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Pre-Feasibility Study of the Production of Gas and Chemicals based on Coal of Antioquia

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C/F COLOMBIA

Final Report

April 1978

UNIDO Contract No 77/45
Project IS/COL/75/016

Coal Processing Consultants

cpc

D R A F T   F I N A L   R E P O R T

This document is issued as a draft of the final report

for examination and comment by UNIDO.

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1. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

The purpose of the Study has been to assess the feasibility of producing gas and chemicals from Antioquian coals.

A mining survey has identified suitable reserves of sufficient size to support a coal based chemical industry in the province of Antioquia. Outline schemes and preliminary costs have been prepared for the new mines necessary to exploit these reserves. Tests have been undertaken on representative coal samples in order to determine their suitability for conversion to chemicals.

A market survey in Colombia and a techno-economic review of suitable coal conversion routes have established that a viable coal based chemical industry could be developed in Antioquia to produce urea and coal tar chemicals. Preliminary costs for the production of these chemicals have been assessed.

The proposed development of a coal based chemical industry in Antioquia could bring considerable benefits to the province and to Colombia in terms of reduced foreign imports, stimulation to agriculture and industry and new employment opportunities.

1.2 Conclusions

1) The existing mines in the Province of Antioquia have a production capacity of around 600 000 tonnes/year. Improved mining methods and higher coal prices are unlikely to increase their output to much above 1 million tonnes/year. Therefore, there are insufficient coal supplies from the existing mines to support a coal based chemical industry.

2) There appear to be exploitable coal reserves in the Amaga-Fredonia region amounting to over 42 million tonnes. It is estimated that suitable investment in three new mines could lead to an additional output from this area of 2 million tonnes/year.

3) Domestic demand for coal in Antioquia is presently around 500 000 tonnes/year. Provided the domestic demand does not grow at a rate exceeding 5% per annum, the new mines and existing mines, suitably upgraded, could meet this demand and support at the same time, for a period of around 20 years, a coal based chemical plant requiring around 1 million tonnes/year of coal.

4) Among all the processes, which can be considered for the conversion of this coal, only the production of urea appears potentially viable. The cogeneration of coal tar products would improve the economics of this production.

5) Colombia will, in 1978, import ?80 000 tonnes of urea. Assuming a growth rate of 7.5 to 10% pa, there is an immediate necessity for Colombia to build a major urea production facility, which would require coming on stream as soon as possible. Because the development time for a coal based urea plant would be of the order of nine years, this first production facility should be based on the use of natural gas. A further plant will be required in 1988/90 having a production capacity of around 580 000 tonnes/year of urea. There is sufficient time for this second unit to be coal based.

6) The mid-1977 capital cost for the proposed chemical plant project and associated mining operations is estimated at around $350 million. A production cost for urea of about $140/tonne could be achieved (assuming financing by 50% loan, 50% equity and 12% return on equity after tax). This compares with sales prices of imported urea of $185/tonne landed Colombian port and around $205/tonne delivered to Antioquia.

1.3 Recommendations

Since this study has indicated the potential economic viability of a coal based plant in Antioquia producing urea and possibly coal tar chemicals, it is recommended that the project be studied further and the following work be undertaken:

1) A detailed mining investigation of the coal reserves in the Amaga-Fredonia region to establish the data necessary for the development of the new mines.

2) A feasibility study for the mine and coal preparation plant to establish the costs and timing for implementation of the mining project.

3) A feasibility study for the chemical plant to confirm the long term supplies for coal and markets for the products, to select a site for the plant, to establish the process route and sources of technology and to provide more comprehensive capital and operating cost estimates.

2. INTRODUCTION

This study has been undertaken by Coal Processing Consultants of Harrow, England, on behalf of the United Nations Industrial Development Organisation (UNIDO). The terms of reference are defined in Contract No. 77/4 and summarised in Appendix 6.

After initial briefing by UNIDO in Vienna, a team of experts spent a total of four months in Colombia collecting the necessary data and undertaking the local surveys. They worked in close cooperation with the Asociacion Nacional de Industriales (ANDI), who assisted with arrangements for many of the visits. A full list of the Companies interviewed in Colombia is given in Appendix 7.

In December 1977, an interim report was submitted to UNIDO summarising the findings of the first phase of the work. By telex dated 30th January, 1978, UNIDO approved the selection of urea production with and without the cogeneration of coal tar chemicals as the process routes for further study.

This report presents the complete findings of the work.

3. COLOMBIA AND ITS ECONOMY

3.1 Geographical

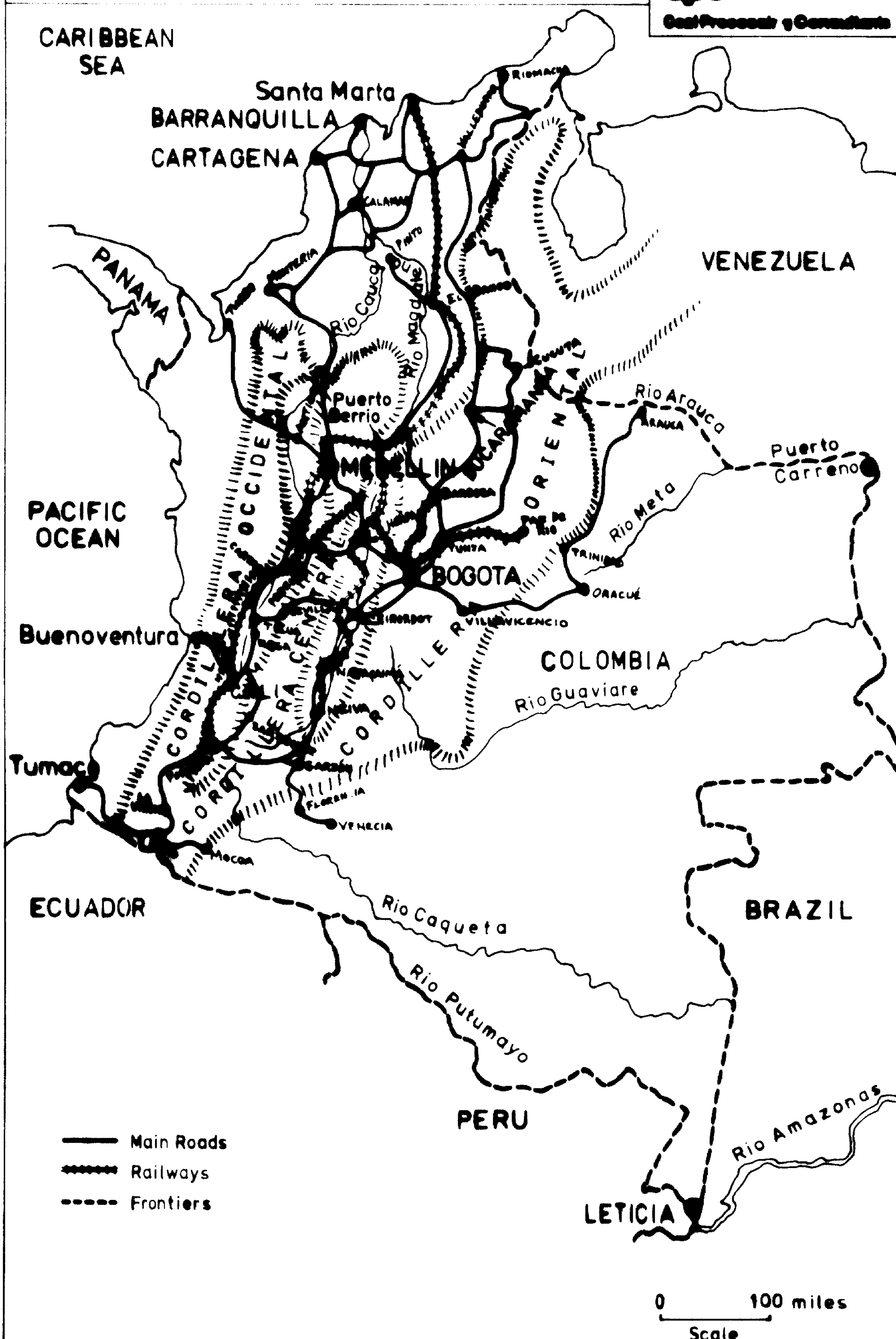
Colombia occupies the north western corner of the South American sub-continent. To the north, it is bounded by the Caribbean Sea on which it has a thousand miles of coast line. To the east it abuts Venezuela, its southern borders are with Ecuador and Peru and, to the south west, it share a common border with Brazil. Its western boundary is the Pacific Ocean except where it joins Panama; the Pacific coast line north and south of the Panamanian border total 800 miles. The total area of the country is around 1.2 million km^2. Its main features are depicted in the map on Figure 1.

Geographically, Colombia is divided into four main regions by the Andes, which in the extreme south of the country, divide into three branches, the Cordillera Occidental or Western Cordillera, the Cordillera Central and the Cordillera Oriental or Eastern Cordillera, which radiate from the Peruvian border in a north-south or north easterly-south westerly direction. To the north of this mountainous Andean region lies the Caribbean plain extending from the foothills of Cordilleras to the coast. To the east extends a vast plain, los Llanos, which is relatively unexplored and almost wholly undeveloped. To the west of the Andes lies the Pacific coastal plain, a region of tropical rain forests, particularly towards the Amazonias region in the south.

The population, now estimated between 26 and 27 million, and increasing by about 3% per annum, is concentrated in the Andean region and the Caribbean plain. The eastern plain, although covering some 65% of the total land area, is inhabited by only 2% of the population.

The main river, the Rio Magdelena, flows from south to north in the rift between the Cordillera Central and the Cordillera Oriental. Its tributary, the Rio Cauca, occupies the almost parallel valley between the Cordillera Occidental and the Cordillera Central. The other

Figure 1. THE GEOGRAPHY OF COLOMBIA.



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main watercourses, the Rio Apure and Rio Meta, drain from the foothills of the eastern branch of the Andes in a west to east direction and join near the border with Venezuela to become the Orinoco.

Colombia lies just north of the equator, but its climate is modified by altitude. The Pacific coastal plain and the lower lands bordering the valleys of the Magdalena and Cauca as well as the southern part of the Llanos are tropical and either covered by savannah or, in the more humid western coast, with tropical rain forests. The lower Andean slopes and the Caribbean coast enjoy a sub-tropical climate, while the higher valleys and plateaus of the Andes are temperate. There are no definite seasons, the temperature variation in any one location in each month of year is remarkably uniform. There is however, a relatively dry season from December to April and a wet season from May to November.

Antioquia, the province with which this report is particularly concerned, occupies an irregular area of about 25 000 square miles (59 750 km^2) to the north west of central Colombia straddling the Cordilleras Central and Occidental. Its western boundary follows the Rio Magdalena in the south and the Rio Tamar in the north and the important river port of Puerto Berrio is located in the centre of the Rio Magdalena boundary. To the west it adjoins the departimento of Choca and a northern extension provides a coast line on the Caribbean from the western end of the Gulf of Uraba to Arboletes. Inland, to the north, it borders the provinces of Cordoba and Sucre and, to the south, those of Caldas and Risaraldo. The Rio Cauca traverses Antioquia in a generally north-south direction following the rift between the Cordilleras.

The population in 1973 was 2 450 000 and is now estimated at well over 3 million. Two-thirds live in urban areas. Medellin, the capital, lies in a plateau valley in the Cordillera Central at a height of 2000 metres. After Bogota and Cali, Medellin is the fastest growing Colombian city; its population increased from 400 000 in 1951 to 950 000 in 1964 and 1 030 000 in 1969. The present population of Medellin and its satellite towns, Envigado and Sabaneta is estimated at 1 450 000. The growth of Medellin, which is now the second largest city in Colombia and the main industrial centre, can be attributed to the combination of cheap coal, availability of hydro-electric power, better than average transport facilities by Colombian standards, a plentiful labour force and a delightful climate. These advantages, particularly adequate supplies of cheap coal, have attracted a variety of industries. It is the centre of the flourishing textile industry, has important leather and paper industries, a large car and truck assembly factory and the largest brewery in Colombia,as well as numerous smaller manufacturing enterprises.

The hilly nature of the Antioquian terrain restricts crop cultivation, but important quantities of maize and sugar cane are grown as well as coffee, rice and bananas in the river valley. Cattle raising is the most important agricultural pursuit and the livestock market at Medellin is reputed to be the largest in South America,handling 10 000 head a week.

3.2 Political

Before its was liberated from Spanish rule in 1819 by Simon Bolivar, Colombia had, from 1550 until 1740 formed part of the audencia of Santa Fe de Bogota and later, of the Viceroyalty of New Granada. After independence, Nueva Granada, as Colombia and Panama were called, formed part of Bolivar's Gran Colombia, a confederation with Ecuador and Venezuela. This combination did not last long; Venezuela withdrew in 1829 and Ecuador in 1830, leaving Nueva Granada, which in 1831 had a population of 1.5 million, as a separate state under the presidency of Francisco de Paul Santander.

The first constitution, established in 1832, was unitary, liberal and anti-clerical, but the efforts made under its authority to end the serfdom of the peasants and lessen the power and privileges of the Roman Catholic Church sowed the seeds for the bitter rivalry between the Liberal and Conservative parties which has lasted for more than a century.

The two main ideological differences which polarised Colombian politics from 1840 to 1957 concerned two main questions - whether the constitution should be federalist with the power vested in assemblies elected by universal suffrage or centralist with the power vested in an elite elected by a restricted section of the population and whether the church and state should be separated. The Liberals were mainly for a federal system with universal suffrage, ownership of land by those who occupied and worked it and freedom of religicn. The Conservatives favoured central authoritarian government, limited suffrage and, above all, the maintenance of the role of the Church as the State religion with all the power which this ensured. Thus, the Liberal became identified as the party of the peasants and artisans and the Conservatives that of the wealthy landowners and the clerics. The division was not as clear cut as this implies; personal ambitions and family feuds played their part.

Twice the smouldering antagonism between the two factions erupted into bloody civil war. The 'War of a Thousand Days' between 1899 and 1902 is estimated to have claimed between 60 000 and 130 000 lives and 'La Violencia', which lasted from 1948 to 1953, is said to have resulted in the slaughter of 200 000. Between these periods of overt violence, were years of guerilla warfare interspersed with brief periods of uncertain peace.

The present constitution was established under the administration of Rafael Nunez in 1886. It is closely modelled on that of the United States of America,with the executive, legislature and judiciary separated. The executive consists of the President who is elected for a four year term by universal suffrage, a Cabinet of thirteen Ministers and a Council of State of seven who are nominated by the President. The legislature consists of Senate and a House of Representatives whose members are elected by popular vote on a regional basis. Certain powers are devolved to the local administrations of the 22 departimentos, four intendencias and four comisarias into which the country is divided. Each of these and the 'distrito especial' of Bogota are administered by a Governor appointed by the President and a Council elected by popular vote. The departimentos, intendencias and comisarias are divided into municipios headed by Mayors appointed by the Governors.

The relationship between the Church and State has been a perennial subject of conflict. The revolutionary government headed by Gen. Tomas Cipriano de Mosquera appropriated church lands in 1861 and in 1863 divorced religion from the State, but the 1886 constitution restored many of the Church's privileges following the signing of a new Concordat with the Vatican.

The tragedy of the Civil War in 1899-1903 was followed by the loss of Panama. In 1903 the United States offered Colombia terms to lease a strip of land to build the Panama canal but the Colombian authorities vacillated and the exasperated Panamanians, covertly supported by the United States, revolted and made their own agreement with the USA. This episode embittered relations between Colombia and the USA for many years and traces of this antagonism and suspicion still linger.

The present era in Colombia can be said to have begun when Gen. Gustavo Rojas Pinilla assumed the presidency following a military coup which deposed Laureano Gomez who was attempting to set up a Fascist regime. Rojas was a popular leader but his support evaporated when his promised reforms failed to materialise. To save the country from a renewal of 'La Violencia', an army junta took over and forced the leaders of the two parties to form a National Coalition government under which the presidency and cabinet posts would alternate between the parties. This coalition rule was to last for 16 years, i.e. from 1958 to 1974. Alberto Llaras Camargo, a Liberal who was the first coalition President, instituted agrarian reform and started an ambitious programme of planning for industrial development assisted by the United States under the 'Alliance for Progress'. His efforts were frustrated by a fall in coffee prices which disrupted the economy and by the high domestic unemployment. In 1962, the Conservative President, Guillermo Leon Valencia devalued the peso, an action which caused considerable unrest and the precarious peace of coalition politics was in danger. Carlos Lleras Restropo who succeeded to the presidency in 1966 is regarded as one of the most successful of Colombia's presidents. He succeeded in stabilising the economy and in accelerating both agricultural and industrial development. This growth continued under Meseal Pastrano who took office in 1970, but, as in most countries, growth came to a halt following the rise in crude oil price 1973 and although the Colombian economy has benefited by the high coffee prices over the past two years, there are few signs that industrial development has been resumed.

