Chapter 5 Raw Materials and Their Uses

Chapter 5 Raw Materials and Their Uses

5.1 Coal

5.1.1 Zimbabwe's Coal Reserves

(1) Size of Reserves

Various studies have been conducted to date to ascertain the total reserves of coal lying in Zimbabwe, but while the existence of deposits has been confirmed, the picture still remains incomplete owing to insufficient exploratory drilling. Therefore, from amongst the data acquired during the field study, the latest report prepared by Montan Consulting has been chosen, and this report is the basis of the present analysis. According to this report, itself based on work done in 1983, total coal reserves in Zimbabwe amount to 10,571 million tonnes. The particulars have been summed up in Table I-5-1.

(2) Origin of Zimbabwe's Coal

The coal in Zimbabwe was formed by carbonification of plants which lived there in the Permian period (289 million to 247 million years ago, at the close of the Paleozoic era), when the region is believed to have been a part of the supercontinent of Gondwanaland. The coal is thought in origin to be the same as that found in India, in Australia and in South America.

The coal in Zimbabwe has been found in the Ecca formation, or overlying the bottommost bed within the Karroo series of rocks. The coal is said to be younger and of poorer quality when compared to coals found, for instance, in Europe.

(3) Regional Distribution of Coalfields

As has been indicated in Fig. I-5-1, areas in which the existence of coal has been confirmed all lie within the river basins of the Zambezi and the Limpopo, and their adjoining lands. Table I-5-1 shows figures for the estimation of coal reserves in each of the coalfields, and their respective proportions thought available to opencast mining. Among the coalfields, only the Wankie Coalfield has yet been exploited, and while there have been plans to open up the greenfield sites at Lubimbi and Sengwa, such plans are still incomplete in their details.

Table I-5-1 Estimation of Coal Reserve in Zimbabwe

Unit: Million T

	Probable Reserve	Opencastable Reserve
Wankie	655	324.8
Wankie western area	908	22.3
Entuba	167	65.4
Sinamatila	110	–
Dahlia	2,510	–
Hankano	127	–
Lubimbi	1,038	207.1
Lusulu	1,425	474.4
Lubu & sebungu	646	273.3
Kaoga & sessani	1,150	–
Nebiri & bari		–
Sengwa	1,038	384.3
Marowa	N.A.	–
Mkushwe*	N.A.	–
Malilongwe	N.A.	–
Bendezi	183	–
Dendere		–
Bubye	291	–
Singwesi		–
Umzingware	25	–
Massabi	102	–
Mkwasine	N.A.	196.3
Total	10,571	1,947.9

* May be same place as Mkwashine

Source : Montan Consulting '83

With regards the supply of feedstock coal for the present ammonia and urea production scheme, only the inexpensive coal worked out of opencast mines is considered, and because only the Wankie Coalfield has actually been mined, the supply source is restricted to the Wankie Coalfield. The amount of coal the plant requires, in all 7.2 million tonnes (an estimate based upon a thirty-year period of plant operation at an annual consumption rate of 240,000 tonnes), amounts to no more than 2.22% of the opencastable reserves (325 million tonnes) estimated to lie in the Wankie Coalfield.

(4) *Plans to Open Up New Greenfield Sites*

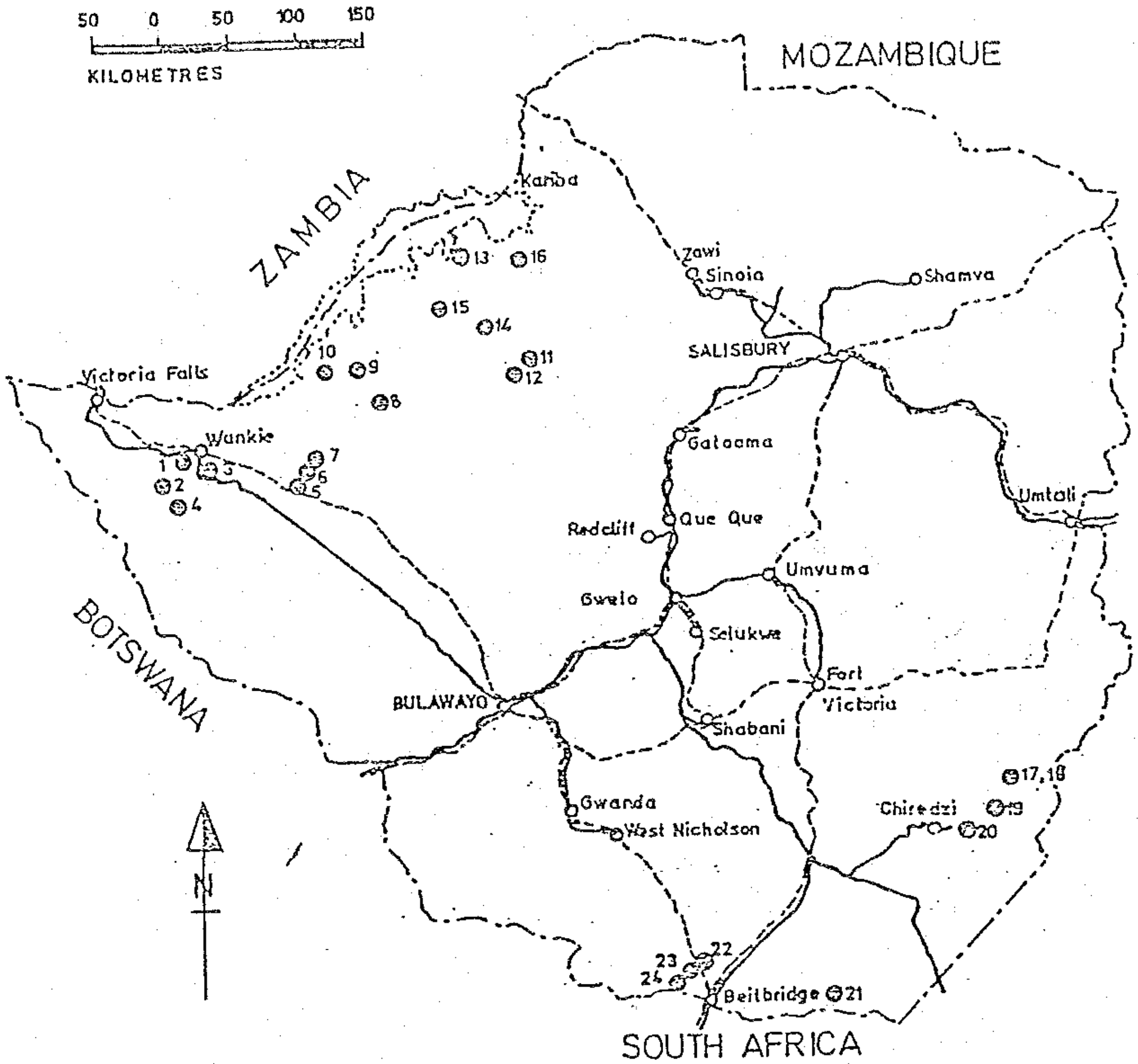
As mentioned before while the Wankie Coalfield has so far been the only field mined, those at Lubimbi and Sengwa hold promise of being exploited. An outline of the two coalfields is as below.

1) Lubimbi Coalfield

This greenfield site has been studied rather more closely than the others, and is held to constitute an excellent mining area which clearly is accessible to opencast mining. Of an estimated 207 million tonnes available to opencast mining, 23 million have now been confirmed. The coalfield is also thought to possess an estimated 830 million tonnes available for deepmining, producing a sum total of 1.037 milliard tonnes in reserves. An outstanding feature of this coalfield is that it is situated close to an existing railway line. The coal in the field is somewhat high in ash, but as its ash fusion temperature is low, at close to 1,150°C, it would find ready use for specific purposes such as coal gasification.

2) Sengwa Coalfield

This coalfield promises to yield relatively high-quality coal, and there have been hopes expressed both among the government of Zimbabwe and within industrial circles that it will be developed for mining. The field contains a coal seam ten to eleven metres in thickness, and is believed to contain 200 million tonnes of coal containing less than 20% ash and having a ratio of overburden to coal of less than 7:1, and an additional 100 million tonnes of coal containing 17.5% ash and showing an overburden ratio of less than 3.5:1. The field, however, despite its relative proximity to the industrial belt in the midland of Zimbabwe (comprising the districts of Gweru and Kwekwe), is far placed from existing railroads and trunk roads, so that either road or rail access would have to be constructed before it could be mined.



K E Y

1	Wankie	7	Lubimbi	13	Nebiri	19	Malilongwe
2	Western Areas	8	Lusulu	14	Bari	20	Benoezi
3	Entuba	9	Lubu	15	Sengwa	21	Busye
4	Sinamatila	10	Sebuncu	16	Marowa	22	Singwesi
5	Dahlia	11	Kaonga	17	Mkushwe	23	Umzingwani
6	Hankano	12	Sessami	18	Dendera	24	Massabi

International Boundaries
Railways
Main Roads
Kariba Lake Shore Line

Fig. I-5-1 Location of Coalfields

5.1.2 Outline of Wankie Colliery Company Limited (WANKIE)

(1) History and Development

The first request for mining authorization on the Wankie Coalfield was placed in 1894 by a German by the name of Albert Giese, and work on the coalfield was subsequently begun in 1899 by the Wankie (Rhodesia) Coal, Railway and Exploration Company. It was in 1903 that the first loads of coal were sent off bound for Bulawayo, and by 1914, an annual 250,000 tonnes of coal were being produced. Production increased rapidly in the years that followed, and by 1927 the annual output had exceeded a million tonnes. In addition to first colliery,No.2 colliery began operations in 1927, and then in 1953, No.3 colliery went into production.

Because safety having been doubted in No.1 colliery, it had been closed down in 1958, when a hydroelectric power plant was completed at the Kariba Dam, reducing the demand of coal for the purposes of power generation. An accident in 1972 further resulted in the closure of No.2 colliery that year. Meanwhile, in order to offset decreases in production resulting from the two closures, opencast mining have been initiated and work begun to mine No.4 colliery. No.4 colliery had however to be closed down, in 1981, owing to economic constraints.

Such having been the course of events, coal mining today concentrates mainly on opencast, while only coking coal is mined out from No.3 colliery. An investment of 128 million Zimbabwe dollars toward opencast operations was made in 1983, and new equipment purchased, including a 3,500-ton dragline. The Wankie Colliery as a result increased its production capacity, now becoming capable of a monthly output of 500,000 tonnes.

(2) No.3 colliery

Although the coal seam at Wankie is about 11 metres thick, the low-ash coal that is marketable is found in only a strip three or four metres in thickness at the bottom of the seam. In addition, the demand for coking coal at present is a comparatively large proportion of the market's demand overall. For these reasons, the overlying portions of the seam, with their high ash content, have been left standing and only the underlying strip of high-grade coal mined in No.3 colliery. Though only in coking coal, the colliery's production capacity still amounts to 70,000 tonnes a month. An inclined shaft leads out from the bottom to the surface, and the coal is raised to the surface by means of a conveyor belt.

(3) Opencast

Fig. I-5-2 roughly indicates the arrangement of coal seam and overburden within the opencast area of WANKIE. The coal seam, about 11 metres in thickness, lies under about 25 metres of overburden. The coal seam is not uniform in composition, but consists at the bottom of caking coal (with 9~12% ash and 28~30% volatile matter), and of low-grade steam coal (with 20~72% ash and 15% volatile matter) at the very top. A middle layer contains coal with 15% ash and 22% volatile matter, and in the intervening layers the quality of coals grades continuously upwards and below.

Opencast requires that the overburden be removed. As outlined in Fig. I-5-3, blastholes are first drilled down at the surface and charged with explosive. The overburden is then blasted and a dragline equipped with a bucket used to shift the loosened material to expose the underlying coal seam. The top layers of steam coal (for use as a power station fuel) are then excavated by power shovels, loaded onto dump lorries, and carried to conveyor belts.

Two sets of conveyor belts are in use at present: one set to convey coal to a coal preparation plant, and the other to transport coal to thermal power plants. The conveyors are each equipped with a shute, and the destination of the coal depends upon into which shute it is unloaded.

Today, almost all of the steam coal (found in the upper strip of the seam) is sent out to the thermal power plants.

Once all of the steam coal has been mined, the underlying high-grade 'commercial' coal — coal, that is, for the general market — is excavated using power shovels, then carried out by dump lorries to the conveyor belts, dispatched to the coal preparation plant, where among other things it is screened and sized and/or washed to be shipped out for the market.

Fig. I-5-4 shows a map of the area in which opencast operations have been planned for mining in the immediate future and near future. The area marked with individual colliery numbers (one through four) is that area in which mining have already been terminated. Plans have been made for the extension of No.3 colliery into No.3 North Area.

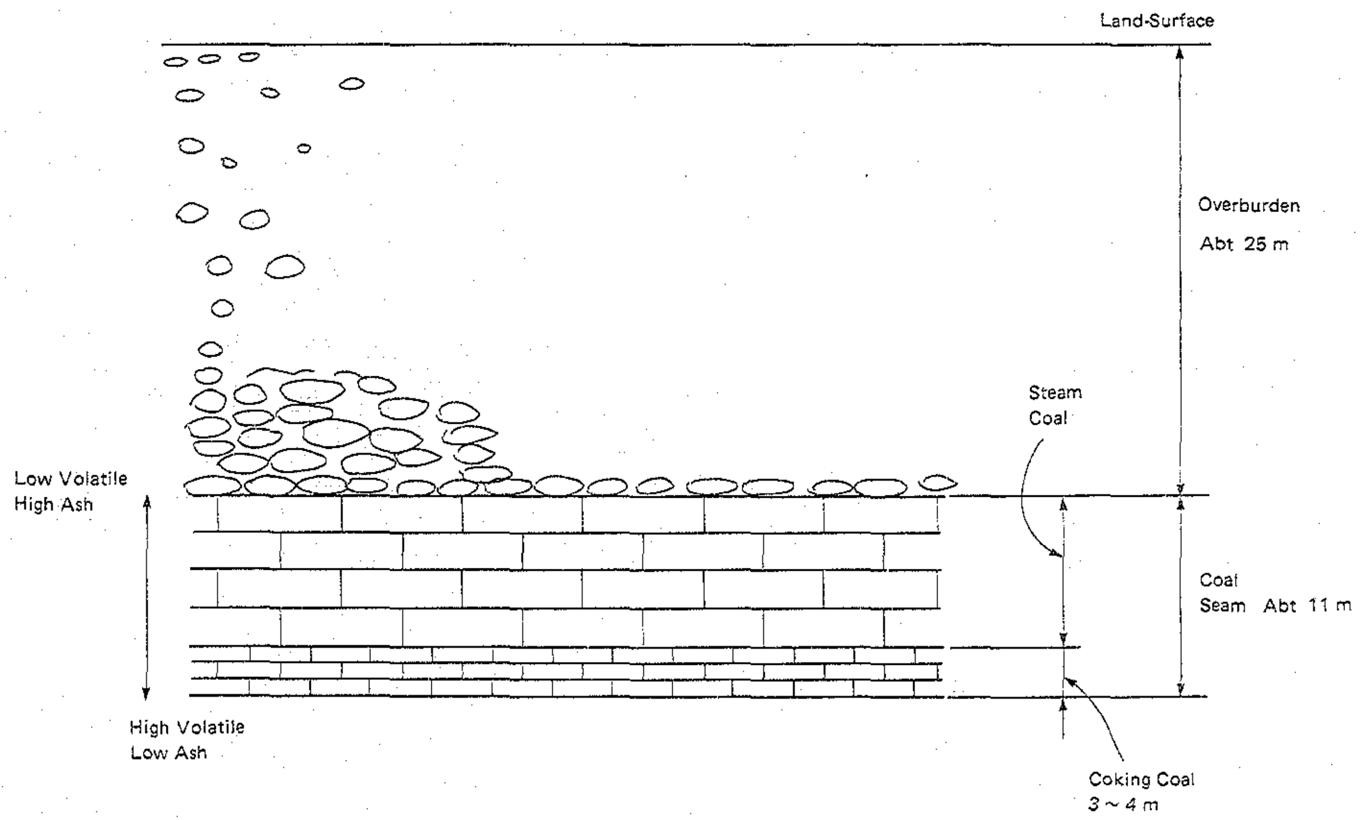


Fig. I-5-2 Coal Seam

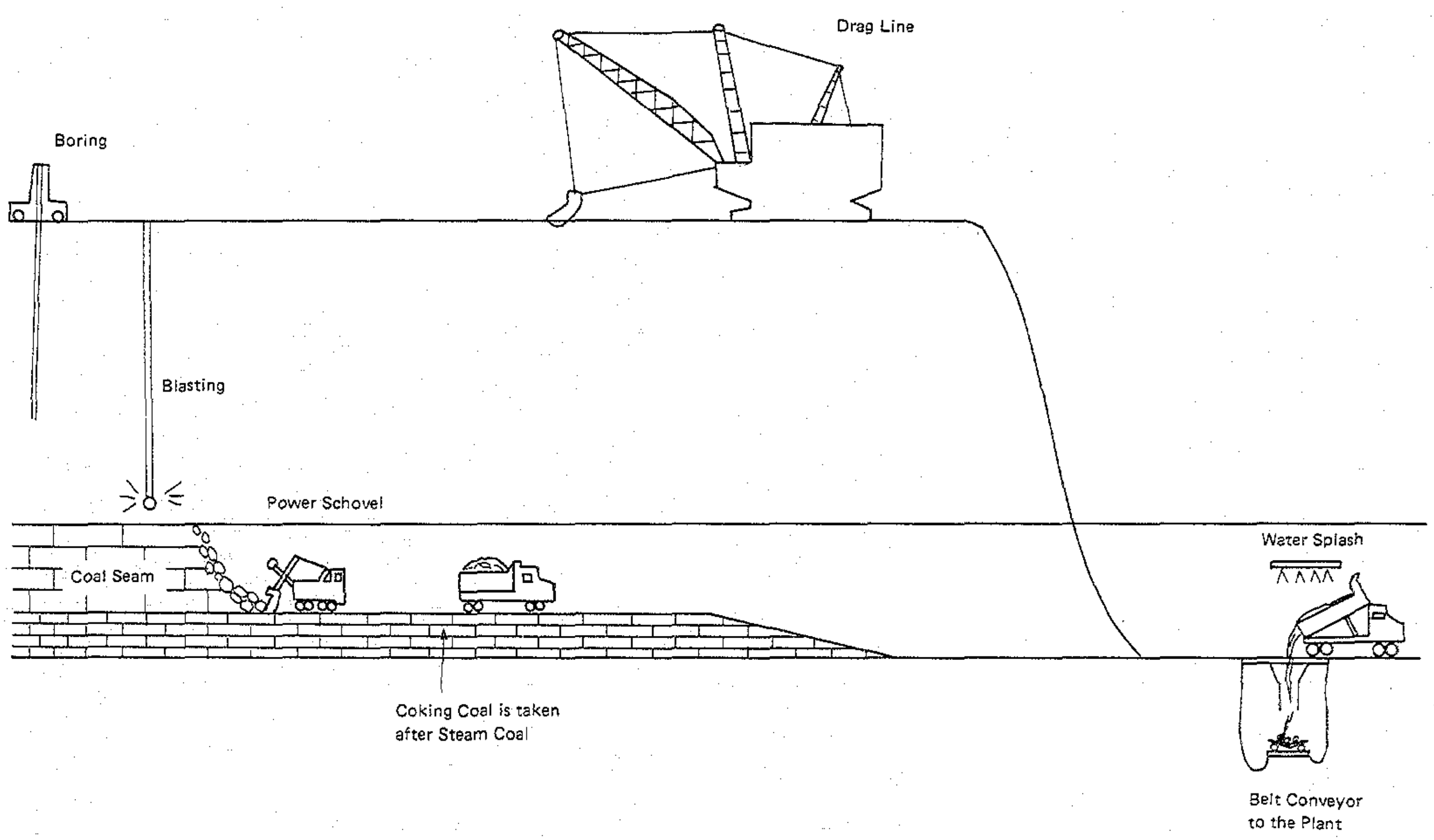


Fig. I-5-3 System of Opencast

(4) Reserves

An overall evaluation of coal reserves on the Wankie Coalfield has already been given in Table I-5-1, where opencastable reserves were given to be 325 million tonnes. Meanwhile, according to figures furnished by WANKIE itself, 174 million tonnes of power station coals (including coals with up to 19.3% volatile matter and 24.7% ash), and 78.7 million tonnes of marketable 'commercial' coal (including coals with up to 25.7% volatile matter and 11.7% ash) have been planned for opencast, while 66 million tonnes of caking coal (including coals with up to 27.3% volatile matter and 10.6% ash) will be mined out of No.3 colliery. These figures give a sum total of 318.7 million tonnes in opencastable coal, which is not far off from the figure given in Table I-5-1 (referred from Montan Consulting's report).

