PRE-FEASIBILITY STUDY
ON
THE SOLVENT REFINED COAL
DEVELOPMENT PROJECT
IN
INDIA

(SUMMARY)

MARCH 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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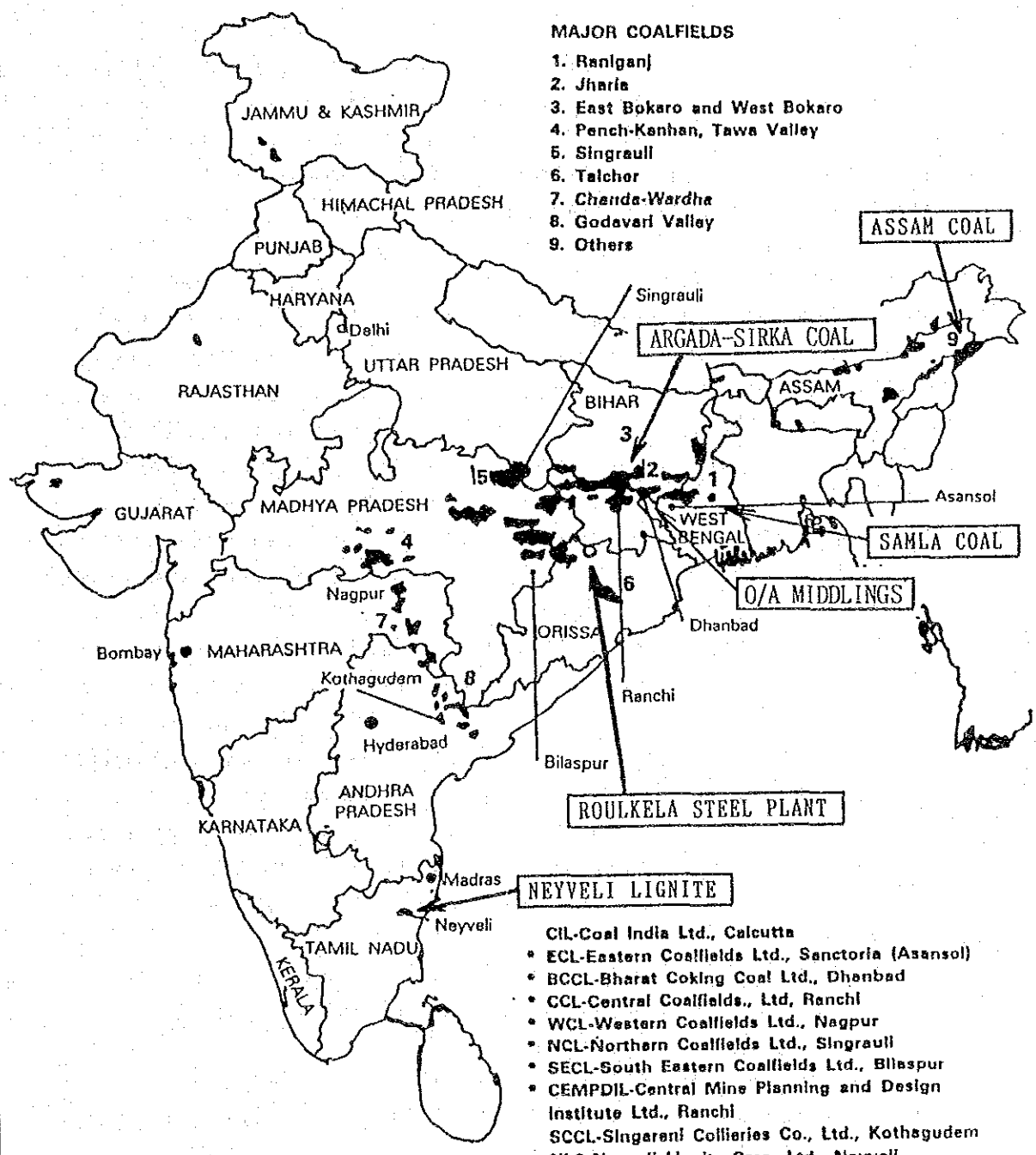
PROJECT SITES AND MAJOR COALFIELDS OF INDIA



CIL-Coal India Ltd., Calcutta
- ECL-Eastern Coalfields Ltd., Sanctoria (Asansol)
- BCCL-Bharat Coking Coal Ltd., Dhanbad
- CCL-Central Coalfields., Ltd, Ranchi
- WCL-Western Coalfields Ltd., Nagpur
- NCL-Northern Coalfields Ltd., Singrauli
- SECL-South Eastern Coalfields Ltd., Bilaspur
- CEMPDIL-Central Mine Planning and Design Institute Ltd., Ranchi

SCCL-Singareni Collieries Co., Ltd., Kothagudem
NLC-Neyveli Lignite Corp. Ltd., Neyveli

*subsidiary of CIL

Ref: Report 1988-89, Government of India Ministry of Energy, Department of Coal

SUMMARY

1. Background and Progress of the Report

Reduction of the ash content in coke and improvement of the coking strength are important tasks for the Indian Steel Industry to accomplish if improved productivity of furnaces and larger scale of production is to be achieved. At present the industry imports coking coal with a low ash content and uses this for blending with domestic varieties but the expenditure of foreign currency for such imports is considered undesirable. The Indian government decided to examine a project for the introduction of the SRC process for producing solvent refined coal with increased coking strength and low ash content from a variety of non-coking coal for which plentiful domestic deposits are found. The Indian government decided to undertake a Feasibility Study on a Construction Project for a Demonstration SRC Plant, and in March, 1989 made a request for technical cooperation to the Japanese government.

In response to the above request, the Japanese government through JICA sent a Preparatory Study Team to India in July, 1989 and on the basis of the report, JICA decided to implement the present Pre-feasibility Study. JICA dispatched a Preliminary Study Team in January, 1990 and agreed with the Department of Steel of the Ministry of Steel and Mines on the terms of Scope of Work for the pre-feasibility study on the Solvent Refined Coal Development Project.

The Pre-feasibility Study Team established the Inception Report included study methods on the basis of the Scope of Work, and the First On Site Survey was carried out from September to October, 1990. This Survey consisted of a general survey of the Indian Steel and Coal Industries, and a study of the proposed construction sites for the Demonstration Plant. Agreement was also reached with MECON on the methods to be used for the SRC production tests and Coke production tests, and the coal samples to be used in these tests for SRC sample production were obtained. After

return to Japan, the Team carried out the SRC production tests, and an Interim Report including the results of these tests was drawn up, and in September, 1991 the Second Team was dispatched for on site survey.