Whether polarised partisan politics will return to Colombia is the important question for the future. The growing support for the more extremist splinter parties - the MRL (Movimento Popular Liberal) and ANOPO (the National Popular Alliance) on the right - the disillusion of the electorate with the main parties as shown by the small turnout of voters at the last two elections and the growing signs of industrial unrest, are all rather disquieting signs.

3.3 Economic

To the Spanish rulers of South America, Colombia was only of interest for the gold dredged from its rivers and the emeralds from the mines of Muzo and Conscuez. When independence came, the economy was purely one of subsistence agriculture. As the brief political history indicates, the periods when the country has been sufficiently free from unrest to allow an economic development have been few and of relatively short duration. The surprising thing is not how relatively undeveloped the country is, but how far, despite all the obstacles, it has succeeded in establishing a flourishing export trade and at least a base for industrial expansion.

The first real period of economic growth was after the loss of Panama from 1903 to 1914, when agriculture, particularly coffee growing, was expanded and the export of coffee and bananas to the USA and Europe was established. This agricultural expansion quickened during the first world war and in the 1920s, American oil companies found crude oil in the Magdalena valley. By the late 1920s, Colombia's exports consisted of coffee (67%), crude petroleum (17%), bananas (6%) and other crops and livestock (10%).

The world depression of 1929-1931 caused a disastrous fall in the price of coffee and a complete collapse of the economy. However, it spurred industrial development in that it encouraged domestic production to replace imported goods which the country could no longer afford.

The second world war gave a dual impulse to the economy. Firstly, the demand for and the price of primary agricultural and mineral products rocketted and encoursged a major expansion in the cultivation of coffee and bananas and the introduction of new crops like cotton, rice and sugar. At the same time it gave further impetus to the replacement of manufactured imports which could no longer be obtained from the warring counties. By the early 1940s, Colombia was practically self sufficient in foodstuffs and consumer non-durables. A flourishing textile industry had been established in Medellin, breweries, cement and brickmaking plants and factories for the manufacture of cigarettes, footwear and other leather goods and for the refining of sugar had been brought into production. A start had been made to develop primary manufacture with the setting up of petroleum refineries and the steelworks at Paz del Rio.

These industrial and agricultural development had, however, their political effects. They spurred the movement of the population from the country to the towns. They resulted in the organisation of the workers and peasants who demanded a fairer share of the country's growing prosperity. The increasing disparity between the living standards of the classes was undoubtedly one of the most potent causes of the increased hostility between the two political parties which erupted in 'La Violencia' and while this lasted from 1948 until the mid 1950s, little real development of the economy was possible.

The second period of growth occurred between 1966 and 1973, from the devaluation of the peso and the reviving of the economy by the Restropo administration and the oil price crisis. During this period, both agriculture, textile and leather manufacture expanded, a petrochemical industry was developed and the heavy chemical industry expanded. Some idea of this growth may be gathered from the figures in Table 3.1 for exports in the years 1968 to 1972.

However, this period of growth was accompanied by rapid inflation which was further accelerated by the oil crisis at the end of 1973. The Colombian authorities clamped down on imports in 1974 and this slowed the growth of the economy from the 6-7% level of 1972 to 2-3% in 1974. While this brought the rate of inflation to a more manageable level, it also had disastrous effects on employment. The high price of coffee in the last two years has allowed some relaxation of the restriction of imports, but it cannot be said that industrial expansion has been resumed at anything like the 1968-1972 rate. The rate of inflation has again risen. From January 1st to July 31st last year, it was over 50%. Interest rates are high; Colombian banks offer 18% on deposit accounts which means that money for industrial development costs around 25% per annum.

Table 3.1 - Exports for Colombia in 1968-1972

Commodity	Value of Exports in Millions of $				
	1968	1969	1970	1971	1972
Coffee	314.1	332.9	405.5	358.6	433.6
Bananas	15.6	18.6	17.7	17.9	19.9
Cotton	33.7	36.4	38.6	35.0	46.5
Sugar	22.0	17.5	21.8	26.6	33.2
Tobacco	7.1	9.1	8.8	13.2	11.6
Livestock	8.9	22.1	36.4	52.0	52.6
Textiles	16.0	15.1	21.8	36.0	43.9
Leather and Furs	6.3	8.7	7.0	7.5	15.7
Cement	4.0	3.2	3.4	2.7	4.7
Chemicals and Pharmaceuticals	2.4	8.1	9.3	17.2	18.3
Others	51.1	52.5	56.7	67.5	132.6
TOTAL	492.6	540.1	642.6	656.4	841.4

There are other constraints against rapid industrialisation. The economy is too dependent on the world price of coffee. During 1975 when this was high, Colombia had a favourable balance of payment of $173 million. A reduction in the coffee price to its former levels could easily bring the economy back into the red.

Secondly, the transport infrastructure is inadequate to sustain a major expansion of manufacturing industry. Thirdly, the educational level is low, although improving rapidly. According to the 1973 census of the department of Antioquia, of the male population over the age of 15 in the urban areas, 8.7% had had no formal education, 50% had only primary schooling, 34% had attended secondary or technical schools and only 5.7% had university training. The figures for the male population in the rural areas were 35% with no formal education, 60.7% with only primary schooling and only 0.2% with university training. The result is that there is severe shortage of skilled workmen and managers and a large surplus of unskilled labour.

Colombians are very nationalistic. Although they may quarrel amongst themselves, they are resentful of any interference in their affairs or exploitation of their resources by foreigners. This is reflected in the restrictions governing foreign investment in the Colombian economy. Profits earned in Colombia cannot be repatriated. An enterprise established in Colombia must have 80% of its employees of Colombian nationality within 5 years and the business must have a majority of Colombian shareholders within 15 years. These restrictions make Colombia less attractive to the multinational combines and hinder the transfer of technology from the industrially developed nations.

Colombia is a country of great potential. The variations of climate allow the cultivation of a wide variety of crops. It is rich in mineral resources whose potential has barely been scratched. Its economy is still mainly based on agriculture, particularly the growing of coffee, on the export of which the balance of payments depends. Manufacturing industry has been concentrated on the production of consumer non-durables - clothing, footwear, food, tobacco and liquor - and of building materials - cement, bricks and refractories. In these, the country is not only self-sufficient, but has, in textile and leather goods particularly, built up a healthy export trade. Heavy industry - mining, steelmaking, engineering, shipbuilding and chemical manufacture - has been developed to only a small extent and there are numerous constraints against its expansion. During the past few years, a great number of feasibility studies have been carried out on various aspects of industrial development. Whether these will ever be implemented depends primarily on whether the cooperation between the political parties can survive the return to partisan politics, whether the income from agricultural products is channelled into industrial investment and whether inflation and interest rates can be brought down to manageable levels.

Colombia's main supplier is the United States of America which is also the main customer for Colombian exports. This dependence on the USA is increasingly being questioned and strenuous efforts are being made to increase bilateral trade with Western and Eastern European countries and with other Latin American nations.

3.4 Transport Infrastructure

The main industrial areas of Colombia are in the mountainous Andean region and the Caribbean plain. The presence of the three Cordilleras imposes severe limitations on the construction of roads or railways in the Andean region. Travel in the north-south direction is not too bad, but in the east-west direction, crossing the mountain ranges, which rise to 3000 to 4000 m above sea level, it is still tedious and dangerous. It takes only 30 minutes to travel from Bogota to Medellin by air but 30 hours by car. The total road network is estimated at about 45 000 km, but there are only three paved trunkroads. The Western Trunk Highway (Troncas Occidental) runs from the Ecuador border to the Caribbean coast passing through Medellin. The Central Trunk Highway (Troncas Central) diverges from the Western Trunk Highway into Bogota and further north east to the border with Venezuela. The third main road is the Caribbean Trunk Highway (Transversal del Corbe) which traverses the northern coastal region roughly from east to west. This route was recently completed with a bridge across the Magdalena at Barranquilla connecting the ports of Barranquilla, Cartagena and Santa Marta.

If these highways are all similar to the Western Trunk road, they are single carriage-way about 8 m wide and surfaced with asphaltic concrete. The standard of the surfacing varies from fairly good in the more recently constructed sections to poor in the older sections, the maintenance of which has been neglected allowing cracks and potholes to develop.

The remainder of the road network consists of graded unpaved narrow roads connecting the main towns with the trunk roads and even more primitive ungraded, unpaved lanes which are the only means of access to many of the smaller towns and villages. Not only are these minor unpaved roads covered with loose stones and projecting boulders, and cut by deep ridges and gulleys, but they pursue a meandering course through the mountain valleys with never more than a few metres of visibility ahead.

Yet, despite these handicaps, 75% of the dry goods and 66% of the liquid products are transported by road because the railway system (Ferrocarriles Nacional) is, if anything, even more primitive. The total railway network currently totals some 3 500 km, most of it built by British engineers at the beginning of this century on the model of the Indian hill railways. Its gauge is only 36" (0.914 m). The main line runs from Santa Marta on the Atlantic coast via Chiraguana, Gamerra, Barrancabermeja to Puerto Berrio on the Rio Magdelena. It then splits,one branch serving Bogota with a spur to the steelworksat Paz del Rio, the other branch serves Medellin and, at one time, extended southwards to Cali and Periera. In fact, the line from Medellin to Periera has been disused for several years.

The 1 550 km long Magdalena river is the main river transport artery and is navigable for barge traffic as far south as Puerto Berrio. Some minor barge traffic is also carried by the Rio Choca, but the Rio Cauca has numerous rapids and shoals which make it unsuitable for bulk goods transport.

Air transport, in contrast to road and rail transport, is well developed. There are eight major airports and 25 to 30 smaller landing strips and it is possible to fly from any of the major towns to any other quickly and comfortably. This is the main form of passenger transport and is increasingly used for moving higher priced, less bulky goods such as finished textiles and footwear.

There are four important ocean terminals in Colombia. The Pacific port of Buenaventura handles about half the total dry goods and is the main outlet for coffee exports. Her twelve berths for handling dry cargo and one for handling liquid products in bulk give a joint capacity of 2.4 million tonnes per year.

Barranquilla, at the head of the Rio Magdalena,has four wharves and two new ones are to be built to bring cargo capacity to 1.2 million tonnes per year. Cartagena, the oldest port, has a handling capacity of 200 000 tonnes per year from its four existing berths. Santa Marta was formerly mainly a banana port but has been transformed into an important ocean terminal with five piers for large ocean freighters and one dock for smaller vessels.

There is a smaller port, Tumaco, on the Pacific coast which handles timber exports exclusively.

Transport costs in Colombia are comparatively high. Current rates for bulk solid transport by truck or bulk liquid transport by tanker vary slightly with the route. Transport by rail is priced at roughly similar rates. Transport by river barge is cheaper, provided no unloading and reloading is involved. However, it costs approximately 30% more to transport bulk solids by barge from Barranquilla to Puerto Berrio and transfer to trucks or rail wagons for carriage to Bogota than rail or road transport directly between Barranquilla and Bogota. Some examples of transport costs are indicated in Table 3.2 below.

Table 3.2 - Transport Costs in Colombia

From	To	Distance km		Cost $/ tonne/km
Cartagena	Bogota	1000	Bulk solid by truck	0.038
Cartagena	Bogota	1000	Bulk liquid by tanker	0.038
Cartagena	Medellin	700	Bulk liquid by tanker	0.027
Cartagena	Medellin	700	Bulk solid by truck or rail	0.031
Buenaventura	Bogota	700	Bulk solid by truck	0.036
Buenaventura	Bogota	700	Bulk liquid by tanker	0.038
Zipaquira	Medellin	410	Coal in rail trucks 6000 tonnes loads	0.038

The severe limitations of the existing transport system are well appreciated and there are numerous plans to improve it, but these must compete for the available finance with other development projects.

A new highway, the Carreteria Marginal del Selva or Jungle Edge Highway, running parallel to the Cordillera Oriental and inter-connecting the middle of the Llanos with subsidiary roads leading to Peru, Ecuador and Venezuela is planned in order to open up the eastern plain for development. The World Bank is reported to be financing a $180 million, four year project to improve 1500 km of roads in the Medellin-Cali-Bogota industrial triangle and in the northern departimentos of Colombia, Magdalena, Santander and Cesar. There are six projects to improve and surface roads, the cost to be borne jointly by the Inter-American Bank and Colombia's Road Construction Fund.

New railroad projects include a 238 km line linking Fundacion with Cartagena and Barranquilla, a 118 km line from Ibique via Armenia to Bogota and a line connecting Baroso and Carere via Puerto Berrio. Part of the infrastructure for the development of the El Cerrejon coal field is a new mine-to-port road from the mine depot to a new large port to be constructed possibly at Palomina.

Air transport is also to be expanded. The World Bank is financing the construction of a new international airport at Medellin and the extension of the airports at Bogota and Cartagena and those important industrial centres which are at present without airports are to be provided with facilities for handling internal passenger and goods traffic.

These developments are, however, future plans. There is little evidence that any work on them has begun.

3.5 Energy Sources of Colombia

3.5.1 Crude Oil and Petroleum Fuels

Output of crude oil in Colombia from 1965 to 1975 was as shown in the following Table 3.3.

Table 3.3 - Colombian Production, Domestic Demand and Exports of Crude Oil

Year	Production of Crude 1000 bbls.	Domestic Consumption 1000 bbls.	Export Value $1000	Unit Value $/bbl.
1965	73 206	37 524	88 169	2.17
1966	71 915	36 340	70 596	1.98
1967	69 416	38 268	61 212	1.96
1968	63 573	45 424	36 334	1.97
1969	77 275	47 422	56 672	1.90
1970	80 090	48 804	58 618	1.88
1971	78 635	53 229	51 236	2.02
1972	71 674	52 790	30 791	2.06
1973	67 089	57 690	26 733	2.94
1974	61 387	60 907	4 452	9.30
1975*	57 522	60 435	-	-
1976*	53 071	59 911	-	-

* estimated

Production was relatively small until 1965 when the Provincia, Payoa and Rio Zulia fields began producing and output climbed to its peak in 1970 due, principally, to increased volumes from the Orito field in the Putumayo region. Since then, crude oil production has steadily declined while domestic consumption of motor spirit and diesel oil has increased. 1977 crude oil output is estimated at 52 million barrels and imports of crude oil to the extent of $82 million and motor spirit imports of the order of $60 million will be required to satisfy domestic demand. Setting against these imports, exports of surplus fuel oil should earn $105 million, so that the net deficit on the balance of payments is expected to be in the region of $37 million.

The deterioration in Colombia's petroleum reserves (now estimated at only 700 million barrels) has been attributed to inadequate exploration drilling. On the other hand, the 213 wells drilled between 1964 and 1972 did not contribute any substantial increase. The low percentage of success in exploration activities, coupled with the low average rate of production of established wells, has led to discouragingly high costs in Colombia compared to other oil producing areas in the world. Another factor, which has discouraged exploration activity, is the Colombian Government's pricing policy. Until October 1973, the price paid by the government to oil producers was only $1.56 per barrel. In February 1974 the price of crude oil from new wells was raised to $4/bbl, but it was not until 1975 that the price was raised to a figure of $9/bbl, nearer the rocketing world price. Early this year, the government announced that, while the price of crude from existing wells would remain at this figure, production from new wells would command the world price of $12.3-13 per barrel. It remains to be seen whether this increase will stimulate exploration drilling and whether, if it does, that activity will be reflected in increased production and reserves. Sources in Colombia are generaly pessimistic and believe that Colombia would be a net importer of crude oil, gasoline and diesel fuel in the foreseeable future.

Refining capacity at present totals over 66 million barrels per year. Empresa Colombiana de Petrolas (Ecopetrol) has its main refinery at Barrancabermeja with a capacity of 38.5 million bbl/year and Intercol's Mamoral refinery processes 22 million bbl/year at Cartagena. The balance is covered by five small plants mostly connected with the main producing fields - Intercol's Dorado refinery (8.89 million bbl/year), Colpet's Tibu refinery (2.1 million bbl/year), Texaco Oil's Guamo plant (900 000 bbl/year), the same company's Orito refinery (350 000 bbl/year) and Antex's Plato refinery (650 000 bbl/year). Output of the main refined products for the years 1971 - 1975 are listed in Table 3.4.

