



ZIMBABWE

INSTITUTE OF DEVELOPMENT STUDIES

ANALYSIS OF A PARTIAL BASE TRANSITION FOR
PETROLEUM ENERGY:

From Fossil Oil to Coal Synthetics

ZIDS WORKING PAPER #8

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ZIDS WORKING PAPERS

Introduction

The petroleum energy supply situation in Zimbabwe has imposed a serious financial, political and economic burden on Zimbabwe for the bulk of the past decade. This burden is the combined result of the Southern African geopolitics which includes wars of liberation, destabilization activities of South Africa, the pressure on limited foreign exchange resources by the high petroleum energy import bill, and the economic effects of fuel supply interruptions resulting from attacks on the oil supply networks.

These problems make it paramount for Zimbabwe to seek to develop alternative oil supply systems particularly those which have the effect of localizing control of the flow of petroleum energy into the Zimbabwean economy.

Notable efforts in this direction so far include the Triangle ethanol plant which produces 36 million litres per year of alcohol fuel, an effort in the early 80's to substitute imported oil for coal tar fuel from local coke works, and some attempt in the early 1960s to go into petrochemicals from coal. In the mass transit system railway electrification has been used to replace diesel electric traction on sections of the railway system.

Despite all these efforts, the role of foreign controlled petroleum energy in the economy remains predominant making Zimbabwe unaccountable for the supply of its own petroleum energy.

This paper is a preliminary analysis of one of the various options by which Zimbabwe can reduce its foreign dependance on liquid fuels. The option chosen for analysis is the coal liquefaction technology.

This is basically an arbitrary choice of the option but a well founded one in that Zimbabwe has an abundance of coal resources and that coal is generally regarded as the most viable transition fuel as the world moves from fossil fuels to more novel energy resources in the face of finite oil resources.

Specifically, this paper assesses the feasibility of coal conversion to light liquids and petrochemicals as a means of indigenizing that part of its petroleum energy requirements which Zimbabwe may find difficult to procure externally.

The analysis done in this paper is very preliminary but indicates that the majority of coal liquefaction technologies currently available are either designed for product slates which are not appropriate for Zimbabwe or do not utilize feedcoals which Zimbabwe would prefer to use for this purpose.

The only suitable technology is the indirect coal liquefaction (gasification - synthesis) process currently operating in South Africa as SASOL II.

Although commercial experience with this technology is limited to South Africa, the technology operates on the Fischer-Tropsch synthesis process and was supplied by the United States in terms of both hardware and construction engineering.

The best operating regime for this technology under the Zimbabwean demand structure for petroleum products would be a very high gasoline ratio in the product base with ammonia as the primary by-product.

The coal liquefaction option in general, however, is infeasible if compared with the import fuels option on a strict conventional project evaluation basis. If extended analysis involving risk and risk damage assessment is applied, the coal option is more desirable than the import option.

ANALYSIS OF A PARTIAL BASE TRANSITION FOR PETROLEUM ENERGY:

(From Fossil to Coal Synthetics)

R.S. MAYA

METHOD:

The historical relationship of petroleum energy utilization Y, and a set of its determinants, X, is analysed by regressing Y on variables X_1 , X_2 , and X_3 representing national population, per capita gross national product and the cost of imported oil respectively. These variables are aggregated measures of petroleum end-use activities levels. An engineering end-use analysis approach used to complement the econometric approach is described later in this paper.

The econometric analysis was based on the expectation that Y and the X set of variables would assume the following functional relationships:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 \quad (1)$$

Various regressions were run based on different combinations of the X variables. The best regression results are shown in Table 1 below.

A log form of the regression equation shown in Table 1 was used to perform econometric forecasts of petroleum requirements for the Zimbabwean Economy. To project the values for the forecasting

TABLE 1

BEST REGRESSION RESULTS

MTB > REGRESS C6 ON C\2,C3 PREDICTORS IN C2,C3,C4

THE REGRESSION EQUATION IS

$$C6 = -2366519 + 0.00208 C2 + 0.830 C3 - 121125 C4$$

COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	-2366519	1226661	-1.93
C2	0.002084	0.001393	1.50
C3	0.8297	0.4836	1.72
C4	-121125	56434	-2.15

S = 468077

R-SQUARED = 83.3 PERCENT

R-SQUARED = 82.0 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	3	1.658497E+13	5.528322E+12
RESIDUAL	13	2.848245E+12	219095777280
TOTAL	16	1.943321E+13	

CONTINUE

FURTHER ANALYSIS OF VARIANCE

SS EXPLAINED BY EACH VARIABLE WHEN ENTERED IN THE ORDER GIVEN

DUE TO	DF	SS
REGRESSION	3	1.658497E+13
C2	1	1.557506E+13
C3	1	614866392
C4	1	1.009208E+12

ROW	C2	Y C6	PRED. Y VALUE	ST. DEV. PRED. Y	RESIDUAL	ST. RES.
	2710000000	1230000	2385856	205110	-1158856	-2.75R

R DENOTES AN OBS. WITH A LARGE ST. RES.