During the visit of the Second Team an agreement with the Indian counterpart was reached on such basic topics as the coal to be used for SRC production, the site for construction of the Demonstration Plant, etc. and new data was obtained regarding the New Industrial Policies determined and adopted by the Indian government. Further, collection of sample materials for Coke production tests was carried out. The team established the Draft Final Report based on the articles agreed during the second visit and on the results of the SRC production tests and the Coke Production Tests and carried out the third visit in January, 1992.

At the third visit, in order to improve financial and economic returns, the proposals were made on modifications of kinds and prices of non-coking coal for SRC production and on shifting a part of imported machinery and equipment to indigenous ones by Indian counterpart. Further, additional evaluation on some cases of coal blend for coke production was also requested by Indian counterpart.
The Final Report presented herein covers above requests made by Indian counterpart.

2. Objectives of the Report

The SRC Production Tests and Coke Production Tests using the produced SRC is to be carried out together with the conceptual design of the SRC Demonstration Plant. An evaluation of the feasibility of the Demonstration Plant in India in technical, financial and economic terms is to be effected and a master plan for SRC Development drawn up.

3. Outline of the Report

(1) The Scale of the Demonstration Plant will be for 500 tones of input coal daily, and the site for construction is to be inside the Rourkela Steel Plant premises.

The 500 tone per day intake of the Demonstration Plant was decided during the visit of the Preliminary Mission, and confirmed at First Visit, details for this scale of design taking into account the capacity of one preheater unit were confirmed in this study.

The Rourkela Steel Plant was chosen for the construction site since it was considered desirable that the SRC user SAIL retains the SRC Development, since steel plant coke oven gas would be utilized as the hydrogen source, and finally since Rourkela possesses equipments relating to SRC production such as the processing equipment for produced oil and personnel with related expertise. The site chosen inside the Rourkela Plant for proposed installation of the SRC Demonstration Plant is shown on Figure 1.

(2) Assam coal was chosen for SRC Coal Production, and its ash content is to be 4-6%.

Five coal varieties were selected for SRC Production Tests by the Indian and Japanese parties. Table 1 indicates the analytical results for these five coal varieties. In the SRC Production Tests carried out in Japan, Assam coal showed an extremely excellent solubility as can be seen for Figure 2. This was followed by Lignite and Samla coal and these three coals were suitable for SRC production. However, in the case of Argada-Sirka and O/A Middlings it was decided that a sufficient quantity of recycled solvent could not be assured in actual operations, due to the small output of produced oil and the large amount of residue, and so these were eliminated as inappropriate to SRC production. Given the choice of a site inside the

Rourkela Steel Plant the great distance to lignite deposits was seen to involve transport problems, and in the first screening only Assam coal and Samla coal were left as candidate feedstock.

From the supply viewpoint it was decided that Samla was a better candidate with regard to geographical conditions but SRC produced using Samla was calculated to be more expensive, and calculations showed that the cost of coke manufactured with Samla SRC would be much higher than the price of the coke currently produced. As a result Assam was chosen as feedstock of SRC production for the base case.

The ash content of Assam as analyzed in Japan was very low (only 2.1%) but a level of 2.1% was found to be exceptional in the Second Visit. It was therefore decided to set the ash content level at between 4 and 6%.

Although Assam coal deposits are located at some distance from the Rourkela Steel Plant, making transport troublesome, the geological deposits are estimated to be around 2.4 hundred million tones and since there are 40 million tones of proved mineable reserves, leaving aside the goaf and safety pillars, there will not be any problems in assuring the necessary amount of supplies.

(3) Samla coal to be used as the non-coking coal for Coke Production.

As the coalification of Samla coal is low, it was questioned whether this was the most appropriate variety to be used as the non-coking coal for blending with SRC to produce coke. However, since no substitute could be specified it was decided to use Samla coal.

(4) Simplification of Solid Separation Process in order to reduce Installation Costs.

It was decided during the Second Visit that the main target of SRC production were, firstly to maintain the necessary coking strength by the addition of SRC and secondly, to reduce the SRC production costs. In other words, if a reduction in SRC production costs could be effected a slight increase in the ash content of the SRC was to be tolerated. In view of this decision it was decided to reduce equipment costs by using a centrifugal type of equipment instead of filter type equipment as solid separation equipment. With the centrifugal method the ash content in SRC is approximately 5%.

By eliminating the solid separation equipment further additional reductions in equipment costs can be obtained, but it remains unclear how ash contents above 5% will effect the coking strength. The base case chosen was the use of centrifugal type facilities as the solid separation equipment. In light of Indian counterparts's view, profitability was evaluated on the case without solid separation equipment.

(5) The Investment Sum for the Demonstration Plant is assumed to be approximately 2 hundred and sixty million US$.

Table 2 indicates the investment cost for Demonstration Plant on which 100% Assam coal is to be used. Table 2 includes 80% import duties on imported machinery and solid separation equipment as well as contingencies, taxes, pre-operational costs, interest during construction, etc. In this case, the local portion will amount to 157.53 million US$, the foreign currency portion tO 97.63 million US$ and the total investment be in the order of 255.16 million US$.
The total investment for other cases such as zero import duty, without solid separation equipment and the capacity to be 1,000 t/d and 3,000 t/d is shown in

Table 3.

(6) SRC Production Cost equals 339 US$ (8,710 Rs) per tone in the Base Case.

Table 4 indicates the production cost of SRC using Assam coal as the feedstock as per conditions of the base case. If import duties are taken to be zero for imported machinery and some solid separation equipment eliminated then the SRC production costs are as shown in Table 5. The evaluation was made in the case of SRC using Assam coal 50% and Samla coal 50%, but the SRC production cost is superior to that of 100% Assam coal (Table 3 and 5).

(7) Coking strength is increased by blending with SRC. If coking coal (imported coal) is replaced by a blend of SRC and non-coking coal in a 1 to 2 Ratio (or less) then present coking strength can be maintained.

Table 6 shows an analysis of the properties of each coal variety. Table 7 shows the blending ratios used in the Coke Production Tests. Table 8 shows the properties of the various blended coals. A1 is taken as the base blend and is the equivalent blend ratio of coals used in the Rourkela Steel Plant at present, without blending of SRC and non-coking coal. Table 9 shows the Roga Drum Strength for cokes produced from the various coal blend ratios with a 500g carbonisation test oven. Figure 3 is a graphic presentation of this data. This data shows that the three cases A2 (5% Samla and 2.5% SRC), A5 (10% Samla and 5% SRC), A8 (15% Samla and 7.5% SRC) are a 2 to 1 ratio of Samla to SRC, and these clear the strength line set in the base blend (A1).