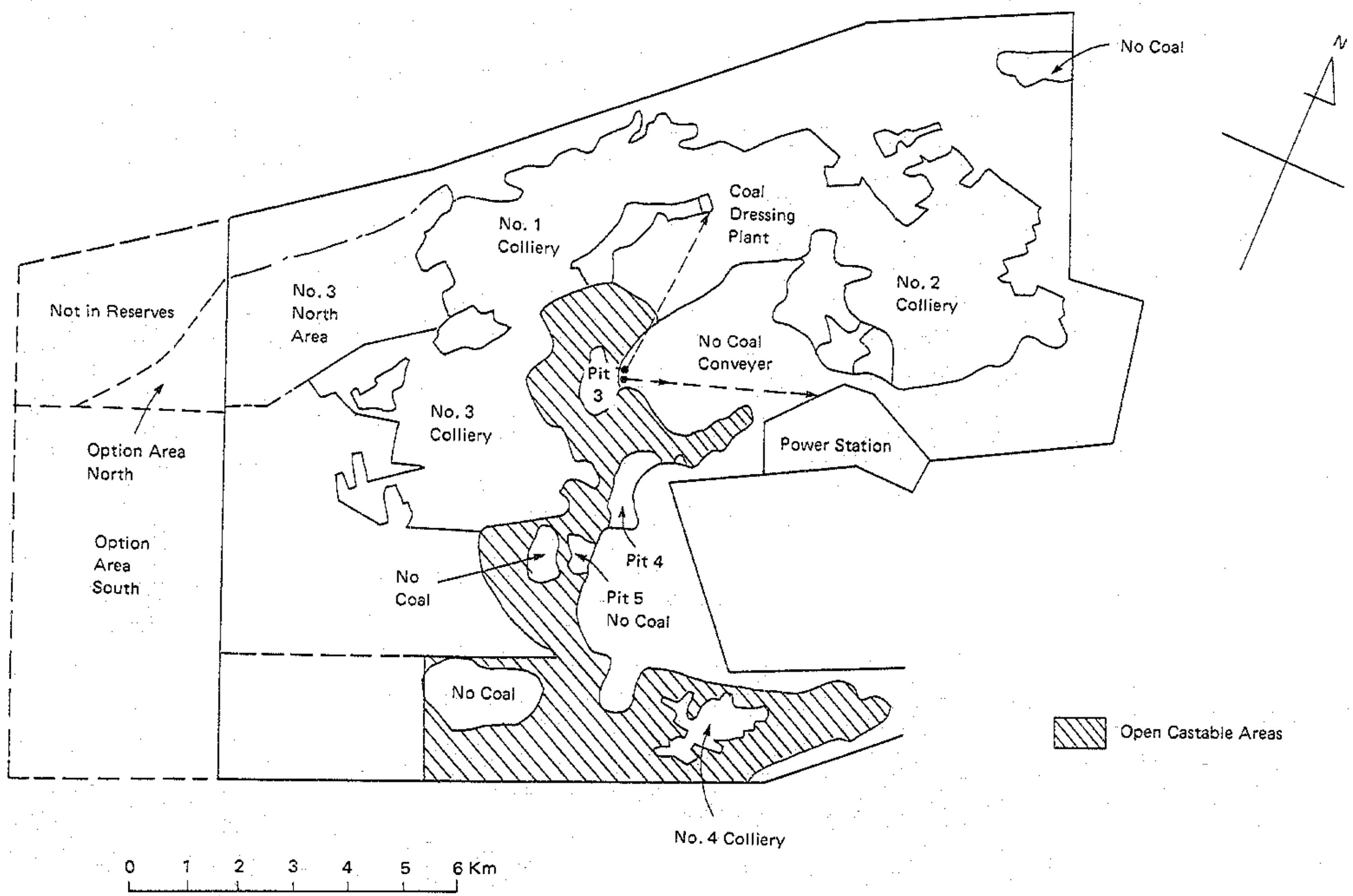


Fig. I-5-4 Wankie Colliery Opencastable Area
(Based on an Introduction to Wankie Colliery Co, Ltd. 1983)

(5) Supply of and Demand for Coal

1) The quality of coals

WANKIE sells the low-grade coal from the upper strip of its coal seam as power station coal to fuel the thermal power plants at Hwange, the high-quality coal in the lower portions of the coal seam as commercial coal, and coal from No.3 colliery as coking coal. The commercial coal is classified into three broad categories: run-of-mine coal; screened coals; and washed screened coals.

① Run-of-mine coal

Ash content : 14% average, 22% maximum

② Screened coals (Rounds, cobble, nuts, peas and duff)*

Ash content : 13% average, 18% maximum

③ Washed screened coals (Rounds, cobble, nuts, peas and duff)*

Ash content : 12% average, 15% maximum

Volatile content: more than 20%

*Note:

Rounds	> 100 (mm)	
Cobble	< 100	> 50 (dry)
	< 60	> 50 (wet)
Nuts	< 40	> 25
Peas	< 25	> 10
Duff	< 10	> 0.5

④ Coking coal

Ash content : 9% to 11%

Volatile matter : 24.5% to 25.5%

Phosphorus content : under 0.1%

Sulphur content : under 1.5%

Expands on heating

Particles under 0.5mm : 15% to 30%

⑤ Power station coals: specifications below by contract with the ZESA

a) Ash content : year-round average of under 25%

b) Calorific value : 24.75 MJ/kg

c) Volatile matter : year-round average of over 24.7% (DAF)

d) Hardgrove Index : 67 to 70

e) Ash fusion temperature : above 1250°C

2) The supply and demand for coal

The coal needs of Zimbabwe are entirely supplied by WANKIE.

① Coal production

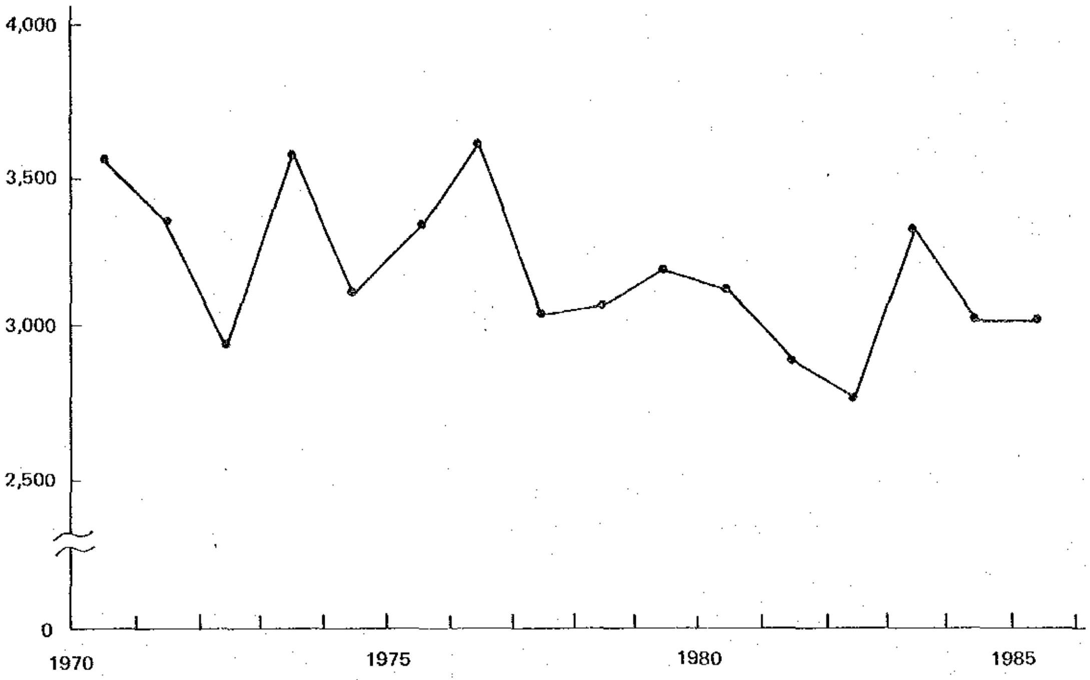
As earlier mentioned, WANKIE works its coal through opencast operations and from No.3 colliery. Of the opencast mined coal, there are for every tonne of commercial coal mined, approximately two tonnes of power station coal produced, which in terms of monthly output amounts to 130,000 tonnes of commercial coal and 260,000 tonnes of power station coal. However, the current production of power station coal is at the level of 170,000 ~ 200,000 T/M due to the shortage of demand. An additional monthly output of 70,000 tonnes of commercial coal comes from No.3 colliery. In all, therefore, the monthly output of coal, from opencast operations and from No.3 colliery amounts to 370,000 ~ 400,000 tonnes.

Meanwhile, at full capacity, the WANKIE could at present produce 500,000 tonnes of coal each month.

② The demand for coal

i) The demand for commercial coal

Fig. I-5-5 shows coal production by WANKIE before the year 1985, when the thermal power plants at Hwange came into operation, and may therefore be considered to describe the commercial demand for coal. This commercial demand began to gradually decline in 1970, until today in 1988, the sum demand for commercial coals has fallen as low as 200,000 tonnes a month, or 2.4 million tonnes a year. And this trend will continue.



Source: Statistical Year Book 1987 Zimbabwe

Fig. I-5-5 Coal Production between 1970~1985

ii) Although the gasification plant planned for use in an ammonia production plant may utilize different types of coal, considering that a high ash content in the feedstock would raise the costs of both constructing and operating the gasifier, plans are for using dry-grade coal (with an average ash content of 14%) from the opencast and facilities are designed as capable of using coals with up to 20% ash. With feedstock coal containing 14% ash, approximately 22,000 tonnes of commercial coal per month would be needed to produce a monthly 600 tonnes of ammonia. When the project goes under way, therefore, there will, in order to satisfy the overall demand for commercial coal, be a need to increase the opencast production rate of commercial coal from the current 130,000 tonnes per month to a monthly 152,000 tonnes, which is considered feasible. Run-of-mine coal has been chosen for use in the ammonia production scheme. This decision has been based an analysis of this coal, the results of which is shown in Table I-5-2.

Table I-5-2 Feedstock Coal for Design

Name	Run of Mine Coal	
Particle size		
50 mm pass	min. 99	wt%
Moisture as received	1.4	wt%
Proximate analysis		
Inherent moisture	1.5	wt%
Ash	13.8	wt%
Volatile matter	24.2	wt%
Fixed carbon	60.5	wt%
Gross heating value	7,090	kcal/kg
(Inherent moisture basis)		
Hardgrove grindability index	57	
Ultimate analysis (Dry basis)		
Ash	14.0 wt%	
Carbon	73.0	wt%
Hydrogen	3.8	wt%
Oxygen	5.28	wt%
Nitrogen	1.5	wt%
Inflammable sulphur	2.29	wt%
Total sulphur	2.40	wt%
Non flammable sulphur	0.11	wt%
Chlorine	0.021	wt%
Ash fusion temperature	Reducing	Oxidizing
Initial deformation temperature	1,100 °C	1,320 °C
Softening temperature	1,300°C	1,350°C
Hemispherical temperature	1,320°C	1,360°C
Fluid temperature	1,330°C	1,365°C

③ The demand for power station coal

According to 1987 annual report by the ZESA, the consumption rate of coal at the thermal power stations at Hwange in 1986/1987 was 130,000 tonnes per month. More recently, however, 170,000 to 200,000 tonnes of coal are being used every month to fuel the Hwange power stations, and when in future years the availability factor of the power stations should rise to about 80%, about 260,000 tonnes of steam coal may be expected to be needed every month.

The current opencast production ratio of coals between power-station and commercial use has been set at 2:1, so that an increase of 22,000 tonnes a month in commercial coal output to satisfy the feedstock needs, namely in total 152,000 tonnes a month production would entail an increase of 304,000 tonnes in power station coal production every month.

When 70,000 tonnes a month production from the No.3 colliery added on the above mentioned opencast production, total will be exceeded a little above existing production capacity of WANKIE, however slight modification of the production ratio between commercial coal and power station coal, the production of total coal demand after the project start will be supplied within 500,000 tonnes a month existing production capacity.

(6) Price of Coal

The price of coal sold by WANKIE has been fixed by an agreement with the government of Zimbabwe, although the agreement does not regulate detailed price differences in grade such as of size. Current prices are as listed in Table I-5-3. Although the various grades of coal cannot, strictly speaking, be assigned individual prices because they are series products, costs as have been indicated by the WANKIE have also been included in the table. These figures represent not only direct costs but also include other costs such as overhead and interest.

The cost of opencast coal is greatly affected by the amount of overburden. In order to maintain current production rates of 400,000 to 500,000 tonnes a month, the opencast site will have to be extended into areas with large amounts of overburden, so that, while it would be difficult to make accurate forecasts, the production costs of coal certainly must rise in the years to come.

Table I-5-3 Coal Cost and Price

Unit : Z$/T

	Cost	*Price
Power station coal for Hwange Power Station	11.84	13.41
Run of mine coal for domestic use	25.6	25
Run of mine coal for export	25.6	28
Washed coal for domestic use	28.41	29
Washed coal for export	28.41	32
Coking coal for domestic use	31.07	33
Coking coal for export	31.76	47
Metallurgic coke	112.9	130

Remark : * Price on rail at Thomson Junction except steam coal for Hwange Power Station.

Steam coal and high-grade commercial coal are mined from upper and lower strips of the same coal seam and so are in some sense co-products. Good-quality commercial coal can only be obtained from the bottom portions of the coal seam, and for this reason the production of steam coal is in excess of the demand for it. It is for this reason, and to increase the production of commercial coal, that No.3 colliery is mined only for its commercial coal, the upper portions of the coal seam being left to stand. Not only does this state of affairs represent wasteful resource management, but it also has a deleterious effect on the production costs of coal. WANKIE has not since 1985, when it concluded its first price agreement with the government, altered the price of its coals. Cost increases in the interim have however created a need raise prices, and the Company is at present negotiating for a price rise of about 10%.

5.1.3 Analyses and Assessment of Wankie Coals

(1) Object

In the project we have proposed to use WANKIE's *coals as a starting material, gasifying it* to form synthesis gas, and using this in its turn as raw material with which to manufacture ammonia and in some case methanol. And also utilization of coking coal from the Wankie Coalfield to evolve gas and the by-products coke and coal tar in a coke oven, and then use of this coke oven gas to produce ammonia, is studied as an alternative.

Applicability of the coals at Wankie to the process based on analysis of samples taken of Wankie's coals is assessed in Japan.

1) Assessment of coals as feedstock for gasification

Texaco's high pressure and temperature gasification procedure has been adopted for the project, as will be explained in detail in Volume II Chapter 2 of this report. The assessment has therefore been carried out to ascertain the suitability of Wankie's coals for this procedure.

① Coal analysis

A study was made with regards to the composition, ash fusion temperature, calorific value and grindability of the coals, and an evaluation made of the suitability of these coals as feedstock for the gasification procedure.

② Slurrying tests

In the Texaco procedure, coal is ground fine and made into a slurry with water, which is then sent on to the gasifier. A study was therefore made of the properties of the coal-water slurry in different mixtures.

Predicted conversion efficiency

③ The efficiency of converting coal to gas was predicted based on the results of the above-mentioned analyses, and then optimum gasification conditions and calculated gas output sought.

2) Assessment of coals as feedstock for the carbonization process

The following analyses were conducted in order to learn the properties of the gas, coke and coal tar, when coke ovens were charged with coals from Wankie Colliery as starting material:

① Proximate and ultimate analyses of the coals

② Destructive distillation to determine products yields, and the firmness and reactivity of the residual coke

③ Tests to determine the properties of the coke and coal-tar residues

④ *Tests to determine the composition and yields of the gases.*

(2) Choice of Samples for Analysis

As stated in section 5.1.2, the Wankie Colliery produces various coals with varying properties. Ten samples were chosen therefore for analysis and assessment. The samples have been listed in Table I-5-4.

Tables I-5-5 and 6 further give the results, furnished by WANKIE, of analyses done from March to June 1988 on the various coals extracted from the coalfield.

(3) Analysis and Assessment of Coals for Purposes of Gasification

The following coals were assessed for the gasification procedure:

Power station coal	Sample 1
Run of mine coal (high-sulphur)	Samples 2 and 3
Run of mine coal (low-sulphur)	Sample 4
Screened coal	Sample 5
Washed and screened coal	Samples 6, 7 and 8

1) Results of analysis and the assessment of coals

Table I-5-7 carries the results for a proximate analysis, for gross calorific values, for an ultimate analysis, for ash fusion temperatures, ash composition, Hardgrove grindability indices, and for crucible swelling numbers.

Table I-5-4 List of Coal Sample

Sample No.	Remarks	
1.	Power Station Coal	For Power Station
2.	Run of mine coal	High Sulphur Coal
3.	Run of mine coal	High Sulphur Coal
4.	Run of mine coal	Low Sulphur Coal
5.	Screened coal (Peas)	
6.	Washed, Screened coal (Duff)	
7.	Washed, Screened coal (Duff)	
8.	Washed, Screened coal (Peas)	
9.	Coking Coal	High Sulphur
10.	Coking Coal	Low Sulphur
Blended Coal (For reference)	Blended Coking Coal (Japanese source)	

Table I-5-5 Quality of Coal

Run of mine coal

	Rounds			Cobbles			N.P.D.		
	Ash	VM	CV	Ash	VM	CV	Ash	VM	CV
Hi	13.4	27.3	30.04	13.3	26.6	30.09	13.3	26.7	30.09
Lo	12.7	25.0	30.36	12.5	25.3	30.45	12.1	25.7	30.63
Ave.	13.0	26.1	30.22	12.9	25.8	30.27	12.9	26.2	30.27

Run of mine coal

	Cobbles			N.P.D.		
	Ash	VM	CV	Ash	VM	CV
Hi	13.4	29.6	30.04	13.6	30.4	29.95
Lo	12.4	28.4	30.50	12.5	29.3	30.45
Ave.	12.9	29.2	30.27	13.1	29.9	30.18

– Note –

N.P.D.: Nuts/Peas/Duff

Ash: Ash %

VM: Volatile Matter

CV: Calorific Value MJ/kg

Screened coal

	Peas			Nuts		
	Ash	VM	CV	Ash	VM	CV
Hi	14.0	26.1	29.77	13.7	26.4	29.90
Lo	13.1	25.2	30.18	12.8	25.0	30.31
Ave.	13.4	25.5	30.04	13.0	25.9	30.22

Washed and screened coal

	Cobbles			Nuts			Peas			Coking Coal		
	Ash	VM	CV	Ash	VM	CV	Ash	VM	CV	Ash	VM	CV
Hi	10.6	28.7	31.32	10.7	28.9	31.27	10.5	28.7	31.36	9.9	27.0	31.6
Lo	10.3	27.0	31.45	10.2	26.8	31.50	9.9	27.0	31.64	9.5	26.3	31.82
Ave.	10.4	28.1	31.41	10.5	28.0	31.36	10.3	28.0	31.45	9.7	26.6	31.7

Table I-5-6 Sulphur and Phosphate Content

1987/88

	Raw Coal				Z.I.S.C.O. Coking Coal		Wet Peas
	No. 3 Colliery		Opencast				
	S%	P%	S%	P%	S%	P%	S%
Hi	3.86	0.015	2.68	0.022	1.36	0.019	2.73
Lo	2.50	0.011	1.71	0.012	1.25	0.013	1.73
Ave.	3.20	0.013	2.34	0.018	1.31	0.16	2.34

1988/89

	Raw Coal				Z.I.S.C.O. Coking Coal		Wet Peas
	No. 3 Colliery		Opencast				
	S%	P%	S%	P%	S%	P%	S%
Hi	3.70	0.014	2.38	0.025	1.41	0.020	2.82
Lo	3.25	0.011	1.91	0.018	1.29	0.014	2.32
Ave.	3.43	0.013	2.18	0.022	1.35	0.017	2.48