Table 3.4 - Output of Petroleum Fuels from Colombian Refineries

Year	1971	1972	1973	1974	1975
	Figures in millions of barrels				
Motor Spirit	17.8	18.6	19.5	20.0	19.7
Diesel Fuel	7.3	9.0	8.1	8.3	6.6
Fuel Oil	18.1	18.1	17.7	17.9	17.5

A new refinery costing $62.5 million with an annual capacity of 27.5 million barrels was planned to be in operation by 1980 but construction has not yet been started; unless there is an unexpected increase in production it is almost certain that this project will be abandoned.

3.5.2 Natural Gas

The position of natural gas production in Colombia is much healthier than that of crude oil. Large on-shore gas fields occur in the north in Ballena within easy reach of the Caribbean ports of Barranquilla and Cartagena. Recently new reserves have been found in the Guajira province and off-shore near Cartagena. Current output is about 450 million standard cubic feet (scf) per day of which only about 6 million scf/day is used for chemical production, mainly ammonia and urea by Ferticol at Barrancabermeja and Abecol at Cartagena. Gas pipelines exist from the production fields to Barranquilla and Cartagena and to the petrochemical plant at Barrancabermeja. The main usage is for industrial heating and thermal electricity generation at locations served by these pipelines.

At present the only town in Colombia equipped with a domestic gas supply is Barranquilla, but it was recently reported that the Ministerio de Minas y Energia has apparently earmarked $162 million for distribution line construction to bring natural gas to the towns of Riohacha, Santa Marta, Cartagena, Bucaramanga, Medellin, Nieva and Cali. From Cartagena the network would run south to the Jobo-Toblon compressor station at Medellin, then branch out to serve Bucaramanga, Nieva and Cali. It is not clear from this report (International Construction World, Dec. 26th, 1977) whether the quoted cost includes the service network in each of these towns, but this seems unlikely in view of the cost of the recently completed gas pipeline from Ballena to Cartagena which was over $50 million.

Currently, the price of natural gas to consumers anywhere in Colombia is $1.033 (38p) per 10^6 Btu. This price is adjusted at six monthly intervals in accordance with variations in the export fuel oil price FOB Cartagena during the preceeding six months.

3.5.3 Electricity

Colombia's total generating capacity is estimated at 6000-7000 MW of which about two-thirds is produced in hydro-electric installations. The remaining third is produced in larger thermoelectric stations using natural gas as fuel at sites near the gas fields or on the existing gas pipelines, or using coal at locations in the major coalfields. In addition to these stations which may serve a town or an area, there are many tiny diesel-fuelled plants each serving a single village or hamlet.

The country's potential for hydro-electric generation is put at between 40 and 50 million MW so that, at present, only 15% of its potential capacity is being utilised.

Consumption of electricity in Colombia is increasing by 8% per annum and to meet future needs, expansion of both thermal and hydro-electric generation is planned as well as the establishment of a national grid. Tenders have been invited for a 150-200 MW capacity station at Corelca, Guajira. Although this will be designed to use coal, natural gas or fuel oil, it is intended to fire it with coal from the El Cerrejon field. It will supply power to the mines and to a two-way power line linking the coastal thermal power system with central Colombia's hydro-electric power network. This power line will carry thermal power inland during the dry season and hydro-electric power to the coast during the wet months.

In Antioquia the total generating capacity is 744 MW of which 94% is accounted for by seven hydro-electric stations in the Medellin area. The remaining 6% is the product of 38 small hydro-electric installations and 33 diesel generators, the output of which varies from 12.5 KW to 300 KW annually. A coal fired generation station with a capacity of 150-200 MW has been proposed for Bolombolo, but the main planned additions to Antioquia's supply will be two new hydro-electric stations with a combined capacity of 270 MW.

3.5.4 Coal

Colombia is ranked twelfth in world coal reserves with an amount variously estimated at between 13 and 65 thousand million tonnes. A detailed estimate made in 1976 put proved reserves at 375 million tonnes of which the El Cerrejon field accounted for 322.5 million tonnes. Probable reserves were estimated at 261 million tonnes plus those of El Cerrejon which are present being estimated. They are unlikely to be less than 750 million tonnes. These and other estimates are based on surface geology and the nature of the seams in existing mines and are almost certainly wildly inaccurate. However, even allowing for the exaggerations implicit in the assumptions that outcrops and seams currently being exploited continue indefinitely at their original thicknesses and angles of dip, it is certain that Colombia has massive reserves of coal ranging from anthracite to sub-bituminous and that the popular estimate that 64% of all the coal in Latin America is located in this country may not be far out. Figure 2 shows the location of the major Colombian coalfields.

The Colombian coal deposits occur mainly as intermontane basins located along the flanks of the five major synclines which extend from the Ecuadorian border in a north easterly direction. The fields currently exploited are in the Bogota-Sagamuse syncline (Boyaca and Cundinamarca or Sabana de Bogota fields) in the Cauca syncline (Antioquia and Valle de Cauca fields) and in the Labateca-Cucuta syncline (Norte de Santander field). Their output in 1974 is given in the following table.

Table 3.5 - Coal Output in Colombia for 1974

Field	No.of Mines	Output tonnes	% of Total	Numbers Employed
Boyaca	242	987 240	31.3	2615
Cundinamarca (Sabana de Bogota)	199	867 576	27.5	2521
Antioquia	74	626 136	19.6	1580
Valle de Cauca	55	507 576	16.1	1339
Norte de Santander	36	88 152	2.8	402
Others	20	76 464	3.7	265
TOTAL	626	3 153 144	100.0	8722

1976 production was 4 271 000 tonnes in roughly the same percentages from the various fields. Considering the probable reserves, exploitation of coal in Colombia has been very small and it will be

Figure 2. THE COALFIELDS OF COLOMBIA.

Coal Processing Consultants

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seen that output per mine averages only 5000-6000 tonnes per year. A little over half of Colombia's coal is produced by eight larger companies, employing 1800 workers. The remainder comes from a large number of very small mines. Mining methods are primitive and, since particularly the smaller mining companies lack technological and organisational sophistication, productivity is low, profits are negligible and there is little money or incentive to undertake expansion or modernisation.

With the increase in world oil prices and the realisation that indigenous crude oil reserves are dwindling, the Colombian authorities have injected a new urgency into coal development. In 1976, they set up Carbones de Colombia (Carbocol) as the spearhead for such development. IFI and Ecopetrol each have a 35% interest in this company with Ingeominas, the Government Organisation responsible for the mining industry, having the remaining 30%. Carbocol has now joined with two of the larger mining companies, Colminas and Ecominas, in the formation of an operating company called Empresa Colombiana del Carbon (Colcarbon) to undertake the development of four major coal fields.

The first of these to be developed as a major producing area is the new El Cerrejon field in the Guajira province in northern Colombia. It is perhaps erroneous to call this region a new field; the existence of excellent steam coal there was known a hundred years ago. What is new is that exploratory drilling by US interests in this field has established proved, easily workable reserves of 40 million tonnes suitable for open-cast mining and probable reserves of 300 million tonnes in seams varying from 6 to 20 feet in thickness.

Peabody Coal Co. of the United States of America were initially interested in that part of the field in which exploration had been carried out and an agreement between Peabody and the Colombian authorities was negotiated. This was so favourable to the American company that it provoked an outcry in the Colombian press and forced the Colombian government to set up Carbocol, which scrapped the original agreement and presented Peabody with new terms. These ensured majority control by Carbocol, provided for a royalty to Colombia based on the realised value of the coal and committed the foreign partner to an extensive technical training programme of Colombian personnel. Peabody was unable to agree to these terms and withdrew. Exxon Coal Development Co., a subsidiary of Exxon Oil Co. of the USA accepted these terms for the development of another lease in this field and are reported to have commenced commercial strip mining at the rate of 1000 tonnes per week. This they hope to expand to 5 million tonnes per year by 1980 and 10 million tonnes per year by 1982.

Ecopetrol have a concession on another part of the El Cerrejon field, but it is not known how far they have proceeded with their exploratory work. Carbocol intend to exploit the original Peabody lease themselves, initially as a low capital open-cast unit producing 300 000 tpa, and are actively seeking foreign partners for development of the remainder of this field.

The second area in which development is to be concentrated is the Cundinamarca-Boyaca region near Bogota. As mentioned earlier, this is, at present, the largest producing field yielding both steam coal and coking coal; the steelworks at Paz del Rio obtain most of their supply of coking coal from this field. It has been the subject of several studies and a certain small amount of exploratory drilling. UNIDO study IS/COL/75/021 carried out by Snr. Xavier Ray Jouvain estimates recoverable reserves in the northern area of the Boyaca field as 102 million tonnes proven and 235 million tonnes probable. Of these, he estimates that half would be coking coal. Reserves of the whole field are not known with certainty, but based on surface geology and data from existing mines and exploratory drilling, may be as much as 2000 to 9000 million tonnes. No major exploration has yet been commenced. Inter-government negotiations have resulted in parts of this field being reserved for Spanish, Brazilian and Romanian interests but, to date, no contracts have been signed with individual foreign partners.

A third field which may be next on the list for exploitation is a relatively new area at La Jagua in the lower Magdalena valley, located in the Madgalena-Cesar syncline which extends north-east into Guajira. This area has been studied, again under the aegis of the United Nations Development Programme, by Mr. E. Charlton and Mr. S. H. Pontin of the National Coal Board who concluded that a strip mining operation with the production of up to 40 million tonnes of good steam coal is a feasible proposition. Some drilling has been carried out in this area and the view has been expressed that the workable reserves by open-cast and deep mining methods exceed even those of the El Cerrejon field. Both South African and Japanese interests are said to have expressed interest in participating in the development of this area.

A fourth new coal producing area is located at Carare near the middle reaches of the Rio Magdalena, also in the Magdalena-Cesar syncline. This contains deposits of anthracite and reserves are estimated at 500 million tonnes. It is already being exploited in a small way for anthracite for export; 90 000 tonnes were mined in 1970 and it was hoped that this could be increased to a million tonnes annually by 1975. This expansion has, however, not occurred and output does not seem to have increased; exports of anthracite in 1975 were only 15 268 tonnes. The Cayman Corporation of California were reported to be interested in partnering Carbones del Carare Ltd. in increasing production from this area.

These deposits by no means exhaust the coal resources of Colombia. Other fields from which some extraction is occurring are the Norte de Santander field in the north part of the province of Santander and the Valle de Cauca field near Cali in the south west. Coal has also been found near San Jacinto and in the Cuanaga de Oro basin north of Antioquia along the northern part of the Cauca syncline, but no mines have been established in these areas.

Finally, there is the Antioquian field near Medellin, which is the subject of this Study. It has not, so far, attracted the attention of any potential foreign partner for a number of reasons. Such evidence as is available suggests that the reserves are smaller than those of the El Cerrejon, La Jagua or Cundinamarca-Boyaca fields and the seams are thinner and more difficult to mine. The coal is mainly high volatile non-coking coal and its relatively low value and the poor transport facilities, which make it difficult and expensive to export, are other factors which hinder the expansion of coal production in Antioquia. These points are elaborated in greater detail in the next section. They are mentioned here as amongst the reasons why, in the context of the overall development of Colombian coal, further exploitation of the reserves in the Medellin basin is of marginal interest to the Colombian Government and has a low priority in their planning.

3.5.5 Overall Energy Policy of Colombia

While the development of the more attractive coal fields is a first priority, the declared intention is to use the coal mainly for purposes other than industrial steam raising or thermoelectric generation. Development of the country's hydro-electric resources is the preferred method of keeping pace with the increasing demands for electric power. Thermoelectric generation will be confined to areas where there are local surplus supplies of natural gas or where there are coal supplies, which cannot be utilised in a more sophisticated way, either for the manufacture of chemicals or liquid fuels, or for export. The major output from El Cerrejon is earmarked for export, either alone or blended with Boyaca coking coal as a coking blend. Plans have been put forward for the establishment of a 3 million tonne/year coking plant at Puerto Berrio using the coking coals mined in the Sabana de Bogota and Boyaca regions; there are also plans for another coking plant at Cucuta City or Pamplona to utilise the Santander coking coal deposits.

Priority in the use of natural gas will be given to the production of chemicals, particularly of ammonia and urea, or for its export in liquefied form from terminals proposed at Cartagena and Barranquilla.

The needs of Antioquia, whose capital, Medellin is the second largest city in Colombia and its chief industrial centre do not feature to any large extent in the overall energy plan. There has been reported, it is true, plans to provide natural gas to Antioquia, but it is not known if these will materialise, and when, and what the resulting price of gas will be. Even at the present price of $1.033 per 10^6 Btu, natural gas would cost more than twice as much as the likely future price of coal in Antioquia on an equal calorific value basis and more than three times the present cost of coal. This difference would be partly compensated, but only partly, by the higher efficiency of gas utilisation, but the cost of converting industrial heating and steam raising equipment from coal to gas would entail considerable capital expenditure.

The development of Medellin as the centre for the textile industry and an important centre for diverse other industries has been encouraged by the availability of cheap coal. Unless the output from the local mines can be expanded, the future growth of Medellin industry is bound to be stifled. The mountainous terrain and poor road and rail communications make the import of coal from other regions or the supply of liquid fuels from Barrancabermeja costly. Moreover, Antioquia is almost wholly dependent for its electric power on hydroelectric stations, which have proved unreliable in periods of drought in recent years.

Thus, the development of the coal resources of Antioquia and their utilisation, although perhaps less attractive and apparently less urgent than many of the other development projects, is of vital importance to the department of Antiquia and the growth of Medellin as an industrial centre. It is, initially at any rate, a local rather than a national priority. Apart from the expansion of local coal output to serve the needs of the Antioquian industry and the expansion of the industrial base by the production of gas and chemicals from coal (the subject of the present study), consideration should be given to the reliable local production of electric power from coal or the products of coal conversion.

4. THE MEDELLIN COALFIELD

4.1 Geography and Topography

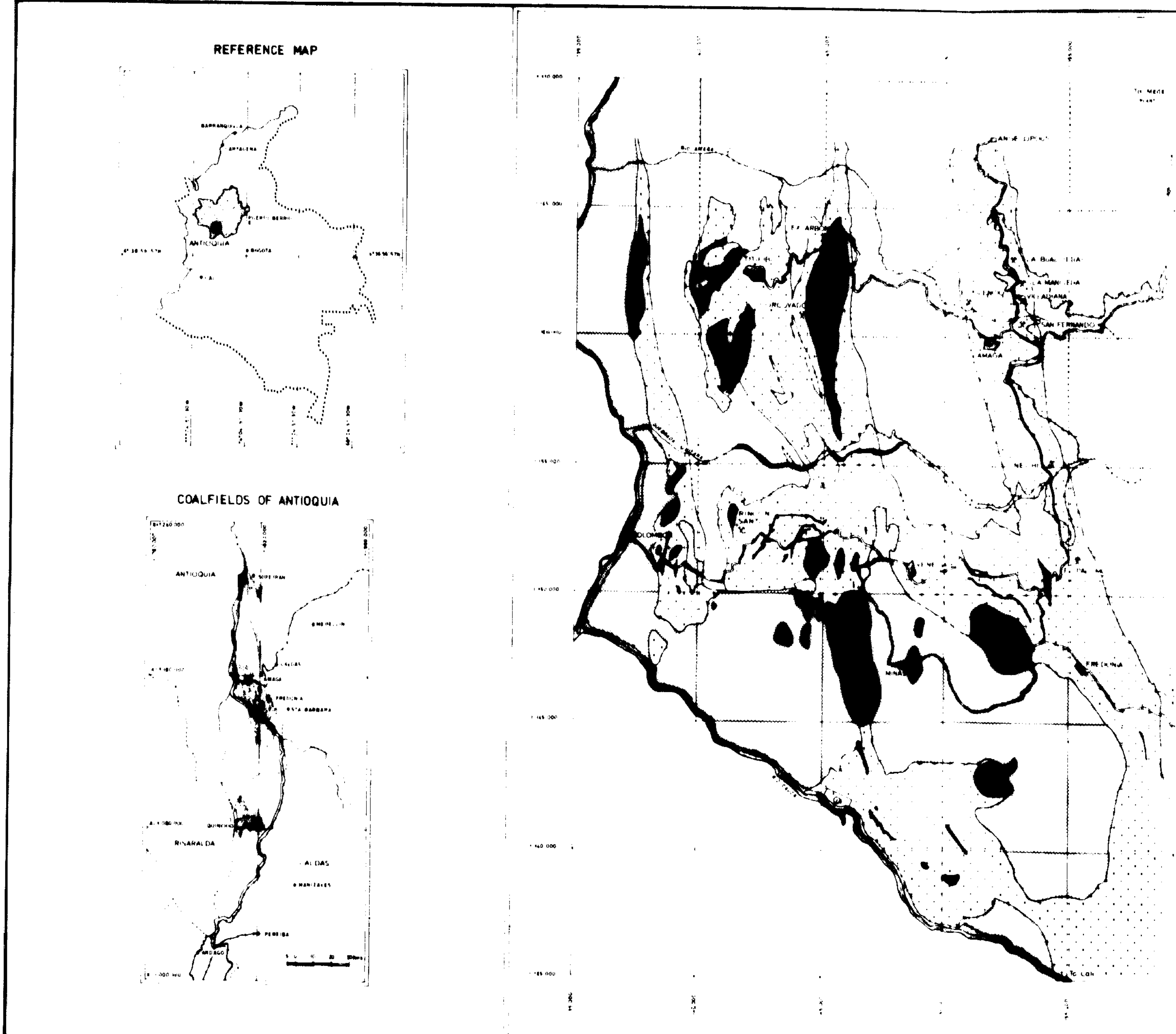
The mines of the Medellin coalfield lie in an area 12 km by 18 km centred on the town of Amaga (population 6000) which lies some 45 km south west of Medellin. The area is dominated by three mountain ridges with elevations of 2000 m to 2200 m above mean sea level with intervening valleys; this forms part of the Cordillera Central complex. To the west, the coalfield is bounded by a mountain ridge which separates it from Medellin. To the east, it is bounded by a further ridge, which separates it from the Rio Cauca, the second largest river in Colombia. The coalfield is drained westwards and southwards into the Rio Cauca by a number of streams, the largest of which, the Rio Amaga and the Rio Sinifana have cut deep gorges through the intervening ridges to reach the Rio Cauca. The Medellin coalfield is depicted in Figure 3.

