

NON-FUEL CHEMICALS FROM COAL

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Introduction

Current research and development activities are demonstrating that liquid and gas fuels can be produced by hydrogenation of coal or coal-derived oil at costs which are in sight of being competitive with natural gas or fuels from petroleum. Most of this work is being done under contract to the Office of Coal Research, Department of the Interior, with the prime objective of assuring that we become self-sufficient in non-nuclear energy resources in the face of declining domestic petroleum and natural gas reserves.

Skeist Laboratories contracted to study the economic contributions to these operations from the recovery of non-fuel by-products. As our study progressed, it became increasingly evident that the production from coal of what we now call "petrochemicals" could eventually make just as great or even a greater contribution to our economy than the production of fuel. Major improvements in the design and construction of refinery and petrochemical equipment, together with production level requirements running into billions of pounds a year, have completely changed production economics in coal conversion from what they were at the time of earlier efforts in this technology.

Although new off-shore and foreign oil reserves frequently are being found, they are increasingly costly to discover. The ratio of domestic reserve to production demand is steadily decreasing; already, high-grade domestic crudes are priced over \$3.00 a barrel. The Alaska discoveries may postpone the petroleum shortage era; but despite predictions of low cost at the well, they are not likely to relieve the cost picture. Pipe lines to distribution sites are estimated to cost \$900 million, and maintenance and operating costs at -60°F . temperatures will contribute further to high transportation costs.

Let us assume, then, that within the foreseeable future, petroleum crudes become scarce enough or costly enough to threaten their usefulness as fuel. Also let us assume that nuclear energy will be cheap enough for electric automobiles to become an economic reality and for electricity to be the prime source of domestic heat. It has been estimated that before the end of the century, fast breeder reactors will be supplying power at as low as 0.2¢ per KWH. It is conceivable, therefore, that a petroleum shortage need not be critical in regard to energy requirements. Energy from coal conversion might complement nuclear energy, but the production of petrochemicals from coal could become of even greater significance. The demand for petrochemicals is expected to climb to 35 million tons in 1975, and possibly to 60-70 million tons by 1985.

Processes for Coal Conversion

Several processes for coal conversion are under development. Those of major interest for potential chemicals recovery are designed to produce a synthetic crude for use as a refinery feed. One process*, now being engineered for large-scale pilot-plant operation, first pyrolyzes coal in four steps under closely controlled conditions to convert about one-half the coal to gas and oil. The oil is hydrogenated to give a synthetic crude-oil refinery feed. The gas can be used to produce olefins and hydrogen as shown in Table 1. Crediting ethylene and propylene at current values could give hydrogen costs of less than 15¢/1000 cu.ft.

This low-cost hydrogen could be an extremely important factor in the overall economics of coal conversion, since hydrogen at costs by conventional steam reforming represent 30-40% of the cost of coal hydrogenation. The unconverted coal or "char" will be hydrodesulfurized and used as powdered fuel.

Another process operated on a large-scale pilot plant basis at Cresap, West Virginia, by Consolidation Coal solvates about 2/3 of the coal by heating with a kerosene-type solvent under pressure at about 700°F. After filtration, removal of solvent by distillation and hot-water washing of the extract, a high melting product is obtained which is hydrogenated to give the refinery feed. If desired, the coal extract can first be treated by typical tar-processing technology to recover tar acids and bases and other typical coal tar chemicals.

The third major process, which has many attractive features, is the H-coal process, developed by Hydrocarbon Research, Inc. Here pulverized coal is hydrogenated directly in an ebullating catalyst bed, by a process similar to fluidized bed technology. A synthetic crude is obtained directly.

Estimates of the cost of fuels obtainable by these processes are given in the reports to the Office of Coal Research by the contractors.