Table I-5-7 Analysis of Coal

Number of Coal		No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
1. Total Moisture (Received Basis)	wt%	1.4	1.1	1.0	1.3	1.1	1.0	1.1	1.0
2. Proximate Analysis									
(1) Inherent Moisture	wt%	1.8	1.2	1.3	1.5	1.4	1.2	1.2	1.2
(2) Ash	wt%	37.2	11.1	11.9	14.4	13.8	7.5	7.0	9.1
(3) Volatile Matter	wt%	17.5	28.6	28.0	24.2	23.8	30.4	30.7	29.7
(4) Fixed Carbon	wt%	43.5	59.1	58.8	59.9	61.0	60.9	61.1	60.0
3. Gross Heating Value (Inherent Moisture Basis)	kcal/kg	4.700	7.440	7.270	7.020	7.090	7.760	7.820	7.620
4. Hardgrove Grindability Index	-	78	57	57	64	60	59	60	56
5. Crucible Swelling Number	-	1/2	1	1 1/2	1/2	1	5 1/2	6 1/2	1 1/2
6. Ultimate Analysis (Dry Basis)									
(1) Ash	wt%	37.9	11.2	12.1	14.6	14.0	7.6	7.1	9.2
(2) Carbon	wt%	50.7	75.7	75.4	72.9	73.1	79.9	80.3	78.4
(3) Hydrogen	wt%	2.7	4.3	4.3	3.7	3.8	4.6	4.6	4.4
(4) Oxygen	wt%	6.2	4.6	4.6	5.5	5.4	4.8	5.0	5.2
(5) Nitrogen	wt%	1.1	1.6	1.5	1.6	1.5	1.7	1.6	1.5
(6) Inflammable Sulfur	wt%	1.40	2.47	2.13	1.71	2.18	1.38	1.37	1.33
(7) Total Sulfur	wt%	1.42	2.58	2.25	1.83	2.28	1.44	1.44	1.43
(8) Nonflammable Sulfur	wt%	0.02	0.11	0.12	0.12	0.10	0.06	0.07	0.10
(9) Chlorine	wt%	0.021	0.021	0.014	0.014	0.021	0.021	0.021	0.014
(10) Fluorine	wt%	0.013	0.014	0.015	0.012	0.012	0.015	0.009	0.009
7. Ash Mineral Analysis									
(1) SiO2	wt%	55.12	35.25	38.97	40.60	44.08	44.80	43.56	42.78
(2) Al2O3	wt%	30.90	21.70	22.48	23.40	24.80	28.76	28.25	27.40
(3) Fe2O3	wt%	8.00	19.00	16.10	13.70	18.50	3.30	2.70	4.92
(4) CaO	wt%	0.90	10.80	10.17	11.90	6.60	9.50	9.10	10.83
(5) MgO	wt%	0.50	0.80	1.36	1.10	0.70	0.70	1.30	1.00
(6) SO3	wt%	0.16	2.48	2.56	1.99	1.71	2.13	2.61	2.82
(7) P2O5	wt%	0.80	0.35	0.40	0.33	0.30	0.35	0.35	0.30
(8) TiO2	wt%	2.10	1.10	1.17	1.43	1.37	1.58	1.66	1.30
(9) Na2O	wt%	0.25	1.85	1.50	0.85	1.10	1.85	1.70	1.72
(10) K2O	wt%	0.70	0.38	0.40	0.30	0.30	0.50	0.58	0.55
8. Ash Fusion Temperature		RT (OT)	RT (OT)		RT (OT)	RT (OT)	RT (OT)		
(1) Initial Deformation Temperature	℃	1.430 (1.550)	1.100 (1.320)		1.260 (1.330)	1.170 (1.310)	1.350 (1.370)		
(2) Softening Temperature	℃	1.580 (1.600)	1.300 (1.350)		1.330 (1.340)	1.240 (1.330)	1.380 (1.400)		
(3) Hemispherical Temperature	℃	1.590 (1.605)	1.320 (1.360)		1.350 (1.350)	1.260 (1.340)	1.390 (1.410)		
(4) Fluid Temperature	℃	>1.600 (>1.610)	1.330 (1.365)		1.390 (1.370)	1.310 (1.350)	1.420 (1.420)		

RT : Reducing , (OT) : Oxidizing

① Proximate analysis

Inherent moisture content: The greater the degree of coalification, the less the water content is of a coal; and the less the water content in a coal, the better slurry are resulted in general. WANKIE's coals are relatively low in moisture content, ranging from 1.0 to 1.4%, and should therefore present no problem in handling as a slurry.

Volatile-matter and fixed carbon content: In general, as coalification proceeds, the gaseous content of a coal is reduced while the fixed carbon increases. The ratio of fixed carbon to volatile matter is called the fuel ratio. WANKIE's coals, with fuel ratios ranging from 2.0 to 2.5, rank as medium-volatile bituminous coals.

Ash content: Ash content does not directly affect the gasification reaction. A high ash content in coal, however, generally means poor slurrying properties, so that the choice of suitable additives becomes a critical issue. It furthermore involves higher capital costs from having to install appropriate ash removal equipment.

Sample 1 can be used but is not preferable.

② Gross heating value

The gross heating value (GHV) of coal greatly alters the calorific value of a unit charge of feedstock but does not affect the gasification reaction itself. In the gasification procedure we would be using, the standard GHV has been set to between 6,700 and 7,200 kcal per kilogramme of coal. In this respect, Wankie's coals are highly suitable.

Sample 1, although it can be used, would give the unit charge of feedstock a poor calorific value.

③ Ultimate analysis

Carbon: The carbon content in the samples, excluding Sample 1, ranges from 82 to 87%, placing the samples on the coalification scale as bituminous coals.

Hydrogen: The samples, excluding Sample 1, have a hydrogen content ranging from 3.7 to 4.6% and are therefore typically bituminous.

Nitrogen: In the coal gasification reaction, 30 to 40% of the nitrogen contained in the coal goes to form ammonia, a part of which then goes on to form cyanogen. The ammonia generated in the gasification process reacts, in the later stages of the process, with carbon dioxide, forming ammonium bicarbonate and ammonium carbamate, substances which have adverse effects such as lead to the occlusion of pipes and vessels. The nitrogen content of the coal samples, however, ranges from 1.1 to 1.7% — standard values which ought not pose any significant problem.

Sulphur: The sulphur contained in the coal will in the gasification reaction react to form hydrogen sulphide, in the form in which it would be removed and recovered using desulphurising equipment. Wankie's coals are high in sulphur, in comparison to standard coals, such that the desulphurising facilities would have to be larger than usual. Apart from this, however, there ought not to be any significant problem.

Chlorine: Subsequent to the gasification reaction, part of the chlorine in the coal would be expelled from the system in the form of a solid, along with the slag, and would dissolve in the circulating water, and so provide a potential cause of corrosion of equipment. The chlorine content of the sample coals — at 140 to 210 ppm — is slightly higher than in standard coals, so that there would be a need to design equipment which would stand for this high chlorine content.

④ Ash fusion temperature

Texaco's gasification procedure is carried out at temperatures that are above the ash fusion temperature of feedstock coal. For this reason, the lower the fluid temperature, F.T., the lower would be the gas temperature, and the smaller would be the unit charges of coal and oxygen feedstocks, thus lengthening the lifetime of the fire brick within the furnace.

In order to maintain uniform temperatures within the reaction chamber, furthermore, it is desirable that the difference between the initial deformation temperature and the fluid temperature of the coal be small.

Fluidized temperatures for Wankie's coals are relatively high, and in the case of Sample 1 specifically, it is greater than 1,600°C. These high temperatures necessitate the addition of calcium carbonate ($CaCO_3$) in order to lower the fusion point of ash. Ash fusion temperatures with the addition of calcium carbonate under reducing conditions are as follows:

	Sample 1		Sample 6	
Percent addition of $CaCO_3$	10%	20%	10%	20%
Initial deformation temperature (°C)	1,300	1,350	1,400	1,290
Softening temperature (°C)	1,360	1,360	1,410	1,310
Hemispherical temperature (°C)	1,400	1,370	1,420	1,370
Fluidized temperature (°C)	1,500	1,400	1,440	1,380

⑤ Composition of ash

The composition of ash affects the fusion temperature of the ash. The melting point is raised in the presence of high contents of such acid components as silicon dioxide (SiO_2)and aluminium oxide (Al_2O_3), while it is lowered in the presence of high concentrations of such basic components as ferric oxide (Fe_2O_3), calcium oxide (CaO) magnesium oxide (MgO), sodium oxide (Na_2O), and potassium oxide (K_2O). The ratio of the concentrations of acid and basic constituents is called the 'acidity coefficient', and is expressed by the following formula.

$$\text{acidity coefficient} = \frac{SiO_2 + Al_2O_3}{Fe_2O_3 + CaO + MgO}$$

An acidity coefficient of 1.0 means that the coal has a relative low ash fusion point, while a value of over 5, means the fusion point over 1,350°C. Increased concentrations of ferric oxide and sodium oxide cause shorter brick life. Wankie's coals have high acidity concentrations and it would be therefore desirable to use basic substances which would lower the fusion point.

⑥ Hardgrove grindability index (H.G.I.)

The Hardgrove grindability index is a measure of the ease with which a coal may be crushed, and the higher its value, the more easily may the coal be ground. Wankie's coals have indices ranging from 56 to 78 and are generally very easily ground.

⑦ Crucible swelling number

The crucible swelling number is a measure of a coal's capacity to coke. Higher values indicate stronger coking properties. Coking capacity is of importance in the Texaco furnace, in which the coal is gasified instantly. Samples 6 and 7 have large indices and therefore possess the capacity to coke. The other six samples, however, have indices ranging from 1.5 and 0.5 and are non-coking coals.

2) The slurrying properties of the coal samples

In Texaco's procedure, the feedstock coal is first pulverized and then fed into the gasifiers in the form of a coal-water slurry. The important properties of this slurry are: particle size distribution, concentration of coal, viscosity, flowability, and stability. With regards particle size distribution, we have used in the tests the standard particle size distribution given for Texaco's slurries. Tests were conducted on the following five samples:

Sample 1 Power station coal

Sample 2 Run of mine coal

Sample 4 Run of mine coal

Sample 5 Screened coal

Sample 6 Washed screened coal

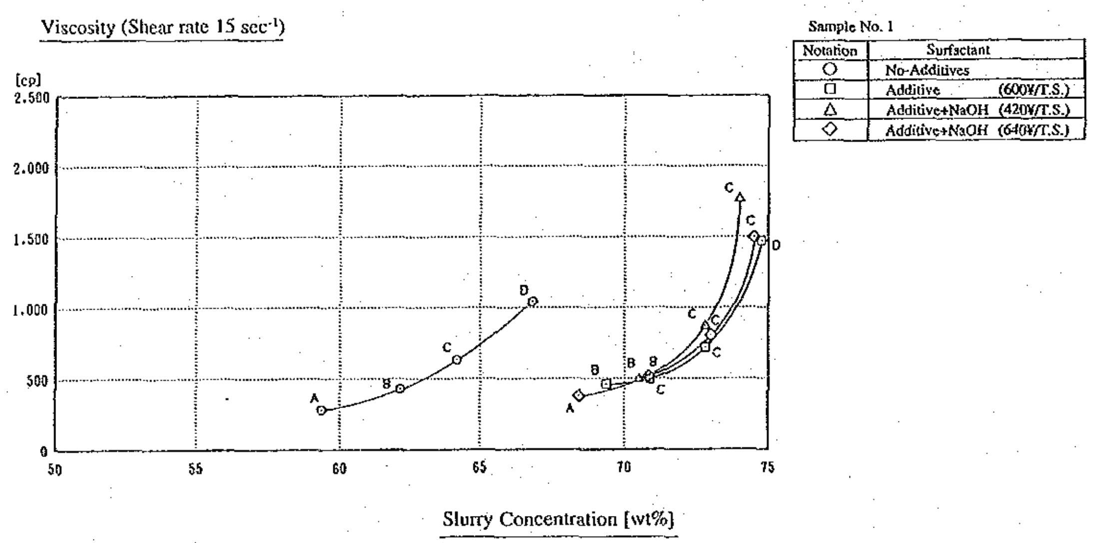
① Test results

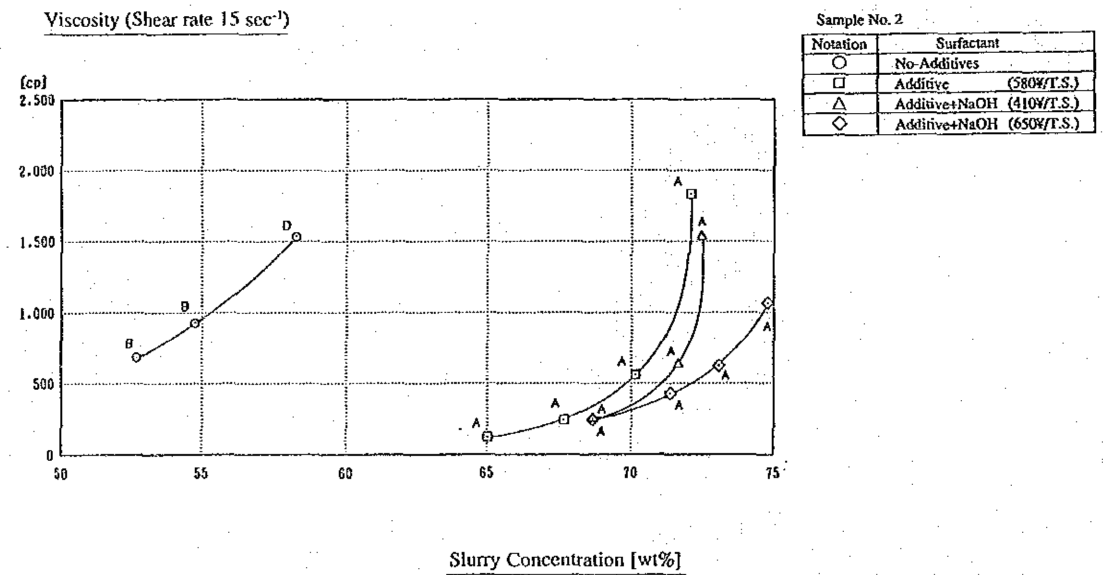
(i) Fig. I-5-6 shows the relationship between a slurry's viscosity and its concentration of coal.

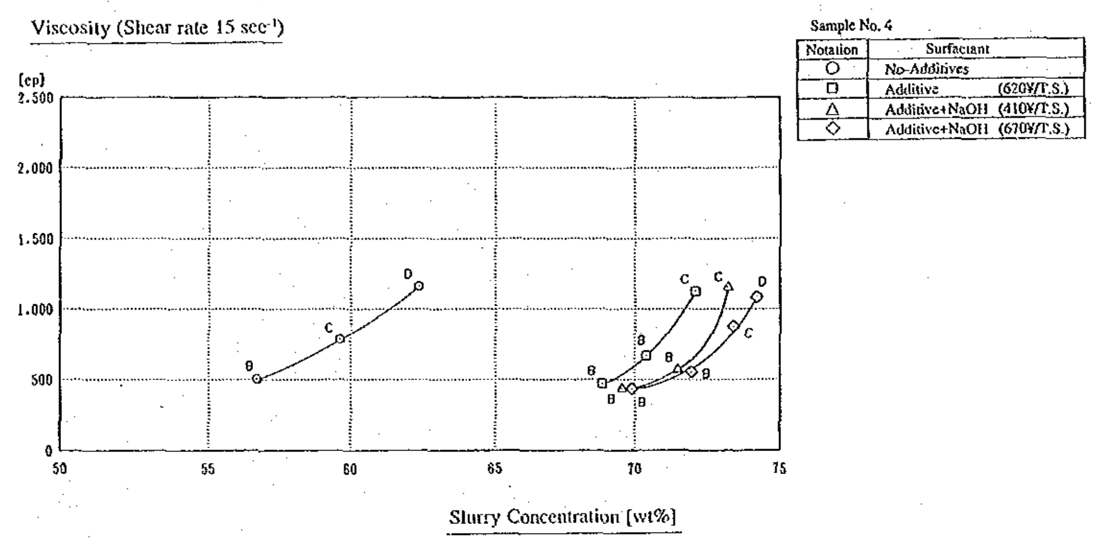
(ii) Fig. I-5-7 relates the concentration of coal in the slurry to the cost of surfactant. The addition of a surfactant improves the properties of the coal-water slurry.

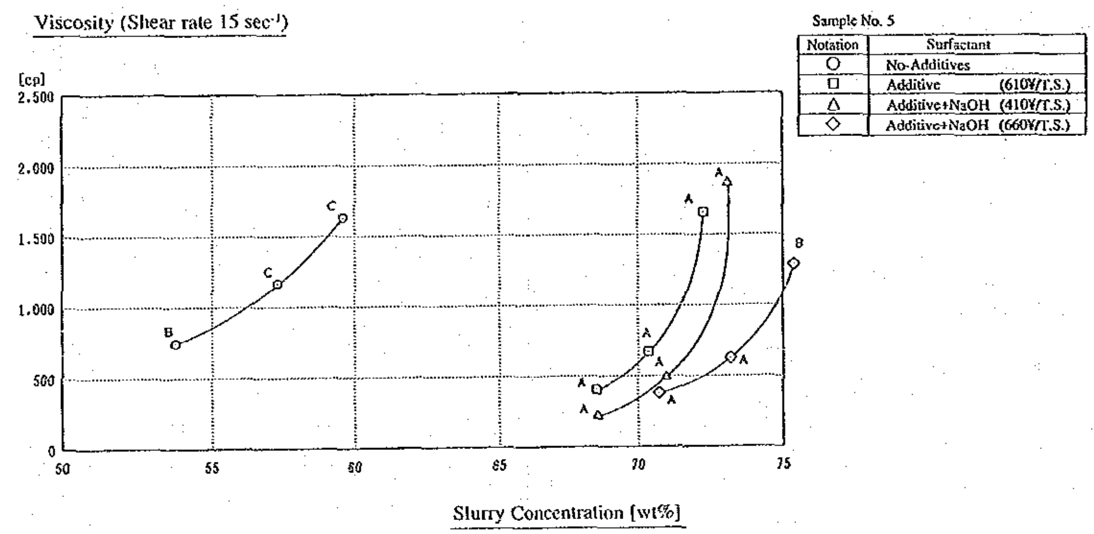
(iii) Test results on slurry flowability (with regards the slurry's viscosity and particle concentration) are given in Fig. I-5-6. Flowability was seen to decline according to the mixture in the order A > B > C > D. Of these, A and B would both be viable, whereas mixtures C and D would conceivably be problematic.

(iv) Table I-5-8 shows the test results for slurry stability. The tests involved letting the slurries stand for one and three days, respectively, after which time they were observed for any segregation.