4.2 Access

Access to the coalfield from Medellin is by way of the Troncas Central, one of the three main Colombian highways, which connects the Caribbean port of Barranquilla to Ecuador. It is a single carriageway, two-lane tarmac road, extremely tortuous since it must follow the mountain valleys. It has not been well maintained and ridges, cracks and pot-holes are numerous. The minor roads connecting the principal towns of the coalfield - Angelopolis, Amaga, Fredonia, Venecia and Bolombolo - are 6-8 m wide mountain roads, graded but unpaved. The access roads to the mines are even more primitive.

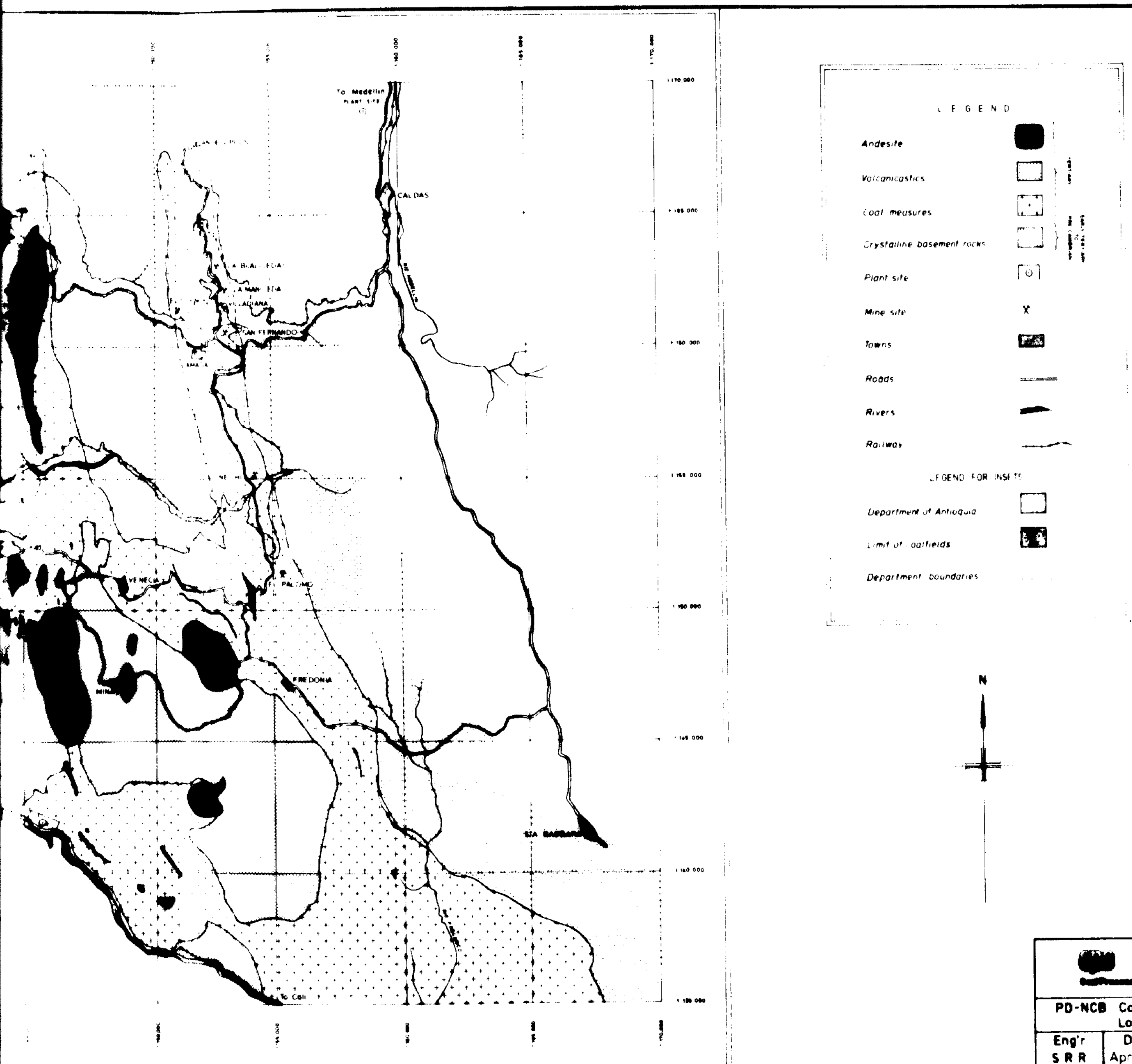
A 36" (91.4 cm) gauge single-track railway crosses the western part of the coalfield and connects Cali to Medellin and further to Puerto Berrio on the Rio Magdalena. It is a branch of the main Colombian railway system linking the northern ports of Bogota in the west and Cali in the south (see Figure 1). This line has, however, been disused for several years south of Medellin, because of landslips and wash-outs. Inspection trains are run along the line at irregular

Figure 3 LOCATION AND GEOLOGY OF THE MEDELL



SECTION 1

ND GEOLOGY OF THE MEDELLIN COALFIELD



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SECTION 2

intervals from Amaga to Medellin (58 km). The first major landslip is reported as occurring on the line several kilometres south of Camilo in the vicinity of the Nechi mine. The section south of Bolombolo is reported to have disappeared for several miles. The maximum gradient of the line is 3%.

4.3 Geology

4.3.1 General

The Medellin coalfield lies centrally within a Tertiary coal-bearing basin in the department of Antioquia. The basin, orientated due north to N15°E, is 130 km long by little more than 20 km at its widest part, the elongated nature of the basin being typical of intermontane sedimentary basins in the northern part of the Andes.

The Tertiary beds within the basin have been severely disrupted by post-depositional block faulting. This has resulted in the uplift of large horsts of crystalline basement rock within the sedimentary strata. The coalfield has also been affected by igneous activity in Late Tertiary times resulting in the emplacement of plutons and sills within the strata together with a massive outpouring of tuffs which cover much of the coal-bearing beds to the south of the Medellin coalfield.

The regional structural trend is orientated north-south and this is reflected in the shape of the basin, the outcrops of the uplifted basement blocks of crystalline basement and alignment of the Late Tertiary igneous intrusions.

4.3.2 Medellin Coalfield

A simplified geological map of the Medellin coalfied, based on the mapping of Dr. E. Grosse, is shown on Figure 3. The geology of the coalfield corresponds closely to the topography. The three mountain ridges which dominate the area comprise uplifted blocks of Pre-Tertiary crystalline basement rocks while the intervening intermontane valleys are infilled with Tertiary coal-bearing sediments.

The central mountain ridge essentially divides the basin into two parts. The eastern limb of the coal-bearing sediments has been named the Titiribi-Venecia area, and that to the west, the Angelopolis-Amaga-Fredonia area. The two limbs of the Tertiary outcrop join in the southern part of the coalfield. However, although the basin is more than 20 km wide at this point, the coal-bearing strata are overlain by an unconformable +500m thickness of volcaniclastics which render further economic extraction of the seams impossible.

4.3.3 Stratigraphy

Dr. Grosse has sub-divided the Tertiary beds of the region into five formations which are listed below:

Age	Formation	Description
Late Tertiary	-	Plutons and sills of andesite and minor basalt.
	DISCONFORMITY	
Upper Tertiary	"Sedimentary"	Conglomerate and sandstone.
Upper Tertiary	"Volcanic"	Conglomerate, sandstone, tuffs, basalts and andesites.
	UNCONFORMITY	
Lower Tertiary	Coal Measures (Upper)	Sandstone, mudstone, minor conglomerate and coal seams.
Lower Tertiary	Coal Measures (Middle)	Claystone, sandstone with minor conglomerate and coal seams.
Lower Tertiary	Coal Measures (Lower)	Sandstone, conglomerate, mudstone, minor coal seams.
	DISCONFORMITY	
Early Tertiary, Mesozoic and Pre-Cambrian crystalline basement rocks.		

Thicknesses of the three formations comprising the Lower Tertiary coal measures are stated by Dr. Grosse to be:

Upper Formation	+360 m
Middle Formation	200 m
Lower Formation	70 m

However, these stratigraphic thicknesses should be treated with some caution as the beds will thicken towards the centre of the basin which is located to the south of the coalfield.

4.3.4 Structure

The original depositional dip of the basin fill has been disrupted by later tectonic movements and igneous intrusions. However, the general dip towards the centre of the basin is preserved, as shown by the increasingly older formations which outcrop from north to south within the coalfield. Locally, the dip of the strata depends on the proximity to the uplifted crystalline basement rocks and to the igneous intrusions.

The Tertiary strata in the two limbs of the coalfield appear to have been flexed to form synclinal structures lying between the horsts of crystalline basement rocks. The general plunge of the synclines is estimated to be less than 5°. Dips away from igneous rocks are commonly 15° to 20° but should approach the horizontal in the troughs of the two structures.

Contacts between the Tertiary strata and the crystalline basement rocks are faulted and nearby the dips are commonly steeped to between 50° and 80° and may be locally reversed. It is unlikely that the contact is a simple reverse fault as shown by Dr. Grosse but rather marked by closely-spaced parallel faulting with imbricate structures.

Underground workings near Amaga show that the eastern limb of the coalfield is also affected by minor transverse, reverse and normal faulting with throws of up to 2.5 m. This suggests the relaxation of the pressures that caused the major uplift of the horsts and the brittle failure of the rocks as they re-settled at a slightly lower level in the earth's crust.

The western limb of the coalfield is strongly affected by Late Tertiary intrusions of andesitic and minor basaltic magma. Dips of the strata have been locally steepened near the plutons to accommodate the increase in volume of rock. Metamorphic aureoles are reported to affect the strata for a distance of 2 m to 100 m away from the igneous contacts.

4.3.5 Coal Seams

The Medellin coalfield is part of an intermontane sedimentary basin bounded by steep-sided blocks of crystalline basement rocks which underwent active uplift during the period of sedimentation. The depositional environment was an alternation of 'quiescent' (low-energy sedimentary regime) and flash flood (high-energy sedimentary regime) conditions. Swamps were established during the quiescent times in parts of the basin where large thicknesses of peat were accumulated - later to form the coal seam of the area. The seams are intercalated with mudstones, originally deposited in deltas which encroached into the basin from the major rivers draining the surrounding high ground.

During uplift of the surrounding horsts or basement rock, the river gradients were altered and resulted in the rapid erosion of hillside detritus and the basement rocks. Torrential rains swept this material into the basin resulting in beds of immature, ill-sorted, coarse-grained sandstones with minor conglomerate units. The accumulations of peat were disrupted during the uplift. The high-energy sedimentary regime active in the basin at this time probably resulted in volumes of peat being washed away, either to be redeposited in areas of quieter conditions towards the centre of the basin or to be mixed and deposited with the incoming coarse detritus (e.g. coal wisps found in the sandstone beds above Seam 1 at San Fernando mine). Parts of the basin also suffered some tilting during the period of deformation. Slumping of the waterlogged peat occurred in areas which suffered severe tilting and has resulted in the irregular thickening and thinning of some of the coal seams (e.g. Seam 1 at Carbones de

Diamante's mine at Rincon Santo varies in thickness between 1 m and 3 m over distances of about 10 m - 'caballo' structure).

Compaction and burial of the peat since deposition has resulted in the transformation of the material to bituminous 'B' and 'C' coal occurring in seams which vary in thickness from a few centimetres to in excess of 3 m. The more common range of seams currently being worked is 1.5 m to 2.5 m.

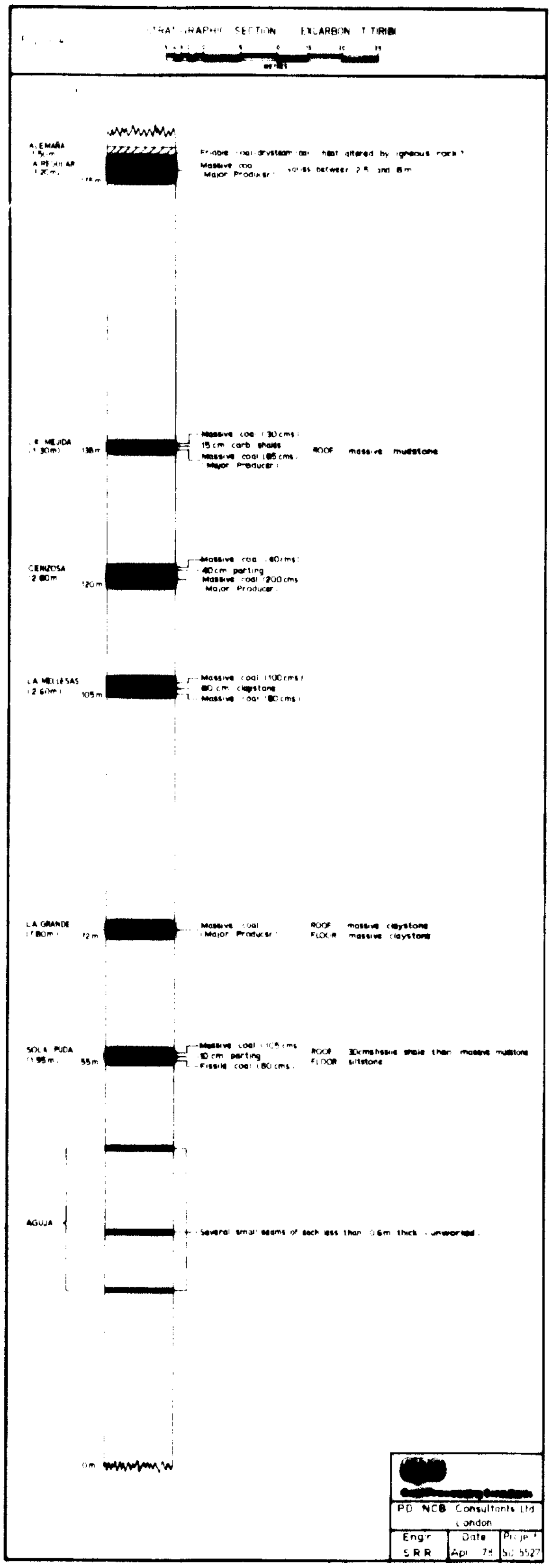
Late Tertiary intrusions of andesitic and basaltic magma locally affect the quality of coal, especially in the western limb of the coalfield. However, the effects of thermal metamorphism have been slight and the coal seams are only altered to low and medium volatile bituminous coal (dry seam coal) within a zone 1 m to 100 m adjacent the igneous contacts.

The coal seams throughout the area have a well-developed cleat which varies from N80°E to S70°E.

