS OF SLIGHTLY LOWER COG)

Table 7.2 - Cost of Gas from CS/R Process with Benzene Credits

Benzene Credit		Base Case*		High Yield Case*	
		In Gasoline	Purified	In Gasoline	Purified
	Cost of Coal \$/Ton				
Financing					
UFM - 1980	\$30	\$4.75	\$4.35	\$5.70	\$4.85
- 1985	40	-	4.90	-	5.05
- 1990	50	5.85	5.50	6.20	5.45
DCFM - 1980	30	6.70	6.35	6.40	5.70
- 1985	40	-	6.80	-	5.80
- 1990	50	7.80	7.40	7.00	6.20

*Refers to carbon conversion to benzene of 5.8%.

**Refers to carbon conversions to benzene of 11.4%

Figure 7.3 Cost of Gas vs. Benzene Byproduct Credit
CS/R Process—Base Case (5.8% Carbon Conversion to Benzene)

SECTION 8 - MISCELLANEOUS COMMENTS

8.1 BENZENE FROM COAL

Benzene is a necessary chemical intermediate in the production of such items as plywood (phenolic adhesives), plastics (styrene), and insecticides. These items are basic to the economy and the U.S. standard of living. Approximately 95% of benzene is derived from petroleum, and the projected demand for 1990 is of the order of three billion gallons. Coal processes that produce benzene have a decided place in the economy in assuring the supply while helping to limit oil imports.

8.2 SAMPLE EVALUATION

The evaluation of the sample of benzene collected by RI in a test was inconclusive in establishing the methods or even desirability of upgrading to commercial standards. At this time, the assured benzene credit is its value as a gasoline octane booster.

8.3 MARKETING OF BENZENE FROM CS/R PROCESS

The potential owners of a commercial coal gasification plant include heavy industry and the gas utilities. An industry, such as a refinery, may be able to consume the gas and market the benzene. Few other industries would be large enough to build and utilize the volume of output.

A gas utility, on the other hand, is in the business of sharing a source of gas among numerous users by managing an extensive distribution system. Gas utilities are controlled by state public utilities commissions, which operate as a regulator of a regional monopoly. They try to balance the risks, costs, and rewards of gas operations between rate payers and stockholders. A regulatory commission would set the price of the gas in consideration of the overall return on investment that it permits the utility to earn. Therefore in the case of a

utility-owned gasification plant in which one byproduct is benzene, any significant profits from benzene operations would be offset by a reduction in profits from the gas. As presently chartered, utilities would not have a pure market incentive to maximize the return from benzene operations unless they could divorce that process from utility operations. It has been suggested that a utility might use byproduct credit by trading for coal.

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APPENDIX A

BENZENE PRODUCTION IN THE UNITED STATES

Appendix A
Benzene Production Capacity in the United States

MILLIONS OF GALLONS PER YEAR

AMERADA HESS	75
AMOCO	85
AMERICAN PETROFINA	71
ARCO CHEMICAL	126
ASHLAND	77
COASTAL STATES	71
CORCO	180
DOW	60
EXXON	134
GULF	190
MOBIL	65
MONSANTO	85
PHILLIPS	147
QUINTANA-HOWELL	84
SHELL	202
SUN CO.	168
TEXACO	80
UNION CARBIDE	70
UNION OIL	42
USS CHEMICALS	55
OTHER	134
TOTAL	2,201

SOURCE: REF 11, DEWITT & CO.

APPENDIX B

DESCRIPTION OF ROCKWELL INTERNATIONAL COAL LIQUIDS SAMPLE

Energy Systems Group
8900 De Soto Avenue
Canoga Park, California 91304

Telephone: (213) 341-1000
TWX: 910-494-1237
ESG CN PK
Telex: 181017
ESG CNPK A

**Rockwell
International**

February 3, 1981

In reply refer to 81ESG-809

Mr. Leonard Spielberger
Systems Development Corporation
360 North Sepulveda Boulevard
El Segundo, California 90245

Dear Len:

This letter will: (1) confirm that we have sent the sample of benzene from Rockwell hydrogasification Run 318-067 to Mr. John Gatsis at UOP Research Corporation's Research Center and (2) give you some background on the sample.

The sample is a portion of the material recovered by steam-stripping the top (upstream) bed of a two-bed activated carbon bed adsorber to ~82% recovery of the adsorbed benzene weight. Please refer to Appendix A of our FY 1980 Annual Report (ET-3125-24, Volume I), Page A-7, for a description of the adsorber and interrelationship between the bed layers and Page A-39 for analyses of several steam-stripped benzene samples.