DURBIN-WATSON STATISTIC = 2.57

MTB > WINTERVAL C2,C3,C4,C6

	N	ESTIMATED CENTER	ACHIEVED CONFIDENCE	INTERVAL
C2	17	1.067E+09	94.8	(9.55E+08, 1.23E+09)
C3	17	5700000	94.8	(5150000, 6300000)
C4	17	5.625	94.8	(3.340, 8.550)
C6	17	3945000	94.8	(3280000, 4530000)

MTB >

variable, X_1 and X_2 the compound growth equation:

$$X_n = X_0(1+r)^n \quad (2)$$

was used.

Where r = the rate of change for X .

n = the number of prediction intervals.

Petroleum prices were projected on the basis of three different possible scenarios to produce the three petroleum price schedules shown in Figure One. The first schedule was an indexation of petroleum prices to the world petroleum reserve life index and petroleum drilling ratios. Petroleum drilling ratios were estimated from field data for North Sea, the Gulf region, and North American exploratory drillings. Global oil reserve indexes were estimated by a simulation equation of the form:

$$R = (QD - QP)/pj. \quad (3)$$

R = Reserve life index, QD = cumulative discoveries,
 QP = Cumulative production, and pj = depletion rate.

Engineering estimates of Y were based on the end-use energy analysis approach. Without access to direct end-use device analyses, aggregated parameters shown in Table Two were used to emulate in-plant end-use device activity levels.

The utilization of petroleum energy was analyzed on the expectation that Y and its determinants would assume the following functional form under the end-use approach.

$$Y = f(u,s,k) \quad (4)$$

FIGURE I

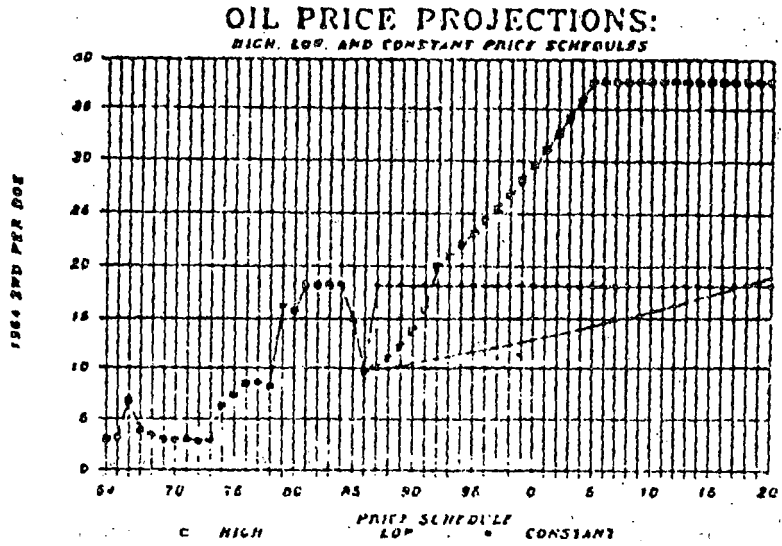


TABLE 2

BREAKDOWN OF ECONOMIC SUBSECTORS AND UNITS OF MEASUREMENT
FOR SECTORIAL ACTIVITY LEVELS

Subsector	Designation	Unit of Measurement
Personal Private		
Transport	S1	Vehicle Kilo Meters —VKM
Railway Transport	S2	Gross Ton Kilo Meters-TKM
Industrial/Commercial	S3	1964 Zimbabwe Dollars - \$
Agriculture	S4	1964 Zimbabwe Dollars - \$
Government Operations	S5	VKM Equivalent ———VKME
Air Transport	S6	Gross Ton Kilo Meters-TKM

All tons are in metric.

with the functional relationship

$$Y = usk.$$

Where u = the first law petroleum efficiency of activity, i.e. the coefficient of performance

s = end-use device or sector activity level

k = a set of operating conditions for a specified end-use device. This variable is excluded from the analysis because of the high level of aggregation in the available data.

From the above argument we get equation 5 which was used to forecast Y under conditions of static factor proportions.

$$Y = \sum_{i=1}^n u_i S_i \quad (5)$$

In this case it was assumed (a) that the petroleum intensity factors for S_i remained unchanged for the period of analysis. (b) that the factor proportions in the industrial and general economic activities remain static as well.