Chemicals Recovery

The main purpose of this paper is to discuss the recovery of hydrocarbon chemicals from these synthetic crudes; but regardless of the ultimate objective of the operation, be it chemicals, liquid or gaseous fuels, the recovery of ammonia and sulfur is an essential feature to eliminate air and stream pollution. We do not propose to go into details of their recovery, but the volume is large and will make a significant contribution to the economics of the operation, as shown in Table 2.

* COED (Char Oil Energy Development) FMC Corporation

TABLE 1

HYDROGEN AND OLEFIN YIELDS FROM PYROLYSIS GASES

Coal consumed: 50,000 tons per diem

Gas volume: 400 MM cu.ft. per diem, CO₂-H₂S-free basis

Composition:	<u>Vol. %</u>
CO	22
H ₂	56
CH ₄	17
C ₂ -C ₄	4-5

ANNUAL VOLUME OF HYDROGEN AND OLEFINS:

	<u>MM lbs./year</u>	<u>Value MM \$</u>
Propylene	150	4.5
Ethylene	200	6.5
Hydrogen	135 billion cu.ft.	<u>27.0</u>
	Total	38.0

TABLE 2

TYPICAL SULFUR, AMMONIA AND TAR ACID RECOVERIES PER ANNUM

Basis: A. Conversion via pyrolysis of 50,000 tons of coal per diemB. Conversion via solvation or direct hydrogenation
of 15,000-17,000 tons coal per diem

Assumes coal with 3% sulfur content

	<u>A</u>		<u>B</u>	
	<u>M tons</u>	<u>Value MM \$</u>	<u>M tons</u>	<u>Value MM \$</u>
Sulfur	400	11	100	2.7
Ammonia	40-50	1.6-2.0	40-50	1.6-2.0
Tar acids*	40	<u>9.6</u>	40	<u>9.6</u>
Total value (rounded)		22		14

* Estimates of recoverable material vary from 30,000 to 100,000 tons

All the volume figures throughout this presentation are based on a refinery, which when operating on all fuel, would produce 50,000 barrels a day of gasoline and fuel oil. This requires the pyrolysis of approximately 50,000 tons a day of as-received coal in the first of the foregoing processes, where only about one-fourth of the coal is converted to oil, or 15,000-17,000 tons of as-received coal a day in the other two processes.

Common also to all three processes is the availability of phenols and cresols, which can be extracted either before or after hydrogenation. The quantity of cresols potentially available would far more than saturate the market; but it would be desirable to extract as much as possible, as oxygenated hydrocarbons must be hydrogenated to extinction of oxygen before the reforming step, consuming valuable hydrogen. The volume of tar acids available is shown in Table 2.

In regard to our future petrochemical requirements, the high potential availability of aromatics is the most significant feature of coal hydrogenation. Table 3 shows a rough composition of a COED syncrude from Utah Coal compared with petroleum crudes. Unfortunately, no corresponding data are yet available on synthetic crudes from other types of coal, but it is believed that the distribution of product types does not vary significantly. The important feature is the high content of naphthenes and aromatic hydrocarbons, which indicates that after the several refining steps and severe reforming, the total aromatics content could approach 90%.

Table 4 shows a chromatographic analysis of another sample of Pittsburgh coal-derived naphtha. Several highly significant features are evident. The 10.2% of combined methylcyclopentane and cyclohexane suggests that it should be easier to recover cyclohexane from coal-derived naphtha than from petroleum naphthas, which contain much less. Methylcyclopentane isomerizes to cyclohexane by heat treatment. The potential availability from the 50,000 barrel operation would be about 5,000 barrels a day, or over 400 million lbs. a year.

The high content of decalins and tetralin theoretically could yield by reforming about 500 million lbs. a year of naphthalene at much lower costs than by dealkylating the alkyl naphthalenes in petroleum naphthas. We believe it should be possible to separate the naphtha of the composition shown in Table 4 into two fractions of 70% and 30%, reform the first fraction for monocyclic aromatics production and separate a decalin-rich cut from the second fraction for naphthalene production.