4.4 Coal Stratigraphy

4.4.1 Western Limb (Titiribi-Venecia area)

This area is characterised by the presence of some seven workable seams varying in thickness from 1.5 m to 8 m and which commonly contain partings of carbonaceous and barren fissile mudstone (2 cm to 30 cm thick). The coal seams appear to attain their maximum thickness in the north half of the area (around Titiribi). They decrease in thickness and are intercalated with greater quantities of fine sediment towards the south. The stratigraphic succession at Excarbon's mine near Titiribi shown on Figure 4 can be taken as a typical example of the coal seams in the northern half of the area. More than 15 m of coal are found in a stratigraphic thickness of mudstones and sandstones some 125 m thick. The coal occurs as seven workable seams, which vary in total thickness from 1.3 m to 3.2 m. At Rincon Santo, 10 km to the south, the number of seams is reduced to four with a total thickness of 5.6 m (2.3 m, 1.4 m, 1 m and 0.9 m).


SECTION
EXCARBON
TIRIBI
A EMAÑA
Friable coal drysteam coal heat altered by igneous rock ?
Massive coal
Major Producer
varies between 2.5 and 8m
138m
Massive coal (30cms)
15cm carb shales
Massive coal (85cms)
Major Producer
ROOF massive mudstone
CENIZOSA
2.80m
120m
Massive coal (80cms)
40cm parting
Massive coal (200cms
Major Producer
105m
Massive coal (100cms)
80cm claystone
Massive coal (80cms)
LA GRANDE
72m
Massive coal
Major Producer
ROOF massive claystone
FLOOR massive claystone
55m
Massive coal
10cm parting
Fissile coal (80cms)
ROOF
FLOOR siltstone
AGUJA
Several small seams of each less than 0.6m thick
0m
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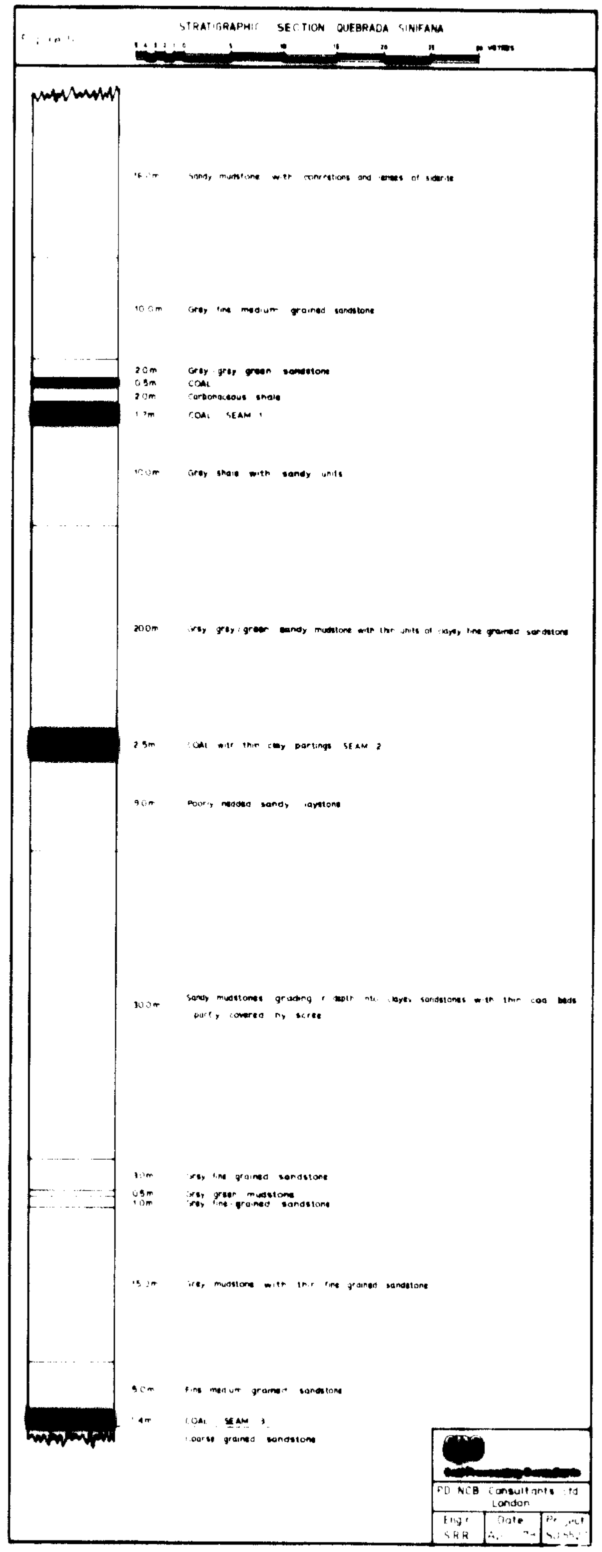

STRATIGRAPHIC SECTION QUEBRADA SINIFANA
Sandy mudstone with concretions and lenses of siderite
10.0m
Grey fine medium grained sandstone
2.0m
Grey gray green sandstone
0.5m
COAL
2.0m
Carbonaceous shale
COAL SEAM
Grey shale with sandy units
20.0m
gray/green sandy mudstone with thin units of clayey fine grained sandstone
2.5m
COAL with thin clay partings SEAM 2
Poorly bedded sandy claystone
Sandy mudstones grading in depth into clayey sandstones with thin coal beds
partly covered by scree
fine grained sandstone
0.5m
green mudstone
fine grained sandstone
mudstone with thin fine grained sandstone
5.0m
Fine medium grained sandstone
COAL SEAM 3
coarse grained sandstone
PD NCB Consultants Ltd
London
Date
SRR

Further to the south-east, midway between Venecia and Fredonia, the coal thickness is reduced to some 2 m occurring in three seams varying from 0.4 m. to 1 m thick with a 32 m stratigraphic thickness (Quebrada San Agustin - Geominas Study, 1974).

4.4.2 Eastern Limb (Angelopolis-Amaga-Fredonia area)

Three major coal seams occur in the area(see Figure 5). A further three seams are reported to exist at depth but no evidence of their existence was seen. Seam and interburden thicknesses in the five mines visited in the area are shown below in Table 4.1.

Table 4.1 - Seam and Interburden Thicknesses in some Mines in the Eastern Limb of the Coalfied

	La Honda (1)	El Silencio-Villadiana (2)	San Fernando (3)	Nechi (4)	El Palomo (2)
	m	m	m	m	m
Seam 1	2.4	2.1	1.8	1.3	1.3
Interburden	-	13.0	15.0	18.0	10.0
Seam 2	1.2	1.4	1.4	1.2	1.0
Interburden	-	13.0	19.0	-	14.0
Seam 3	1.6	1.4	1.6	-	1.5

Notes: Mines owned by:

(1) Empresa de Departimento de Antioquia, Angelopolis
(2) Industrial Hullera SA, Amaga
(3) Carbones San Fernando, Amaga
(4) Geominas Ltda, Amaga

The coal seams, as also seen in the eastern limb, appear to thin to the south and have increasing quantities of intercalated waste in the form of fissile mudstone partings. The total thickness of coal at San Fernando is 6.2 m, including 1.4 m of the Capotera seam, an irregularly occurring seam in the Amaga-Angelopolis area, while at El Paloma, in the south near Fredonia, the coal thickness has reduced to 3.8 m.

4.5 Coalfield Statistics

4.5.1 Production

The recent annual production of the Medellin coalfield, prior to July 1977[(1)], is estimated to be between 600 000 and 650 000 tonnes. Some 100 000 to 200 000 tonnes are sent annually to Cali and the remainder is used in Medellin for heating, raising steam and power generation.

No on-going statistics on the mines and production are available. However, the total production since 1900 is estimated to be some 17 million tonnes, as shown below in Table 4.2.

Table 4.2 - Estimate of Production from the Medellin Coalfield 1900-1977

	10^6 tonnes
1900 to 1930 at 200 000 tpa	6
1930 to 1960 at 100 000 tpa	3
1960 to mid-1977 at 500 000 tpa	8
TOTAL	17

The current situation has changed little from that reported in a mining survey carried out in 1975 by the Ministry of Mines and Energy. The number of active mines in the area is estimated at 74, located severally in the municipalities of Titiribi, Angelopolis, Amaga, Fredonia and Venecia. A breakdown of production in 1974, by municipality, is given below and shows that the municipalities of Amaga and Angelopolis (eastern limb) accounted for 93% of the production from the coalfield.

(1) On 14th July, 1977, a major gas explosion occurred in the El Silencio-Villadiana mine belonging to Industrial Hullera SA, killing 86 miners. This disaster resulted in the loss of some 35% of the production from Medellin coalfield and the mine was closed down for a period. Loss in production was further aggravated by a wave of strikes by miners demanding higher pay and improved working conditions.

Table 4.3 - Output of the Medellin Coal Mines

Municipality	Mines		Production		Average tonnes/ month
	No.	%	tonnes/ month	%	
Eastern Limb					
Angelopolis	37	50.0	6 718	12.9	182
Amaga	27	36.5	41 225	79.0	928 (1)
Fredonia	2	2.7	580	1.1	290
Western Limb					
Titiribi	7	9.4	3 095	5.9	442
Venecia	1	1.4	560	1.1	560
TOTAL	74	100.0	52 178 (2)	100.0	474 (1)

(1) Excludes Industrial Hullera which produces about 17 000 tonnes per month.

(2) Equivalent to 626 000 tpa.

By far the largest mine is the El Silencio-Villadiana mine belonging to Industrial Hullera, which until the disaster, had a production between 200 000 and 210 000 tonnes per year, employed some 350 people and had a productivity of about 2 tonnes output per man shift (OMS).

The remaining 60% of the production comes from numerous small mines which are either owned by small independent companies or are owner-operated. The largest of these, producing some 40 000 to 50 000 tpa, belongs to Carbones de San Fernando. Apart from Industrial Hullera, the mining operations are small with more than 77% of the mines producing less than 500 tonnes per month as seen in Table 4.4.

A more recent estimate of the number of mines with production capacity of 500 or more tonnes per month is given in Appendix 2, Table A2.1. The estimate suggests that the 19 mines listed have a total annual production capacity in excess of 0.5 million tonnes. However, it is doubtful if all the mines were working to the stated capacity at the time of the visit to the area.

Table 4.4 - Breakdown of Mine Output
(Modified after W. Balbin A, 1975)

Production	Mines	
tonnes/month	No.	%
0 - 100	36	48.6
101 - 500	21	28.4
501 - 1 000	7	9.4
1 001 - 5 000	8	10.8
5 001 - 10 000	1	1.4
+ 10 000	1	1.4

4.5.2 Manpower

Some 1600 people were employed in the Medellin coalfield in 1974 and it is estimated that the figure was similar in 1977. Excluding Industrial Hullera, the average monthly production per man was 28 tonnes and the average mine employed 17 people, reflecting the small size of mines in the area and the low productivity (1.0 tonne OMS) resulting from primitive mining methods. Table 4.5 shows the manpower and productivity statistics for the various municipalities.

Table 4.5 - Manpower and Productivity in the Medellin Coalfield
(Modified after W. Balbin A, 1975)

Municipality	Manpower		Mines	Monthly Production	Output/ Man	Men/ Mine
	No.	%	No.	tonnes	tonnes	No.
Eastern Limb						
Angelopolis	335	21.2	37	6 718	20.1	9
Amaga	1015	64.2	27	41 225	30.6*	27
Fredonia	36	2.3	2	580	16.1	18
Western Limb						
Titiribi	166	10.5	7	3 095	18.6	24
Venecia	28	1.8	1	560	20.0	28
TOTAL	1580	100.0	74	52 178	27.9*	17*

* excludes Industrial Hullera

4.6 Mine Conditions

The results of the mining survey serve only to substantiate the findings of Dr. William Balbin A., who carried out a similar survey for the Colombian Ministry of Mines and Energy in 1974. Excluding Industrial Hullera's operation, the mines are small producers (the average mine produces 474 tonnes per month), use primitive methods and by modern mine standards are extremely hazardous. Only 7% of the mines have forced ventilation and 87% of the operations win coal exclusively with hand-pick and shovel. Lighting is by carbide lamp in 20% of the mines, electricity in 39% and the rest use candles. Proper safety and mine rescue equipment and procedures are not in evidence.

New mines are started on the surface outcrop and follow the seams down-dip. Smaller producers rarely extend their workings more than 50 m to 150 m below the surface and therefore are largely unaffected by problems of ground pressure in the workings and concentrations of gas in the seams.

The larger mines of the area are beginning to work coal below 200 m but the mining practices currently employed are inadequate to cope with the dangers inherent in mining coal at these depths. Most unfortunately this fact was exemplified by the 1977 gas explosion at the El Silencio-Villadiana mine belonging to Industrial Hullera which resulted in the temporary closure of the mine and the temporary loss of some 35% of the coalfield's annual output.

4.7 Longwall Workings

Industrial Hullera's mine, El Silencio-Villadiana, located 1 km north of Amaga in the eastern limb of the coalfield, is the only mine currently using semi-mechanical longwall mining. Annual production from the mine up to July 1977 averaged 200 000 to 210 000 tonnes, representing some 35% of the output from the coalfield. The production figures from the mine over the past eight years are given in Table 4.6.

Table 4.6 - Annual Production from the El Silencio-Villadiana Mine

Year	Production tonnes/year
1970	218 653
1971	195 767
1972	204 521
1973	206 160
1974	205 024
1975	194 209
1976	203 869
1977 (1)	111 000

(1) Estimated up to mid-July 1977

The mine property, covering some 300 ha, spans the entire 2 km width of the Tertiary coal-bearing outcrop, immediately north of the Rio Amaga. Access to the underground workings is by a tunnel driven the length of the strike of Seam 1 between the portals of Villadiana (east side) and El Silencio (west side). A 350 m drift in rock from Villadiana connects the tunnel with the surface.

All three seams (Seams 1, 2 and 3) have been worked in the past by room and pillar. In 1960, the mining method was changed to longwall and two semi-mechanised faces were installed in Seams 1 and 2. Some 3.4 million tonnes have been extracted since that date.

Present workings are located in the southern part of the property. They cover about 1 km^2 of which 20% has been lost due to a fire in Seam 1 adjacent the El Silencio portal.

Prior to the explosion in mid-1977, two longwall faces, one working in advance and one in retreat, accounted for 86% of the 200 000 - 210 000 tonne/year output. Panels were 300 m long with faces of 150 m which advance along the strike. The faces being worked at 180-210 m depth were equipped with friction props set at 65 cm centres, bars, panzer face conveyor and stage loader. On each of the faces an 18 hour cycle was used, employing a total of 58 men. Coal was drilled with a 1 m staggered pattern using electric drills and blasted with explosive (½ lb (227 g) per hole) and safety fuse. The advance was about 1.25 m per round, yielding 300-350 tonnes of coal. Thirty per cent of the blasted face fell on the panzer and the remainder was hand loaded from the floor. The OMS, calculated on a 3 shift per day basis, was 5 to 6 tonnes for the face workers. A conveyor belt system (60 tonnes per hour capacity) transports the coal from the longwall face to the Villadiana portal. Although the faces are only some 1 km from the portals, between four and six separate conveyors are used because of the tortuous layout of the mine. Eleven development headings accounted for the remaining 14% of the production. These were worked on two shifts per day using pick and shovel. Each heading was advanced 1 m per shift yielding

4.9 tonnes, which was manually loaded into 600-1000 kg capacity tubs and hand-trammed either to the conveyor belt or to the main haulage way with the aid of small electrically operated winches on the inclines connecting the seams. Once on the main haulage way, they were either pulled by diesel locomotive or hand-trammed to the El Silencio portal.

The main haulage way and development drifts are supported by timber props and bars. A small section of the main haulage way at the Villadiana portal is also supported by steel arches. Roof and floor characteristics on the longwall face in Seam 1, when the mine was visited before the explosion, were good. However, the caving characteristics of the massive mudstone roof are poor and cavities up to 20 m long regularly occur in the gob before the roof caves. Roof conditions were poorer in Seam 2, which is overlain by a metre of fissile shales and coal stringers. Seam 3 was not being worked, but it was considered that roof and floor conditions there would be as good as in Seam 1.

The ventilation system used in the El Silencio-Villadiana mine consisted of a 128 hp main fan located near the El Silencio portal and ten auxiliary fans ranging from 10 hp to 40 hp at the working faces. Power for the mine was tapped from a 13.2 KV line connected to the local Antioquian grid. Power was delivered underground at 440 V and stepped down to 220 V where required. The faces were unlit, but winch stations and some of the conveyor transfer stations were lit by electric light bulbs. Miners were equipped with standard miner's Ni-Cd battery lamps. No flame-proof electrical equipment was seen underground.