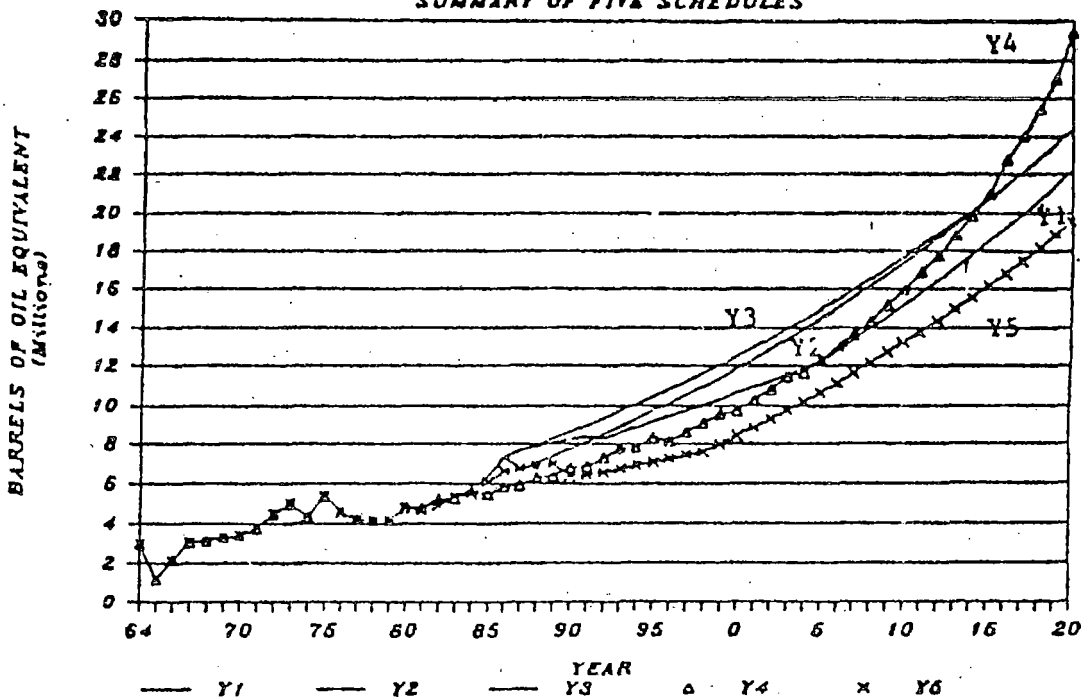
To incorporate dynamic intensity factors equation 6 was used.

$$Y = \sum_{i=1}^n \sum_{j=1}^n u_{ij} S_{ij} \quad (6)$$

Simulation results for the engineering approach, equation 5 and 6, and the econometric approach, the log form of equation 1, are given in figure Two. These are the projected petroleum energy requirements.

FIGURE 11

ESTIMATES OF PETROLEUM REQUIREMENTS
SUMMARY OF FIVE SCHEDULES



- Y1 = Econometric forecast based on high oil prices
- Y2 = Econometric forecasts based on constant oil prices
- Y3 = Econometric forecasts based on low oil prices
- Y4 = Enduse forecasts based on dynamic factor proportions
- Y5 = Enduse forecasts based on static factor proportions

ESTIMATING THE PETROLEUM ENERGY DEFICIT:

A shortfall in the supply of petroleum energy is likely to result if (a) sabotage on Zimbabwe's oil supply facilities occurs, (b) the cost of imported oil prohibits procurement of the required quantities of oil. Calling the required quantity of petroleum Z^* , previously Y , and the procured or "received" quantity Z , we have, in the event of a forced supply interruption, a supply deficit, Z_1 , such that

$$Z_1 = Z^* - Z \quad (7)$$

To offset Z_1 a quantity of petroleum energy, Z_2 , must be provided by alternative means such that $Z_1 = Z_2$ if the economy must continue to operate normally. And for a given period of time, t ,

$$Z_2 = \int_0^{\pi} dZ^*/dt - \int_0^{\pi} dZ/dt. \quad (8)$$

The deficit thus defined is shown in Figure Three. This is a cost based deficit. A deficit resulting from other causes of forced outage would be assessed by probabilistic methods as shown later in this paper.

The deficit offsetting alternative could take many forms. The easiest of these is a "housekeeping" response which involves most energy conservation, petroleum substitution and minor changes in the population's "life-style". Other alternatives involve fundamental alterations in the petroleum end-use technology base. e.g. introduction of new and more efficient end-use technologies, and adopting hitherto unconventional liquid fuels supply technologies. e.g. ethanol, methanol, and coal synthetics. All these options can be applied

to the elimination of Z_2 but with different costs and effectiveness. Because Zimbabwe has an abundance of coal and has itself considered the coal liquefaction option before, this study applies itself to the further examination of the coal liquefaction option.

The coal liquefaction industry has produced numerous technologies for the conversion of coalified hydrocarbons into light liquids and petrochemicals. [See Appendix I for a review of the coal liquefaction industry]. All these technologies are based on either direct coal liquefaction (ie. direct hydrogenation) or indirect liquefaction which basically is a gasification-synthesis technique. A variety of these technologies is given in the taxonomic summary of existing and developing coal liquefaction technologies in Figure Four. Flow diagrams and product slate summaries of three basic conversion processes, pyrolysis, direct hydrogenation, and indirect liquefaction are shown in Figure three.

From these processes best coal conversion technology for Zimbabwe was selected on the basis of equation 9 below,

$$U(A_i) = \prod wU(N_i) \quad (9)$$

Where : $U(A_i)$ = measure of appropriateness for technology i.

$U(N_i)$ = level of appropriateness for technology i on the
ith criterion.

w = scaling factor

N includes thermal efficiency of energy conversion, product ratio compatibility, product range, reliability factor, feedcoal compatibility, operation regime flexibility factor, and cost.