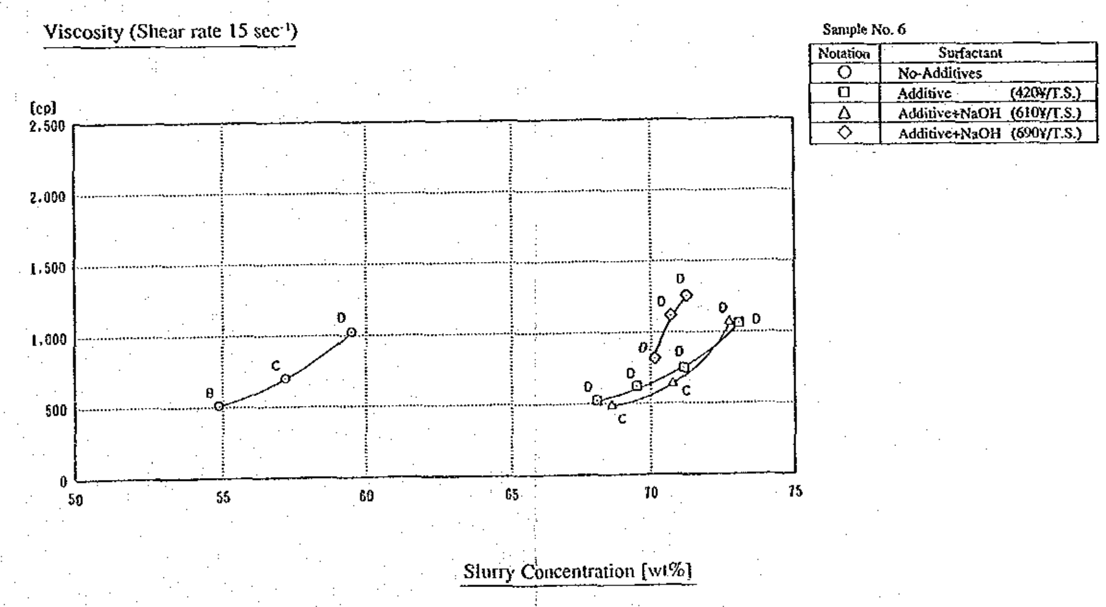


Fig. I-5-6 Relationship between Slurry's Viscosity and Concentration of Coal

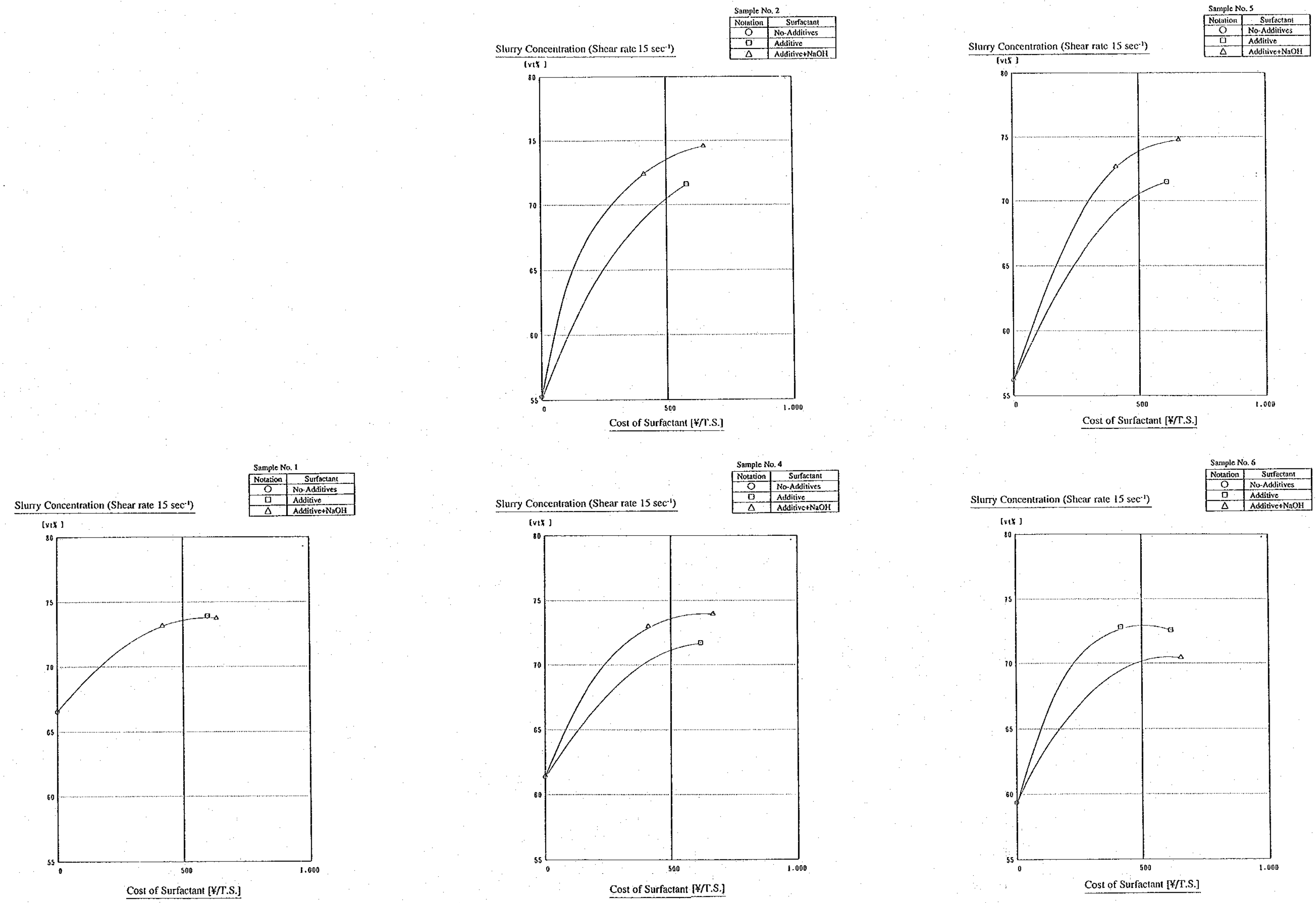


Fig. I-5-7 Relationship between Concentration of Slurry and Cost of Surfactant

Table I-5-8 Slurry Stability

Sample	Surfactant	Quantity of Additive (¥/T-Slurry)	1 Day After	3 Days After
No. 1	Non-Additive	—	△	×
	Additive	600	×	×
	Additive + NaOH	420	○	△
	Additive + NaOH	640	○	△
No. 2	Non-Additive	—	○	○
	Additive	580	○	○
	Additive + NaOH	410	○	△
	Additive + NaOH	650	△	×
No. 4	Non-Additive	—	○	○
	Additive	620	○	△
	Additive + NaOH	410	△	×
	Additive + NaOH	670	△	×
No. 5	Non-Additive	—	○	○
	Additive	610	○	○
	Additive + NaOH	410	△	×
	Additive + NaOH	660	○	○
No. 6	Non-Additive	—	○	△
	Additive	420	×	×
	Additive	610	×	×
	Additive + NaOH	690	×	×

Note: ○ : No segregation
△ : Some segregation
× : Considerable segregation

② Evaluation of test results

(i) With most of WANKIE's coals, slurries with the highest coal concentrations are formed when surfactant and sodium hydroxide (NaOH) are added to the slurry. However, the slurry's stability and flowability are relatively poor.

(ii) The study of a slurry's coal concentration is in general done at a standard slurry viscosity of 1,000 centipoise (share rate of 15 s^{-1}). Coal samples 1, 4 and 6, however, were found to show poor flow, indicating a need to give further study to finding optimum mixes of flowability and particle concentration.

(iii) The cost for additives is set at ¥400 per tonne of slurry. At this additives cost, the particle concentration of the slurry for each of the coal samples was found to be:

Sample Number	Coal concentration in slurry	
1	73%	(with surfactant and NaOH)
2	72%	(idem)
4	73%	(idem)
5	72.5%	(idem)
6	72.5%	(with surfactant only)

(iv) It is seen that a fairly high particle concentration of 72 to 73% can be achieved in the slurries. For plant operation in Zimbabwe, however, further study into reducing the amount of additives to be used is recommended if cost of additives were high.

3) Choice of design base feedstock coal for coal gasification purposes

Following overall consideration of the results of the coal analysis and the assessment of these, and of the assessment of the slurrying properties of coal samples, and of the market prices of Wankie coals — all of which have been detailed in the preceding sections — it have been determined that for purposes of gasifications, Coal Sample 2 would be the most suitable feedstock coal. The sample, according to the classification scheme used by WANKIE, comes from a run-of-mine steam coal. The following design base specifications have thus been obtained for feedstock coal based on the results of the analysis of Coal Sample 2:

Design base specification (Coal)

1. Ultimate analysis (Dry basis)

(1)	Carbon	:	73.0 wt%
(2)	Hydrogen	:	3.8 wt%
(3)	Oxygen	:	5.1 wt%
(4)	Nitrogen	:	1.4 wt%
(5)	Sulphur	:	2.7 wt%
(6)	Ash	:	14.0 wt%

2. Proximate Analysis

(1)	Inherent Moisture	:	1.5 wt%
(2)	Ash	:	13.8 wt%
(3)	Volatile Matter	:	24.2 wt%
(4)	Fixed Carbon	:	60.5 wt%

3. Gross Heating Value : 7,090 kcal/kg
(Inherent Moisture Basis)

From the design base specifications above, the following gasification conditions obtain:

Table I-5-9 The Results of Gasification Study

Item		Unit	Case-1
Oxygen purity		Mol%	98.0
Feed stock	Coal (Dry basis)	kg	1,000
	Oxygen (as 100%)	Nm^3	621.5
Gasification Conditions	Pressure	kg/cm^2G	65
	Temperature	°C	1,380
Estimated gas composition	H_2	Mol%	33.97
	CO	Mol%	49.74
	CO_2	Mol%	14.22
	H_2S	Mol%	0.77
	COS	Mol%	0.05
	N_2	Mol%	0.64
	Ar	Mol%	0.55
	CH_4	Mol%	0.06
Product gas rate (Dry gas basis)		Nm^3	2,062.5
(H_2+CO) gas rate		Nm^3	1,726.6
C-Conversion rate		%	97
Cold gas efficiency		%	72.8
Unit consumption 1,000 Nm^3H_2+CO	Coal (Dry basis)	kg	579.2
	Oxygen (as 100%)	Nm^3	360.0

This concludes the study on the possibility of utilizing coals from the Wankie Coalfield as feedstock for the gasification reaction, and on determining the design base specifications of this feedstock as a first step toward drawing up the conceptual design for plant operations.

(4) Analysis and Assessment of Wankie Colliery's Coals as Feedstock for the Coke Oven

The following samples of coal were assessed for possible use in the coke oven:

Sample 1	Power station coal*
Sample 2	Run of mine coal*
Sample 9	Coking coal
Sample 10	Coking coal
Blended coal sample*	A mixed coal for purposes of coking, blended to proportion and in general use by coke companies in Japan

* Reference samples against which the coking coals were compared.

1) Results of analysis on coking coals

The following tests and analyses were carried out with a view to assessing the coking coals:

① Ultimate analysis and volatile matter

② Destructive distillation test

③ Reactivity of the coke

④ Chemical analysis of the coke and tar

⑤ Determination of the composition and output of gas generated.

The results of these procedures are given in Table I-5-10.

Table I-5-10 Coal Analysis (coking coal)

(1) Proximate & Ultimate Analysis (%)

Sample	Volatile matter	Ash	C	H	N	S
1	17.5	37.9	50.7	2.7	1.1	1.42
2	28.6	11.2	75.7	4.3	1.6	2.58
9	30.78	8.34	78.78	4.55	1.48	1.81
10	26.52	9.64	77.24	4.22	1.44	1.09

(2) Coking Coal Test

Sample	Yield %				Coke ash %	DI 15 30*
	Coke	Crude tar	Gas	NH_3 aq.		
1	84.4	2.9	5.4	4.9	50.56	
2	74.7	9.3	10.9	2.7	17.96	
9	72.1	7.7	10.5	3.6	12.57	82.4
10	74.7	8.8	11.9	3.1	13.70	80.7
Blend coal	77.3	6.9	10.5	2.6	11.41	93.2

*Note Cokes strength

Reactivity

Sample	1	2	9	10	Blend coal
Reactivity	55	61	56	60	49

(3) Character of Coke & Tar

Analysis of Coke (%)

(% dry base)

Sample	Volatile matter	Ash	C	H	N	S
9	1.2	12.57	84.76	0.19	1.03	1.42
10	0.89	13.70	83.70	0.19	1.13	0.96
Blend coal	0.4	11.41	85.72	0.16	10.3	0.44

Analysis of Tar (%)

Sample	C	H	N	S
9	90.18	5.26	1.40	1.70
10	90.68	5.03	1.47	1.19
Blend coal	89.96	5.19	1.15	0.75

Sample	Solvent extraction %		Tar distillation %		
	B1	Q1	Low fruction	High fruction	Residue
9	19.91	14.64	17.8	26.3	53.2
10	17.49	12.39	11.0	28.8	56.6
Blend coal	21.32	12.03	19.3	15.8	54.1

B1 : Benzene insoluble
Q1 : Quinolin insoluble
Low fraction : Bpt ~ 182°C
High fraction : Bpt 182 ~ 295°C
Residue : Bpt 295°C ~

Composition of Coke Gas

(%) (l/kg)

Sample	H_2	CO	CO_2	CH_4	C_2H_6	Gas volume
1	53.27	5.92	3.35	17.2	0.92	122.7
2	49.39	6.13	0.93	25.3	2.14	252.7
9	61.01	6.85	0.89	20.68	1.58	276.4
10	53.63	6.13	1.71	27.40	1.42	276.2
Blend coal	52.70	4.97	0.85	27.69	1.862	254.9

2) Assessment of the results of analysis

① Elementary analysis

The coking coals at Wankie are rather high in ash and sulphur. They may, however, be used as general-purpose coking coals.

② Destructive distillation test

In terms of carbonization yields, Sample 1 yields a great deal of coke but little tar and gas. This is because Sample 1 is a power station coal and so contains much ash. When compared to the blended coal sample, WANKIE's coking coals (Samples 9 and 10), yield more coal tar, light oil distillates and aqueous ammonia, but less coke.

③ Properties of the coke

(i) Strength (DI 15^{30}): The strength of coke derived from WANKIE's coals is inferior to that of the mixed coal sample, and is comparable to that of weaker coking coals. It is possible, however, to obtain good strength either through additions of prime coking coals or by pelletized coal.

At the low levels of strength observed, the manufacture of coke in large coke ovens (6 to 7 metres across and each of the chambers holding 30 tonnes) solely from WANKIE's coals may readily cause problems of the coke crumbling during retrieval from the oven, so that the use of a medium-sized coke oven (4 metres across and carrying 20 tonnes per chamber) is more to be recommended.

(ii) Coke composition: Coke derived from WANKIE's coking coals has a greater volatile component than that produced from the mixed coal sample. The volatile-matter content can however be controlled through adjustment in the manufacturing conditions of the coke.

As the sulphur content of the coke is high, this will affect its marketing price.

(iii) Reactivity of coke: The coke is highly reactive, making it highly suitable for use as a fuel.

④ Properties of the by-products of carbonization

(i) By-product yields

WANKIE's coking coals yield large quantities of coal tar and light oil distillates. It would therefore appear to be advantageous to have uses provided for these by-products. In view, however, of the fact that the minimum economical unit of a tar refinery is generally held to be an annual 200,000-tonne output in each of the by-products, while the project would produce only about 40,000 tonnes of coal tar annually, it shows an economic constraint for the implementation of the tar project.

(ii) Coal tar properties

The coal tar component has properties similar to the coal tar obtained from the blended coal sample, but is of inferior quality owing to its high content of sulphur. Meanwhile, that its distillate fractions should include a large number of heavy oils but few light oils is probably due to the fact that it contains many phenols but few hydrocarbons (in benzene-like compounds).

(iii) Gas composition

In comparison to the blended coal sample, WANKIE's coking coals evolve less gaseous hydrocarbons and more hydrogen gas, making them suitable as feedstock coal for the synthesis of ammonia.

3) Summary

① WANKIE's coking coals are suitable as coke oven feedstock, and the strength of their coke can be adjusted by use of appropriate manufacturing technologies.

② The coke, coal tar and gas derived from WANKIE's coals contain much sulphur, and are therefore wanting in quality. It is possible for use however, by installing proper desulphurizing equipment.

5.2 Chemicals

5.2.1 Gas-Washing Solvent

The gas generated in a gasifier contains various sulphides (H_2S, COS, etc.) which have their origin in the sulphur content of coal. These sulphides not only act to spoil the effect of catalysts used in the synthetic ammonia process, but can also cause corrosion of equipment, including reaction tower, heat exchangers, and compressors. In order to maintain catalytic activity and to prevent corrosion of equipment, it is necessary to restrict the concentration of sulphide in the gas to about 5 ppm. Although many desulphurization processes are practised which used different absorbents, the method adopted in the project would be to use methanol as the washing solvent (the Rectisol Process). This would require a supply of about 290 tonnes of methanol per year, and because the alcohol is not produced in Zimbabwe, these would have to be imported.

5.2.2 Chemicals for Treating the Cooling Water

As will be later mentioned, the project would utilize water from the river Zambezi as raw water with which to form a coolant. This water is of comparatively good quality, and would need very little treatment save filtration. Inhibitors would however have to be added to the water in order to promote the formation of a metal-protection coating on the inner surfaces of equipment. There would be further requirements for various chemicals for the prevention of microbial growth in the cooling water, to adjust the pH of the water, and for coagulation and sedimentation of suspended matter. Table I-5-11 lists the various chemicals that would be required in the project in treating the cooling water.

Although a variety of alternative chemicals may be used for treatment rather than those listed, in our study those substances which are generally in wide use and therefore easily obtained, are chosen. It shall be noted that of the listed chemicals only slaked lime is produced in Zimbabwe. In every case, however, less than 25 kg of the substance would be needed each year.

Table I-5-11 Chemicals for Treatment of Cooling Water

Application	Chemical
Inhibitor	Phosphate
Prevention of microbial growth	Sodium thiosulphate (Hypo)
pH adjustment	Slaked lime
	Caustic soda
	Calcium carbonate
	Hydrochloric acid
	Sulphuric acid
Sedimentation of suspended matter	*Aluminum sulphate*

5.2.3 Chemicals for the Treatment of Boiler Water

In order to obtain a pure water supply for the boilers, there would be a need for ion exchange resins, and further for concentrated hydrochloric acid and caustic soda for regeneration of these resins. At the outset of project operations, 200 litres and 360 litres, respectively, of strongly acidic and strongly basic resins would be needed, and about 5% of the resins would have to be replenished each year thereafter. The circulating water would, after having been sent through a condenser, have to be passed through a polisher in each cycle. Ion exchange resins would be used in the polisher as well. Because ion exchange resins are rather difficult to obtain in Zimbabwe, it would be advisable to have at all times a complete (100%) imported stock of the materials. There would also be a need for concentrated hydrochloric acid and caustic soda for re-generation of the resins.

In order to maintain purity in the steam generated by the boilers and to prevent corrosion of the boilers, in addition to the above an oxygen scavenger would be needed to remove oxygen from the boiler water, and pH regulators for making pH adjustments. These substances are not manufactured in Zimbabwe, but as they are widely available for different types of boilers, they should not be difficult to obtain.

Table I-5-12 lists the substances necessary for the treatment of boiler water.

Table I-5-12 Chemicals for Treatment of Boiler Water

Application	Chemical
Pure water supply	Strong acid ion exchange resin
	Strong base ion exchange resin
Regeneration of ion exchange resin	Hydrochloric acid
	Caustic soda
Deoxization	Hydrazine
pH adjustment	Ammonia sodium phosphates

5.3 Electric Power

5.3.1 The Electric Power in Zimbabwe

(1) Power Supply Network

Up until the year 1984/1985, Zimbabwe's electric power had been supplied not only by the Zimbabwe Electric Supply Authority (a public power utility), but also by independent, municipal distribution networks in the cities of Harare, Bulawayo, Gweru and Mutare. In addition, the Kariba power station and its outgoing trunk feeders had belonged to CAPCO (the Central African Power Corporation). On January 24, 1986, however, the Electric Act 1985 came into effect, by which all power supply operations in Zimbabwe were integrated under the Zimbabwe Electric Supply Authority (ZESA).

As shown in Fig. I-5-8, ZESA's trunk transmission network offers a stable supply of power over 330 kV transmission lines linking the hydroelectric generating station at Kariba (666 MW), the thermal power plants at Hwange (920 MW), and the three switching stations in Harare, Bulawayo and Sherwood, the latter of which lies at the heart of the industrial region in the Midlands.

Several areas do not access these supply lines. The area around Beitbridge is isolated from Zimbabwe's power facilities, and receives its power instead from ESCOM (the Electricity Supply Commission, South Africa). Construction of a diesel-fired power plant has however been planned for the near future in this area with a view to securing a stable supply of power. The city of Triangle, in the south and near the end of the 330 kV supply lines, has a generating station of its own that uses the bagasse from sugar mills to fuel its generators, and which sells its surplus power to ZESA. Finally, the city of Victoria Falls and its environs receive their power from a hydroelectric plant in Victoria Falls belonging to ZESCO (the Zambia Electricity Supply Corporation).

The geographical relationship of the areas proposed for the construction of the plant to the power supply network is outlined as follows: the Hwange region being served by their thermal power stations, and the Kwekwe area by the switching station in Sherwood, these areas have access to the power supplied by generating station and the 330 kV supply lines, respectively.