The coal emerging from the Villadiana portal was passed over an 8 cm screen and stored in a 4-bin bunker. Some 5% of the production is larger than 8 cm ('cozinas') which commands a higher price than the fines ('cisco'). In addition to the storage bunker, the surface installations at Villadiana comprise a workshop, offices, dispensary, rescue station and changing house for miners and staff. The main office of the company is in Medellin.

The total complement of the El Silencio-Villadiana mine was 329, comprising 272 underground workers, 25 surface workers, 28 supervisory and clerical staff and 4 personnel administrators. A further 20-30 contract miners were employed on the development headings.

4.8 Room and Pillar Workings

In the other mines exploiting the main seams, the mining method is room and pillar with subsequent recovery of the pillars wherever possible. Access to the seams is gained by adit which connects to a main haulage way driven in the dip of the seam (15^{o} to 30^{o}). This inclined haulage way is furnished with a rail and a wire rope hoist powered by a 10 to 25 hp motor.

Room and pillar workings are developed from the surface and generally extend no more than 300 m to 400 m along the strike from the main haulage incline. The maximum lateral development is no more than 1000 m which is considered to be the economic limit for this type of mining. The size of the rooms and pillars varies within a single mine, depending on the roof conditions and the seam being exploited. A typical example would be a system of 10 m square pillars (up to 50 m) and 1.5 m wide rooms (up to 6 m).

The maximum economic depth for the small mines is mainly dictated by the size of the main haulage winch and the length of the workings along the strike; a depth of between 200 and 300 m is considered to be about the maximum,which results in the maximum depth of workings being no more than 150 m,depending on the dip of the seam and the nature of the topography. Commonly the workings in the small mines are little more than 50-100 m deep.

More than one seam is commonly developed in each mine, working in descending order from the surface. Once the maximum strike development of a level has been reached, the pillars are recovered in retreat. The percentage extraction of pillars varies considerably, depending on the nature of the roof and the amount of subsidence which will be tolerated by the surface owner. Two methods are commonly used.

With the first method the pillar is divided into four with further rooms leaving small (say 5 m) pillars to support the roof. With the second method the pillar is extracted in total by mining parallel slices taken at an angle to the dip and starting at one of up-dip pillar corners. Apart from a row of pillars to support the main haulage way, the mines attempt to achieve total recovery. The shallow depth of the workings and the strength of the interburden mudstones and sandstones (10 m to 20 m thick) are such that the stresses induced by total extraction of the upper seam do not materially affect the roof conditions in the lower seams.

For the most part, the coal is won by pick and shovel. A few mines use electric drills and explosives lit by safety fuse, but with no particular precautions for detecting dangerous accumulations of gas.

When the dip of the seam is 30° or more, the coal is allowed to gravitate down the floor of the seam to collect in a pile at the lower level. Otherwise the coal mined from the openings is hand loaded into cut-down oil drums holding 100-200 kg and pushed down to the lower level. From there it is manually loaded into tubs on the haulage level and hand-trammed to the main haulage incline and thence to the surface.

Adit entrances and main inclines are supported by notched timbers of either pine, or more rarely from the local countryside, eucalyptus or tropical woods imported from the department of El Choca. 10-12.5 cm bamboo is also used, especially in packs during pillar extraction. Within the workings the minimum of timber is used.

The majority of the small mines rely on the difference in temperature and pressure between the adit entrances to supply natural ventilation. Only in some of the larger mines, where the main haulage inclines are being extended in length beyond 300 m (Nechi, San Fernando, Industrial Hullera) is any attempt being made to install electrically driven fans.

Gas has been reported in some of the mines and, although to date, it has never been considered a hazard to safety by the Colombian authorities, the recent gas explosion indicates that all mines must now be regared as potentially dangerous and corresponding precautions taken.

The mines in the eastern limb of the coalfield (Amaga-Angelopolis) are supplied with power from the local Antioquian electricity grid. Main haulage ways and some working faces are illuminated by electric bulbs, but only the larger mines supply the miners with standard miners Ni-Cd battery lamps. In the smaller mines, carbide lamps, candles and electric torches supply what lighting there is. Much of the hand-tramming is carried out in complete darkness.

Coal tubs, once on the surface, are hand-trammed to wooden or concrete bunkers (100-200 tonne capacity) where they are tipped over an 8 cm grizzly to separate the 'cozinas' from the 'cisco'. Other pit head buildings are, at the best, rudimentary and in many cases non-existent.

The greater part of the mine production is won by contract miners who are paid on the basis of the tonnage extracted or, less commonly, on the basis of metres of advance. Only where the mine is company-owned rather than owner operated are the foremen and engineers salaried personnel. Most mines are worked on a one shift per day basis.

4.9 Marginal Mines

It will be seen that over three-quarters of the mines have outputs of less than 500 tonnes/month. A large number of these are owner-operated and the primitive mine workings - a vertical shaft following the surface outcrop with bucket and winch haulage to the surface - are in small holdings in which crops like bananas, maize and sugar are grown. The families operating these mines regard the coal as a 'cash crop' and the time devoted to coal extraction appears to depend on the exigencies of the crop cultivation and the relative return on coal production and land cultivation.

4.10 Transport and Marketing

All the coal from the Medellin coalfield is transported by truck to the consumers in Medellin, to the Argos cement plant at Santa Barbara or to Cali. Part of the output is stockpiled at an intermediate point, Primavera, located on the top of the mountain divide between the coalfield and Medellin. The trucks hauling the coal are mainly 10 tonne lorries operated by contractors; Argos owns its own 25 tonne trucks which haul directly from Industrial Hullera's mine and from Primavera to the cement plant.

The coal trucks are partly responsible for the vehicle congestion on both the mountain roads connecting the mines within the coalfield and on the main two-lane highway between Medellin and Caldas. Any significant increase in production from the coalfield would seriously add to the congestion and deterioration of the roads, especially on the divide between Amaga and Medellin.

Transport costs to the consumers, which include a 14 cent/tonne municipal tax, vary from $1.60 to $4.90 per tonne depending on the distance and state of the roads. Examples of transport costs from the larger mines to Medellin are given in Table 4.7.

Table 4.7 - Transport Costs of Coal from Mine to Medellin

Mine Area	Distance km	Total Cost $/tonne	Unit Cost cents/tonne/km
El Silencio-Villadiana (Amaga)	45	2.17	4.8
San Fernando (Amaga)	40	2.04	5.1
Nechi	43	2.31	5.4
Excarbon (Titiribi)	52	2.53	6.8
Rincon Santo	66	4.81	7.4

4.11 Costs

A breakdown of the costs for the El Silencio-Villadiana mine for May, 1977 was obtained and is given below in Table 4.8.

Table 4.8 - Production and Breakdown of Cost for El Silencio-Villadiana Mine

Production tonnes	May, 1977 22 000	Annual Estimated 210 000	
Operating Costs	10^3\$	10^3\$	\$/tonne
Direct Costs:			
Salaries and wages	12.4	148.8	0.71
Payroll overhead	13.9	166.8	0.79
Contract miners*	25.0	238.6	1.13
Explosives*	4.8	45.8	0.22
Timber*	3.5	33.4	0.16
Materials*	3.0	28.6	0.14
TOTAL DIRECT COSTS	62.6	1314.8	6.26
Ownership Costs:			
Depreciation	10.2	122.4	0.58
Finance and Administration charges	12.7	152.4	0.73
Profit (loss) on sales	21.6	(48.1)	(0.23)
TOTAL OWNERSHIP COSTS	44.5	226.7	1.08
TOTAL COSTS AND PROFIT (LOSS)	161.5	1541.5	7.34

* tonnage dependent variable costs.

The sales price of Industrial Hulleras coal at the mine was at this time \$7.34 per tonne, which at an annual production rate of 210 000 tonnes would have yielded a gross revenue of \$1.54 million. Total costs would have amounted to \$1.59 million, resulting in an annual loss of \$48 000 (\$0.23/tonne). It is, however, probable that the monthly price of coal was adjusted by the owners so that the coal was sold at cost (i.e. the mine-mouth price of coal for 1977, prior to the explosion, would have averaged \$7.57/tonne).

No costs are available for the smaller mines. However, Industrial Hullera acts as price fixer in the market since their El Silencio-Villadiana mine produces some 35% of the coal output of the field and Industrial Hullera is owned by the major coal consumers. The mine price of the coal is thus determined by the price of Industrial Hullera coal at Medellin less the small producers' transport costs. A profit margin is available to the small producer because their mining method is cheaper than that of Industrial Hullera. Farther from Medellin, as in the Rincon Santo and Titiribi areas, the profit margin is reduced by the increased transport costs. The maximum estimated price per tonne of coal at the mine in various areas is given below in Table 4.9, based on a sales price of $9.51/tonne in Medellin, as calculated from the May 1977 mine price at El Silencio-Villadiana.

Table 4.9 - Estimated Mine Price of Coal at mid-1977

Mine/Area	Medellin Price	Transport Cost	Mine Price
	US$	US$	US$
Industrial Hullera	9.51	2.17	7.34
San Fernando	9.51	2.04	7.47
Nechi	9.51	2.31	7.20
Excarbon (Titiribi)	9.51	3.53	5.98
Rincon Santo	9.51	4.89	4.62

The coarser +8 mm lump coal commanded a premium of $1.35 to $4.10 per tonne at the point of sale. Where marginal outcrop producers sell to contractors, which is the common practice, the mine price averages $0.82 to $1.09 less than that shown in the table.

Table 4.9 shows the severe financial constraints imposed on the small coal mines, especially those located in the remoter parts of the coalfield. Under such price constraints it is impossible for owners to consider any type of mechanisation, as the mine site price of the coal would scarcely cover the direct costs of production, giving no excess for capital repayment.

4.12 Analysis of Antioquian Coal

Forty samples of coal were collected from the mines visited in the Medellin coalfield. These samples are listed in Appendix 3, Table A3.1, whilst Table A3.2 gives their proximate analyses and coking properties as determined at the Coal Research Establishment (CRE) of the National Coal Board (of Great Britain). The result of these analyses show that the coal throughout the field is of reasonable uniformity. The samples were bulked into seven composite samples representative of the three seams occurring in the northern and southern ends of the Amaga-Angelopolis-Fredonia area and all the seams in the Titiribi area (Table A3.3). These were submitted to CRE for more detailed analyses with the results listed in Table A3.4. A further two samples taken from the longwall face of Seam 1 of the El Silencio-Villadiana mine were analysed for ash composition, ultimate analysis and coking properties. Also one of them was carbonised in the Gray-King assay apparatus to determine tar and gas yields. These data are recorded in Table A3.5 to A3.8.

The coal from the Amaga-Fredonia part of the field is classified as a non-coking, high volatile, sub-bituminous coal. Sulphur, phosphorus and chlorine content are low. The ash content is also low, but the high sodium content of the ash results in a low ash fusion temperature. The ash content may increase towards the southern end of the field where there are indications that the seams contain clay partings. Consistent with the non-swelling properties and relatively low calorific value, the oxygen and moisture contents are relatively high.

The analytical results from the Titiribi coals are marginally different from those of the Amaga-Fredonia coals because of their close proximity to an igneous intrusion. There is a slight increase in fixed carbon and a corresponding decrease in volatile matter content. The moisture content is reduced and the calorific value increased. The coking properties are marginally improved, the BS swelling number increasing from zero to a half.

Table 4.10 gives average properties of the Medellin coals. These analyses are used as the guide to the results to be expected when the coal is submitted to conversion processes.

Table 4.10 - Average Properties of Medellin Coals

	Amaga-Fredonia*	Titiribi°
Proximate Analysis		
Moisture (as analysed) %	13.0	7.0
Ash (as analysed) %	5.4	5.8
Volatile matter (as analysed) %	39.1	38.9
Fixed carbon (as analysed) %	42.5	48.3
Volatile matter (daf) %	47.9	44.6
Coking Properties		
BS Swelling No.	0	½
Gray-King Coal Type	A	B
Calorific Value		
Btu/lb (daf)	13 100	13 840
kJ/kg	30 500	32 240
Ash Fusion		
Deformation temperature °C	1 120	1 230
Hemisphere temperature °C	1 160	1 350
Flow temperature °C	1 210	1 400
Atmosphere	mildly reducing, 50% H_2/50% CO_2	
Ultimate Analysis		
Carbon (d.mm.f) %	75.1	78.6
Hydrogen (d.mm.f) %	5.5	5.8
Oxygen (d.mm.f) %	17.2	13.5
Nitrogen (d.mm.f) %	1.87	1.85
Mineral matter (calc.) %	6.2	6.8
Elemental Analysis		
Total sulphur (as analysed) %	0.52	0.70
Chlorine %	0.03	0.02
CO_2 %	0.49	0.50

* Average of results of analyses of six composite samples made up from 22 individual samples.

° Analysis of one composite sample made up from 8 individual samples.

4.13 Reserves

The reserves of the existing mines are difficult to estimate. In the case of the largest mine, the El Silencio-Villadiana mine, the larger part of the easily workable reserves has been mined and the remaining reserves are put at 2.9 million tonnes proven, a further 2.6 million probable, i.e. a total of 5.5 million tonnes demonstrated, located in the three seams as shown in Table 4.6. Further reserves amounting to say 5 million tonnes are possible, but have not been demonstrated.

Table 4.11 - Seams and Estimated Reserves at El Silencio-Villadiana Mine

Seam	Thickness m	Geological Reserves 10^6 tonnes	%
1	2.0	1.1	20
2	1.7	2.3	42
3	1.4	2.1	38
TOTAL	5.1	5.5	100

This mine, therefore, is probably capable of supporting the present output, 200 000 tonnes/year, for some 18-20 years, based on an extraction rate of 65%. At an increased output of 300 000 tonnes/year, the probable mine life would be around 12-15 years.

The San Fernando reserves are believed to be of the same order - about 5-6 million tonnes - of which 20% are in the first seam and 40% each in the more lightly exploited second and third seams. At its present output of 78 000 tonnes/year, the life of this mine could be 40-50 years. At an increased capacity of 200 000 to 250 000 tonnes/year, the probable mine life would be some 15 years.

The Nechi reserves are believed to be of the order of 2-3 million tonnes. At its present capacity of around 18 000 tonnes/yar, the probable mine life would be 80-100 years. At an increased capacity of around 100 000 tonnes/year, the probable mine life would be reduced to around 15-20 years.

4.14 The Explosion at the El Silencio-Villadiana Mine and its Aftermath

On July 14th, 1977 while the mining survey for this project was in progress, a major gas explosion occurred in the El Silencio-Villadiana mine, killing 86 miners and injuring more than 50. The causes of the disaster were not known at the time of preparing this report, but such information as is available suggests that the explosion originated in the vicinity of the relatively new face established to exploit the lower No. 2 seam, probably by the release of a pocket of methane during a blasting operation.

Until fairly recently, coal production at this major mine had been by longwall operation on No. 1 seam. Originally, this had been done from the El Silencio end, but when the working there reached an uneconomic distance from the portal, the transport of the coal was switched to the Villadiana end and the El Silencio adit was employed to establish development headings to No. 2 seam where a new longwall face was set up.

The explosion occurred, unfortunately, when the shifts were changing so that there were more than the usual number of miners underground. The blast appears to have travelled along the upper part of the entire workings; those miners who were walking upright coming on shift or going off shift were killed instantly, while those who were bent down cleaning up the face or loading escaped the full force of the explosion but sustained injuries by being thrown to the floor or against the face.

The mine itself was not badly damaged. The conveyor belts were dislodged from the guides and there were some local roof falls. By August 23rd, production from No. 1 seam had been resumed at a reduced rate. No. 2 seam face was isolated and was not reopened for some time.

The effect of the stoppage of production at El Silencio-Villadiana was not only to reduce the output from the field by 16 500 tonnes per month, but to trigger a strike by the mining force so that, in the week after the disaster, the output from the entire field was negligible and had only recovered to 638 tonnes/day by the end of July. There was also the inevitable outcry in the press at the primitive and dangerous conditions under which the miners worked for low wages. In some cases it was stated that contract miners were being paid only $1.63 per shift. The lack of safety precautions and rescue equipment in the mines and hospital facilities nearer than Medellin were other defects which were highlighted. The Ministy of Mines was castigated for not enforcing adequate safety precautions, although it was not clear whether legislation to this effect had ever been enacted.