TABLE 3

TYPICAL COED SYNCRUDE COMPOSITION VS. PETROLEUM CRUDES

	COED Syncrude	Naphthenic petroleum crude	Paraffinic petroleum crude
Paraffins	13.5	40-46	70-75
Naphthenes	57.8	47	19-23
Alkyl benzenes	7.9	7-13	7-12
Polycyclic and thio-aromatics	20.8		

* * * * *

TABLE 4

COMPOSITION OF COAL-DERIVED NAPHTHA AFTER ISOMAX HYDROCRACKING

	Vol. %	Reform Product
Paraffins	11.4	
Methyl cyclopentane + cyclohexane	10.2	Benzene
C7 Naphthenes	10.7	Toluene
C8 "	13.9	Xylene and ethylbenzene
C9 "	7.6	Trimethylbenzenes
C10+ "	6.0	Tetramethylbenzenes
Benzene	0	
Toluene	1.4	
Xylene	3.9	
Other alkyl benzenes	4.8	
Dicycloparaffins:		
Cis and trans-decalin	10.2	Napthalene
Tetralin (includes indanes)	3.5	
Other dicycloparaffins	14.8	
Hydrindane	1.2	
Napthalene	0.4	

100

Polymethylbenzenes. If all the naphthenes including the C₆'s are reformed, about 50% of the naphtha would be converted to benzene and alkyl benzenes. The recoverable volumes of benzene, toluene and xylene are shown later. Of considerable significance to our plastics and coatings industries is the volume of tri- and tetramethylbenzenes obtainable from reforming of the C₆⁺ naphthenes. Another analysis of coal-derived gasoline gives the percentages of significant components shown in Table 5, showing 16 times as high a content of durenes as in regular petroleum gasoline. Pseudocumene, although much lower, is present in significant quantities, and naphthenic pseudocumene precursors are presumably present also.

Polycyclic aromatics. Another series of analyses was made by the Atlantic Refining Co. on four fractions, including middle distillate and gas oil from the FMC Syncrude (Table 6). The important features are the high content of naphthalenes, tricyclic aromatics, acenaphthene, acenaphthylene and pyrene. Table 7 shows the potential availability of these compounds from 50,000 barrels of feed.

The tricyclic aromatics, although not individually identified, are probably of about the same distribution as those derived from coal tar, primarily anthracene, phenanthrene and fluoranthrene. Separation of these products, including acenaphthene and acenaphthylene, is long-established coal-tar processing technology; but new technologies in solvent extraction and fractional distillation could facilitate their recovery at very favorable costs. Also, it may be easier to isolate them in higher yield and purity from hydrogenated crudes than from coal tar since the content of many sulfur-, nitrogen- and oxygen-containing co-products, which complicate separation, has been reduced or eliminated by hydrogenation. The same possibility may apply to pyrene, which has been difficult to isolate from coal tar. Carbazole, in which, as explained later, there is revived interest, is found in the anthracene fraction in coal tar. About two-thirds of the nitrogen in the coal oil is removed as ammonia by hydrogenation to synthetic crude, but it could be extracted before hydrogenation.

End Uses for Polymethylbenzenes and Polycyclic Aromatics

There are numerous existing and potential uses for these materials. Some of the major end-uses are shown in Table 8. H. W. Earhart of Sun Oil Co. (see CW Report), Feb. 22, 1969, on polymethylbenzenes) lists a wide variety of real and potential uses for the tri- and tetramethyl benzenes in several fields, primarily plastics and coatings. Pseudocumene is already isolated by distillation from petroleum naphtha for oxidation to trimellitic anhydride, which is used mainly for conversion to tri-esters for plasticizers and to polyamide-imides for heat-resistant wire coatings. Durene, 1,2,4,5-tetramethylbenzene, is of high interest in the production of pyromellitic dianhydride, also used commercially to prepare heat-resistant imide polymers for wire.

TABLE 5.