FIGURE III

TAXONOMIC SUMMARY OF COAL CONVERSIONS TECHNOLOGY

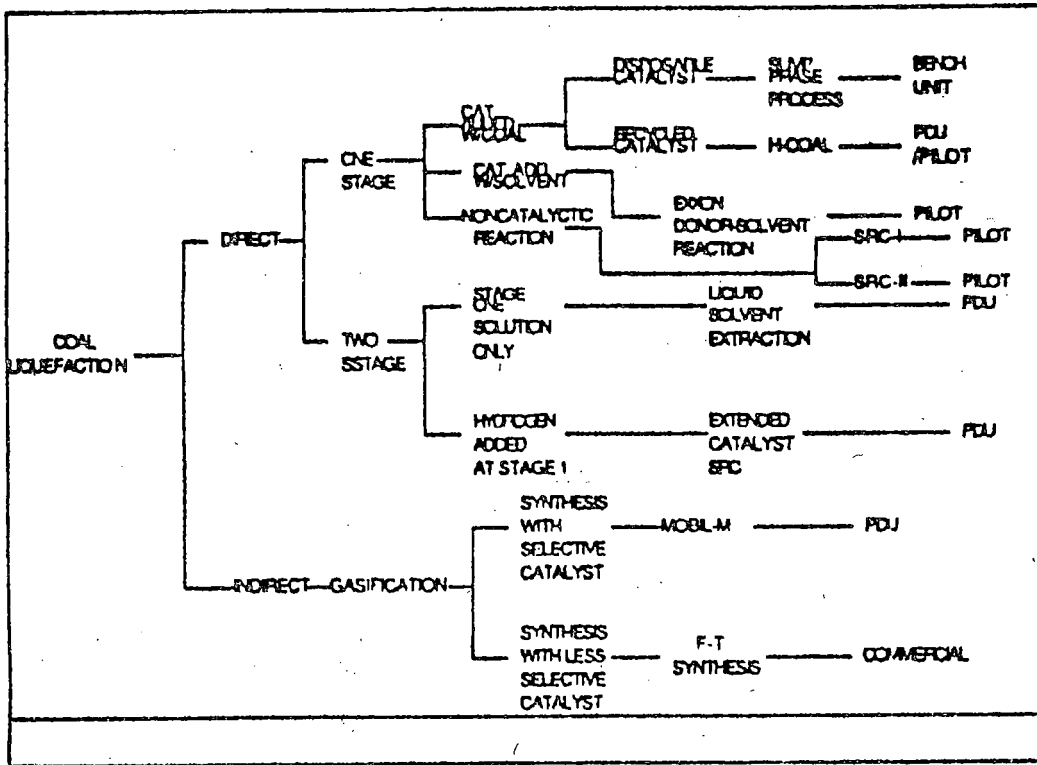
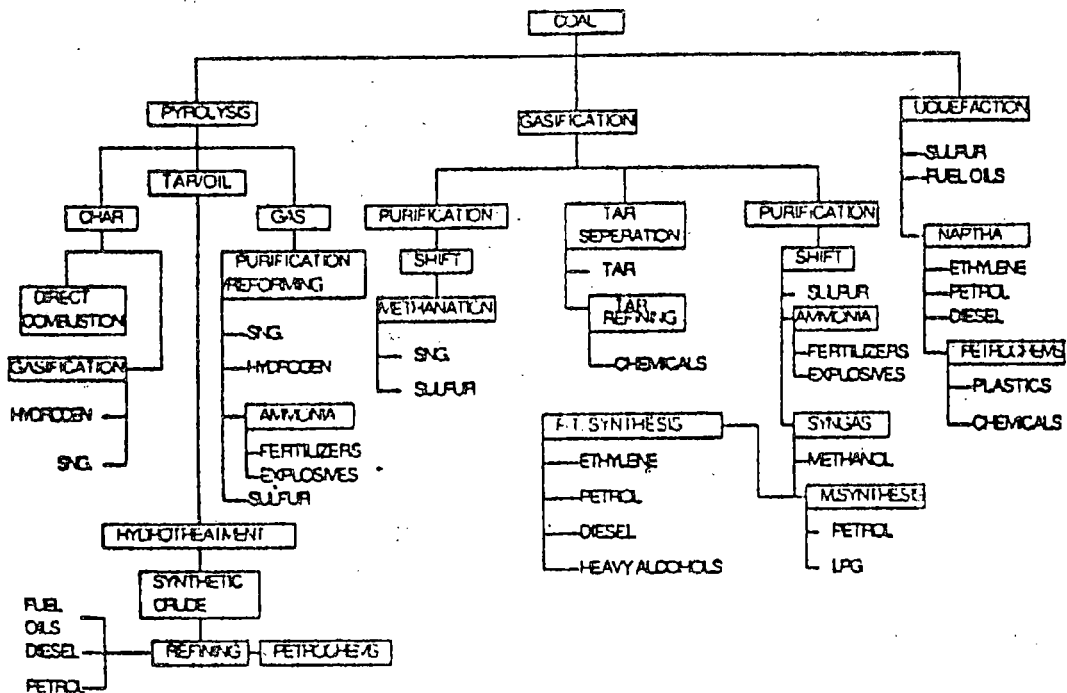


FIGURE IV

PROCESS AND PRODUCT SUMMARY FOR THE THREE BASIC COAL LIQUEFACTION PROCESS



Data for feedcoal compatibility analysis was based on available proximate and ultimate analyses of Zimbabwean coals, Table III. Design feed-coal compatibility for contending energy transformation technologies are analysed in Table IV.

The product slate criterion in equation 9 seeks to satisfy expected end-use product slate configurations in Zimbabwe. The present configurations are shown in Table V.