The sample we sent to Mr. Gatsis is comparable to the first one listed on Page A-39 (i.e., top carbon bed extracted to 82% recovery). Our analytical chemistry laboratory analyzed the specific sample before it was sent, using the same gas chromatograph columns listed on Page A-39, and nearly duplicated the analysis reported there, viz:

<u>Compound</u>	<u>Wt %</u>
Benzene	98.8
Toluene	1.02
Thiophene	0.07
Xylenes	0.04
Naphthalene	0.02
Other Volatiles	0.06 (Below Benzene)
Other Volatiles	0.01 (From Benzene to Naphthalene)
	<u>100.02</u>

I would appreciate your letting me know what you learn from UOP's analyses of this hydrogasification byproduct.

Very truly yours,

L. P. Combs
Project Engineer

The low-pressure product gases were passed through the activated carbon bed adsorber unit during Test 318-67. The bed was separated into two layers in order to determine whether or not all of the adsorbable hydrocarbons were captured by the bed according to the following reasoning: If the downstream layer is unsaturated in adsorbable hydrocarbons, then it implies complete capture; if the downstream layer is saturated, it implies partial capture. Post-test analysis of the carbon-bed layers from Test 318-67 indicated that both layers were saturated with benzene, implying partial capture of benzene in the total product gas stream.

The upstream layer was steam-stripped and about 82% of its adsorbed benzene was recovered. The stripped liquid was colorless, having a composition of approximately 98.8% benzene, approximately 1.1% toluene, approximately 0.08% thiophene, and only traces of other species (Table A-4). The lower layer, similarly stripped to 82% recovery, had only 0.62% toluene, 0.06% thiophene and even smaller traces of other compounds in the stripped specimen. The clear implication of this is that the minor species (toluene, thiophene, etc.) had not reached saturation in the lower bed, so must have been essentially completely captured. Since benzene had broken through the lower bed and was partially lost with the product gases, it follows that both the upper and lower layers were enriched in the minor species.

TABLE A-1
ACRONYMS USED IN COMPUTER PRINTOUTS

SOL	: Solids and Oils (dry basis)
LIQ	: Aqueous Condensate (solids-and-oil-free)
PRO-1	: Pressure at Reactor Outlet
PPGLR	: Pressure at Product Gas Line Orifice (upstream)
TPGLO	: Temperature at Product Gas Line Orifice (upstream)
DPPGLR	: Pressure Differential Across Product Gas Line Orifice
PCPO	: Pressure at Condenser Product Outlet
TCPO	: Temperature at Condenser Product Outlet
O.V.	: Other Volatiles (having boiling point <425°F)
N.V.R.	: Nonvolatile Residue
MAF	: Moisture and Ash Free

Figure 3. Simplified Flow Diagram of ETU Reactor System

TABLE A-4
COMPOSITION OF BENZENE STEAM-STRIPPED FROM CARBON BED ADSORBER
TEST 318-67

Species Sample	Benzene (by difference)	Toluene	Thiophene	Xylenes	Naphthalene	Other Volat- to Naphth.
Benzene Extracted to 82% recovery Top carbon bed	98.8%	1.1%	0.08%	0.02%	0.02%	<0.01%
Benzene Extracted to 82% recovery Bottom carbon bed	99.3%	0.62%	0.06%	<0.01%	<0.01%	<0.01%
Benzene Cut between 82 and 96% Top carbon bed	97.6%	2.3%	0.08%	0.05%	0.01%	<0.01%
Method:	Difference	GC: Carbopak Column MIBK Internal Standard		GC: OV-101 Column MIBK Internal Standard		Summation

APPENDIX C

UOP LABORATORY REPORT ON BENZENE SAMPLE FROM ROCKWELL INTERNATIONAL

Rockwell International Benzene Sample

Sample	Benzene Steam Distilled from Coal Gasification, Run 318-067
UOP No.	11-349
Sample No.	3930-35
Carbon, wt.%	92.29
Hydrogen, wt.%	8.09
Oxygen, wt.ppm	54
Sulfur, wt.ppm	491
Nitrogen, wt.ppm	42
H ₂ O, wt.ppm	356
FIA Analysis:	
Aromatics, vol.%	100
Olefins, vol.%	trace
Paraffins + Naphthenes, vol.%	-
High Resolution - Mass Spectrometer Analysis:	
Benzene, wt.%	98.85
Toluene, wt.%	1.01
Xylene, wt.%	0.04
Naphthalene, wt.%	0.02
Thiophene, wt.%	0.07
Methyl Thiophene, wt.%	0.006
Specific Gravity @ 60°F	0.8838
Distillation, ASTM D850	
IBP, °C	79.2
5	79.7
10	79.8
20	79.9
30	80.0
40	80.0
50	80.1
60	80.2
70	80.3
80	80.5
90	81.0
95	82.4
BP	86.4