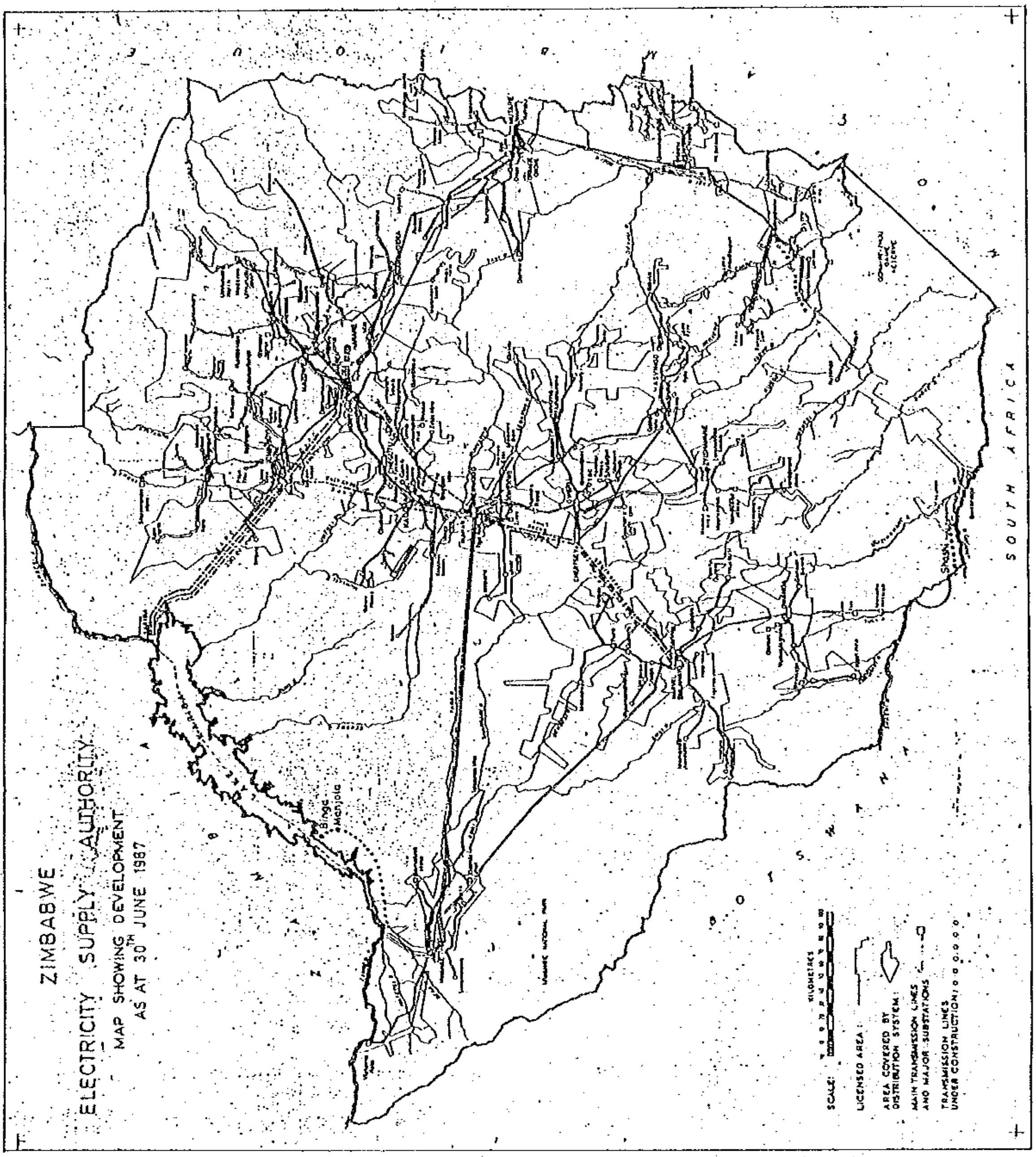


Fig. I-5-8 ZESA Network of Electricity

(2) Electric Power Facilities

Apart from the thermal power stations of Hwange-I and Hwange-II, all other power stations in Zimbabwe were constructed more than twenty years ago. The Kariba South hydroelectric plant was built twenty-eight years ago, although it still operates with a high availability factor and remains of major importance for Zimbabwe's supply of electric power. Besides the Hwange installation, Zimbabwe's thermal power station, as well as having become obsolete, have been running at average available output that the considerably lower than their rated power output. Table I-5-13 lists Zimbabwe's major generating station.

Table I-5-13 Power Station in Zimbabwe

Power Station	Type	Unit x Output MW	Total output MW	Start of operation
Kariba South	Hydro	6 x 111	666	1960
Hwange-I	Coal	4 x 120	480	1986
Hwange-II	Coal	2 x 220	440	1988
Munyati	Coal	2 x 60	120	Before 1966
Harare	Coal	2 x 10 2 x 20	60	ditto
Bulawayo	Coal	2 x 15 3 x 30	120	ditto
Total			1,886	

1) Kariba South Power Station

Two generating stations have been built on the Kariba Dam: one on the south bank, and the other on the north. The station on the south bank, operated by ZESA, is one of Zimbabwe's major generating stations. The plant on the north bank belongs to ZESCO of Zambia.

Number of generators	:	6
Unit capacity	:	111 MW
Voltage generated	:	18 kV
Generator speed	:	167 r.p.m.
Flow rate	:	130 m^3/s
Head	:	93 m

Power generated at this station in 1986/1987 was 3,022,725,700 kWh. The station's availability factor, expressed as a percentage of actual output to that obtained for 666 MW generated for 365 days, is 51.8%, so the station is running under variable loads, between, for instance, night and day.

2) Hwange Thermal Power Stations

The power installations at Hwange were constructed in two phases, construction in the first phase having been completed in June 1983, and that in the second in December 1986. The major descriptions of the installations are as follows.

First phase installations:

Number of generators	:	4
Unit capacity	:	120 MW
Voltage generated	:	10.5 kV
Steam condition	:	8.9 MPa, 510°C

Second phase installations:

Number of generators	:	2
Unit capacity	:	220 MW
Voltage generated	:	17 kV
Steam condition	:	15.8 MPa 538°C/538°C (reheat)

The stations' total generation for 1986/1987 has been disclosed as having been 3,441,809,000 kWh. The plant's availability factor, calculated as a percentage of actual output to the output when plant are operated at full capacity for 365 days, turns out to be 42.7%. We see then that the stations have not yet, as of fiscal year 1986/1987, been running at full capacity.

In general, thermal power stations need time for both increasing or decreasing their output, and for starting or stopping operations, and are not therefore suited for running to save peak load. For this reason, ZESA operates the Hwange thermal installations for base load of power.

3) Other thermal power stations

Besides the two major power installations at Kariba and Hwange, there are the old thermal power stations at Munyati, Harare and Bulawayo. These, however, with the exception of that at Harare, show low availability factors.

These thermals, in comparison with those at Hwange, run at low efficiency. This is both because their steam conditions are low, and because their equipment is obsolete. The stations have engaged expectations to play an important part in emergency operations in case supply lines should fail, and plans are therefore being drawn up to re-equip them along those lines.

(3) Supply and Demand Situation in Electric Power

1) Past performance in the supply of electric power

Zimbabwe's domestic power is today supplied solely by the ZESA. As can be shown from Table I-5-14, the supply of power has through 1980/81 to 1984/85 seen only an average 0.6% annual increase, however absorbed municipal electric companies with total energy sales by 1986/87 reaching 8,180,489,000 kWh. Table I-5-15 further compiles energy sales in a breakdown by sector to whom the power has been supplied. The table shows that farming received a comparatively large increase of 27.5% in 1986/87 over its previous year. This has been the result of a favorable policy having been taken with regards power for irrigation purposes. Table I-5-16 sets out ZESA's energy balance as seen from the supplying side. Although greater self-sufficiency can be seen to have been attained through operations at the Hwange Thermal Power Stations and through comparable reductions in imports from Zambia, a substantial volume of imports can still be noted for the year of 1986/1987.

2) Projected demand for electric power

Table I-5-17 shows figures calculated by separate agencies of projected demand for electric power. The figures indicate that the demand for electric power may rise from the annual figure of 8,180 GWh in 1986/1987 to something near an annual 10,000 GWh by 1994. This means that an estimated 1,564 MW capacity would be needed. This is equivalent to the combined capacity of the existing stations of Kariba South, Hwange-I and Hwange-II.

Table I-5-14 Electric Supply

Unit: GWh

Year	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87
ESC	4,979	5,132	5,400	5,127	5,078	5,306	—	—
Growth		3.1	5.2	–5.1	–1.0	4.5	—	—
HMED	1,248	1,323	1,390	1,433	1,367	1,360	—	—
Growth		6.0	5.1	3.1	–4.6	–0.5	—	—
BULAWAYO	653	692	751	776	778	775	—	—
Growth		6.0	8.5	3.3	0.3	–0.4	—	—
TOTAL	6,880	7,147	7,541	7,336	7,223	7,441	7,883	8,180
Growth		3.9	5.5	–2.7	–1.5	3.0	5.9	3.8

Table I-5-15 ZESA Sales of Electricity

Class of consumer	Energy sales (million kWh)			Revenue 1985/86		Revenue 1986/87	
	1985/86	1986/87	% Increase/ Decrease	$000s	Average Price cents/ kWh	$000s	Average Price cents/ kWh
Mining	1,362.542	1,395.274	+2,40	66,570	4.886	69,342	4.970
Industrial	2,962.147	2,976.150	+0,54	102,300	3.456	105,900	3.558
Farming	500.942	638.824	+27,52	34,283	6.844	43,470	6.805
Municipal (1)	2,633.466	2,726.547	+3,53	104,739	3.977	121,257	4.447
Commercial and Lighting	217.657	228.283	+4,88	16,943	7.784	18,415	8.067
Domestic	208.376	215.411	+3,38	15,694	7.532	17,406	8.080
Totals	7,883.130	8,180.489	+3,77	340,529	4.320	375,790	4.594

Note 1: Sales to Harare, Bulawayo, Mutare and Gweru Municipal Electricity Undertakings.

All categories recorded growth but as mentioned earlier the minimal growth in the Industrial Sector had an adverse effect on overall growth.

Table I-5-16 ZESA Energy Balance

1985/86 Energy in kWh	Source	1986/87 Energy in kWh	
3,146,077,790	Import ex Zambia (1)	2,214,964,600	
3,291,318,000	Kariba entitlement	3,022,725,700	
6,437,395,790	Sub total	5,237,690,300	
1,863,618,000	Hwange power station sent out	3,441,809,000	
211,367,210	Old thermals sent out	201,777,790	
8,512,381,000	Interconnected System Sent Out	8,881,277,090	(3)
322,349,576	Transmission losses (6)	354,275,065	
8,190,031,424	Bulk supply sent out	8,527,002,025	(4)
577,191	Triangle Ltd (2)	479,621	
631,410	ZESCO Chirundu and Victoria Falls (2)	439,780	
13,966,306	ESCOM (Beitbridge) (2)	16,937,335	
8,205,206,331		8,544,858,761	
322,076,823	Distribution losses (7)	364,369,873	
7,883,129,508	Total sales	8,180,488,888	

NOTE:
1) Excess of Kariba entitlement
2) Imports at distribution voltage
3) Maximum demand on interconnected system 1,342.0 MW
4) Maximum demand at bulk supply points 1,294.5 MW
5) Load factors @ 3) 75.55%
   @ 4) 75.22%
6) Transmission losses 3.99%
7) Distribution losses 4.26%

Table I-5-17 Energy Forecast

ZESA Energy Forecast — Unit: GWh

	1984/85	1989/90	1994/95
Gold mining	283.8	367.0	437.0
Base metal mining	960.8	1,129.1	1,345.0
Industrial	3,543.6	4,314.5	5,143.0
Agriculture	468.1	519.0	618.0
Commercial	571.9	680.0	807.0
Domestic metered	911.2	1,046.0	1,211.3
Domestic unmetered	296.2	343.0	406.0
Total	7,035.6	8,398.6	9,977.4

CAPC Energy Forecast — Unit: GWh

	1984/85	1989/90	1993/94
ESC	5,306	—	—
HMED	1,360	—	—
Bulawayo	775	—	—
Total	7,441	8,654	10,277
Maximum demand (MW)	1,141	1,317	1,564

CAPC Forecast for Zimbabwe as at 1st December 1984

	1984/85	1989/90	1993/94
Energy (GWh)	7,739	9,315	10,688
Maximum demand (MW)	1,187	1,418	1,627

3) Future plans

In preparation for future increases in the demand for electric power, ZESA is in the process of drawing up its next plans for electric service. While the thermal power stations at Harare, Munyati, and Bulawayo are growing obsolete and their availability factors declining, these stations exist in cities and industrial areas of major importance, and are still valuable as back-up facilities in the power supply network. ZESA therefore plans to undertake repairs on these stations in an aim to secure 270 MW amongst the stations, and the thereby increase the reliability of its power supply network.

It is furthermore considering renovations and expansion on the Kariba South station and a third-phase expansion on the Hwange thermals. Table I-5-18 summarizes these plans.

Table I-5-18 Development Plan of Electric Power

Project	Type	Unit x Output (MW)	Planed Completion	Remarks
Kariba south modernization	Hydro	6 x 111 ↓ 6 x 125	1991	Under construction
Kariba south expansion	Hydro	2 x 180	1992	Completion of design
Hwange-III	Coal	2 x 220	1990	Study

5.3.2 The Electric Power Situation in the Kwekwe Region

As has already been described in Fig. I-5-8, electric power to the Kwekwe area is supplied over a considerable distance along the 330 kV supply lines from the two generating stations at Kariba and Hwange, being received initially by the switching station in Sherwood and distributed along a branch line to the Kwekwe area.

In Munyati, near where the Sable Chemical Company (SABLE) is located, there existed a long-established generating station, but currently it is not used at all. A switching station attached to the generating plant is being used as a branch point, from which SABLE receives its power.

The Kwekwe area houses a host of plants, including iron mill ferroalloy refineries and a fertilizer plant, and the Sherwood switching station is already operating at maximum capacity. In order therefore to handle additional demand for power, plans are being drawn up for the construction of another switching station (2 x 125 kVA) in Kadoma. Extant transmission lines have also reached maximum capacity, and ZESA holds that within the region it would be impossible to accommodate an increase in demand of even 10,000 kW.

Implementing the project in the Kwekwe area would mean, however, terminating the *current production of hydrogen by electrolysis*, the result of which would be to make available an additional 100,000 kW of electric power in the area, and, in effect, not only would there be any problem securing electric power for the new enterprise, but there would in fact be a surplus of some 83,000 kW available to the area.

Although the Kwekwe region is situated 350 km from the generating stations in both Kariba and Hwange, it is fed by these stations along 330 kV supply lines and enjoys good reliability in its supply of power. SABLE therefore possesses no private generating equipment. Should the enterprise be situated in Kwekwe, 100,000 kW of surplus power would become available as a result. When taken in conjunction with the fact that the current reliability of the electric power supply may be expected to remain unchanged, neither will the new plant in probability need its own generating equipment.

5.3.3 The Electric Power Situation in the Hwange Region

Before the Hwange thermals had begun their operations, the Hwange region had depended heavily on the private generating facilities of WANKIE. After, however, the first Hwange station was completed in 1983, these private generating facilities were closed down. The region is now dependent entirely on ZESA's supply of power.

As previously mentioned, the Hwange installations comprise several generating units. They also house several boilers and other equipment, so that they provide a sufficiently reliable source of power. Their supply of coolant water has been furnished by a pumping station at Deka, which however had provided only a single feeder pipe, but here arrangements have been made to correct the drawback through the construction of a new reservoir with a capacity of 150,000 m^3 to supplement the existing reservoir at the Hwange power station site. The water stored in the new reservoir can meet Hwange's requirements of a period of four days, a significant improvement in the reliability of its water supply.

Because in this region WANKIE is the only plant besides the power station, there is nothing to impair the reliability of the supply of power.

Should the plant be constructed in the Hwange region, therefore, there would, as the power supply there is stable, be no need for private generating facilities.

5.3.4 The Price of Electricity

Table I-5-19 shows average rates of electric service charge by sector for the years 1985/1986 and 1986/1987. The figures indicate that charges in Zimbabwe are far below the international level.

Table I-5-19 Price of Electricity

Unit: Z$/kWh

	1985/1986	1986/1987
Mining	0.04886	0.04970
Industrial	0.03456	0.03558
Farming	0.06844	0.06805
Municipal	0.03977	0.04447
Commercial & Lighting	0.07784	0.08067
Domestic	0.07532	0.08080
Weighted average	0.04320	0.04594

Approval has been given, however, for charge revisions to take effect in October 1988, whereby rates for the industrial sector will be as follows:

Facility charge (Fixed)		22 Z$/month
Max. Demand charge		18.74 Z$/kVA-month
	or	20.26 Z$/kW-month
Consumption charge		6 a.m. to 9 p.m. 1.91 Z¢/kWh
		9 p.m. to 6 a.m. 1.69 Z¢/kWh

A tentative calculation of electric service charges based on these figures for a consumption of 10,000 kW for 8,000 hours per year, or 80,000,000 kWh/year, gives the following:

	(in units of Z$)	
Facility charge	22 x 12	= 264
Max. Demand charge (at 11,000 kVA)	11,000 x 18.74 x 12	= 2,473,680
Consumption charge	80 x 10^6 x 15/24 x 0.0191	= 955,000
	80 x 10^6 x 9/24 x 0.0169	= 507,000
Total charges		= 3,935,944
Average unit charge	3,935,944 ÷ (80 x 10^6)	= 0.049199 Z$/kWh

In comparison with the average unit charge for industry in 1986/1987, which was Z$0.03558 /kWh, this new figure represents a 38.3% rise, which is a considerable increase in the light of previous years.

Should the demand for power increase in future, and new thermal power stations be installed to meet the increased demand, one would expect that, as installation costs would most certainly exceed greatly those which have been involved in building existing thermal power stations, electric service charges will have to be raised even further.

5.4 Industrial Water

5.4.1 The Availability and Use of Water in Zimbabwe

The mean annual rainfall are in almost all parts of Zimbabwe below 800 mm, this figure being exceeded in only the mountainous area in the east, and a second region near the Mozambique border. Zimbabwe's rainy season lasts from October to the following April, and it hardly rains at all for the rest of the year owing to the effects of a high-atmospheric-pressure system which during those months lies across the African continent. In most areas, therefore, farming is limited to only six months of the year.

Because of these climatic conditions, Zimbabwe has a well-developed system of reservoirs for storing the rainfall of the rainy season. Most of these reservoirs have been built by damming up small rivers. The largest of them include Lake Kyle, near Masvingo, and the lakes Robertson and McIlwaine near Harare. The water of reservoirs is used mainly for farming (although its use is limited to large farms equipped with irrigation facilities), while part of it goes to feed the water supply systems of cities and to feed industry. The majority of reservoirs are managed either by the central government or by regional public bodies, and it is no easy matter to have water shifted from agricultural to industrial use as water rights, needless to say, are of extreme importance to the agricultural sector.

5.4.2 Kwekwe's Industrial Water Source

In the Kwekwe area, as in others, river water and reservoir water are used in common by agriculture and the municipal water system. The major river feeding the Kwekwe area is the river Sebakwe, which upstream stretches eastward to the highlands around Chibu, whose rainfall it carries downstream. Near Kwekwe, the river Sebakwe turns into a reservoir called the "Dutchman's pool", upstream from which lies the Sebakwe Dam, which also stores water. The "Dutchman's pool" is equipped with a pumping station operated by the municipal authorities of Kwekwe, and conveys 45,000 tonnes of water a day to the city. This water supply system is the largest among Zimbabwe's municipal waterworks, and a considerable number of plants tap its water. There is, in addition, a tributary of the Sebakwe called the Kwekwe, across which the ZISCO (an iron mill) has built a weir, and from which it takes water. The river being short and having no storage dam, however, it is not a suitable source of large amounts of water. Fig. I-5-9 shows a map indicating the rivers and reservoirs in the Kwekwe area.

The Kwekwe area offers conditions that are relatively good for water utilization purposes in comparison to other regions, and the Sebakwe river system still has some surplus water. Taking into account, however, future demands for general industrial water, for household domestic water, and for local agricultural water — all of which will almost certainly increase — the existing storage capacity of the Sebakwe drainage system would not be able to provide the daily 7,200 tonnes or so of water necessary for the present project.