SOME SIGNIFICANT COMPONENTS OF COAL-DERIVED GASOLINE
AND REGULAR NON-PREMIUM GASOLINE (GAS CHROMATOGRAPH)

	% by Volume	
	<u>Coal derived</u>	<u>Typical regular petroleum gasoline</u>
Methylcyclopentane	2.2	1.5
Cyclohexane	3.5	0.4
Ethylbenzene	3.8	2.7
Pseudocumene	0.6	2.8
Durene	2.1	0.2
Isodurene	8.5	0.4

TABLE 6.

SOME SIGNIFICANT COMPONENTS OF DISTILLATE CUTS FROM COED SYNCRUDE

	<u>Cut 1</u>	<u>Cut 2</u>	<u>Cut 3</u>	<u>Cut 4</u>
Boiling range	0.335	335-420	420-600	600-875
% distillate	3.8	8.3	25.9	48.9
Monocycloparaffins	71.4	55.1	19.7	4.3
Dicycloparaffins	9.2	8.7	11.0	3.6
Indanes and tetralin	0.9	16.4	23.7	8.3
Alkylbenzenes	7.4	9.9	9.2	4.8
Acenaphthene	-	-	1.2	6.9
Acenaphthylene	-	-	0.7	11.7
Tricydic aromatics			0.3	4.2
Pyrene			-	0.8
Chrysene			-	6.8

TABLE 7

VOLUMES OF POLYCYCLIC AROMATICS POTENTIALLY AVAILABLE
FROM A 50,000 BARRELS/DAY REFINERY

	<u>MM lbs./day</u>	<u>MM lbs./year</u>
Naphthalene	1.6+	500+
Acenaphthene	.6	200
Acenaphthylene	.9	300
Pyrene	.08	26
Tricyclic aromatics*	.4	130

* Probably at least 10% anthracene = 13 MM lbs/year; the other major component is phenanthrene.

TABLE 8

END USES FOR POLYMETHYLBENZENES AND POLYCYCLIC AROMATICS

<u>Product</u>	<u>End Use</u>
Pseudocumene	Trimellitic anhydride for heat-resistant plastics and coatings.
1,2,4,5-tetramethylbenzene (durene)	Pyromellitic dianhydride for polyimide heat-resistant fibers and coatings.
1,2,3,5-tetramethylbenzene (isodurene)	Tetracarboxylic acid esters for non-volatile plasticizers.
Acenaphthene	Naphthalic anhydride for chemical specialties. Conversion via naphthalimide to perylene derivatives.
Acenaphthylene	Reactive ethylenic monomer for plastics.
Pyrene	Conversion to 1,4,5,8-naphthalene tetracarboxylic acid dianhydride for production of super-heat-resistant polyimides.
Anthracene	Production of anthraquinone.
Phenanthrene	Oxidation to diphenic acid for use in alkyd resins and polyesters.
Carbazole	N-vinyl carbazole for electrical grade polymers and photosensitive polymer systems.

enamel and fiber production. Its high content in the coal-derived naphtha reformat could eventually lead to a price comparable to that for paraxylene, i.e. less than 10¢/lb. vs. the current 50¢-60¢ range. The analyses indicate a potential availability of about 100 MM lbs. a year from the 50,000 bbl. refinery. Even larger quantities of the 1,2,3,5 isomer, isodurene, appear to be available. This could be oxidized to a tetracarboxylic acid for esterification to useful low-volatility plasticizers.

Pyrene is of paramount potential interest. Oxidation gives 1,4,5,8-naphthalene tetracarboxylic acid dianhydride, from which is made the exotic pyrrole polymer BBB or poly(benzimidazobenzophenanthroline) dione which, in fibers, retains strength up to 700°C. At \$400.00/lb., it is being produced and used to make drogue parachutes for spacecraft. Pyrene is difficult to isolate in high purity from coal tar, in which it is associated with benzodiphenylene oxides having the same boiling points and solubility. Since the content of materials of this type might be reduced or eliminated by hydrogenation, the isolation of pyrene from the heavy gas oil fraction from the synthetic crude might not be as difficult. The potential availability appears to be about 20 MM lbs./yr. Possibly its isolation at low cost could bring the price of its unique pyrrole polymer derivatives to a level suitable for industrial usage.