Standard Analytical Methods

<u>Method Title</u>	<u>DOP Method No.</u>	<u>ASTM Method No.</u>
API Gravity of Liquid Petroleum Products		D-287
Distillation - Engler		D-850
Hydrogen and Carbon (Micro)	U-638	
Oxygen, Total, in Organic Material	U-649	
Total Sulfur in Naphthas and Petrocove Distillates by Oxidation Pyrolysis and Microcoulometric Titration	U-727-72	
Water in Liquid Hydrocarbons by Coulometry	U-481-80	
Hydrocarbon Types by Fluorescent Indicator Absorption (FIA)	U-311-72	
Nitrogen by Chemiluminescence Detection		

APPENDIX D
TYPICAL COMPUTER PRINTOUT FROM PRP PROGRAM

INPUT DATA SUPPLIED BY USER

CARD 1 1 0 1 1 1 0 2 0 1 0 UOP/SEC INPLIS FCF ROCKWELL(UFM HIGH YIELD) PROCES

TXCHD, FITTXR, STAINC, STAREV 0.1000 0.4800 0.0300 0.0
 PRUPTX, INSURE, CRTFRC, ECFRAC 0.0 0.0 0.7500 0.2500
 RTNEQV, INTCHT, PROJLF, CPSTRT 0.1500 0.0900 15.0000 1.0000
 PRPEXP, TOLER, SALVGE, CASTLN 79.7000 0.0100 0.0 1520.1000
 INTCUN, INTTOT 0.0500 0.0 0.0
 NYRS, NSTRT, NTRIES, NCFERS 15 1 50 3
 NEOMAX, NCARRY, NCREDIT, ACNSTR 1 5 7 5

UFM WITH INFLATION @ 9%
 5 YEARS CONSTRUCTION
 10 YEARS (ADDITIONAL) LIFE

DEPRECIABLE CAPITAL INVESTMT INPUTTED ON CARD 5 FOR EACH YEAR OF PROJECT LIFE, INVESTIN)

100.000000	500.000000	500.000000	500.000000	140.000000	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WORKING CAPITAL INVESTMENT INPUTTED ON CARD 6 FOR EACH YEAR OF PROJECT LIFE, WORKCAPIN)

55.500000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

OPERATING EXPENSES INPUTTED ON CARD 7 FOR EACH YEAR OF PROJECT LIFE, ENTEXPIN)

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PLANT OASTREAD FACTOR INPUTTED ON CARD 17 FOR EACH YEAR OF PROJECT LIFE, EFFNCYINI)

0.900000	0.900000	0.900000	0.900000	0.900000	0.900000	0.900000	0.900000
0.900000	0.900000	0.900000	0.900000	0.900000	0.900000	0.900000	0.900000

EXINIT. EXPCEN

0.0 35.2000

PRICES AND BASE PRODUCTION RATES FOR 4 PRODUCTS. PRICE RATIOS AND RATIO SIGNALS.

TRIAL VALUE OF GAS	BENZENE \$/bbl	AMMONIA \$/TON	SULFUR \$/TON
35.0000	36.0000	120.0000	37.8000
15.3300	0.2300	0.0540	1.2240
1.0000	0.0	0.0	0.0
0	0	0	0

PRICES AND CONSUMPTION RATES FOR 1 FEEDSTOCKS

25.00000
 7.130000

RECEIVED DATA. CALCULATED FROM INPUT DATA

INCLUDES ESCALATION IF CALLED FOR BY USER.