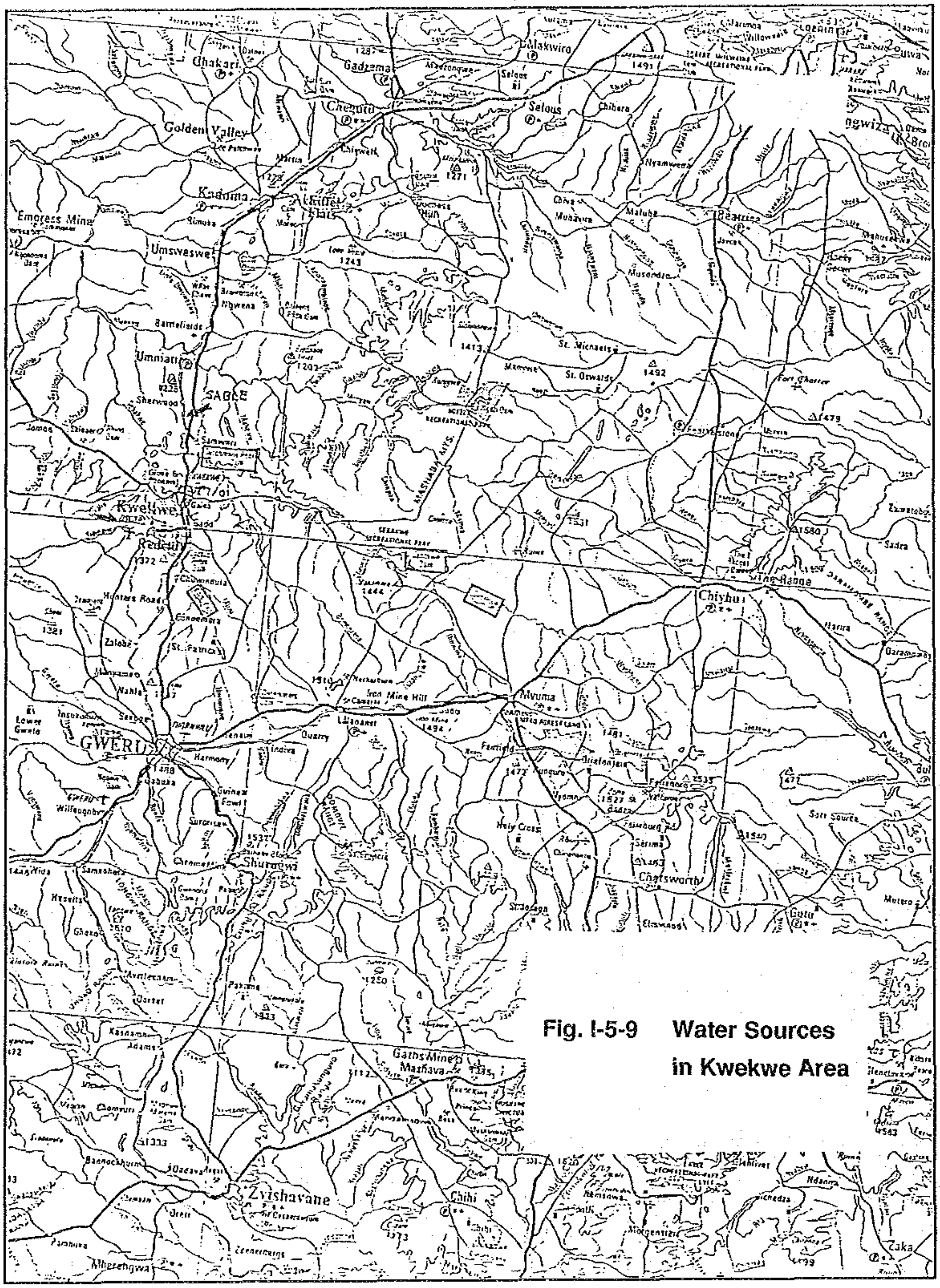


Fig. I-5-9 Water Sources in Kwekwe Area

5.4.3 Hwange's Industrial Water Source

Hwange, as with Kwekwe, lies in an area that receives little rainfall during the dry season. Neither has its rivers, however, been dammed up for reservoirs because irrigated agriculture is not very much developed in the area. The Hwange generating stations and WANKIE obtain their water by the following three methods:

— weirs constructed across the river Deka

— deep wells

— and pumping station erected on the river Zambezi.

The subterranean water obtained in the second method is used as city water, while those from the other two sources are used as industrial water. The water of the Deka falls to very low levels during the dry season and the river is consequently unsuitable as a water source for the project. In addition, because the thermal generating stations and the WANKIE already use the river as their water source, there is no surplus that could supply the project.

With respect to the deep wells, while there is a vein of water at a considerable depth of about 180 to 270 m below ground, the deep well is not a practical method for procuring large quantities of water.

With its source in Angola, the Zambezi River is the third largest river in Africa, carrying 40 million tonnes of water every hour, and in places exceeding 500 m in breadth. Although its water level does vary with the seasons, this is never great enough to pose problems of shortage. The distance from the Hwange area to the Zambezi River is some 45 km by a route along the river Deka, but because pumping stations, as earlier mentioned, have already been erected, and water supply pipes to the Hwange area already laid, the river will be available as a source of water for the project if pumping stations and supply lines are constructed alongside the existing facilities. Fig. I-5-10 indicates local geographical names, the location of the plants in the project, rivers and other features concerning the water supply situation.

The Zambezi River constitutes a national border with Zambia, then downstream from the proposed point of water intake, flows across the Kariba Dam, which is managed jointly by the two bordering countries, and finally flows on into Mozambique. One would therefore have expected that Zimbabwe, Zambia and Mozambique to all have a strong voice with regards the use of the river's water, but there are as yet no specific restrictions as to its use.

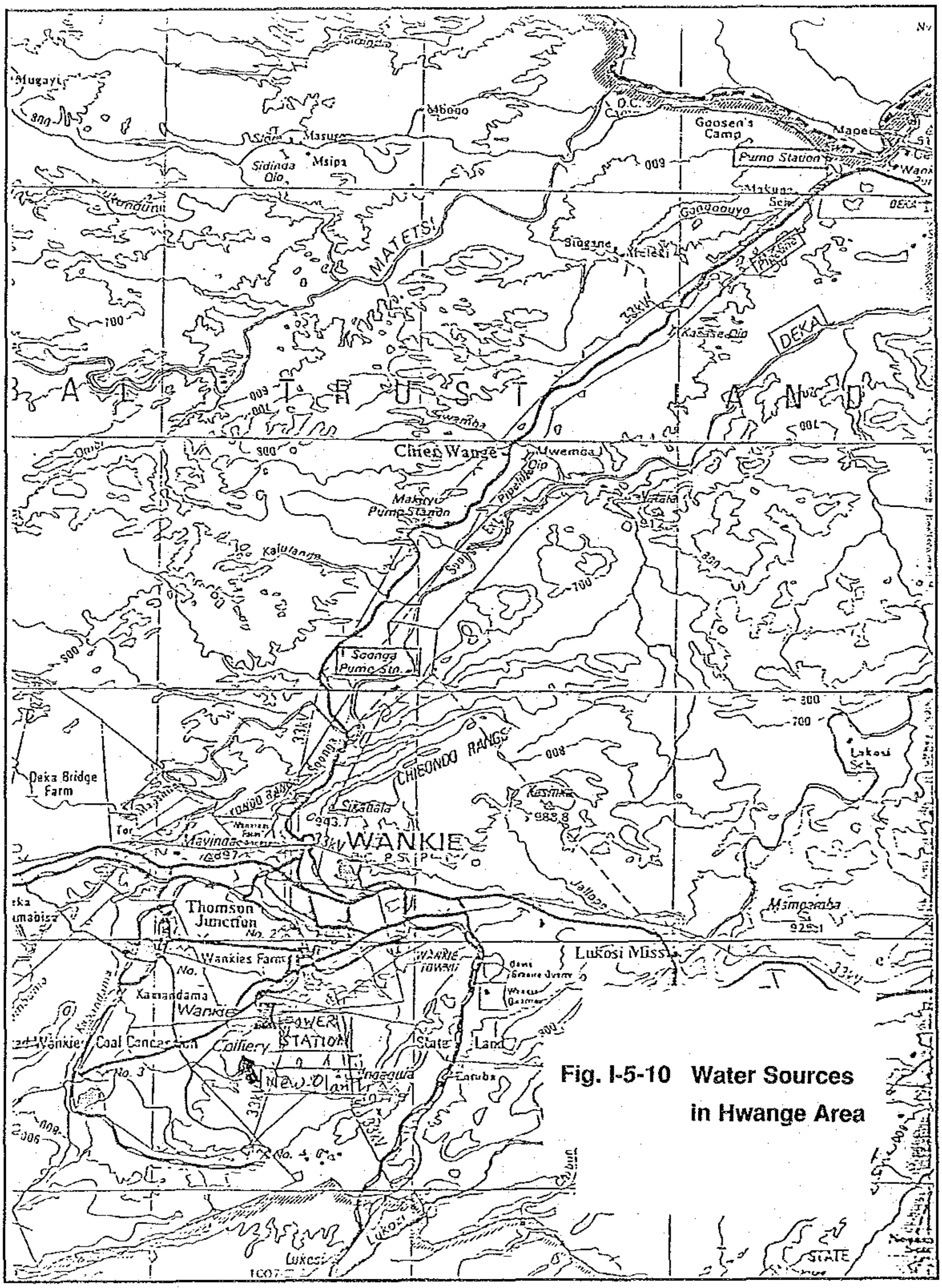


Fig. I-5-10 Water Sources in Hwange Area

5.4.4 Comment

In Zimbabwe, where hardly any rain falls from about the beginning of May to about the end of September, water is stored in reservoirs for use during the dry months. Because the water in these reservoirs is necessarily used jointly by agriculture, the domestic household, and industry in general, it would be difficult to obtain the large amounts of water needed for the project from the reservoirs. Meanwhile, subterranean water may be obtained only by deep wells and even this is limited in quantity. Such reasons place difficulties on obtaining in the Kwekwe area the necessary industrial water. In the Hwange region, however, it would be possible to obtain sufficient quantities of water if it were to be conveyed across some 45 km from the Zambezi River. There are no special restrictions concerning the intake of water from the river.

Chapter 6 Plant Site

Chapter 6 Plant Site

6.1 Characteristics of Candidate Sites (Hwange, Kwekwe)

It has been confirmed between JICA survey team and Ministry of Industry and Technology that the candidate sites for this project are Hwange or Kwekwe areas.

Hwange area is the only region in the nation presently producing coal which is the main raw material of this project, and Kwekwe area is the main region with demand for ammonia, the main product of this project.

6.1.1 Characteristics of Hwange Area

(1) Overview of Hwange Area

Hwange city is in Zimbabwe's northwestern corner, located near the border with Zambia, and has a population of approx. 40,000. Hwange city is the base of Wankie Colliery Company Ltd. (WANKIE), the nation's only coal production company; located near it are Victoria Falls, famous as the widest in the world, and Hwange National Park, one of the most remarkable parks in the world.

A road and railway route starting from Harare, Zimbabwe's capital, passes through Bulawayo, the second major city, to Hwange and Victoria Falls, and through Livingstone in Zambia, on the opposite side of Victoria Falls, to Zambia's capital Lusaka. The line not only connects Zimbabwe and Zambia but also is one of the main routes in southern Africa.

WANKIE as mentioned above is at present the nation's sole coal production company. Since starting operation in 1903, WANKIE's coal and hydroelectric power stations have supplied energy to this nation which doesn't produce petroleum. The importance of coal as an energy source is increasing as a consequence of increasing energy consumption resulting from modernization. In fact, projects to expand Hwange thermal power station and to utilize coal as raw material are indicative of the importance of coal utilization in this country.

Hwange city has developed with WANKIE and as mentioned above is expected to continue functioning as an important area in the nation's politics, economy, and tourism, etc.

(2) The Condition of Hwange Area as Project Site

1) Supply of raw material

Since coal is the main raw material of this project and the sole prodution company, WANKIE is located in the area, this area is the most advantageous as a project site in terms of supply of raw material.

2) Transportation of product

Ammonia, the main product of this project, presently is primarily consumed in the nation as raw material for nitrogenous fertilizer production. The nation's main area of fertilizer consumption is the northern region (Mashonaland) and the consumption area of ammonia for fertilizer production is at present Kwekwe. Consequently this region is less suitable than kwekwe as project site in terms of transportation of product.

3) Electricity

Since Hwange thermal power station of ZESA is located near the site, this region is most practical in terms of electricity supply.

4) Water

Since chemical plants require a relatively large amount of water, possible project sites for chemical plants are limited in a nation where there is almost no rainfall during the dry season approximately half the year. However, as water can be obtained in this region from the Zambezi River abundant in water flow throughout the year, there is little risk of water shortage.

However, there is one disadvantage: an approx. 250 m difference in altitude exists between the candidate site and the water-gathering point at Zambezi River approx. 45 km away, and thus the cost of electric power for transporting water is relatively high.

5) Infrastructure and others

The candidate site being between the new Hwange station and the Bulawayo-Victoria Falls main road as described in Fig. I-6-1, an access road and an access railway siding can be readily installed. As it is near Hwange city, the city's school, church, hospital, shopping center, and health and welfare facilities are also readily available. No problems are expected in recruiting plant labour and the relations between the plant and community because of the existing infrastructures of WANKIE and Hwange thermal power station. However, it has an unsatisfactory development for chemical industry and is distant from the capital, Harare, so the preparation of living facilities for accommodating managers and engineers with experience in the chemical industry is presumably necessary.

6.1.2 Characteristics of Kwekwe Region

(1) Overview of Kwekwe Area

Kwekwe city is located midway between the nation's capital, Harare, and the second major city, Bulawayo, and has a population of approx. 50,000.

Kwekwe city has developed as a consequence of the steel industry, mining-related industry, and chemical industry. In particular, it is the base of the nation's only nitrogenous fertilizer production company, SABLE.

The area from the capital Harare through Kadoma, Kwekwe, and Gweru, up to Bulawayo is geographically part of the gently-sloping savannah area spreading over the middle of the nation called the "High Veld." As described in Fig. I-6-4, it was historically developed as the "Gold Belt," and later has developed into the nation's industrial center in such fields as steel, mining and related industries of ferrochromium, etc., as well as mechanical, chemical, and other industries. The road and railway between Harare and Bulawayo has consequently become the nation's most important transportation line, and the railway between Harare and Bulawayo in particular has recently been electrified.

SABLE started operation in 1969, and as mentioned above, is the nation's sole nitrogenous fertilizer production company. Its policy at the start of operation was to effectively utilize the hydroelectric energy resources, which were at the time in relative surplus, in supplying the fertilizer demand resulting from the promotion of agriculture, as well as to strengthen the base of the nation's chemical industry. It has been successful in fulfilling these expectations. As a consequence of increased domestic consumption of energy in recent years, a plan to change from producing nitrogenous fertilizer by hydroelectrolysis to production by coal gasification is being considered. The city, based on the industrial infrastructure that has been developed, is expected to continue playing a major role as the nation's industrial city.

(2) The Condition of Kwekwe Area as Project Site

1) Supply of raw material

Since coal is the main raw material of this project and the sole coal production company, WANKIE is located in Hwange, this location is less suitable than Hwange as project site in terms of raw material transportation. However, there is one main rail line, the national railway (NRZ), between Hwange and Kwekwe. Moreover, no problems are expected in NRZ transporting coal since it is at present transporting coal as raw material for coke in iron manufacturing from WANKIE to ZISCO in Redcliffe, near Kwekwe.

2) Transportation of product

This region is most suitable as project site in terms of transportation of product because SABLE in Kwekwe is the present consumer of the main product of this project, ammonia, and Mashonaland neighboring Kwekwe is the main area of fertilizer consumption.

3) Electricity

This project requires 26,000 kW of electricity and according to ZESA, there are difficulties in supplying it to this area in addition to the present electricity demand. However, they have replied that it is possible to supply the project since as a consequence of this project, approx. 100,000 kW of electricity consumed as power for hydroelectrolysis by SABLE will become available for other purposes. Hence, in the plan, the substation of SABLE will be available for this project in case the project site is in Kwekwe.

4) Water

As mentioned above, the locations suitable for a chemical plant which requires a relatively large quantity of water are limited in this nation, and installation of a chemical plant in this region is most dependent upon the intake possibility of water. Sebakwe River and Kwekwe River are located in this area but they both are limited in water intake quantity. That is, Sebakwe River has Sebakwe Dam and Dutchman's Pool Dam and supplies water for use by the residents of Kwekwe city and surrounding areas, irrigation water, and industrial water to SABLE. From Kwekwe River industrial water to ZISCO is taken. However, according to Ministry of Water and Energy, there is no surplus to supply industrial water from these two river for this project.

5) Infrastructure and others

As described in Fig. I-6-3, the candidate site is near SABLE, and to the main road and railway which connect the capital, Harare, and Kwekwe, so an access road and railway siding are readily installable. In addition, since it is near the town of Kwekwe (approx. 20 km), it's school, church, hospital, shopping center, and health and welfare facilities are available. Also, SABLE being nearby means that this location has a chemical industry infrastructure, that technical information can be exchanged with SABLE that is very experienced in chemical engineering, and that the maintenance facilities, and educational facilities of SABLE Ltd. are readily available.

6.2 Comparison and Recommendation of Candidate Sites (Hwange and Kwekwe)

6.2.1 Comparison of Candidate Sites

The advantages and disadvantages to this project of the two candidate sites, Hwange area and Kwekwe area, mentioned above, are qualitatively compared in Table I-6-1.

Table I-6-1 Site Comparison/Qualitative

		Hwange	Kwekwe
i. Location			
a)	Adjacent township	○	○
b)	Area availability	○	○
c)	Land cost	○	○
d)	Weather condition	○	○
e)	Soil condition	○	○
ii. Utilities			
a)	Water supply		
	- Availability	○	×
	- Quality	○	○
	- Cost	Δ	×
b)	Electric power		
	- Availability	◎	○
	- Cost	○	○
iii. Transport Infrastructure			
a)	Road condition	○	○
b)	Railway condition	○	○
iv. Transportation and Distribution			
a)	Raw coal transportation	◎	Δ
b)	Product ammonia distribution	Δ	◎
c)	Product distribution (Fertilizer, Methanol, Tar)	Δ	○
v. Employee Recruiting		○	◎

Notes:

◎	Excellent
○	Adequate
Δ	Inadequate
×	Unavailable

Sites in Hwange and Kwekwe areas are compared in terms of transportation of raw material, as described in Table I-6-2. In terms of variable costs resulting from transportation of raw material and product, Kwekwe is a better location (Kwekwe is also better in terms of plant investment cost as mentioned below).

Table I-6-2 Site Comparison on Transportation and Distribution Cost (Variable Cost)

i. Product; Ammonia 600 T/D only

		Hwange	Kwekwe	Difference
(1)	Raw Coal	——	$600^{T/D} \times 1.2^{T/T} \times 330^{D/Y}$ $\doteqdot 237{,}600^{T/Y}$ $14.27^{Z\$/T} \times 237{,}600^{T/Y}$ $= 3{,}391^{Thousand\ Z\$/Y}$	
(2)	Product Ammonia	$600^{T/D} \times 330^{D/Y} = 198{,}000^{T/Y}$ $32.51^{Z\$/T} \times 198{,}000^{T/Y} = 6{,}437^{Thousand\ Z\$/Y}$		
	Total	$6{,}437^{Thousand\ Z\$/Y}$	$3{,}391^{Thousand\ Z\$/Y}$	$3{,}046^{Thousand\ Z\$/Y}$

ii. Product; Ammonia 300 T/D, Urea 525 T/D

		Hwange	Kwekwe	Difference
(1)	Raw Coal	——	$3{,}391^{Thousand\ Z\$/Y}$	
(2)	Product Ammonia	$300^{T/D} \times 330^{D/Y} = 99{,}000^{T/Y}$ $32.51^{Z\$/T} \times 99{,}000^{T/Y} = 3{,}218^{Thousand\ Z\$/Y}$	——	
(3)	Product Urea	$525^{T/D} \times 330^{D/Y} \doteqdot 173{,}250^{T/Y}$ $16.49^{Z\$/T} \times 173{,}250^{T/Y} = 2{,}857^{Thousand\ Z\$/Y}$	——	
	Total	$6{,}075^{Thousand\ Z\$/Y}$	$3{,}391^{Thousand\ Z\$/Y}$	$2{,}684^{Thousand\ Z\$/Y}$

Sites in Hwange and Kwekwe regions are compared in terms of plant investment in Table I-6-3.

Table I-6-3 Site Comparison on Production and Transportation Facilities

(in case of Products; Ammonia $300^{T/D}$ Urea $525^{T/D}$)

		Hwange	Kwekwe	Note
(1)	Ammonia Tank Wagon	*1) ——	——	*1) 50 nos. out of existing Sable Chemical's 25.5T/ car will be utilized.
(2)	Ammonia Storage Tank	2 nos. × $3{,}000^{T}$ Tank	1 no. × $3{,}000^{T}$ Tank	
(3)	Transportation Facilities for Raw Coal	8 nos. × 25^{T} Dump Truck	Turning Facility for Railway Wagon	
(4)	Raw Water Intake and Transfer Facilities	Nor. $350^{T/h}$ (max $400^{T/h}$) × 45^{Km} × 250^{m} of Altitude Difference	*2) —— *2) Assumed $200^{T/h}$ of Raw Water will be available through existing Sable Chemical's Plant	
(5)	Cooling Water Facilities	Cooling Tower Type	Air Fin Type Heat Exchanger	
(6)	Electricity Receiving Facilities	33^{KV} Receiving Facility From 33^{KV} to 6.6^{KV} Transformer	*3) 8.8^{KV} Existing Sable Chemical's Receiving Facility will be utilized.	