Medellin coal consumers, the larger of whom not only owned the mine, but depended on it for cheap coal, were badly hit and frantic efforts were made to find supplies to fill the gap. The main burden of these efforts fell on Sr. Luis Edmondo Ortiz, the director of Hullera Colombiana, an organisation which has been set up in 1976, after a previous miners' strike, to organise the orderly marketing of Medellin coal. The miners were induced to resume work by an increase in wages and the extension of social benefits to all miners and promises that improved ventilation, better lighting and gas alarm systems would, as a matter of urgency, be installed in all company mines. The price of coal at Primavera increased to $10.86/tonne or $13/tonne delivered to Medellin. This was, however, preferable to coal imported from other parts of Colombia. Hullera Colombiana were offered supplies from Cundinamarca at $8.42-9.24/tonne FOB Zipiquiri, but to this had to be added transport costs amounting to $15.6/tonne. Supplies were also available from Boyaca, but again, the high transport costs increasedthe price at Medellin to $26-27/tonne.

The temporary switch to fuel oil, which some of the textile firms opted for, involved even greater costs. Fuel oil delivered to Medellin costs 21 cents/US gallon, equivalent to coal at $60/tonne on an equal calorific value basis.

In addition to negotiating emergency supplies of coal from other Colombian coalfiels, Sr. Ortiz identified a number of locations where emergency supplies could possibly be obtained on a short term basis. He also visited most of the proprietors of the marginal mines. He found that the price they were receiving from the contractors was only around $6.25 per tonne. By promising them $8.15/tonne, he induced a number of them to promise to raise their output and to deal directly with Hullera Colombiana. By this means, he believed that output from the small outcrop mines could be increased from 100 000 tonnes/year to 200 000 tonnes/year.

The other effect of the El Silencio-Villadiana disaster was to cause the owners of the larger room-and-pillar mines, specifically San Fernando and Excarbon, to consider changing to longwall operation. All the Medellin mine owners are reconciled to the facts that they will have to pay their underground labour force much higher rates and that they will have to spend money on improved ventilation, lighting and safety precautions. There is therefore some incentive, particularly as it is now clear that the price of coal in Antioquia in the future will be considerably higher than in the past, to move to more productive forms of coal getting. Sr. Betancur, the owner of Carbones San Fernando, had had quotations for the equipment he would require to convert this mine to longwall mining and believed that, by using some of the existing equipment in the present room-and-pillar mine, this conversion could be accomplished for an expenditure of around $1.5 million. This change could increase the output from San Fernando from around 6500 tonnes/month to 10 000 tonnes/month. A similar change is contemplated by Sr. Abelardo Moreno, the proprietor of Excarbon, and would boost the output from this Titiribi mine from around 2000 tonnes/month to 5000 tonnes/month.

The future price of Antioquian coal from existing mines can only be guessed at. The members of the ANDI Committee responsible for the Antioquian coal industry were of the view that wages of the miners would have to be increased to $6.52 per shift (this includes the cost of social benefits). In the case of Industrial Hullera, this would increase costs by around $3-4/tonne bringing the mine-mouth price to around $11-12/tonne. If to this is added the capital recovery charges on the $500 000 which, it is estimated will be required to replace damaged equipment and bring the mine to the required safety standard, and the repayment over, say, 20 years of the $274 000 paid out in compensation to dependents of miners who were killed, then the minehead price of coal could be expected to settle out at around $13/tonne or $15/tonne delivered to Medellin.

The El Silencio-Villadiana mine has resumed limited production. The output at the beginning of March 1978 was at a rate of 13 750 tonnes/month, equivalent to 165 000 tonnes/year. It is hoped that full mine production will be achieved by mid-1978.

5. THE POTENTIAL DEVELOPMENT OF THE MEDELLIN COALFIELD

5.1 Constraints on Increasing Production

The following constraints exist in the Medellin coalfield which may hamper any major production increase.

5.1.1 Sales Price of Coal

Hitherto the sales price of the coal at Medellin has been kept artificially low. Industrial Hullera produces about 35% of the coalfield's output and is owned jointly by the major coal consumers in Medellin who buy it at production cost,allowing no profit margin to the company. This price, in effect, has fixed the general price and the smaller producers can only make a profit to the extent that their production costs are less than thoae of Industrial Hullera. This profit, after allowing for transport costs and the margin paid to intermediaries, has been inadequate and has served as a disincentive for the necessary capital expenditure required to improve conditions in, and output from the mines. This position, it is only fair to report, is now becoming appreciated by the Medellin coal users.

The cost of coal is only a small proportion of the total costs of Medellin industry and to date has not attracted the attention of industrial management. Consumers have come to rely on the low price of coal and are largely unaware that the quantity of reserves which can be exploited at such low pricea is finite. Although the small mines will continued to produce some 400 000 tpa at the present price level for some time to come, there is evidence that the reserves of shallow depth coal are becoming exhausted in the Angelopolis-Amaga area. The small producers' costs will rise steadily as an increasing amount of coal will have to come from the mines further afield in Titiribi and Rincon Santo. This will reduce the profit margin available to the mining entrepreneurs, thus restricting supplies from the small mines, unless the price of coal in Medellin is allowed to rise.

The demand for coal in the region has been flat for several years. Annual consumption by Medellin industry is estimated to be betwsen 400 000 and 500 000 tonnes with a further 100 000 to 200 000 tonnes shipped to Cali in the department of Valle.

The mid 1977 price of -8 cm coal in Medellin was \$9.50 to \$10.00/tonne and is said to have increased at the rate of 5% per annum in the years prior to the El Silencio mine disaster. The +8 cm coal commanded a premium of \$1.35 to \$4.10/tonne but comprises little more than 15% of the total production of the coalfield. Price increases did not keep up with inflation, which has varied from 20% to 40% pa in recent years. The position, however, is now changing, following the mine disaster, and some of the Medellin coal users are becoming aware of the problems caused by too low a coal price. The likely price following the mine disaster is discussed in Section 4.14. A probable coal price delivered to Medellin was predicted at around \$14-\$15/tonne.

The maximum price to which Medellin coal could rise is constrained by the cost of coal either imported from the USA or brought in from other Colombian coalfields in Cali and Boyaca. Estimates of the cost of imported coal landed in Medellin are given below in Table 5.1.

Table 5.1 - Estimated Cost of Imported Coal in Medellin

	\$/tonne
USA Coal	
FOB Atlantic port	50
Sea freight	6
Inland freight - barge	15
Inland freight - rail	7
TOTAL	78
Cali Coal	
FOB mine	12
Inland freight - truck	22
TOTAL	34

Table 5.1 continued

	$/tonne
Santander Coal	
FOB mine	12
Inland freight - truck	7
Inland freight - rail	9
TOTAL	28

The cheapest imported source of coal is that from Santander, costing $28/tonne. However, it is doubtful if the mines in Santander could supply any major quantity of coal, as the mines in this department are in much the same condition as those in the Medellin coalfield. It is more likely that any significant imports of coal would come from Cali, which has better developed mines, and that this coal would sell at $34/tonne in Medellin.

However, it is unlikely that the price of coal in Medellin will reach the price of coal brought in from Cali or Santander. Provided the price rises to in excess of $15 to $25/tonne, it should be possible to raise sufficient capital to re-equip the existing larger mines in order to satisfy any increased demand.

5.1.2 Title

Many of the smaller mines do not have a proper title from the government to work coal. This leads to disputes over ownership and sub-surface coal rights. There exists a deep suspicion on the part of the marginal miners regarding any intervention by government in the coalfield. The exact position, production and reserves of many mines remain uncertain as no formal surveys or statistics are maintained by the Ministry of Mines. Intervention or aid offered by government agencies is suspected of being a precursor to increased taxation.

5.1.3 Mine Design

Production is from numerous small mines (74 in 1976) with no coordinated development of the field. Little or no forward planning is evident and any future plans appear likely to be pursued by individual owners. Seams are developed from the surface downwards on a day-to-day basis until production becomes uneconomic because of rising costs or some mining difficulty. The exploitation of the coalfield by such small mines, using primitive mining methods, has led to the inefficient exploitation of the available reserves. Many blocks of coal are isolated from further extraction, being left between the small mines and as roadway pillars between the numerous adit and drift entrances in the area. Several large fires in Seam No.1 in the Angelopolis-Amaga area have been left uncontrolled, which has further reduced the amount of exploitable reserves. Flooding has probably alao been a factor in the premature abandoning of workings in some areas of the smaller mines.

5.1.4 Technology and Management

The primitive mining methode have led to low productivity and high accident rates. The smaller mines can rarely work to much more than 100 m below the surface before the workings become uneconomic and are abandoned. The larger mines, such as Industrial Hullera and San Fernando, are presently working at some 200 m depth, but extraction is becoming more difficult and dangerous as they encounter increased lithostatic pressures and methane, which they are unable to combat by the existing mining practice and layout.

Technical management is minimal. Many of the smaller mines are owner operated using contract miners. They are paid on a production basis and little regard is paid to either safety or the proper layout of the mines. Even when the mine is company owned, the senior management is located in Medellin, more than one hour's journey away from the coalfield. The absence of management living close to the mines has contributed to the generally poor housekeeping at the mines, lack of safety measures, inadequate supervision and poor rescue capabilities.

The poor state of the mines and the low level of technology is not attractive to new engineering graduates. This has been partially responsible for a shortage of trained mining staff in the industry.

5.1.5 **Labour**

The low level of wages paid to miners and the dangerous working conditions underground have caused a general labour drift away from the coal mines and into Medellin. The daily take home pay for a miner has been only marginally higher than that which can be earned in Medellin and is insufficient to prevent labour drift. Until recently, few of the mines were unionised, in strong contrast to the unionactivity in the Medellin industry. Most of the miners did not have the advantages of the social benefits and extra payments which unions have negotiated for their members in other industries and which compensate, in part, for the relatively low daily wages of workers.

The El Silencio-Villadiana disaster has given wide publicity to these circumstances and appears likely to result, not only in the organisation of the miners into a union, but also to higher wages and better conditions and it is probable that this constraint will be of less moment in the future.

5.1.6 **Exploration**

No drilling of the local reserves has been carried out in the Antioquian coalfield. Mines are developed from the surface outcrops with little knowledge of the geological conditions they are likely to encounter. Lack of knowledge of the exploitable reserves is, in part, responsible for the proliferation of small mines as the owners are unable to offer sufficient security to raise the large sums of money required for the proper and orderly development of the coalfield.

5.1.7 Infrastructure

The mountain roads serving the smaller mines have a hard core surface, are narrow and made dangerous by numerous tight bends. Accidents and breakdowns involving the coal trucks are frequent. The main tarmac road over the mountain divide from the coalfield to Medellin is being destroyed by the high axle loading of the coal trucks. Unfortunately, the railway, which would be an alternative method of transport between Angelopolis-Amaga and Medellin, has been abandoned.

The eastern limb of the coalfield is served by 13.2 kV electric lines and is used by the mines in the area. However, last year production had to be curtailed on account of power shortages resulting from a drought which restricted the output from the hydro-electric stations.

5.1.8 Government Policy

Development of the Antioquian reserves has not, in the past, and apparently will not, in the future, enjoy a high priority in the overall development of Colombia's resources. Although the government, through Colcarbon, is actively seeking foreign partners to exploit the country's coal resources, the Medellin coalfields are unattractive to foreign mining interests compared with the El Cerrejon, La Jagua and Cundinamarca-Boyaca fields. This has restricted the transfer of modern mining technology and management expertise and has resulted in the under-utilisation of the coal resources. Coal mining companies have been further dissuaded from using foreign consultants, who could bring about the transfer of technology, by a 30% tax on any work carried out.

5.1.9 Investment Funds

Interest rates are high in Colombia and the Medellin consumers policy of cheap coal and low mining profits does not favour investment in the coal industry. The profits taken from mining, reflected in the profits of the Medellin manufacturing industry, are not invested in mining but in more attractive and less risky ventures such as in building and in secondary and service industries. The under-capitalisation of the coal mining industry has led to its run-down appearance, which contrasts markedly with the modern industrial practices found in Medellin.

5.2 Possibilities for Expanding Output from Existing Mines

It is in the light of the above constraints that the potential future output of the existing mines must be considered.

5.2.1 Present Plans for Existing Mines

At the beginning of March 1978, output from the El Silencio-Villediane mine, reduced after the explosion, had reached a rate equivalent to 165 000 tpa and the management believe that by mid-1978, the mine could be fully operational again with an output increased from 200 000 tonnes/year before the explosion to 255 000 tonnes/year. Investment in additional ventilation, improved lighting and a visual/audible alarm system and other development costs which have been sanctioned are reported to have totalled $500 000. At this output, the likely mine life based on proven and probable reserves is of the order of 15 years.

Sr. Betancur, the owner of Carbones San Fernando, plans to abandon the present room-and-pillar operation and establish a double longwall face mine adjacent the present workings at the northern end of his property. He estimates the necessary investment at around $1.2 million. The drift to this new mine is reported as two-thirds complete. He believed that the necessary finance would be forthcoming and expects thus, to raise the output of the mine from the present 78 000 tonnes/year to some 150 000 tonnes/year.

A longer term project which is being considered for San Fernando is the development of a new longwall face mine at the southern end of Haciendo San Fernando. This could have an output of

100 000 tonnes/year. An order of magnitude capital cost for such a mine was worked out by Sr. Betancur at some $3 million.

Sr. Abalardo Moreno, the owner of the Excarbon mine at Titiribi, also has plans to abandon room-and-pillar mining in favour of longwall operation with the establishment of two faces giving an output of 150 000 tonnes/year. He estimates the capital expenditure at around $1.5 million.

5.2.2 Possible New Longwall Faces

A maximum of some eight new longwall faces, each producing 100 000 tpa could conceivably be installed in the Industrial Hullera, San Fernando and Nechi mines, as shown in Table 5.2.

Table 5.2 - Maximum Possible Conversion to Longwall Operation

Mina	Seam	Reserves (10^6 tonnes)	New Faces	Life (years)*
Industrial Hullera	3	2.1	2	7.5
San Fernando	2	+2.0	2	+6.5
San Fernando	3	+2.(	2	+6.5
Nechi	1	+1.0	1	+6.5
Nechi	2	+1.0	1	+6.5

* Life calculated by using a 65% extraction rate and a production rate of 100 000 tpa for each longwall face.

Installation of all these faces would give an annual production of some 800 000 tonnes for an estimated period of 6.5 to 7.5 years. Installation of half the number would result in an annual production of 400 000 tonnes for some 15 years - the minimum viable mine life that would be expected.

5.2.3 Small Mines

A subjective analysis of the elasticity of supply from the small mines, excluding Industrial Hullera, was carried out before production was affected by the explosion at the El Silencio-Villadiana mine. Four senior mining engineers conversant with the conditions in the Medellin coalfield were asked to estimate the possible increase from existing mines using existing technology, which would result from raising the Medellin coal price by varying amounts. Table 5.3 and Figure 6 summarise the results of the survey.