OBJECTIVE IS TO CALCULATE PRODUCT PRICE

BREAKDOWN OF TOTAL CAPITAL INVESTMENT

TOTAL DEPRECIABLE INVESTMENT AS IMPLIED	2092.6563
CALCULATED INTEREST DURING CONSTRUCTION	421.35122
TOTAL DEPRECIABLE INVESTMENT	2514.04785
TOTAL WORKING CAPITAL AS INPUTTED	55.90000
TOTAL CALCULATED CAPITAL INVESTMENT	2569.94785

TOTAL DEPRECIATION FOR TAX PURPOSES	2514.04785
SALVAGE VALUE AT END OF PROJECT	C.C
TOTAL	2514.04785

CALCULATED ANNUAL DEPRECIATION ALLOWANCES

BY STR METHOD

167.603100	167.603100	167.603100	167.603100	167.603100	167.603100	167.603100	167.603100
167.603100	167.603100	167.603100	167.603100	167.603100	167.603100	167.603100	167.603100

SUM OF DEPRECIATION ALLOWANCES

2514.04785

CALCULATION OF INTEREST DURING CONSTRUCTION

COMPOUND INVESTMENT FACTOR CMPEFC	1.21122
TOTAL INTEREST DURING CONSTR INTDC	421.35122

ESCALATION FACTORS, FRACTION/YEAR

CAPITAL, WORK CAPITAL, EXTRA EXP	0.0900	0.0900	0.0900
OPERATING EXPENSES	0.0900	0.0900	0.0900
PRICES OF ALL FEEDSTOCKS	0.0900		
PRICES OF ALL PRODUCTS	0.0900		

PAYOUT TABULATION

UDP/SDC INPUTS FOR ROCKWELL/UHM HIGH YIELD PROCES

FEED PRICE = 25.00

TRIAL 17 COG PRICE = 20.2710 \$/bbl* DEBT AT 9.00 % RATE OF RETURN ON EQUITY = 15.000 % D/E = 0.75/0.25

	1	2	3	4	5	6	7	8	9	10	11
	CPSTRT	EFFNCY	INCOME	PLTEXP	STLTAX	INCRDT	FECTAX	CASHFL	TOTRTN	AMORTZ	CAPEND
1	576.2572	C.9000	485.0380	291.4165	0.0	C.0	0.0	193.6223	60.5742	133.0481	443.8489
2	988.8484	0.9000	528.6919	317.6438	0.0	C.0	C.C	211.0481	103.8291	107.2190	881.6292
3	1475.6780	0.9000	576.2732	346.2312	0.0	C.0	C.0	230.0420	154.5461	75.0959	1400.5820
4	2248.0942	0.5000	628.1375	377.3918	0.0	C.0	C.C	250.7456	215.0498	35.6958	2012.3984
5	2218.4885	0.9000	684.6689	411.3564	0.0	0.0	0.0	273.3125	232.9412	40.3713	2178.1172
6	2178.1172	0.9000	746.2828	446.3782	0.0	C.0	0.0	297.9106	228.7023	69.2084	2108.9087
7	2108.9087	0.9000	813.4536	488.7317	0.4430	0.0	C.0	324.2788	221.4354	102.8434	2006.0652
8	2006.0652	0.9000	886.6638	532.7173	1.5280	C.0	0.0	352.4185	210.6368	141.7816	1864.2834
9	1864.2834	0.9000	966.4628	580.6611	2.7708	C.0	C.C	383.0305	195.7497	187.2808	1677.0024
10	1677.0024	0.9000	1053.4436	632.9202	4.1917	0.0	58.3192	358.0122	176.0852	181.9270	1495.0754
11	1495.0754	0.9000	1148.2517	685.8818	5.6555	C.0	11.3937	364.2805	156.9829	207.2976	1287.7778
12	1287.7778	0.9000	1251.5535	751.9707	7.3528	C.0	114.1161	378.1536	135.2167	242.9369	1044.8408
13	1044.8408	0.9000	1364.2351	815.6472	9.1937	C.0	142.6867	392.7073	109.7083	282.9588	761.8420
14	761.8420	0.9000	1487.0156	893.4148	11.2372	0.0	174.4012	407.5622	79.9935	327.5685	433.8735
15	433.8735	0.9000	1620.6440	973.8206	13.5040	C.C	205.5822	423.9370	45.5568	378.3801	55.4934

THE LAST ENTRY IN THE FINAL YEAR SHOULD BE EQUAL TO THE WORKING CAPITAL INVESTMENT PLUS SALVAGE VALUE

WORKING CAPITAL RECOVERED INTACT AT END OF PROJECT LIFE =	55.5000C
SALVAGE VALUE RECOVERED INTACT AT END OF PROJECT LIFE =	0.0
TOTAL	55.50000

KEY TO CALCULATIONS IS AS FOLLOWS.