6.2.2 Recommendation of Candidate Site

The comparison of Hwange and Kwekwe areas as candidate sites has been made in the previous section. Although Kwekwe region has a chemical industry infrastructure and is close to the product market, and thus is favorable from an economic standpoint, it is limited in terms of water supply, one of the most important factors in chemical industry. Taking into consideration severe droughts that may occur in the future, irrigation water will be given priority, and the stable operation of a newly established chemical plant would be improbable due to the shortage of water supply to the plant.

On the other hand, although Hwange region is distant from the product market and is less favorable economically, it is of course favorable from the standpoint of supply of raw material coal, and though electric power is necessary for pumping water directly from Zambezi River, this is a reliable supply source.

Therefore, Hwange region is recommended as the site for this project. Establishment of a new industry in Hwange region will also comply with the decentralization policy, one of Zimbabwe's policies.

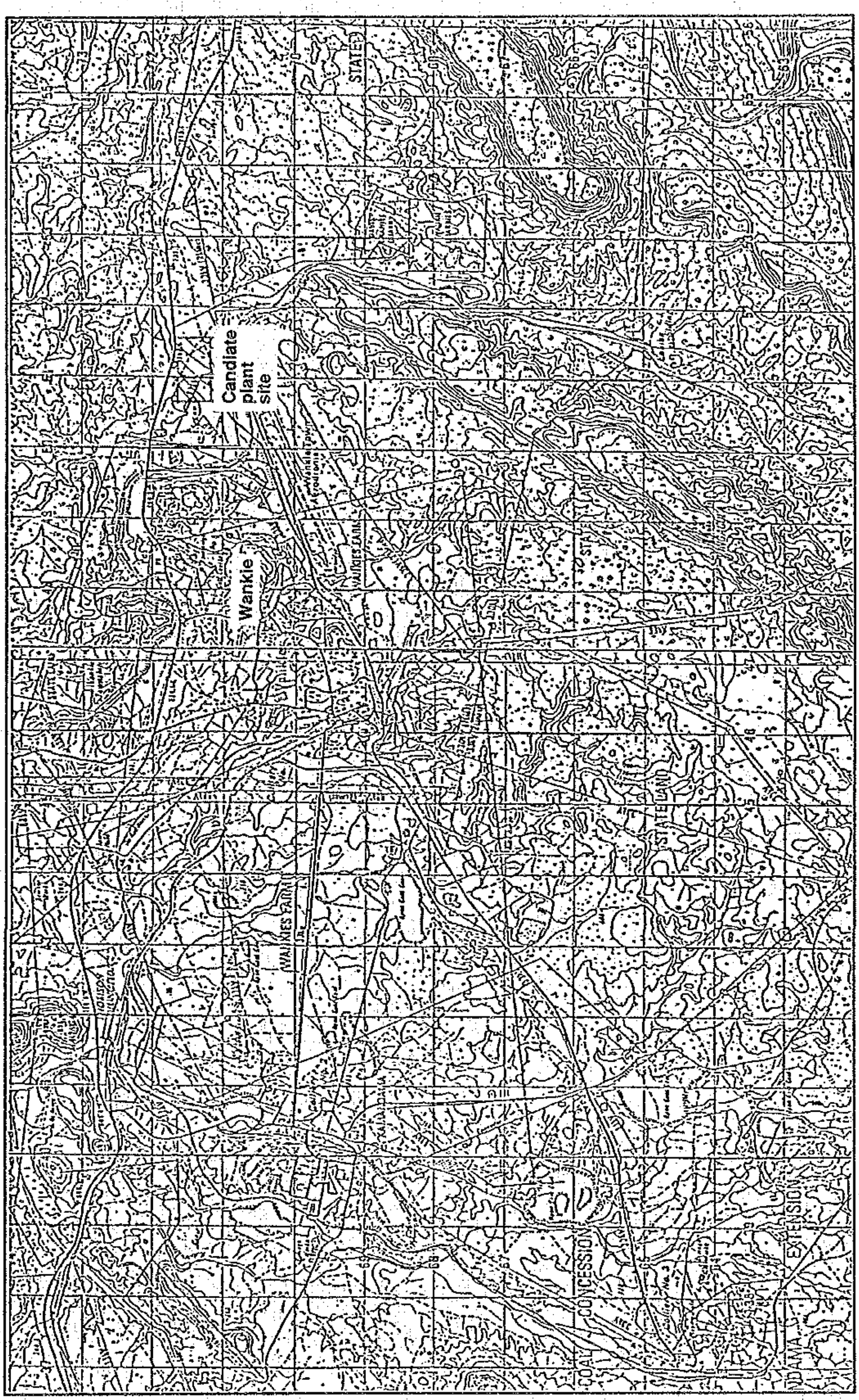


Fig. I-6-1 Candidate Plant Site in Hwange

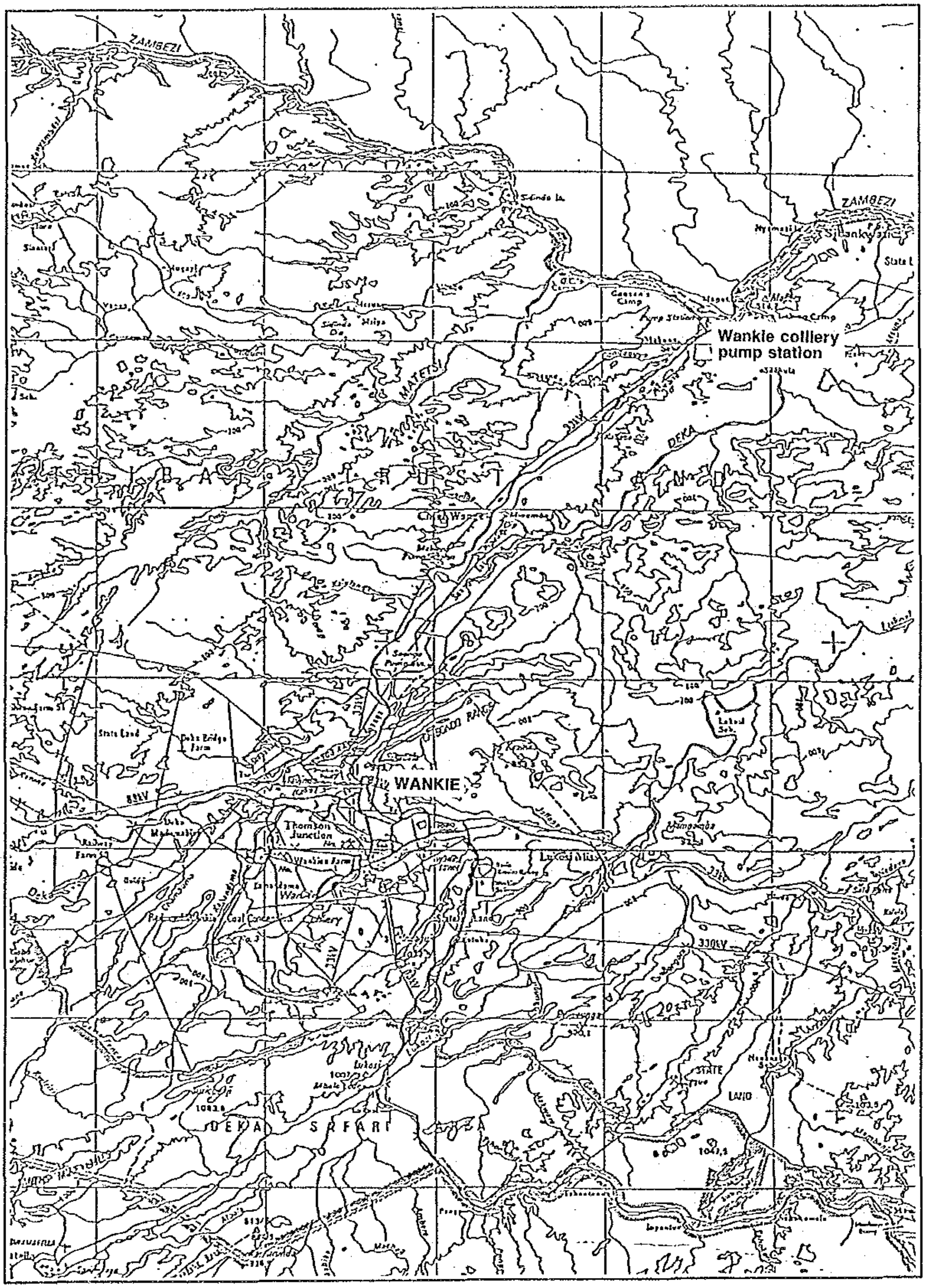


Fig. I-6-2 Candidate Plant Site and Water Intake Point in Hwange

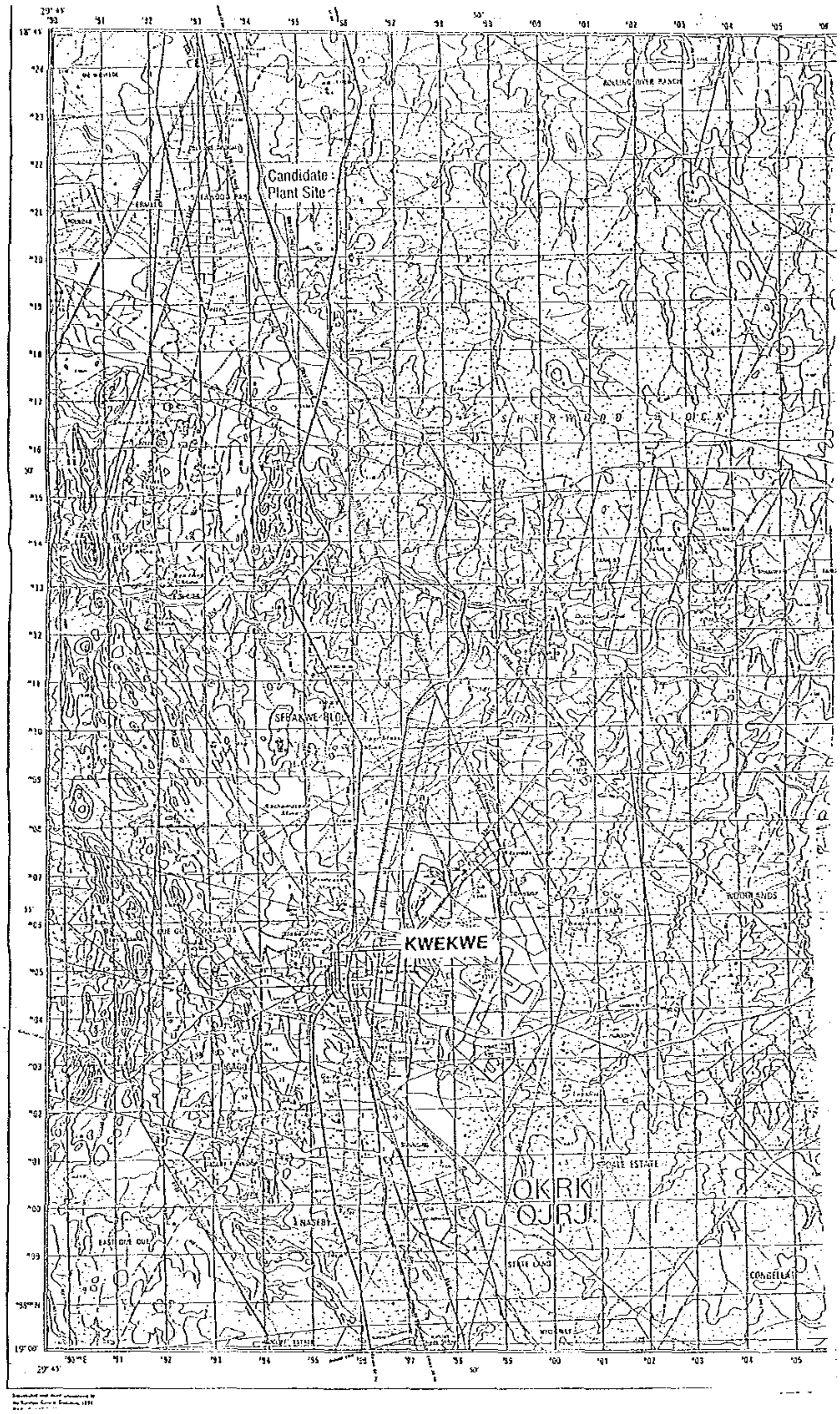
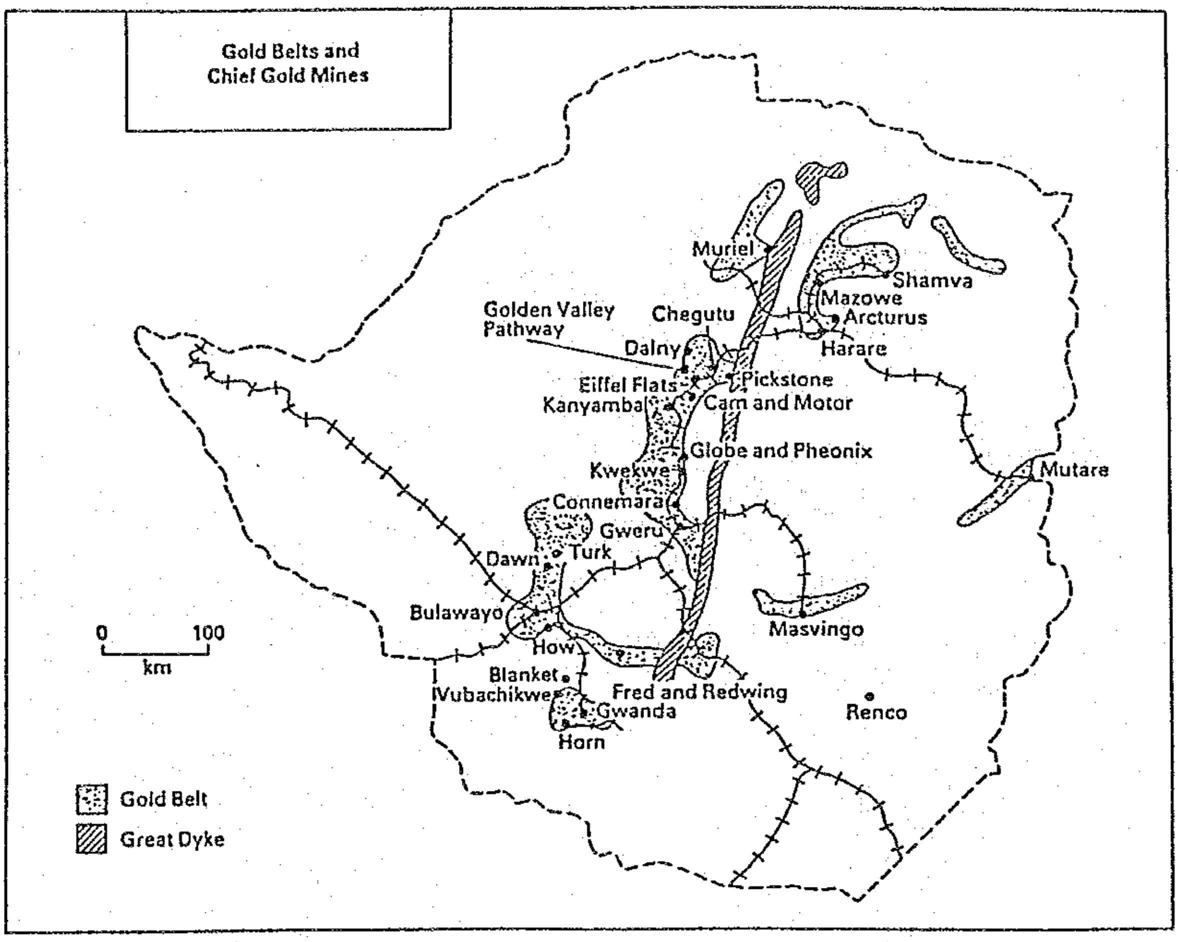


Fig. I-6-3 Candidate Plant Site in Kwekwe



Source: Lands and Peoples of Central Africa

Fig. I-6-4 Location of Gold Mines

Chapter 7 Sable Chemical Company

Chapter 7 Sable Chemical Company

7.1 Brief Description of SABLE

SABLE is Zimbabwe's only producer of nitrogenous fertiliszers. Lying 16 to 17 km to the north of Kwekwe, it is situated about 230 km to the southwest of Harare along the main highway joining Harare and Bulawayo. It stands on forty acres of land. Fig. I-7-1 outlines the basic layout of the plant, while Fig. I-7-2 gives a rough sketch of the plant's geographical location. There are large factories near SABLE, such as ZISCO, OXYCO and etc., as it lies in one of Zimbabwe's remarkable industrial areas.

7.1.1 History of SABLE

Zimbabwe made the decision in 1966 to build a plant that would meet a growing domestic demand for nitrogenous fertilizer, and by March 1969 had begun to operate a fertilizer plant capable of an annual output of 22,000 tonnes of ammonium nitrate. As for feedstock ammonia, this had to be entirely imported, and brought in by rail from the port of Maputo in Mozambique.

Landlocked as Zimbabwe is, however, transport has been extremely costly, and highly pushing up the price of the final product, fertilizer. In order to reduce these costs of transport, Zimbabwe therefore began domestic production of ammonia in 1972 using hydrogen obtained by the water electrolysis as a feed stock.

The facilities for the water electrolysis process were then expanded upon in 1975 to their present scale. Installations for the ammonia plant, however, which have been set up by relocating an existing French plant, are unable to produce enough ammonia to feed the plant for ammonium nitrate production to their full capacity, and about one-third of the required ammonia is therefore still having to be imported today.