Acenaphthene and acenaphthylene, as shown in Table 7, are present in the synthetic crude to the extent of several hundreds of million pounds. Acenaphthene can be quantitatively oxidized in fixed or fluid-bed converters to naphthalene 1:8 dicarboxylic acid dianhydride which, by boiling with aqueous ammonia, gives a quantitative yield of naphthalimide. By alkali fusion, two molecules of naphthalimide condense to perylene tetracarboxylic acid diimide, used in small amounts to produce pigments. The imide rings can be hydrolyzed back to the dianhydride which, by reaction with diamines, could give polyimides with extremely high heat resistance. The situation could be like that for pyrene. Low-cost raw material could give product costs within a practical range. Naphthalic anhydride itself, potentially a low-cost product, has many interesting potential uses.

Acenaphthylene has been investigated on a limited scale as a reactive monomer capable of homo- and copolymerization, but the products to date have shown no outstanding performance. Presumably, it also can be oxidized to naphthalic anhydride, but we know of no evidence of this.

At a low enough price, anthracene would be the preferred raw material for anthraquinone, an important dyestuff intermediate. The quantity available per annum from the 50,000 bbl operation would be more than enough to meet all current requirements for anthraquinone. The production of this material is estimated at 10-12 million lbs./year, which, if

anthracene were the raw material, would require 12-15 MM lbs. of 90% anthracene. Modern distillation technology could possibly deliver a material containing only phenanthrene as a co-product. Anthracene can be separated from phenanthrene by recrystallization from furfural or pyridine bases. Phenanthrene to date has found but minor uses. It can, however, be oxidized to diphenic acid which, at a low enough price, could be used in fair volume in alkyd and chemical-resistant polyester resins and as an intermediate for many other interesting polymers.

Carbazole, as previously mentioned, may have been destroyed by hydrogenation but, if demanded, could be recovered from the crude before hydrogenation. The demand may increase substantially.

Poly-N-vinyl carbazole has found uses in electrical applications, and is now being used as a photosensitive polymer.

All-Chemical Refinery

Recovery of polycyclic aromatics has been emphasized mainly because, in most cases, they are not readily available from petroleum sources and production costs from coal tar have been relatively high. They represent but a small percentage of the total volume of hydrocarbons which can be produced from the synthetic crude. It is the production of olefins, dienes, benzene, toluene and xylene which we expect will make an invaluable contribution to our future economy. Synthetic crude is a much better feedstock than petroleum crudes for BTX production. The light naphtha cut is just as good a feedstock for olefin production, and the C₂-C₄ hydrocarbons produced during hydrogenation can be processed to olefins.

Table 9 shows a concept of a production schedule for a chemical refinery. It is largely hypothetical since the input and output balances from coal to reformat feed are based on data submitted to OCR by Hydrocarbon Research, Inc., and the assumption is made that the composition of the reformat feed is comparable to that of the Isomaxate obtained from Pittsburgh seam coal-derived synthetic crude. The latter would reform to give the product distribution shown in Table 11, and is the only material for which we have a composition breakdown, as shown under naphtha feed in Table 11. However, we believe that the concept is an indication of what could be accomplished. In any case, such a production schedule would be highly flexible. The total volume and distribution of olefins and butadiene can be varied over wide ranges. Far more naphthalene could be produced if conditions warranted it, or any surplus of its precursor, decalin, could probably be isolated and converted to supersonic jet fuel. Decalin is currently priced at over 50¢/lb. Durene recovery could be increased severalfold if the demand increased. Cyclohexane could be added to the production schedule either by fractionation of the appropriate naphtha cut or by hydrogenating benzene. The latter method might prove to be better.