- COLUMN 1 = CAPITAL INVESTMENT OUTSTANDING AT START OF YEAR INCLUDING WORKING CAPITAL (\$MM)
- COLUMN 2 = INSTREAM EFFICIENCY (PLANT OPERATING FACTOR)
- COLUMN 3 = GROSS INCOME FROM SALE
- COLUMN 4 = OPERATING EXPENSES EXCLUDING TAXES
- COLUMN 5 = STATE AND LOCAL TAXES
- COLUMN 6 = FEDERAL INVESTMENT TAX CREDIT
- COLUMN 7 = NET FEDERAL INCOME TAX PAID
- COLUMN 8 = CASH FLOW AFTER TAXES
- COLUMN 9 = INTEREST ON DEBT AND RETURN ON EQUITY BASED ON COLUMN 1
- COLUMN 10 = REDUCTION OF OUTSTANDING CAPITAL INVESTMENT, COLUMN 8-9
- COLUMN 11 = OUTSTANDING CAPITAL INVESTMENT AT END OF YEAR INCL WORKING CAPITAL. COL 1-10

COLUMN 11 PLUS NEW INVESTMENT = NEXT ENTRY OF COLUMN 1

* TO CONVERT TO \$/MMBtu, DIVIDE BY 5.02

ADDITIONAL DETAILS OF CALCULATION

UOP/SCC INPUTS FOR RECKWELL (UFM HIGH YIELD) PROCESS

	1	2	3	4	5	6	7	8	9	10	11
	CPSTRT	COSTRT	ECSTRT	DETAO	INTRST	TAXREL	STXREL	EQUIN	PROPTY	DETPAY	ECTPAY
1	576.8972	432.6729	144.2244	432.6729	38.9405	-12.9214	-12.9214	21.6336	0.0	99.7861	33.2620
2	988.8484	741.6362	247.2122	408.3495	66.7472	-23.3023	-23.3023	37.0818	0.0	80.4143	26.8048
3	1475.6780	1106.7585	368.9194	445.5366	99.6082	-37.1654	-37.1654	55.3379	0.0	56.3219	18.7740
4	2048.0942	1536.1706	512.0237	485.8340	138.2463	-55.1039	-55.1039	76.8035	0.0	26.7718	8.9240
5	2218.4885	1663.8660	554.6226	154.5676	149.7475	-44.0386	-44.0386	83.1934	0.0	30.2784	10.0928
6	2178.1172	1633.5874	544.5298	0.0	147.0228	-16.7153	-16.7153	81.6794	0.0	51.5063	17.3021
7	2108.9087	1511.6809	527.2278	0.0	142.3512	14.3245	14.3245	79.0842	0.0	77.1326	25.7109
8	2006.0652	1504.5483	501.5168	0.0	135.4093	49.4060	50.5341	75.2275	0.0	106.3362	35.4454
9	1864.2834	1398.7119	466.0715	0.0	125.8390	85.5865	92.3593	69.9107	0.0	140.4606	46.8202
10	1677.0024	1257.7512	419.2512	0.0	113.1974	135.5310	135.7227	62.8877	0.0	136.4452	45.4818
11	1495.0754	1121.3059	373.7695	0.0	100.9175	184.1536	189.8491	56.0654	0.0	155.4732	51.8244
12	1287.7778	965.8325	321.9453	0.0	86.9249	237.7418	245.0946	48.2918	0.0	182.2027	60.7342
13	1044.8408	783.6256	261.2112	0.0	70.5266	257.2639	306.4578	39.1817	0.0	212.2491	70.7497
14	761.8420	571.3804	190.4617	0.0	51.4242	363.3359	374.5732	28.5692	0.0	245.9764	81.9921
15	433.8735	325.4038	108.4697	0.0	29.2863	436.6296	450.1330	16.2704	0.0	283.7849	94.5952

KEY TO CALCULATIONS IS AS FOLLOWS.

- COLUMN 1 = TOTAL CAPITAL AT START OF YEAR
- COLUMN 2 = DEBT OUTSTANDING AT START OF YEAR
- COLUMN 3 = EQUITY CAPITAL OF START OF YEAR
- COLUMN 4 = AMOUNT ADDED TO DEBT
- COLUMN 5 = INTEREST ON DEBT
- COLUMN 6 = FEDERAL TAXABLE INCOME
- COLUMN 7 = STATE TAXABLE INCOME
- COLUMN 8 = AFTER-TAX RETURN ON EQUITY
- COLUMN 9 = LOCAL PROPERTY TAX PAID
- COLUMN 10 = RETIREMENT OF DEBT
- COLUMN 11 = RETIREMENT OF EQUITY