For confirmation a carbonisation test using SCO was conducted on A1 and A5. As shown in Table 10, A5 maintains the Roga-Drum strength in A1. Also calculations of coke Roga-Drum Strength of a 500 g Carbonisation Test Oven by conversion equations applied

to A1 with SCO at DI_{50}^{150} gave results similar to actual test data. Table 12 shows that when the base case A1 is assumed to be M_{10} in actual oven conditions this becomes 9.3 which clears the target value of ≤10.0 set for the coke M_{10} for determining the efficacy of SRC addition as well as 11.6 which is the value actually produced in the Rourkela Steel Plant at present. As Table 11 shows, when the proportion of Samla coal is lowered, higher coking strength than A1 is achieved such as in cases of A3 (5% Samla, 5% SRC) and A6 (10% Samla, 7.5% SRC).

B cases refer to an increase in the amount of medium coking coal (MCC) used instead of Samla coal, and in case B3 a 6% addition of SRC complements a 25% increase in MCC (65%-40% = 25%), so that the MCC/SRC ratio is 4 to 1 which also almost clears the A1 conditions. Actually, the high ash content of MCC excludes the use of such MCC increases but the above data shows that if a more suitable coal than Samla is selected then it would be possible to set the ratio against SRC at a level higher than 2. Table 13 shows the ash content of the coals and of coke in cases A1, A2, A5, A8 and B3.

(8) <u>The price of coke using SRC is superior to the present coke price, and so the financial and economic internal rates of return register quite low.</u>

Table 13, 14, 15 and 16 indicate ash content, coke price, financial and economic internal rates of return and foreign currency balance respectively on alternated cases of coal blend ratios using SRC as compared to similar coal blend ratio of Rourkela steel plant, that is domestic coking coal 30%, medium coking coal 40% and imported coal 30%. Also the case with premium against imported coal is shown.

In A5 and B3, Coke Production Tests were conducted in Japan and coke strength were confirmed to be equal to A1 (coke strength at RSP), however, in C1 and C2, no test was conducted. But, it is assumed that similar coke

strength to A1 could be obtained in C1 and C2. FIRR on B3 is higher than that of A5, C1 and C2, but due to high ash content B3 is not adopted. In the case of the premium against imported coal, FIRR is of course improved, but for EIRR calculation, premium is not taken account of, EIRR is the same low level as without premium. Although C2 gains the best result among A5, C1 and C2, coke price is higher than that of A5 and both FIRR and EIRR are low being 1.64 and 5.22 respectively.

Table 17 shows the case of imported coal 55% and domestic low volatile matter coking coal 45% which may have the possibility of private firms to adopt in the future. In this case, while getting higher FIRR, as it is not probable that private firms adopt coal blend which results in higher coke price, it is not appropriate to include in the considerations.

Table 14 indicates coke prices of zero import duty on imported machinery and equipment, on without solid separation equipment and on capacity of 1,000 t/d and 3,000 t/d. Coke price are higher than that of A1 (present coke price) in each case. In the case of a 1,000 tone and 3,000 tone scale the financial internal rates of return are minus 1.89% and plus 2.21% respectively.

The above cases represent those with conditions which lower the construction costs, but the sensitivity analysis is also conducted on the following variable factors, (1) with an increase in the price of imported coal, (2) with an decrease in the price of Indian non-coking coal and (3) if the capital investment is decreased. The result of above sensitivity analysis is shown in Table 18.

(9) A saving of an order of 142 million US $ on foreign currency is to be calculated result over a 20 year period if the entire foreign portion returned on the international balance is calculated, and calculated as

the return on the foreign currency against imported part a sum equaling 327 million US $ is saved over 20 years.

Table 16 shows the saving made in foreign currency by the reduction in imported coal previously needed for coke production but substituted for by SRC and non-coking coal with the completion of a 500 tone per day Demonstration Plant. The table shows the returns on a plant where 80% of total investment is financed from foreign currency (20% with domestic capital), whereby US$ 142 million (A5) is saved over 20 years in view of the expenditure of foreign currency which would be needed for repayment of the principal and interest of the foreign portion. If foreign currency payment on the imported part only is compared then over a 20 year period US$ 327 million can be saved. In all above cases, foreign currency saving can be anticipated from the initial year of operations.

(10) A global evaluation reveals that technically it is possible to raise coking strength by using SRC, and that the project can be expected to result in a plus on the international balance of payments, but that the cost of coke and internal rate of return will not give rise to profit. Since there are alternative measures for effecting an improvement in the quality of coke and for realising savings in foreign currency these alternatives should be examined and compared to the present project for an objective evaluation.

(11) It is necessary to adopt a very prudent attitude with regard to the SRC Development Project.

On the basis of the evaluation results of the present Pre F/S Report for the SRC Development Project it is necessary to give thorough consideration to whether a full stage F/S (incorporating bench scale plant tests) is to be undertaken or not. If such an undertaking is decided on it will be necessary to consider relation with the development of SRC technology to other developments

in coal liquefaction and coal chemistry technology besides coke production.

Under present survey, although the technical effect and the effect to improve foreign currency position are achieved, the present project has low internal rates of return both alternating coal blend ratio based on present RSP coke production and the extension to a commercial plant. Therefore, under the present economic conditions, it is considered that it is difficult to proceed to implement a full stage F/S including bench scale plant.

When the substantial changes on various conditions occur in the future, SRC development project is to be considered. In such a case it may take approximately 3 years for a full stage F/S to cover a construction of bench scale plant, a test of SRC production and coke production, a design of demonstration plant and economic evaluation. Further, as a result, if the construction of a demonstration plant is decided, approximately 3.5 years are required for the construction of demonstration plant. Taking due account of preparatory period in each stage, it would require at least 9 - 10 years for a demonstration plant to initially operate.