TABLE 9

CONCEPTUAL MAJOR PETROCHEMICAL PRODUCTION FROM
50,000 BARRELS A DAY REFINERY

	<u>MM lbs./year</u>	<u>Price ¢/lb.</u>	<u>Value MM \$</u>
<u>Olefins and butadiene</u>			
Ethylene	585	3.25	19
Propylene	140	3	4.2
Butadiene	370	8.5	31.5
Butylene	60	5	<u>3</u>
			57.7
<u>Aromatics</u>			
	<u>MM gals. or lbs./year</u>		
Benzene	52.3 gals.	20	10.5
Toluene	65.7 "	16	10.5
Xylene	98.2 "	16.4	16.1
C ₉ + aromatics	80	13.5	10.8
Pseudocumene	60 MM lbs.	6.5	3.9
Durene	10 " "	25	2.5
Naphthalene	256	3	<u>7.7</u>
			62.0
			<u>119.7</u>
	GRAND TOTAL		119.7

TABLE 10

OTHER PRODUCTS FROM CONCEPTUAL SYNTHETIC CRUDE REFINERY

	<u>Volume</u>	<u>Price</u>	<u>Value MM \$</u>
<u>Chemicals</u>			
Hydrogen	22 billion cu.ft.	15¢/1000	3.0
Tar acids	82 MM lbs.	11.7¢/lb.	9.6
Sulfur	80,000 long tons	\$30/ton	2.4
Ammonia	50,000 short tons	\$40/ton	<u>2.0</u>
			17.0
<u>Fuel</u>			
Fuel oil	0.4 MM barrels	\$2.00	0.8
Surplus heavy naphtha	4 MM "	\$2.00	<u>8.0</u>
			8.8
<u>Polycyclic Aromatics</u>			
Anthracene	10 MM lbs.	20¢	2
Phenanthrene	"	10¢	1
Pyrene	"	30¢	3
Acenaphthene	"	20¢	<u>2</u>
			8
	Grand Total		<u>33.8</u>
	Products from Table 9		119.7
	Overall total		153.5

TABLE 11

COMPOSITION OF REFORMATE FEED AND REFORMATE
PRODUCT AFTER AROMATICS EXTRACTION

<u>Naphtha feed</u>	4287 MM lbs.	<u>Reformate product:</u>		
Composition:	<u>MM lbs.</u>		<u>MM lbs.</u>	<u>MM gals.</u>
Paraffins	414	Hydrogen	139	
Naphthenes:		Benzene	382	52.3
C ₆	417	Toluene	474	65.7
C ₇	442	C ₈ aromatics	707	98.2
C ₈	573	C ₉₊ aromatics	648	90.0
C ₉	311	Naphthalene	256	
C ₁₀₊	164	Heavy naphtha	1228	
Toluene	61	Raffinate	262	
C ₈ aromatics	167	C ₁ hydrocarbon	33	
C ₉₊ "	234	C ₂ "	36	
Dicycloparaffins	1236	C ₃ "	56	
Other cyclics	<u>268</u>	C ₄ "	<u>66</u>	
	4287		4287	

The total volume of hydrocarbons represents a recovery of about 900 lbs. from one ton of moisture and ash-free coal. BTX recovery is about 370 lbs. a ton vs. about 20 lbs. as originally obtained by conventional coal and coke technology. About 2000 million lbs. of C₁-C₄ gases a year are produced in the initial coal hydrogenation and subsequent refining operations. After processing the C₂-C₄ fractions plus the aromatics extraction raffinate to olefins and butadiene, it is believed that the C₁ fraction plus off-gases should be sufficient in quantity to provide most of the hydrogen requirements for the overall operation.