Analysis based on these conditions indicated that the Fischer-Tropsch Synthesis process as represented by the SASOL-II technology is most appropriate for Zimbabwe. This is mostly because of this technology's ability to utilize low grade coal and to have a significant amount of ammonia as a by-product. The direct liquefaction technologies although slightly lower in cost than the F-T Sasol process have a very narrow product range and are designed to utilize high grade "western" coals.

COMPARING F-T SYNTHESIS WITH THE FOSSIL OIL PRODUCTS ROUTE:

The previous analysis compared contending coal liquefaction technologies only. In this section we compare the best of these technologies with the existing oil supply technology --importing fossil oil products. We will call the existing option, option A, and the contending option, option B. To determine if it is better for Zimbabwe to stay with option A or to adopt option B for the supply of Z2 (the deficit) two approaches are used.

First we utilize conventional analysis for the comparison of two

ANALYSIS OF ZIMBABWEAN COALS

Deposit	Moisture	Carbon	Hydrogen	Oxygen	Sulphur	Nitrogen	Ash	Average Heat Value MJ/kg	Volatiles
MAKKE					2.3		35	24.7	25.6
EMTUBA	3.3	60.8	NDA	NDA	1.9	NDA	29.5	27.1	18.1
ELHAMATELA	NDA	NDA	NDA	NDA	NDA	NDA	7	NDA	14
DAHLA	NDA	74.0	6.1	17.1	1.0	1.8	20.5	31.0	7
HARARAO	NDA	NDA	NDA	NDA	NDA	NDA	35.0	20.0	7
LUSULU	NDA	NDA	NDA	NDA	NDA	NDA	40	18.3	7
LUBUNSI	NDA	60.5	2.7	7.3	1.1	1.1	4.7	28.7	NDA
LUBU & SEBUNGU	NDA	44.0	NDA	NDA	0.7	NDA	23.2	27.5	32
SENGWA	4.2	56.0	3.3	8.5	0.3	1.5	17.4	25.6	22.4
MAUSWITZ	1	50.0	NDA	NDA	NDA		38.0	20.4	11

TABLE 4
ANALYSIS OF FEEDCOAL COMPATIBILITY
FOR THE SHORT-LISTED LIQUEFACTION TECHNOLOGIES

TECHNOLOGY	MAIN PRODUCT	FEEDCOAL			
		LIGNITES		BITUMINOUS	
		HIGH GRADE	LOW GRADE	HIGH GRADE	LOW GRADE
H-COAL	G	48 - 52	NOT COMP	57 - 62	NOT COMP
	G-SNG	60	NOT COMP	60 - 65	NOT COMP
	D	48 - 52	NOT COMP	NA	NOT COMP
	D-SNG	NA	NOT COMP	NA	NOT COMP
SRC II	G	NDA	NOT COMP	NA	NOT COMP
	G-SNG	NDA	NOT COMP	NA	NOT COMP
	D	NDA	NOT COMP	NA	NOT COMP
	D-SNG	NDA	NOT COMP	NA	NOT COMP
	SNG-FUEL OIL			70	
SASOL II	G	47 - 52	34 - 37	47 - 52	46
	G-SNG	55	54 - 55	57 - 59	51 - 58
	D	NA	40 - 42	NA	44
	D-SNG	55 - 56	55 - 56	56 - 58	56 - 58
F-T SLA.	G	NOT COMP	49 - 56	NOT COMP	49 - 50

Source: European Community Survey. (23)

G = Gasoline SNG = Substitute Natural Gas D = Diesel
 NA = Technology is not available for specified conditions.
 NDA = No information available.
 F-T Sla. = F-T Slagger.
 Not Comp. = Not compatible with specified coal type.

TABLE 5

ANALYSIS OF PRODUCT SLATE CONFIGURATION - ENERGY BASIS

YEAR	MJ PRODUCT CONSUMED					PRODUCT SHARE OF MARKET			
	PTRL	DSL	PARA	LPG	SUM	PTRL	DSL	PARA	LPG
70	.711	.867	.251	.018	1.847	.39	.47	.14	.01
71	.790	.948	.292	.021	2.051	.39	.46	.14	.01
72	.936	1.14	.312	.024	2.412	.39	.47	.13	.01
73	1.003	1.27	.388	.027	2.689	.37	.47	.14	.01
74	.806	1.12	.399	.027	2.351	.34	.48	.17	.01
75	1.022	1.42	.423	.029	2.898	.35	.49	.16	.01
76	.829	1.26	.440	.034	2.560	.32	.49	.17	.01
77	.857	1.24	.400	.031	2.532	.34	.49	.16	.01
78	.812	1.32	.464	.030	2.624	.31	.50	.18	.01
79	.698	1.21	.336	.028	2.270	.31	.53	.15	.01
80	.806	1.29	.360	.026	2.485	.33	.52	.15	.01
SUM	9.270	13.08	4.073	.295	26.719				
AVERAGE						.35	.49	.15	.01

PTRL = Petrol, DSL = Diesel, PARA = Parafinns.