Table 1 ANALYTICAL DATA FOR COAL

Analytical Item			SAMLA Coal	ASSAM Coal	ARGADA-SIRKA Coal	NEYVELI Lignite	OA Middlings	Deoiled OA Coal	Analysis Method
Moisture (As received)	Total moisture	(wt%)	20.4	16.6	11.5	56.4	1.7	--	JIS M 8811
	Adherent moisture	(wt%)	10.9	14.5	8.4	46.3	0.0	--	
Proximate Analysis (Equilibrium Moisture Basis)	Moisture	(wt%)	10.7	2.4	3.4	18.8	1.7	1.0	JIS M 8812
	Ash content	(wt%)	12.6	2.1	17.9	3.5	21.0	26.4	
	Volatile matter	(wt%)	33.6	41.9	33.6	41.6	32.2	20.8	
	Fixed carbon	(wt%)	43.1	53.6	45.1	36.1	45.1	51.8	
Calorific Value (daf basis)		(kcal/kg)	7870	8380	7940	6610	8930	8400	JIS M 8814
Ultimate Analysis (daf basis)	Carbon	(wt%)	80.6	83.5	82.8	71.1	86.5	86.2	JIS M 8813
	Hydrogen	(wt%)	5.1	5.8	5.4	5.0	6.5	4.9	
	Oxygen	(wt%)	11.4	7.9	9.4	22.3	4.2	6.2	
	Nitrogen	(wt%)	2.4	1.2	1.5	0.7	1.4	1.9	
	Sulphur	(wt%)	0.5	1.6	0.9	0.9	1.4	0.8	
Grindability (HGI)			48	47	44	141	--	--	JIS M 8801
Petrographic Analysis	Vitrinite	(%)	72.8	91.4	50.1	92.5	--	41.2	JIS M 8816
	Exinite	(%)	5.5	3.7	8.3	1.9	--	0.9	
	Inertinite	(%)	13.6	3.3	30.6	2.9	--	41.3	
	Minerals	(%)	8.1	1.6	11.0	2.7	--	16.6	
Mean Maximum Reflectance (Ro)		(%)	0.63	0.72	0.78	0.42	--	1.18	JIS M 8816

Table 2 CAPITAL INVESTMENT COST

- Feedstock Coal: Assam Coal -

Items	Capital Investment Cost, US$, million		
	Foreign Currency	Local Currency	Total
1. Land & Site Development	-	0.0	0.0
2. Plant Direct Cost	55.75	74.47	130.22
- Equipment and Materials	(52.11)	(50.31)	(102.42)
- Spare Parts	(3.64)	(3.52)	(7.16)
- Erection and Installation Works	(-)	(6.64)	(6.64)
- Civil and Building Works	(-)	(13.87)	(13.87)
- Additional Facilities	(-)	(0.13)	(0.13)
3. Ocean Freight and Insurance	1.35	-	1.35
4. Local Handling and Inland Transportation	-	0.36	0.36
5. Indirect Field Expenses	-	2.21	2.21
6. Engineering Services	12.95	4.64	17.59
- License Fee	(2.71)	(-)	(2.71)
- Basic Design	(0.84)	(-)	(0.84)
- Engineering Services	(6.76)	(3.25)	(10.01)
- Project Management	(2.64)	(1.39)	(4.03)
Base Project Cost - 1991	70.05	81.68	151.73
7. Contingency	5.58	8.13	13.71
- Physical Contingency	(5.58)	(8.13)	(13.71)
- Price Escalation	(Not considered in the analysis)		
8. Tax and Duty	-	61.11	61.11
- Import Duty	-	(50.14)	(50.14)
- Excise Duty, Sales Tax and R & D Cess	-	(10.97)	(10.97)
Erected Plant Cost - 1991	75.63	150.92	226.55
9. Pre-Operation Expenses	-	4.63	4.63
10. Interest during Construction (F:6%)	22.00	-	22.00
11. Initial Working Capital	-	1.98	1.98
Capital Investment Cost - 1991	97.63	157.53	255.16

Table 3 TOTAL CAPITAL INVESTMENT COST

(Unit: US$ million)

Coal Capacity t/d (Dry Coal)		Assam			Samla	Assam + Samla
Import Duty	Sep. P.	500	1000	3000	500	500
80%	Y (Base)	255.16	408.57	843.16	306.65	271.24
0%	Y	200.14				
80%	N	214.03				
0%	N	174.06				

Table 4 SRC PRODUCTION COST
- Assam Coal Base Case -

Inputs and Pricing (CIF at the Plant in 1991 Price Base)

Inputs	Unit		Per Feed Coal(Dry)		Per SRC	Annual as of 2009	
	Unit	Cost	Consumption	Cost	Cost	Consumption	Cost
		$/Unit	Unit/Unit	$/Unit	$/Unit	Unit	$, million
Raw Material							
- Feedstock Coal (Purchase)	ton	56.02	1.10742	62.04	91.34	182,724	10.236
- Coke Oven Gas	ton	65.42	0.6336	41.45	61.03	104,544	6.839
Utilities							
- Fuel Coal	ton	30.21	0.3984	12.04	17.72	65,736	1.986
- Electricity	kWh	0.0401	62.88	2.52	3.71	10.375×10^6	0.416
- Steam(57kg/cm^{2}G)	ton	9.776	0.48	4.69	6.91	79,200	0.774
- Make-up Water	m^3	0.03	9.60	0.29	0.43	$1,584 \times 10^3$	0.048
- Nitrogen	Nm^3	0.0288	24.0	0.69	1.02	$3,960 \times 10^3$	0.114
- Catalyst(Iron Ore)	ton	35.71	0.0309	1.10	1.62	5,100	0.182
- Catalyst (Sulfur)	ton	136.13	0.0074	1.01	1.48	1,212	0.165
- Chem.(Filter Aid)	ton	250.00	0.0112	2.80	4.12	1,848	0.462
- Chemicals, etc.	ton	-	-	-	0.38	-	0.043
(1) Variable Cost	-	-	-	-	189.76	112,063	21.265
Operating Labor	M-Y	2226			2.66	134	0.298
Overhead	Ope. Labor x 50%				1.33	-	0.149
Maintenance(Materials)	E&M, CIF x 1.5%				27.97	-	3.134
(Labor)	M-Y	2227			1.05	53	0.118
Administration (Supplies)	Admi. Staff x 100%				0.45	-	0.050
(Staff)	M-Y	2633			0.45	19	0.050
Tax & Insurance	Book Value x 0.5%				5.89	-	0.661
(2) Direct Fixed Cost	-	-	-	-	39.80	-	4.460
Credits							
- Return Gas	ton	62.93	0.6427	40.45	59.56	106,049	6.674
- Light Distillate	ton	156.20	0.036	5.61	8.26	5,931	0.926
- Middle Distillate	ton	147.22	0.006	0.88	1.25	950	0.140
- Residue	ton	5.266	0.087	0.46	0.67	14,303	0.075
(3) Total Credits	-	-	-	-	69.74	-	7.815
(4) Production Cost = (1)+(2)-(3)					159.82	112,063	17.910
(5) Depreciation & Interest (D & I)	See Item 5.				178.95	-	20.054
(6) Total Production Cost inc. D&I = (4)+(5)					338.77	112,063	37.964

Table 5 SRC PRODUCTION COST (IN 10 YEARS AFTER START-UP)

Unit: US$/t, Dry (Rs/t, Dry)