Other chemicals and fuels and their estimated value are shown in Table 10. The total value of all products from Tables 9 and 10 is \$153.5 million. The values are, we believe, conservative. Increased durenene or naphthalene production could add several million dollars to the total. The surplus heavy naphtha is credited at fuel value, whereas it could be a valuable source of other material such as decalin.

The overall material balance from coal to final products is shown in Table 12.

Table 13 shows the projected order of profitability of the refinery, using a rounded total product value of \$150 million. Basic hydrogenation and refining cost estimates are based on OCR contractor reports. The investments and operating costs for chemicals production are based largely on information provided by major petrochemical engineers. Depreciation is 15 years straight line. The return on investment after taxes is 8.5% and the pay-out time 6.6 years. This is for an operation processing about 55,000 barrels a day of synthetic crude oil and consuming via the H-coal or Consolidation Coal process about 4½ million tons of coal a year, moisture-free, ash-free basis. An operation twice this size, probably requiring an investment of about \$550 million would probably show a return of close to 10%.

In conclusion, it appears almost certain that the resurgence of coal as a chemical source could make several important contributions to our economy. It could aid in assuring self-sufficiency in energy resources, it could provide at low cost all the foreseeable requirements for what we now call petrochemicals for generations to come, and could also make available to industry new families of intermediates for fibers, plastics and chemical specialties.

Perhaps the most constructive production facility would be a two-purpose 100,000 bbls. a day refinery for both fuel and chemicals. Socio-economic factors would be important. Refineries could be located in distressed mining areas such as in Kentucky or West Virginia. Factors such as market demands, profitability data on individual items, freight charges, etc. could be integrated by computer to establish requisite optimum production schedules for overall maximum profitability. Finally, it should be noted that the extremely high polymethyl benzene content of coal naphtha reformat indicates

TABLE 12

OVERALL MATERIAL BALANCE FROM COAL TO ALL FINAL PRODUCTS* (per annum)						
		<u>MM lbs.</u>				
Input - Moisture, ash-free coal		8378				
Hydrogen		<u>695</u>				
		9073				
		<u>MM lbs.</u>	<u>MM lbs.</u>	<u>MM lbs.</u>		
Output:	Hydrogen	139	Benzene	382	Char-coke	1570
	Fuel gas	994	Toluene	474	H ₂ O	981
	Ethylene	585	C ₈ aromatics	707	H ₂ S	220
	Propylene	138	C ₉ + "	648	NH ₃	<u>99</u>
	Butadiene	370	Naphthalene	256		
	Butylene	<u>60</u>	Heavy naphtha	1228		2870
		2286	Fuel oil	<u>137</u>		
				3832		
	Total output:	2286				
				3832		
				2870		
	Unaccounted for			<u>85</u>		
				9074		

* Based on HRI "H Coal" hydrogenation procedure

TABLE 13

PROFITABILITY OF COAL CHEMICAL REFINERY*

	<u>MM \$</u>
Basic investment for naphtha production, including off-site	217
Investment for chemicals production	86.5
Additional off-site investment	<u>16.5</u>
	320
Operating costs estimated at \$74 MM.	

	MM \$
Product value	150
15 year depreciation	21.4
Operating costs	74
Gross profit	54.6
After tax profit	27.3
Return on investment after taxes	8.5%
Cash flow	48.7
Pay-out time	6.6 years

* Basic investment based on American Oil Report (Project 6120) to OCR. This report was an evaluation of the HRI "H Coal" project.

the possibility of producing premium 100+ octane fuel without recourse to lead. Many of these aromatics have research octane ratings exceeding 140.

Much work would, of course, be required to reduce many of these concepts to practice. Much more analytical data on process streams is needed. The fractionation of heavy naphtha would require considerable study to separate decalins and to the best of our knowledge, there are no available data on the reforming of decalin to naphthalene. The application of solvent extraction methods and fractionation techniques would have to be studied to recover the polycyclic aromatics. Analytical techniques must be refined.

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