Source: Data Base from Ministry of Energy and Water Resources Development. Administrative Records.

projects, namely present value analysis. Because option A involves only the supply of petroleum products and option B includes a significant ratio of ammonia, we should remove the cost of ammonia from the present value of the coal option in order to achieve an unbiased comparison. The present value of the coal option, therefore, is:

$$PVB = \left\{ \left[K + \sum_{i=1}^n P_{cj} Q_{cj} + M \right] - \left[K_b + \sum_{i=1}^n P_{cj} Q_{bj} + M_b \right] \right\} / (1+i)^n \quad (10)$$

Where K = capital cost for the combined coal conversion plant

P_{cj} = the average cost of coal per ton in year j

Q_{cj} = the quantity of feedcoal used by the coal and by-products plant in year j

M_b = Operating and Maintenance costs ascribed to by-product.

M = operating and maintenance cost

K_b = quantity of feedcoal ascribed to by-product.

The present value for the import of fossil oil products is

$$PVA = \sum_{i=1}^n Y_j P_{oj} \quad (11)$$

Where P_{oj} = the unit cost of oil products in year j.

By this analysis the present value for coal synthetics is \$1.8 E9 deflated to \$1964 for year '0' = 1995. That for the fossil oil products option is \$9.8 E8 deflated to \$1964.

We must, however, incorporate into our analysis the problems of sabotage on oil facilities and the risk accompanying the decision to adopt or not to adopt coal liquefaction. This can be done by

risk and risk damage analysis.

Two basic sources of risk are attendant to the problem of choosing between the coal option and the fossil oil option. The first involves the probability of a negative product cost differentiation with respect to the oil supply option we may choose. The second risk involves the probability of sabotage or accident on oil transportation or storage facilities if we chose to remain with the import option. Assessment of these risks is summarized by event diagrams in figures Five and Six. The mathematical assessment of risk and risk consequence is summarized in equations 12 and 13 below.

$$D_c = P(Y).P(X_B > X_A).u.o.x1. \quad (12)$$

$$D_s = P(S).P(I).P(u).P(o)k-k1 \quad (13)$$

and for the joint probability of D_c and D_s ,

$$P(CS) (D_c + D_s).$$

Where: $P(Y)$ = the probability of a cost differential

X_B = the cost associated with option B.

X_A = the cost associated with option A

o = expected duration of condition $X_B > X_A$ and of u

u = expected magnitude of cost differential

S = sabotage or accident

$P(I)$ = probability that petroleum flow

interruption will result from S .

k = risk damage multiplier

$k1$ = risk damage mitigated by emergency fuel supplies.

FIGURE V

PROBABILITY TREE FOR ANALYZING THE RISK OF PRODUCTS COST DIFFERENTIATION

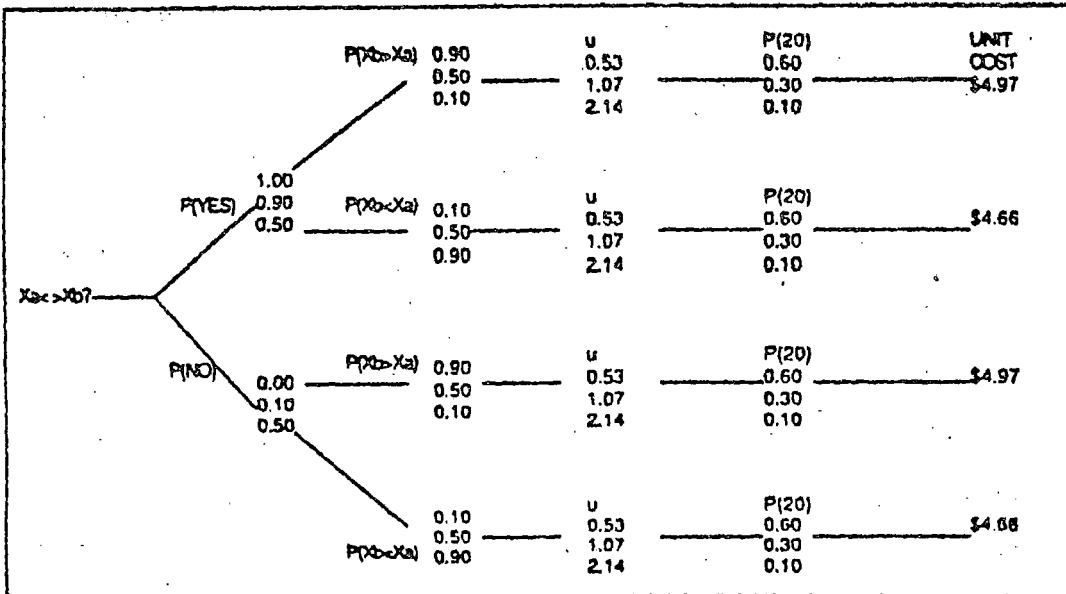
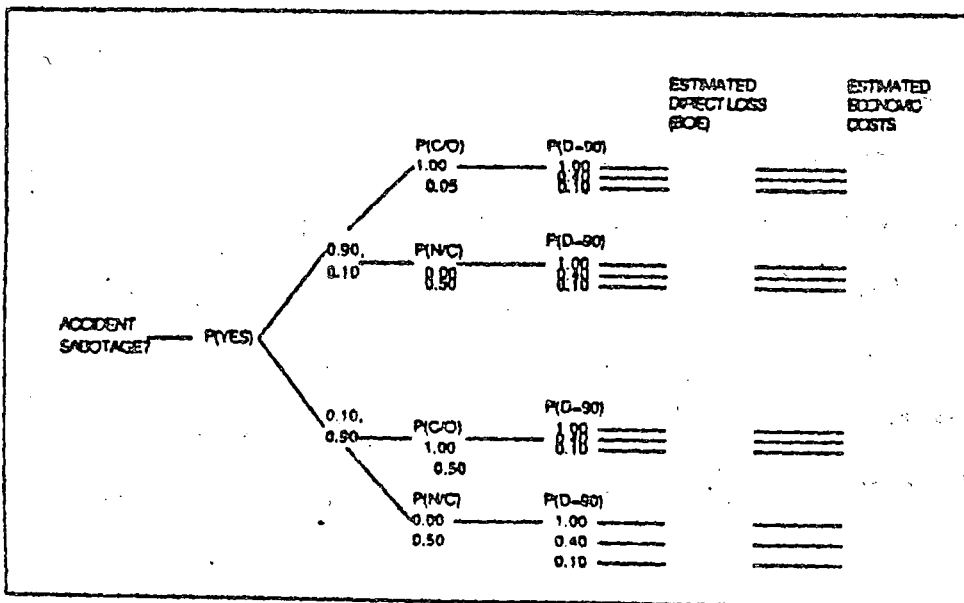