Coal Capacity t/d (Dry Coal)		Assam			Samla	Assam + Samla
Import Duty	Sep. P.	500	1000	3000	500	500
80%	Y	338.77 (8,710)	307.93 (7,917)	251.40 (6,463)	515.34 (13,249)	369.59 (9,502)
0%	Y	292.08 (7,509)				
80%	N	289.88 (7,453)				
0%	N	255.96 (6,581)				

Ref: prices of coals:

	(Rs/t, Wet)	(Rs/t, Dry)
P.C.C.	1,009.92	1,074.38
M.C.C.	995.20	1,073.10
N.C.C.	776.68	940.29
Imp.C.	2,450.00	2,663.04
SRC	8,274.29	8,709.78

Table 6 PROPERTIES OF SINGLE COALS

Brand Name	Proximate Analysis (%, d)		TS (%, d)	Fluidity				Dilatation							
	Ash	VM		Softening Temperature (℃)	Max. Fluidity Temperature (℃)	Solidification Temperature (℃)	Log. Max. Fluidity	Softening Temperature (℃)	Temperature of Max. Contraction (℃)	Temperature of Max. Dilatation (℃)	Contraction (%)	Dilatation (%)	Total Dilatation (%)	Ro (%)	TI (%)
Bhojudih	24.00	20.3	0.50	420	463	495	2.07	388	452	470	21	-7	14	1.32	44.1
Sudamdih	24.20	21.7	0.56	481	449	488	3.08	370	438	448	25	-17	8	1.20	47.9
Chasnala	17.80	24.8	0.51	400	441	479	2.64	383	442	463	23	-3	20	1.16	50.9
Kargali	19.50	24.4	0.60	414	452	491	2.62	373	439	448	25	-19	6	1.15	49.9
Swang	21.80	22.3	0.55	395	446	481	3.30	373	435	471	23	23	46	1.19	51.3
Rajrappa	20.90	29.5	0.71	394	429	465	3.29	370	438	448	25	-17	8	0.85	48.7
Imported Coal	9.10	23.8	0.57	413	458	493	2.61	392	440	480	25	78	103	1.19	41.1
Samla	13.80	34.6	0.45	(Coal Briquetting Not Possible)				365	480	-	16	-16	0	0.56	27.5

Table 7 BLENDING RATIO (%) OF COAL BLEND USED IN THE CARBONIZATION TEST

Brand Name	A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3
Bhojudih	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	14.55	14.1
Sudamdih	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.70	9.4
Chasnala	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.85	4.7
Kargali	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	20.0	19.40	18.8
Swang	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	20.0	19.40	18.8
Rajrappa	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	30.0	29.10	28.2
Imported Coal	30.0	22.5	20.0	17.5	15.0	12.5	10.0	7.5				
Samla		5.0	5.0	10.0	10.0	10.0	15.0	15.0	22.5			
SRC		2.5	5.0	2.5	5.0	7.5	5.0	7.5	7.5		3.00	6.0

Table 8 PROPERTIES OF COAL BLEND FOR 500g CARBONIZATION TEST

No.	Proximate Analysis (%, d)		TS (%, d)	Fluidity				Dilatation					
	Ash	VM		Softening Temperature (℃)	Max. Fluidity Temperature (℃)	Solidification Temperature (℃)	Log. Max. Fluidity	Softening Temperature (℃)	Temperature of Max. Contraction (℃)	Temperature of Max. Dilatation (℃)	Contraction (%)	Dilatation (%)	Total Dilatation (%)
A1	18.0	24.2	0.59	411	458	493	2.85	388	439	455	24	16	40
A2	17.8	25.7	0.59	384	439	478	3.35	355	427	464	25	10	35
A3	17.7	25.6	0.59	394	447	492	3.53	364	426	463	25	8	33
A4	18.3	25.7	0.58	406	453	494	2.95	370	436	457	24	-8	16
A5	18.0	26.6	0.58	397	446	490	3.37	365	428	453	23	-6	17
A6	18.0	27.0	0.57	363	429	479	3.94	343	423	456	22	-1	21
A7	18.4	26.7	0.57	396	446	488	3.24	366	435	453	24	-15	9
A8	18.2	27.2	0.59	377	430	478	3.62	347	426	451	23	-15	8
A9	18.7	28.0	0.59	374	428	470	3.56	363	436	436	25	-25	0
B1	21.6	24.5	0.60	397	441	476	2.83	385	443	459	25	-11	14
B2	20.9	25.3	0.61	403	450	486	3.41	343	425	456	23	-4	19
B3	20.4	25.7	0.62	370	435	480	4.70	364	430	454	22	-4	18

Table 9 RESULTS OF 500g CARBONIZATION TEST

No.	Proximate Analysis (%, d)		TS (%, d)	Roga-Drum Strength	True Specific Gravity	Apparent Specific Gravity	Porosity (%)	JIS Reactivity (%, AG)	MSI
	Ash	VM							
A1	23.2	0.7	0.4	70.9	2.01	1.03	48.7	18	25.6
A2	23.2	0.6	0.4	72.8	2.02	1.07	47.0	20	25.4
A3	23.3	0.8	0.5	75.5	2.02	1.13	44.1	21	25.3
A4	23.4	0.7	0.4	65.6	2.02	1.00	50.4	25	26.9
A5	23.8	0.5	0.4	71.3	2.05	1.10	46.4	26	25.9
A6	23.5	0.8	0.5	72.8	2.02	1.14	43.6	24	24.6
A7	24.2	0.6	0.4	65.3	2.02	1.01	49.8	31	25.9
A8	23.7	0.6	0.5	71.7	2.01	1.08	46.2	27	25.4
A9	24.8	0.7	0.4	63.8	2.02	1.05	48.3	35	25.5
B1	27.9	0.5	0.4	67.6	2.05	1.05	48.9	21	26.9
B2	26.5	0.7	0.5	68.8	2.04	1.08	47.2	17	26.8
B3	26.4	0.7	0.5	70.2	2.05	1.04	49.0	15	27.3

Table 10 RESULTS OF SCO TEST

	Proximate Analysis (%,d)		TS	Size Distribution (%)						Mean Size	Drum Strength		CRI	CSR
	Ash	VM	(%,d)	125~100	100~75	75~50	50~38	38~25	<25mm	(mm)	DI$^{?}_{?}$	DI$^{?}_{?}$		
A1	23.4	0.7	0.5	4.0	23.4	36.9	23.1	4.4	8.2	60.6	91.0	73.9	23.7	38.8
A5	23.2	0.6	0.5	12.3	21.3	39.5	15.4	4.5	7.0	66.2	91.1	73.0	25.3	40.9