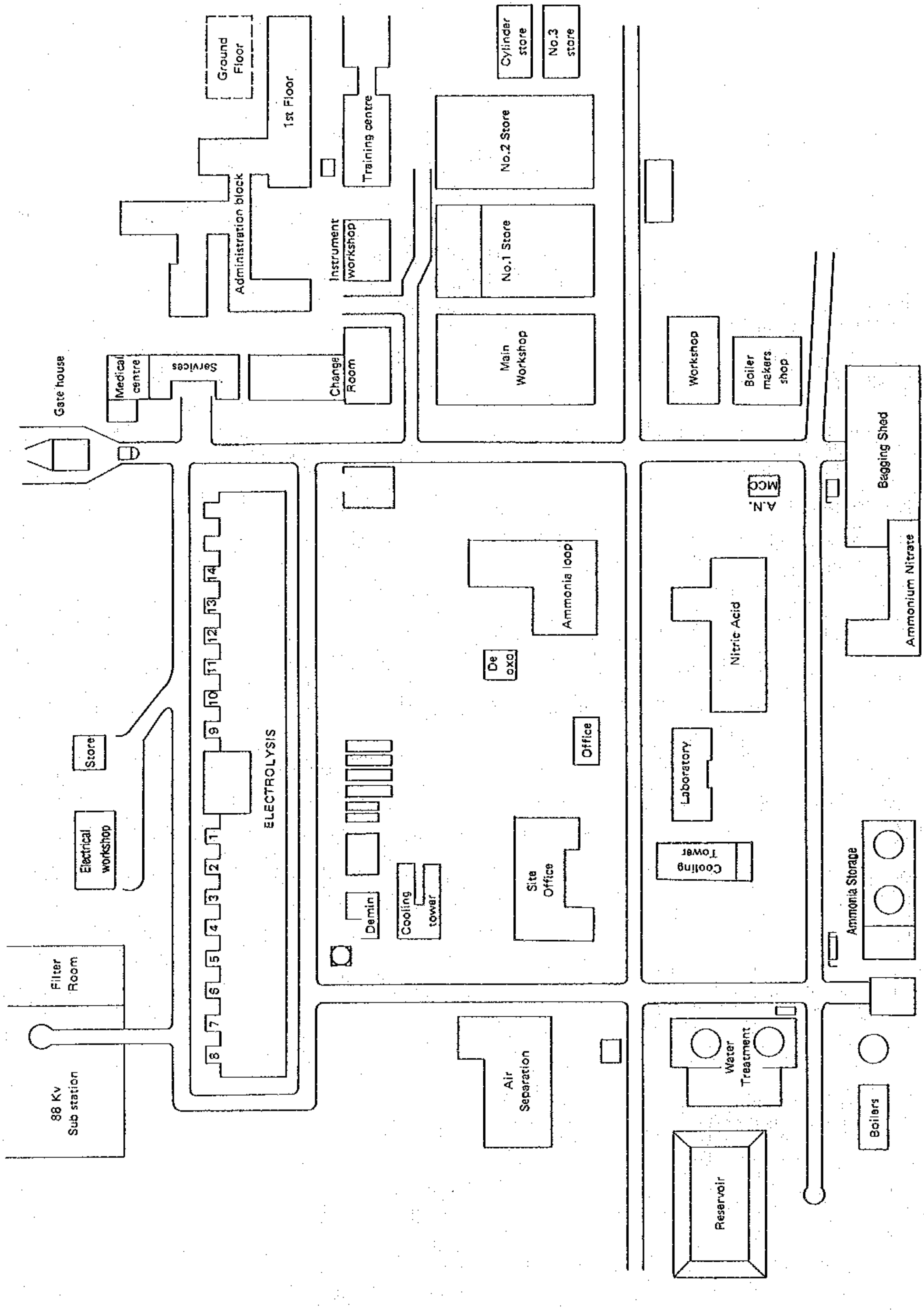


Fig. I-7-1 Layout of SABLE Plant

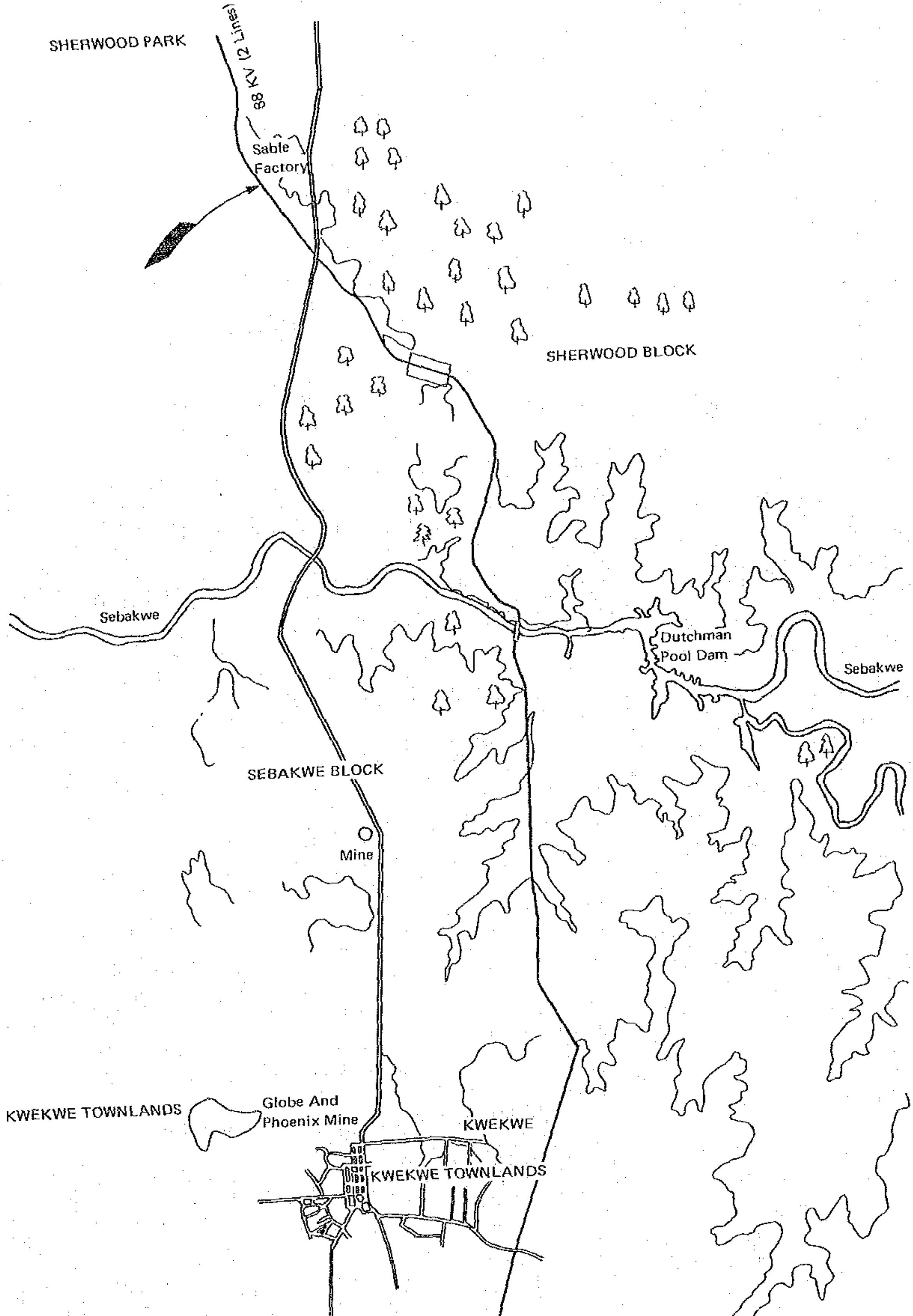


Fig. I-7-2 Location of SABLE

7.1.2 Production Capacity of SABLE

SABLE's production capacity in each of its products are today as follows:

Ammonia	70,000 T/Y
Nitric acid (57.5%)	82,000 T/Y x 2 trains
	(100% HNO_3)
Ammonium nitrate	215,000* T/Y (34.5% N)

* Note: This includes 15,000 T/Y for explosive grade ammonium nitrate for use in mining operations.

Because imported ammonia cannot at present enter the port of Maputo, and land transportation takes many days, the ammonia is carried over land from Richard's Bay (about 300 km north of Durban) in South Africa. SABLE uses both the ammonia it produces itself and that which it imports in its production of nitric acid and of ammonium nitrate.

Besides activities described above, SABLE sells 6,000 m^3/h oxygen gas to the nearby ZISCO plant, sending it at a pressure of 36 kg/cm^2G along 10" pipes.

Table I-7-1 gives figures for SABLE's activities in recent years.

Table I-7-1 SABLE- Historical Production

Unit : T/Y

	1981	1982	1983	1984	1985
Ammonia Produced	72,000	74,000	72,000	70,000	n.a.
Ammonia Imported	31,274	39,696	25,887	24,800	n.a.
Ammonium Nitrate	*225,000	243,000	243,000	198,000	206,000**

Note: * Includes about 15,000 T/Y for explosive grade ammonium nitrate

** Estimate

7.1.3 Description of SABLE's Facilities

The following gives a brief description of the main facilities of SABLE:

(1) Water electrolysis cells:

Lurgi-type high-pressure water electrolysis cell (30 bars) with 14 pairs (filter-press type)

Output capacity: 1,500 $Nm^3 - H_2$/h/pair

750 $Nm^3 - O_2$/h/pair

(2) Air separator: Air Liquid Co. Cryogenic-type 1 set.

(3) Ammonia converter: 1 unit

Pressure: 300 kg/cm^2

Output capacity: 220 T/D

(4) Nitric acid production plant: Grande Paroisse, Single-pressure type, 2 trains

Output capacity: 82,000 T/Y (100% HNO_3) x 2

Acid concentration: 57.5%

(5) Ammonium nitrate production plant:

1 train

Output capacity: 215,000 T/Y Ammonium nitrate (34.5% NH)

(6) Utilities:

1) Electric power supply: Delivered over 8 ~ 9 km at 88 kV from branch at Muniati

Service power: off-peak 110 MW

on-peak 100 MW

As the power supplied is stable, presenting no such difficulties as power failures and voltage drops, own power generating facility has not been installed.

2) Water supply: Water is supplied from the river Sebakwe, some 5 ~ 6 km to the south

Intake capacity: 300,000 m^3/M

Normal delivery: 100,000 m^3/M

Raw water is the dammed water delivered from the river Sebakwe, and because public and agricultural needs take precedence over industrial requirements, it may be expected that this source would present our project with severe restrictions, both in terms of quantity and quality of supply, during the dry season or during droughts. The quality of this raw water is as indicated in Table I-7-2.

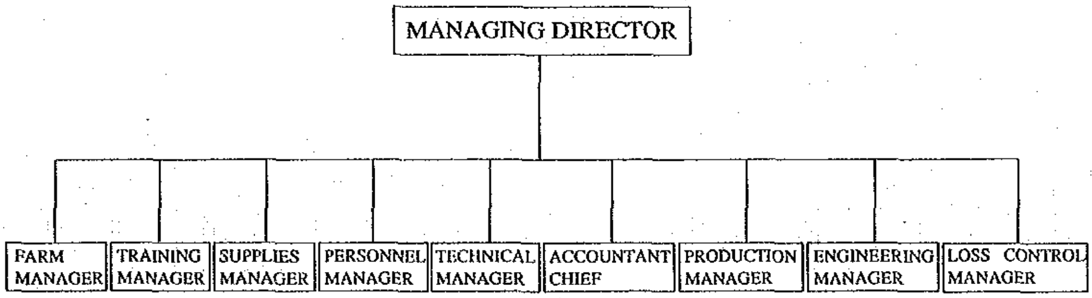
Table I-7-2 Raw Water Analysis at SABLE

Raw water		Mean	Range
pH		8.18	7.84 - 8.53
Conductivity	µS/cm	146.31	130 - 170
Silica	mg/l	14.09	6.0 - 17.0
T.D.S.	"	123.31	86 - 170
Total hard	"	71.18	60 - 95
C.A. hard	"	24.18	19 - 38
MG hard	"	47.22	39 - 63
Sulphates	"	24.86	12 - 48
Chlorides	"	8.00	5 - 11
'M' Alkalinity	"	74.80	68 - 97
Iron	"	0.36	0.25 - 0.46
Phosphates	"	1.00	0.10 - 1.90
Turbidity	%	62.26	57.41 - 70.63

Source: SABLE Laboratory's Analysis Data

7.1.4 Organization and Personnel of SABLE

The current organization of SABLE is shown in Fig. I-7-3



Its personnel number:

Sable	601
Sebakwe Farms	15
Total	616

Fig. I-7-3 SABLE Organization and Management (July 1988)

7.1.5 Outline of Current Operations at SABLE

The flow chart in Fig. I-7-4 gives some idea of current operations of SABLE.

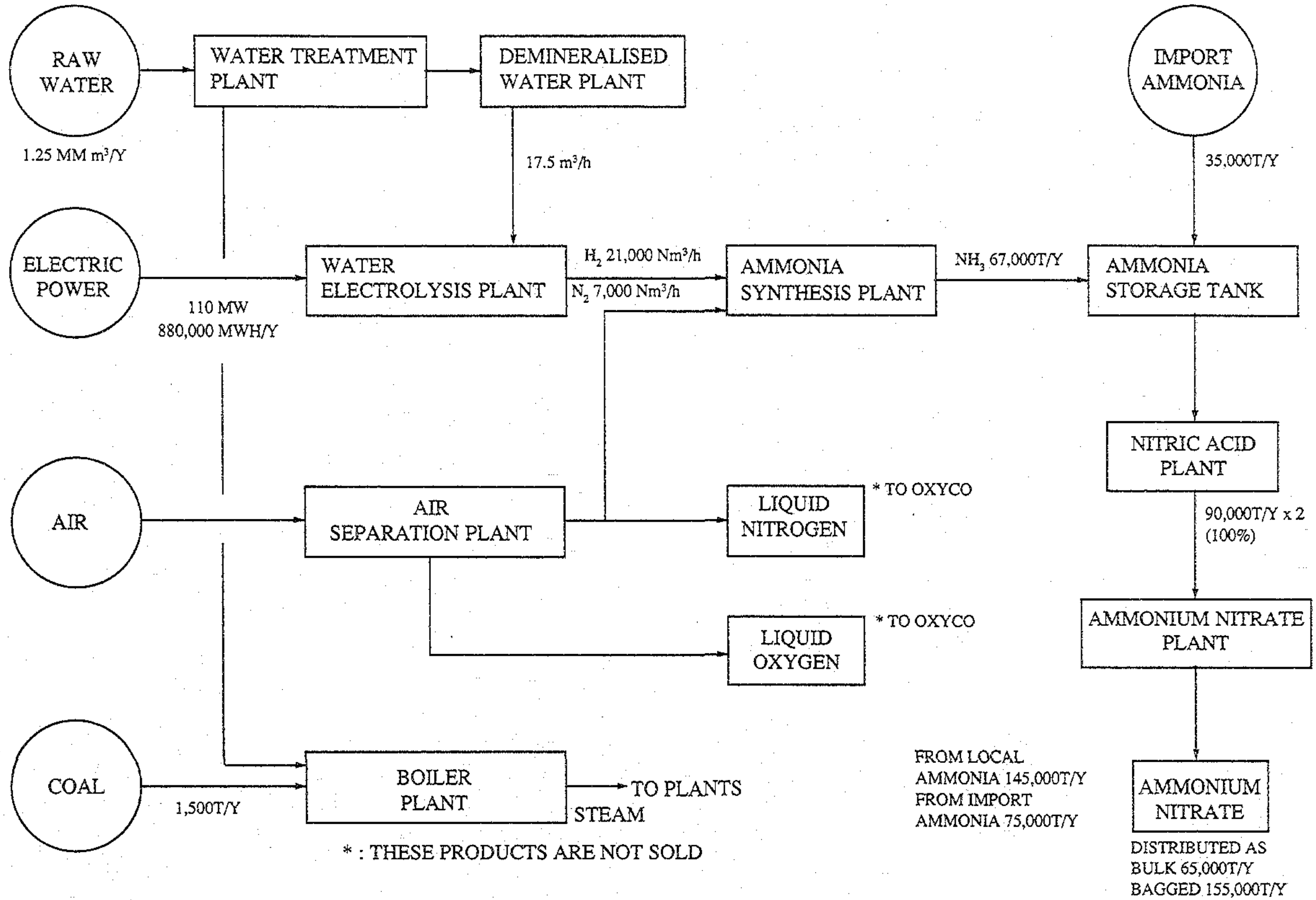


Fig. I-7-4 General Plant Operation

7.2 Relationship between SABLE and Designated Project

7.2.1 Ammonia Production Using Water Electrolysis

In order to meet the significant increases in the consumption of nitrogenous fertilizers which had occured in the country since 1965, the Government of Zimbabwe had drawn up plans for the production of ammonia from domestic resources. The question arose, however, of whether to adopt coal or hydroelectrolysis for obtaining the hydrogen to produce ammonia. It was finally decided to use the latter, the reasons for which were twofold. First, coal gasification technology had, at the time, not been sufficiently developed for the production of synthesis gas for chemicals. Secondly, the completion of the Kariba Dam had placed a 600 MW hydroelectric station in service, while Zimbabwe's domestic demand for electricity only amounted to 120 MW. It was therefore decided that the production of ammonia would be best done through the water electrolysis, using this abundant and inexpensive electricity.

However, the demand of electric power has increased and presently, the electric power sometimes has to be imported to meet the shortage of domestic supply.

Table I-7-3 gives the past supply and demand for electric power in Zimbabwe. This power has been furnished by the Kariba South Hydroelectric Station, small-size thermal power stations, and imports from Zambia (the Kariba North Hydroelectric Station), and because these are mainly hydroelectricity plants, prices had been kept at a low level.

In the National Development Plans for the periods 1982 - 1985 and 1986 - 1990, however, an ambitious objective of striving for self-sufficiency of power supply by 1993 was adopted, and coal-fired thermal power stations of Hwange-I (four 120 MW units) and Hwange-II (two 220 MW units) were installed in order to replace the imports from Zambia and to meet increases in the demand for electric power for the modernization of Zimbabwe.

Table I-7-3 Energy Balance in Zimbabwe

	1980	1981	1982	1983	1984	1985
Coal (1,000 T)						
Production	3,134	2,867	2,769	3,326	3,109	3,114
Imports	-	43	38	4	...	...
Exports (incl. coke)	342	229	194	249	277	...
Electricity (GWh)						
Production of which:	4,540	4,519	4,134	4,381	4,538	5,023
thermal	532	403	529	647	1,080	1,926
hydro*	4,008	4,116	3,605	3,734	3,458	3,097
Imports	2,732	3,005	3,609	3,086	2,917	3,070
Consumption	7,272	7,524	7,743	7,467	7,455	8,093
Liquid fuels (Z$ million)						
Imports	174.1	189.0	154.7	200.2	230.0	294.4

Note: *From Kariba South Bank

Surces: Quarterly Digest of Statistics; Stats-Flash

Furthermore, in order to meet future increases in power consumption, plans are being made for the installation of a coal-fired Hwange-III thermal power station (two 220 MW units), and for the modernization of the Kariba South Hydroelectric Station (from the present 6 x 111 MW to 6 x 125 MW), as well as making new additions to the Kariba South Hydroelectric Station (2 x 150 MW).

Although SABLE's ammonia production facilities had at the outset been planned to make effective use of the surplus power generated by the Kariba South Station, today it accounts for about 10% of Zimbabwe's total consumption of electricity, and is placing a heavy load on the supply of electric power.

Meanwhile, the start of operation of coal-fired power stations has increased the price of electricity in Zimbabwe, pushing up the costs of producing ammonia. Electricity tariff for industry use has in recent years increased in the following manner:

Unit: Z¢/kWh

1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1988
1.073	1.657	3.008	2.900	3.456	3.588	4.9199

The electric tariff may be expected to continue rising.

7.2.2 Production Costs of Ammonia at SABLE

According to the present survey, current costs of fertilizers at SABLE were found to be as follows:

Produced ammonia	Z\$ 530/T-NH_3	(US\$ 295/T)
Imported ammonia	Z\$ 534/T-NH_3	(US\$ 297/T)
Ammonium nitrate	Z\$ 280/T-Bagged	

The ex-plant price of ammonium nitrate has turned out to be:

Ammonium nitrate	Z\$ 324/T-Bagged
	Z\$313/T-Bulk

The cost of producing ammonia turns out to be two to three times that of ammonia in the international market. In a preliminary computation of the share of electric costs in the production costs of ammonia produced by SABLE, the following values could be assumed, since SABLE's electrolytic cells are new high-pressure Lurgi models: a unit consumption of 4.3 kWh/m^3-H_2, a rate of power consumption in the electrolytic process of 8,600 kWh/T-NH_3, and a rate of overall power consumption 10,200 kWh/T-NH_3. From these values the cost of electric power in producing one tonne of ammonia are found to be as follows:

	Unit cost of electric service	Power costs
1986/87:		
	average US¢1.977/kWh	US$202/T-$NH_3$
1988 (after price revisions):		
	average US¢2.3/kWh	US$235/T-$NH_3$

With the cost of electric power alone amounting to more than US$ 200/T-NH_3, endeavouring on a new enterprise at any such cost would be out of question.

The tariff of electricity, which may be expected to continue rising even further in coming years, would no doubt increase substantially the price of SABLE's ammonia, making it ever more difficult for the company to supply inexpensive fertilizer.

7.2.3 Relationship between SABLE and the Project

SABLE provides the only plant for the production of nitrogenous fertilizers in Zimbabwe. Its manufactured ammonium nitrate is supplied to ZFC and WINDMILL, and constitutes the main ingredient in their composite NPK fertilizers. SABLE's ammonium nitrate fertilizer and that for the production of NPK together account for the nation's entire output of fertilizer. SABLE, indeed, plays a main role in the chemical industry of Zimbabwe. Although its installations have been in operation for over fourteen years and are out of date, good maintenance practice has sustained their designated production capacity, so that with the appropriate maintenance work, their production capacity may be expected to continue unchanged. In the designated ammonia and urea production project, plans are to produce 600 T/D ammonia with coal as raw material and then produce urea as one candidate of end product. In the light of SABLE's current performance, it is recommendable to supply 300 T/D ammonia, a part of 600 tonnes ammonia above, to SABLE and continue the production of ammonium nitrate, utilizing effectively its existing facilities. The remaining 300 daily tonnes of ammonia would then be used to produce urea.

If urea is not to be manufactured, other ammonia derivatives have to be in its place considered for production. When the manufacture of urea goes underway, Zimbabwe will be itself producing two types of nitrogenous fertilizer, ammonium nitrate and urea, which is a good configuration from the standpoint of agricultural policy. In addition, the following advantages may be considered:

(1) SABLE will be able to shut down both their plants for hydroelectrolysis and ammonia synthesis, and purchase ammonia at an inexpensive price, thus reducing the production costs of ammonium nitrate and providing farmers with inexpensive fertiliser.

(2) SABLE will be able to save on foreign currency as they will obtain 100 tonnes of ammonia from domestic supply.

(3) Shutdown of the currently operative water electrolysis plant would provide 90 to 100 MW of surplus electric power for Zimbabwe, and contribute substantially to the nation's energy balance.

In so far as the Kwekwe region holds promise of developing into a center of Zimbabwe industry, this would enable to cover future increases in the demand for electric power using only existing power generating facilities.

(4) While funds of about 150 million US dollars would be required to construct the 100 MW coal-fired power station, such funds would have become unnecessary with this project, thereby offering Zimbabwe a significant advantage.