FIGURE VI

PROBABILITY TREE FOR ANALYSING THE RISK OF FORCED OIL SUPPLY INTERRUPTIONS



x1 = unit cost for petroleum energy supplied via option B.

Because the function of the cost differential, $P(XA < > XB)$, must exhibit a sinusoidal behaviour over time the actual damage expected from the risk of negative cost differentiation is the sum of compensating periodic differentiations in the cost. ie.

$$D_c = [P(Y)P(XB > XA)u.21P(21)c1] - [P(Y)P(XA > XB)u.21P(21)c2] \quad (14).$$

Combining this simulation equation with each set of possible outcomes in figures Five and Six will produce about 480 estimated values of risk damage. Such a large number of outcomes would be meaningless for policy purposed. Further probabilistic analysis was undertaken and a narrower range of outcomes was achieved as shown in Table six. From this range further analysis produced the estimates of damage shown below.

Damage of $P(XB > XA) = \$80. E6.$

Damage of $P(CS) = \$0.71 E9$

Damage of $P(S) = \$0.7 E9$

CONCLUSION AND RECOMMENDATIONS:

Of the wide range of coal conversion technologies currently in development or in industrial application, the F-T Synthesis indirect coal liquefaction technology is best suited for offsetting a possible petroleum energy deficit in Zimbabwe. However, conventional engineering economics based on present value analysis indicates that maintaining the fossil oil base for petroleum energy is better for Zimbabwe than making a transition to coal synthetics. Risk analysis incorporating forced systems outages and the possibility of negative product

TABLE IV

P(YES)	$P(X_A > X_B)$	$P(X_A < X_B)$	u	P(21)	UC	DAMAGE	
(1)							
1.00	0.90	--	--	0.53	0.60	4.97	313.0E6
1.00	0.90	--	--	2.14	0.60	4.97	1.3E9
1.00	--	0.90	0.90	0.53	0.60	4.66	-294.0E6
1.00	--	0.90	0.90	2.14	0.60	4.66	-1.22E9
(2)							
0.00	0.00	--	--	0.00	0.00	4.97	0.00E9
0.00	0.00	--	--	0.00	0.00	4.97	0.00E9
0.00	--	0.00	0.00	0.00	0.00	4.97	0.00E9
0.00	--	0.00	0.00	0.00	0.00	4.97	0.00E9
(3)							
0.50	0.10	--	--	0.53	0.10	4.97	2.90E6
0.50	0.10	--	--	2.14	0.10	4.97	11.7E6
0.50	--	0.10	0.10	0.53	0.10	4.66	-2.7E6
0.50	--	0.10	0.10	2.14	0.10	4.66	-11.0E6
(4)							
0.50	0.90	--	--	0.53	0.60	4.97	157.0E6
0.50	0.90	--	--	2.14	0.60	4.97	633.0E6
0.50	--	0.90	0.90	0.53	0.60	4.66	147.0E6
0.50	--	0.90	0.90	2.14	0.60	4.66	594.0E6

Line explanation of table VI-1:

1.1 reflects the top most branch of the event tree. If the scenario depicted on this branch prevailed, 1964 \$313.0 will be lost because of the decision to switch the liquid fuels base to coal synthetics.

cost differentials favours the adoption of the coal liquefaction option.

In view of the problems facing Zimbabwe today it is more appropriate to adopt the results of the later method of analysis than those of the earlier method.

However, the infancy of the coal liquefaction industry and the low probability of radical improvements in coal conversion technology, make it exceptionally risky for Zimbabwe to commit itself to any coal liquefaction technology under its present stage of development. Major breakthroughs must occur to make coal liquefaction less expensive and less risky than it is today.

Under these circumstances a cautious program involving continuous reviews of coal liquefaction technologies and effective training of coal conversion engineers and chemists is recommended in anticipation of an eventual transition to a coal base for liquid fuels world-wide.

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APPENDIX I

REVIEW OF THE COAL LIQUEFACTION INDUSTRY

General Definition of Coal Liquefaction:

Coal liquefaction is the conversion of coalified hydrocarbons into liquid hydrocarbons and associated compounds. The primary product is generally liquid fuels, the light liquids or heating oil, but varied ranges of other compounds, gases and petrochemicals are accompanying results of almost all currently known liquefaction processes and technologies.