Table 11 RELATION BETWEEN DRUM STRENGTH (SCO) AND M_{10} (ACTUAL OVEN)

$DI^{5}_{5}{}^{\circ}$ (SCO) = 73.9 (Test Result) Case "A1"

Conversion Equation-3:

$DI^{5}_{5}{}^{\circ}$ (Actual Oven) = 0.884 x $DI^{5}_{5}{}^{\circ}$ (SCO) + 11.9 = 77.2

Conversion Equation-4:

M_{10} (Actual Oven) = -0.43 x $DI^{5}_{5}{}^{\circ}$ (Actual Oven) + 42.5 = 9.29

$9.29 \leqq 10$ (Target M_{10})

Table 12 RELATION BETWEEN DRUM STRENGTH (SCO) AND ROGA-DRUM STRENGTH (500g)

Conversion Equation-2:

$DI^{5}_{5}{}^{\circ}$ (SCO) = 0.936 x Roga-Drum Strength (SCO) + 0.4

$DI^{5}_{5}{}^{\circ}$ (SCO) = 73.9 (Test Result) Roga-Drum Strength (SCO) = 78.5

Conversion Equation-1:

Roga-Drum Strength (SCO) = 0.665 x Roga-Drum Strength (500g) + 33.7

Roga-Drum Strength (500g) = 67.4 $\fallingdotseq$ 70.9 (Test Result)

Table 13 ASH CONTENT IN COAL AND COKE BY VARIOUS COAL MIXTURE

	Present Ope	Cases Using SRC					
	RSP '90	Test A2	Test A5	Test A8	Test B3	Case C1	Case C2
Ash in Blended Coal [%]	18.2	18.1	18.2	18.3	20.4	18.2	18.3
Ash in Coke [%]	22.7	23.0	23.5	23.9	25.9	23.5	23.7
Coal Blend Ratio [%]							
--PCC	(37.9)	(30.0)	(30.0)	(30.0)	(28.2)	(30.0)	(10.0)
Bhojudih	19.0	15.0	15.0	15.0	14.1	15.0	5.0
Sudamdih	12.6	10.0	10.0	10.0	9.4	10.0	0.0
Chasnala	6.3	5.0	5.0	5.0	4.7	5.0	5.0
--MCC	(32.5)	(40.0)	(40.0)	(40.0)	(65.8)	(47.0)	(72.5)
Kargali	8.1	10.0	10.0	10.0	18.8	10.0	20.0
Swang	8.1	10.0	10.0	10.0	18.8	10.0	20.0
Rajrappa	16.3	20.0	20.0	20.0	28.2	27.0	32.5
--HVC	(0.4)					(10.0)	(5.0)
--IMPORTED COAL	(29.2)	(22.5)	(15.0)	(7.5)	(0.0)	(8.0)	(7.5)
--NCC	(0.0)	(5.0)	(10.0)	(15.0)	(0.0)	(0.0)	(0.0)
--SRC		(2.5)	(5.0)	(7.5)	(6.0)	(5.0)	(5.0)
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[Acoke]=[Acoal]/[yield]
[yield]=[yield0]*f(x)/f(x0)
f(x)=(98-0.84*[vm])*(1-[wa])

[Acoke]: ash in coke
[Acoal]: ash in coal
[yield]: BF coke yield
[vm]: volatile matter[%]
[wa]: water in coal[-]
f(x): formula estimating coke yield
suffix 0:figure in With-out Case

Case C1 and C2: Blend ratio was given by Indian Side

Table 14 COKE PRODUCTION COST

Assumption: - In 10 years after start-up
- Coke Cost Adjusted by Ash Content
- Coke Cost without SRC of Test-A1: 2,276.9 Rs/t

(Unit: Rs/t)

Coal			Assam			Samla	Assam + Samla
Capacity [t dry coal/d]			500	1000	3000	500	500
Case using SRC	Imp.Duty	Solid Sep.					
Test A5	80%	Y	2,496.5	2,437.1	2,328.4	2,836.3	2,555.8
Test A5	0%	Y	2,406.6	-	-	-	-
Test A5	80%	N	2,402.4	-	-	-	-
Test A5	0%	N	2,337.1	-	-	-	-
Test B3	80%	Y	2,350.4	-	-	-	-
Case C1	80%	Y	2,426.6	-	-	-	-
Case C2	80%	Y	2,384.5	-	-	-	-

[Ctot]=([Cmate]-[Cbypro]+[Cope])*[coke]/[coke0]

[Cmate]=[Ccoal]/[yield]

[Cbypro]=[Cbypro0]*g(x)/g(x0)

g(x)=0.84*[vm]*(1-[wa])/f(x)

[Ctot]: unit coke production cost

[Cmat]: unit material cost

[Cbypro]: unit by-product credit

[Cope]: unit operating and other cost

[Ccoal]: unit coal cost

Table 15 FINANCIAL INTERNAL RATE OF RETURN AND ECONOMIC INTERNAL RATE OF RETURN

I. FINANCIAL INTERNAL RATE OF RETURN (FIRR)

(%)

Coal Capacity t/d (Dry Coal)			Assam			Samla	Assam + Samla	Assam *1
Case using SRC	Import Duty	Sep. P.	500	1000	3000	500	500	500
Test A5	80%	Y (Base)	-2.77	-1.89	2.21	-10.69	-4.49	0.77
Test A5	0%	Y	-0.38					3.38
Test A5	80%	N	0.18					3.60
Test A5	0%	N	2.35					5.98
Test B3	80%	Y	3.24					7.14
Case C1	80%	Y	0.13					4.25
Case C2	80%	Y	1.64					5.49

*1: Case with premium (20%) on imported coal

II. ECONOMIC INTERNAL RATE OF RETURN (EIRR)

(%)

Coal Capacity t/d (Dry Coal)			Assam
Case using SRC	Import Duty	Sep. P.	500
Test A5	0%	Y	3.11
Test B3	0%	Y	1.50
Case C1	0%	Y	4.02
Case C2	0%	Y	5.22

Table 16 FOREIGN CURRENCY SAVING DURING 20 YEARS

(US$ million)

Case using SRC	Coal Capacity t/d (Dry Coal) Import Duty	Sep. P.	Assam 500	Assam 1000	Assam 3000	Samla 500	Assam + Samla 500
Test A5	80%	Y (Base)	141.9 *	430.8	1,858.1	-80.8	98.2
Test A5	0%	Y	218.6				
Test A5	80%	N	204.4				
Test A5	0%	N	260.0				
Test B3	80%	Y	486.0				
Test C1	80%	Y	382.8				
Test C2	80%	Y	400.0				

* Foreign currency saving is US$ 327 million in case foreign loan equaling foreign portion only instead of 80% of capital investment cost.

Table 17 FINANCIAL ANALYSIS FOR VARIOUS BLENDS ASSUMED TO BE APPLIED TO PRIVATE SECTOR (P SERIES)

I. ASH CONTENT IN COAL AND COKE

(%)

	W/O SRC	Case P1	Case P2	Case P3
Ash in Blended Coal	14.0	15.3	16.0	16.5
Ash in Coke	17.2	18.7	19.4	20.0
- IMPORTED COAL	(55.0)	(39.0)	(30.0)	(25.0)
- LVMC	(45.0)	(58.0)	(65.0)	(70.0)
- SRC	(0.0)	(3.0)	(5.0)	(5.0)
Total	100.0	100.0	100.0	100.0

II. COKE PRODUCTION COST

	W/O SRC	Case P1	Case P2	Case P3
Coke Production Cost, Rs/t	2,845.5	2,859.7	2,900.9	2,805.4

Notes: - In 10 years after start-up
- Coke Cost Adjusted by Ash Content

III. FINANCIAL INTERNAL RATE OF RETURN (FIRR)

(%)

	W/O SRC	Case P1	Case P2	Case P3
FIRR w/o Premium	-	4.33	3.37	6.13
FIRR with Premium *	-	8.25	7.24	10.14

* Case with premium (20%) on imported coal

IV. FOREIGN CURRENCY SAVING (FCS) DURING 20 YEARS

	W/O SRC	Case P1	Case P2	Case P3
FCS, US$, MM	-	543.3	486.0	658.0

Table 18 FINANCIAL I.R.R. SENSITIVE ANALYSIS

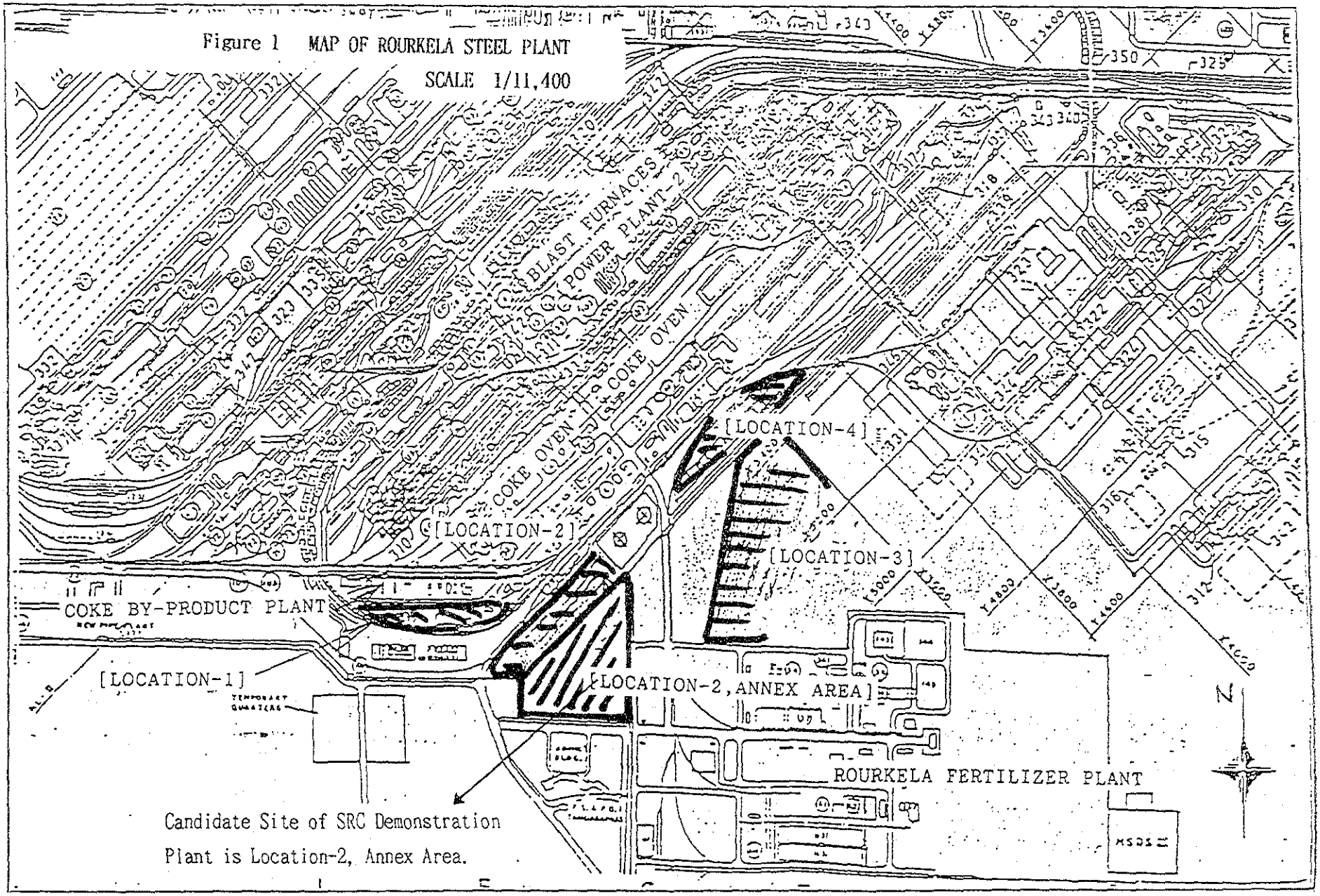
(SRC/Samla = 1/2)

(%)

	Imported Coal		Non-Coking Coal		Investment Cost	
Base Case	10% Up	20% Up	10% Down	20% Down	10% Down	20% Down
-2.77	-0.32	1.74	-1.20	0.20	-1.77	-0.65

Figure 1 MAP OF ROURKELA STEEL PLANT

SCALE 1/11,400



Candidate Site of SRC Demonstration Plant is Location-2, Annex Area.