Coal technologies vary widely in capabilities, cost, product orientation, origin and the degree to which they are being pursued for commercial application. Below is a brief review of the history of the industry and a detailed comparative analysis of selected processes and technologies.

Historical Overview of the Coal Liquefaction Industry:

The science of coal liquefaction has its historical base in Germany. Its processes development R&D is attributed to F. Bergius who developed high temperature, high pressure direct coal hydrogenation over the period 1910-1933 in Germany, and to Fischer and Tropsch who developed the catalytic indirect coal liquefaction process during the period 1923 to 1933, also in Germany. ⁽¹⁾

Industrial adaptation (scaling up) for both processes was exclusively

military for some time in the early history of the coal liquefaction industry. By 1939 Bergius's direct liquefaction process had passed into government control and was commissioned to the IG Farben Syndicate of Germany which by 1939 had set up and operationalized a 400,000 tons per year (TPY) oil plant in Germany.⁽²⁾ By the end of that year Germany was producing 1.4 million TPY of coal derivatives in oil and liquefied gas. By 1944 all aviation fuels for the Germany air force were produced from 18 direct hydrogenation plants with a total capacity of 4.0 million TPY synthetic crude.

Also during World War-Two Mitsui of Japan and the British Fuel Research in London independently pursued application of the direct hydrogenation process. The British produced 150,000 TPY liquids.⁽³⁾ The United States, responding to a post WW-II oil shortage allocated US\$87.6 million to synthetic fuels research over a period of 11 years but only managed to produce 73,000 barrels per year of gasoline from a converted ammonia plant in Louisiana, Montana.⁽⁴⁾

The indirect liquefaction process, now commonly known as the Fischer - Tropsch Synthesis process was applied in Germany parallel to direct hydrogenation, albeit at a lower industrial scale. Development and application of this process was controlled by Ruhrchemie. Plants were constructed in Germany and in France to produce mainly gasoline and diesel.

Since the World War, leadership in coal based synthetic fuels development has passed mostly to the United States which appears to have

leadership in research into almost all known processes and South Africa which has only current experience with commercial operations under the F-T Synthesis technology.

South Africa has maintained industrial/commercial operations of the F-T Synthesis process since 1954 when it built a 6000 TPD coal plant based on the Kellogg supplied Lurgi gasifiers and F-T synthesis units. Since then improvements on the Lurgi/F-T technology have been made under the name SASOL. A second and third plant has been built under the names Sasol II and Sasol III respectively. These plants are narrow range systems with gasoline as the main product. They operate under Kellogg Synthol reactors and F-T synthesis and have a combined capacity of about 100,000 TPD coal which gives the coal fuels industry about 60 per cent of the South African liquid fuels market, and a significant portion of the ammoniacal fertilizers market.

Although research and development work on the direct hydrogenation process is going on in many countries, the United States leads the rest with the H-Coal technology developed by Hydrocarbon Research International of New Jersey.⁽⁵⁾ Noyse p18]. Various other technologies are being pursued on the basis of the direct liquefaction process. Success and effort seems to be in the SRC (Solvent Refined Coal) process pioneered in the United States by Gulf Oil and being pursued as well by various other interests in the United States and elsewhere in the world.

Despite all the apparent effort in the coal synthetic fuels industry,

only the F-T based technology has been commercialized and very few other systems have passed the PDU (Process Development Unit) stage and an even smaller number has been piloted.

SUMMARY OF THE GENERAL COAL LIQUEFACTION PROCESS:

The basic process in coal liquefaction is the removal of ash and the raising of the hydrogen carbon ratio in the coal. Three basic processes for increasing the hydrogen carbon ratio are

1. direct coal hydrogenation (direct liquefaction),
2. indirect liquefaction, and
3. pyrolysis

Direct hydrogenation involves adding hydrogen directly to the coal under specific temperature and pressure conditions (generally 850 F and 2500 psi). In general this process increases the atomic hydrogen/carbon ratio by up to 2.5 times and yields synthetic crude and offgas as base products. From these products light liquids, fuel oils, and LPG can be derived by refining. Ammonia and methanol can be derived by farther treatment of the LPG. (6)

Indirect liquefaction is a two stage process involving coal gasification and synthesis, (gasification-synthesis process). The gasification stage produces a synthesis gas containing hydrogen, carbon monoxide, carbon dioxide, tars, and sulfur. Almost no ash is produced. The synthesis gas can be used as feedstock for producing various downstream products including SNG, ammonia, and through the F-T synthesis process, a wide range of light liquids and petrochemicals, as well as aromatics. The still experimental Mobil-M reactor if combined with the F-T process enables the production of olefins from the synthesis gas. (7)

Pyrolysis is a version of the carbonization coking process. It involves partial liquefaction for coal by heating it in the absence of air to break it down producing char as the main product and heavy liquids and gases as by products. This process has the wrong main product and an inherently low liquid yield.

NOTES TO APPENDIX

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6. Shultz, H.D. Ed. Coal Liquefaction Products: NMR Spectroscopic Characterization and Production Processes. John Wiley and Sons. Toronto 1983.
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