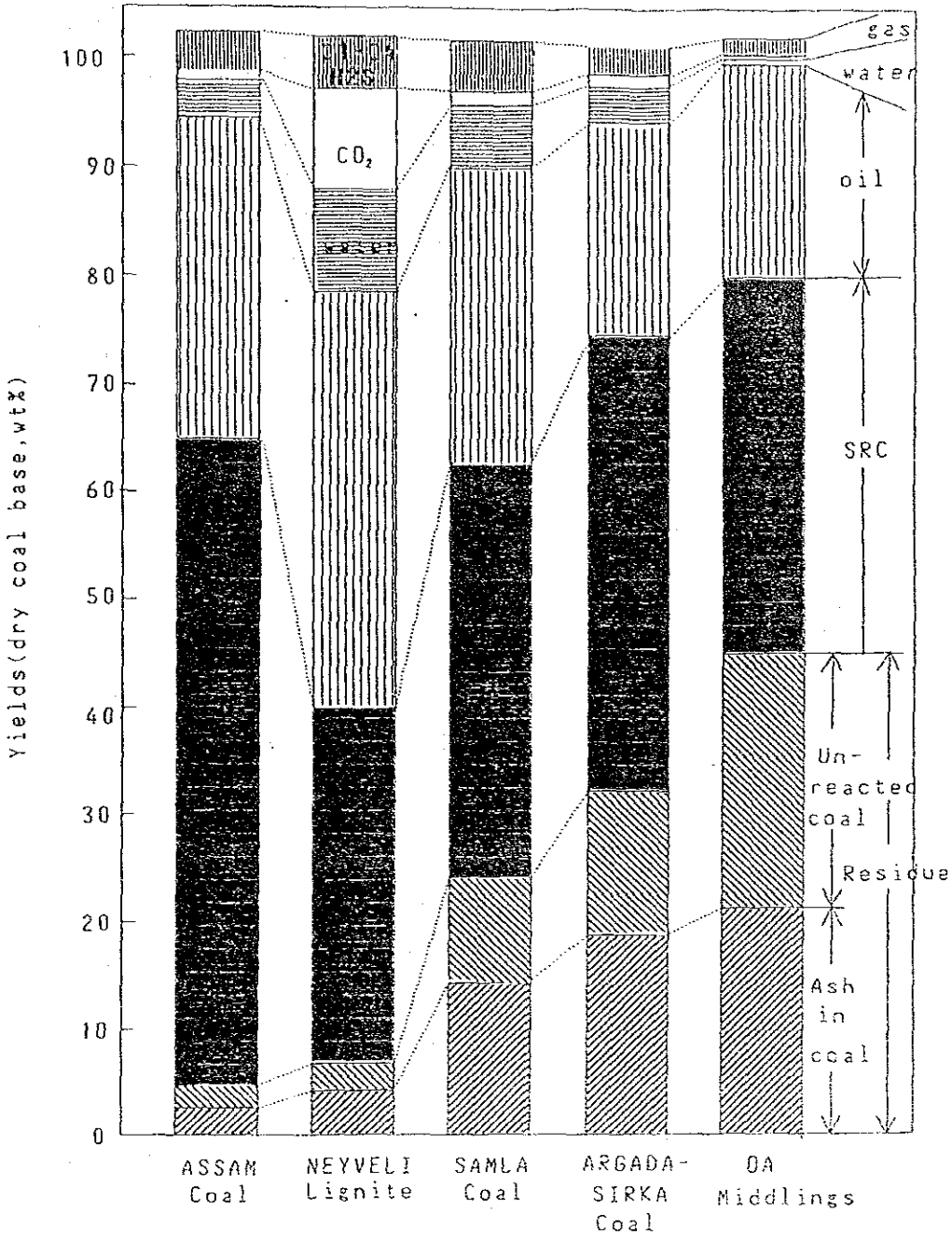


Figure 2 YIELDS OF VARIOUS COALS

(Condition: Tetralin-430°C-60min.-100Kg/cm^{2}G-3wt%)

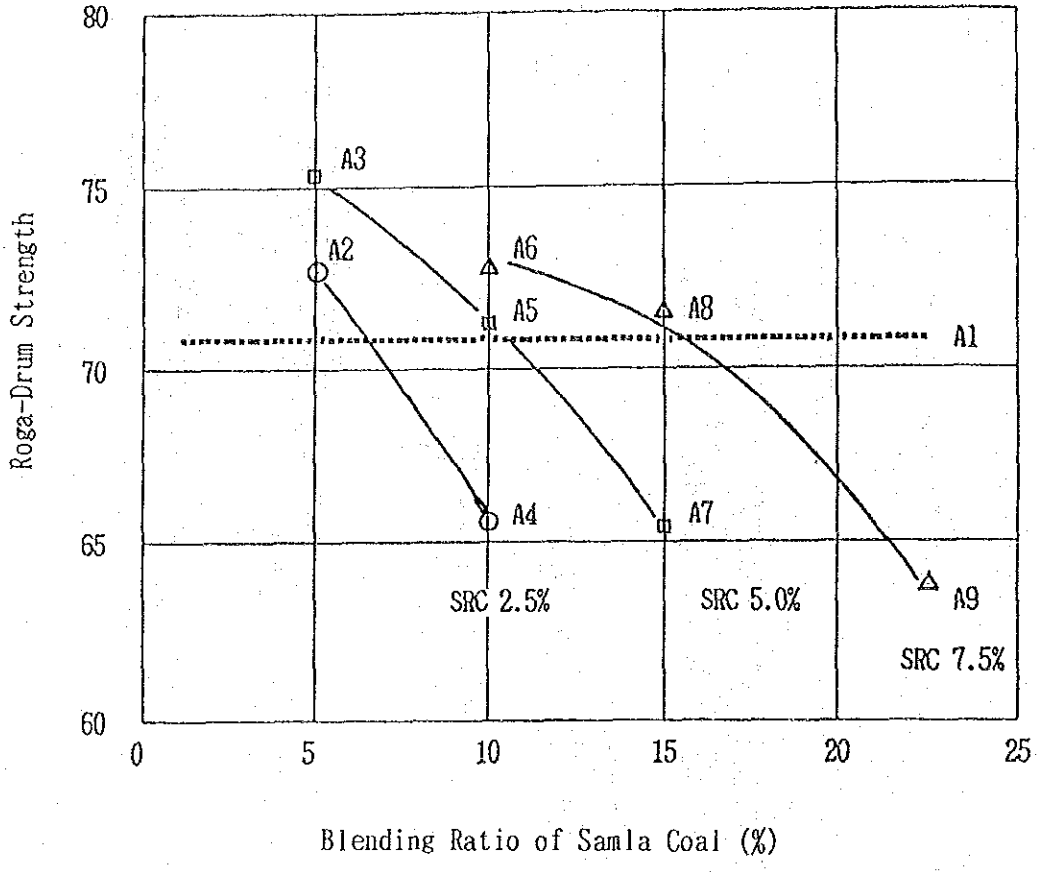


Figure 3 ROGA-DRUM STRENGTH OF COKE PRODUCED WITH BLENDING SAMLA COAL AND SRC

JICA