Table 5.3 - Relation between Production and Price of Coal from Medellin Mines excluding Industrial Hullera and San Fernando

Change in Price		Change in Production		
%	$/tonne	%	Total 10^3 tonnes	Incremental 10^3 tonnes
+50	14.27	+70	578	+238
+20	11.41	+54	524	+184
+10	10.46	+23	418	+ 78
0	9.51	0	340	0
-10	8.56	-16	286	- 54
-20	7.61	-24	258	- 82
-50	4.76	-83	58	-282

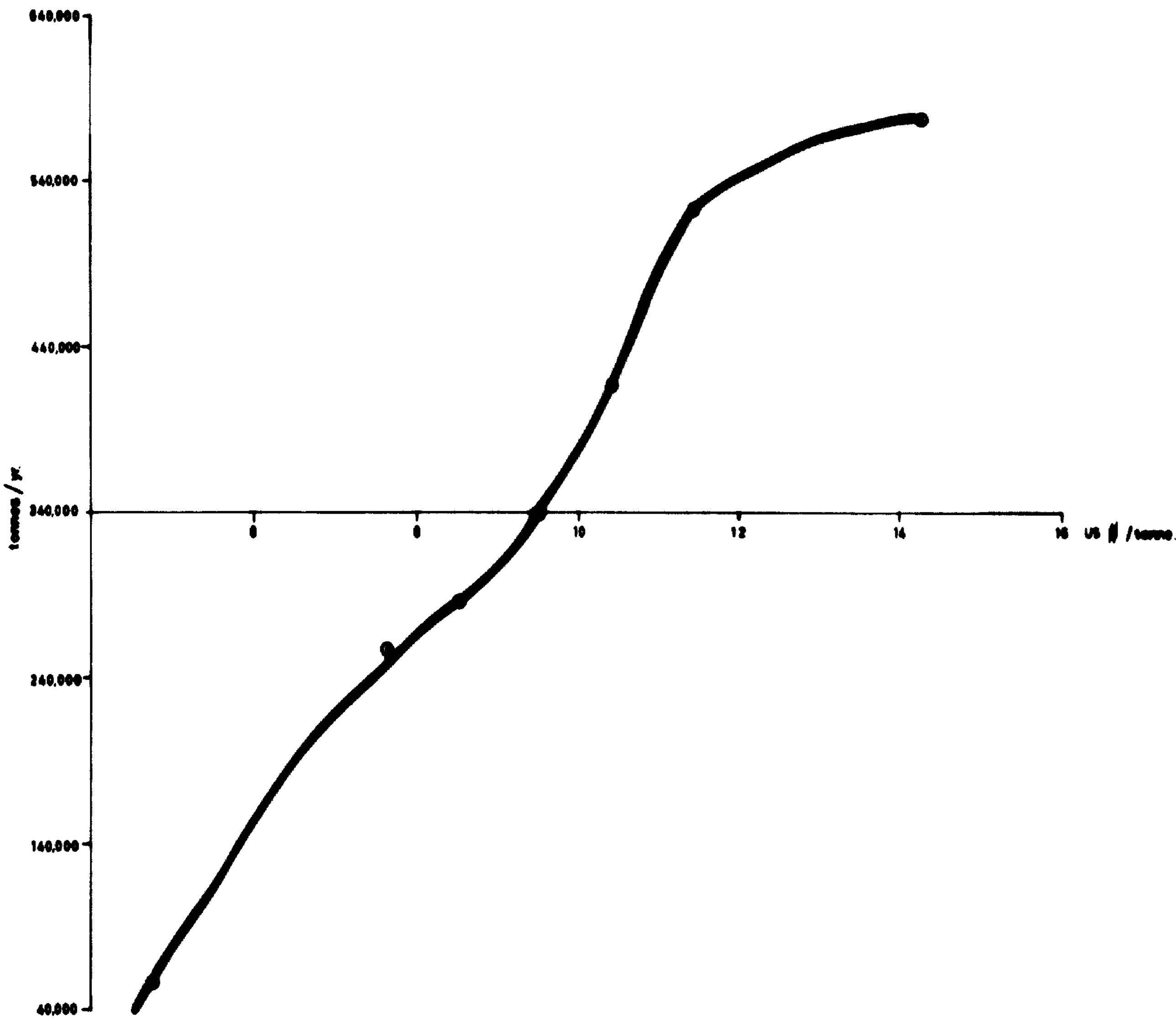
The results of the survey show that, provided the markets exist, a sharp increase in production could be expected from the small mines with price increases of up to 50%. However, further price increases would have little effect on production as the existing mines will be constrained by such factors as shorages of labour and workable reserves. Further expansion of production beyond the increase of 238 000 tonnes resulting from a 50% increase in price could only come from new modern mines exploiting the deeper reserves or from the installation of new longwall faces in the larger mines such es in Seam 3 at Industrial Hullera and in Seams 1, 2 and 3 in San Fernando and Nechi.

Figure 6.

ESTIMATED SUPPLY - PRICE RELATIONSHIP

FOR SMALL MINES OF THE MEDELLIN COALFIELD

(excluding the El Silencio - Villadiana Mine)



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S.R.R.	April '78	SD 5527

Thus for a coal price at Medellin of around $15/tonne, the small mines could, it is believed, increase output to around 500 000 tonnes per year.

5.2.4 Possible Future Output from Existing Mines

Summarising, the possible short term future production from the existing mines in the Medellin coalfield, when the price of coal at Medellin reaches $15/tonne could be as indicated in Table 5.4 below.

Table 5.4 - Possible Future Output from Existing Mines in the Medellin Coalfield

Mine	tonnes/year
Industrial Hullera	255 000
San Fernando (existing mine converted to longwall)	150 000
Others	550 000
TOTAL	955 000

In the longer term some further 400 000 tonnes/year output could possibly be produced from longwall operation in the Excarbon mine and increased capacity longwall operation in the San Fernando and Nechi mines. Capital for these various projects is, however, only likely to be forthcoming if the demand for coal in Antioquia and the coal prices increase to amounts sufficient to justify the investments.

5.3 Areas for Potential New Mines

5.3.1 Titiribi-Venecia Area (Western Limb)

The western limb of the coalfield is some 25 km long and averages some 2 km to 3 km wide. It stretches from Titiribi in the north to Venecia in the south and continues south east to Fredonia to join the eastern limb.

The geology of this part of the coalfield is dominated by the presence of numerous platons and sills of igneous rocks, aligned parallel to the regional trend. These have disrupted the continuity of the seams and caused local steepening of the dip, especially in the northern half of the area. Coal seams in the southern half of the limb are thinner and less numerous and appear to have been affected by major faulting.

The western limb accounts for some 10% of the production from the coalfield (60 000 tpa). The mining in the area is dominated by Excarbon's mine at Titiribi, which produces some 1500 tonnes per month from the northern part of the area. The principal disadvantage of this part of the coalfield is its distance from Medellin. Coal has to be trucked 52 km on poor roads across two mountain divides to the market. This results in above average transport costs, thus reducing the profit margin available to the mine owners. However, mining in the area is made attractive by the presence of over 15 m of coal, as seen in the Excarbon mine.

The potential exists for further mines in the northernmost part of the area, north of the Excarbon mine. Based on the northward extension of the coal section at Excarbon, there exists the potential for 20 million to 40 million tonnes of in-situ coal reserves in a 2.3 km^2 area.

The southern part of the western limb offer less potential on account of the apparent thinning and disappearance of the seams and the effects of faulting.

5.3.2 Angelopolis-Amaga-Fredonia Area

The eastern limb of the coalfield is some 10 km long and averages between 1 and 2 km wide. It stretches from Angelopolis in the north to Fredonia in the south, where it is joined by the western limb.

Current mine workings are located at the head of the basin in the Angelopolis-Amaga area and along its flanks southwards towards Fredonia. The majority of small mines are located in the Angelopolis-Amaga area, where three workable seams (Seams 1, 2 and 3) outcrop. This area accounts for some 90% of the coalfield's production (540 000 tpa). The mining in the area is dominated by Industrial Hullera's mine at El Silencio-Villadiana and that of Carbones de San Fernando, which both work deeper coal at the head of the coal basin.

Little or no potential exists to develop a modern mine north of Amaga unless new unexploited seams are found beneath Seam 3. The seams in the Angelopolis-Amaga region are shallow and have been intensively exploited by numerous small mines. It is estimated that the remaining reserves are unexploitable by all but the smallest of mines as the coal occurs either in small isolated blocks or in areas isolated by fires burning in Seam 1.

There does, however, exist the potential to develop a series of new mines in the deeper sections of the basin south of the existing workings of Industrial Hullera and Carbones San Fernando. This area is some 11 km long and covers an area of 16.6 km^2. Apart from the Nechi mine operated by Geominas Ltda, lying on the east side of the area and covering some 0.5 km^2 to 1 km^2, the coal reserves are unworked. Its geological reserves have been estimated at around 110 million tonnes.

5.4 Possible Coal Supplies for a Coal Chemical Plant

The objective of the present study is to assess the possibility of expanding the coal production in the province of Antioquia and producing saleable coal chemicals. A commercially viable coal chemical plant will require a coal input of at least 0.5 to 1 million tonnes/year over a period of at least 15-20 years.

The possible expansions to the existing mines, described in Section 5.2, would produce at the most a total capacity increase of some 800 000 tonnes/year. The use of coal from these expanded mines as feadstocks to a coal chemical plant is not considerad a viable option for a number of reasons:

- The coalfield would not have any reserve capacity against any future increase in local demand.
- The finite reserves of the existing mines would in the long term have repercussions on the coalfield's capacity to meet local demand.
- During the expansion phase there could be disruptions to existing working which in turn could interfere with the supply of coal to existing customers.
- The coal chemical plant would not have the certainty of a stable coal input, as the coal would come from a number of mines, many of them using primitive mining and management methods.
- The chemical plant would ba subject to any fluctuations in the coal supply-demand conditions existing in the rest of the Medallin coalfield.

The development of one or more mines specifically for the purpose of supplying coal for chemical production is therefore favoured. The new mines, which could operata as captive mines for the chemical plant, could then be designed and operatsd specifically to the chemical plant's requirements. Their production could ba controlled and expanded according to the demands of the chsmical plant which would then be unaffactad by the local supply-demand conditions regarding coal.

Of course, if for any raason the chemical plant dsvelopment was not to take place, the new mines could still be built at the appropriate times to supplement tha coalfield's output in meating other local demands for coal.

Two areas in tha Medellin coalfiald have been selectad as potantial sitas for new mines, capable of supplying coal to a coal chemical plant, as dascribed in Section 5.3. The first of these is the 2.3 km^2 area north of the Excarbon mine at Titiribi in the westarn limb of the coalfield, which could contain 20 to 40 million tonnes of geological reservas. The other is a 16.6 km^2 area in the eastarn limb of tha coalfiald immediately south of Amaga, which could contain some 110 million tonnes of geological raserves.

The Amaga-Fredonia area is preferred to the Titiribi-Venecia area for a number of reasons:

- It is closer to the narrow gauge railway joining Bolombolo to Medellin, and the access is easier.
- Electric power (13.2 kV line) is on site.
- It is closer to Angelopolis and Amaga which are the main sources of skilled mining labour.
- The geological conditions are better known.
- The economic possibilities of longwall mining have been proved in two of the three seams known to occur in the area.
- The potential coal reserves are larger and give more opportunity of expanding production as required.

The Amaga-Fredonia area has therefore been selected as the most favourable area for the installation of a new mine.

5.5 Reserves of the New Amaga-Fredonia Mining Area

5.5.1 Geological Reserves

Cross-sections have been drawn for the area at 1 km spacing from x = 1 160 000 m to x = 1 151 000 m, at a scale of 1:25 000 (see Figures 7, 8 and 9). The sub-surface geology has been interpreted from the dip and outcrop information taken from Dr. Grosse's 1:50 000 scale map of the area. The coal measures form a syncline extending the length of the basin with a smaller anticline appearing on the eastern margin in the vicinity of Nechi mine. The coal seams are represented by a line which has been arbitrarily located in the centre of the middle coal measure bed.

The basin is confined between two horsts of crystalline basement and the contacts are faulted. Field evidence suggests that the contact may be marked by a series of faults with imbricate structure, but for purposes of reserve calculations only one major boundary fault is shown.

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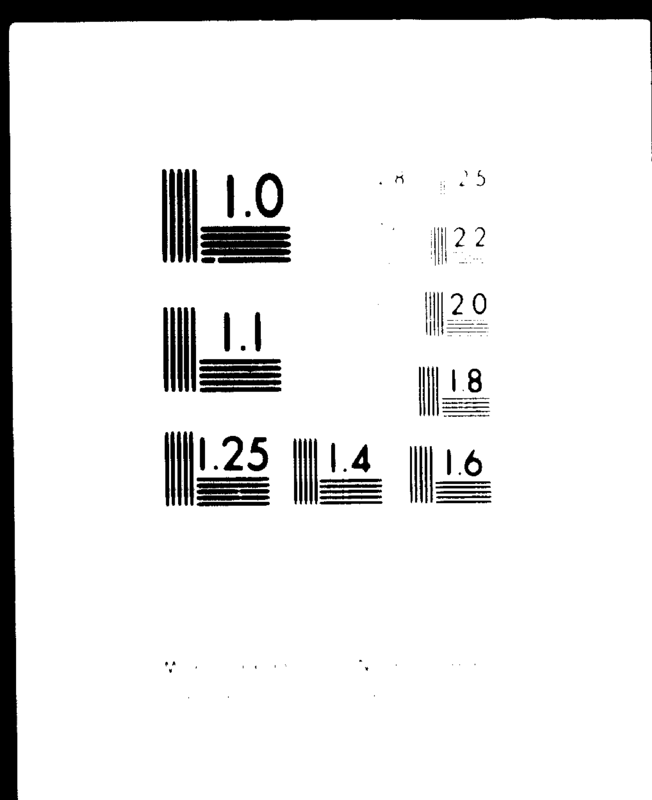

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5

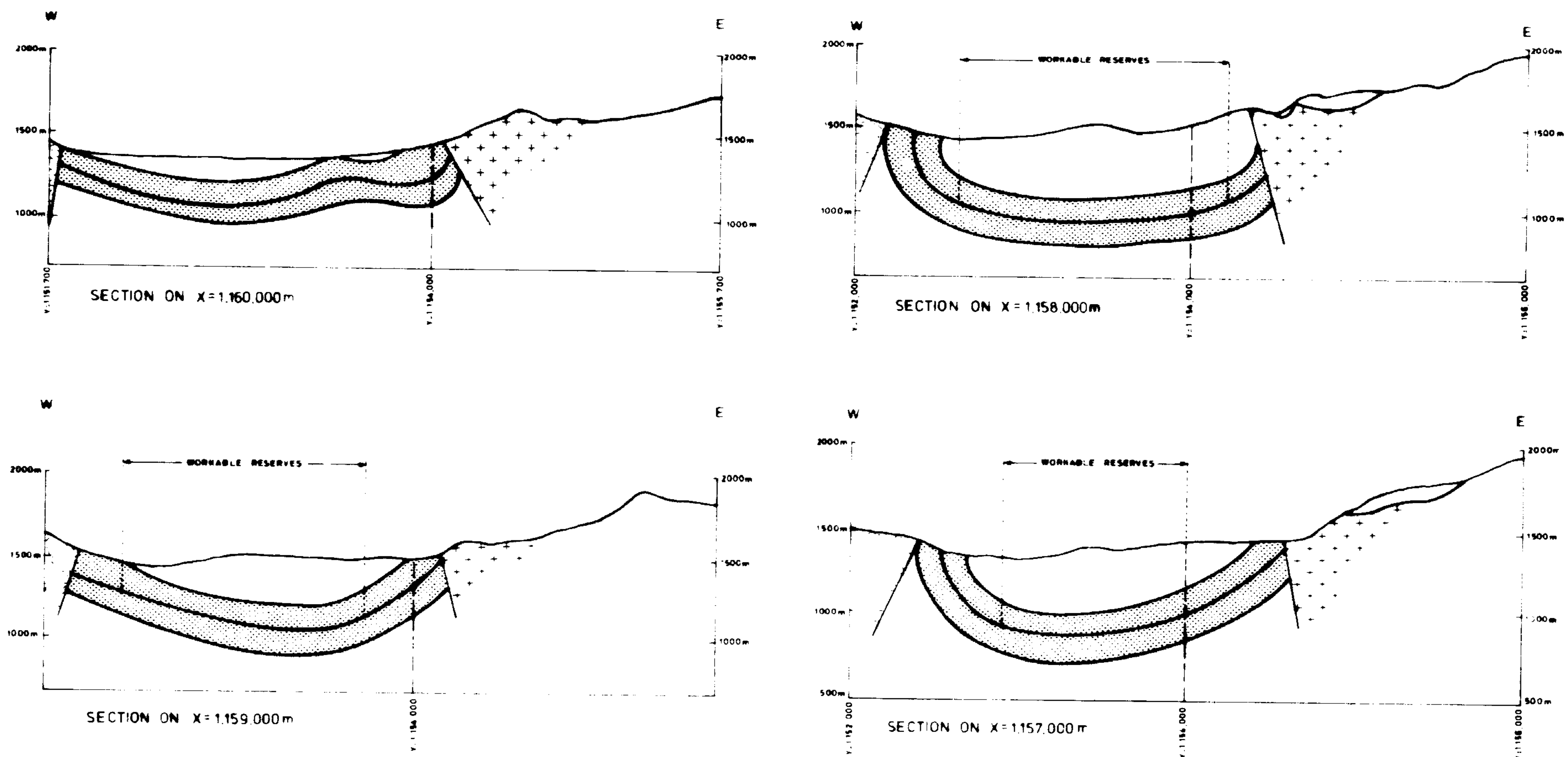
Figure 7

GEOLOGICAL CROSS SECTIONS

AMAGÁ - FREDONIA AREA

SHEET 1

Scale : 1 2500



NOTE No vertical exaggeration - Looking north - For legend see plate 7

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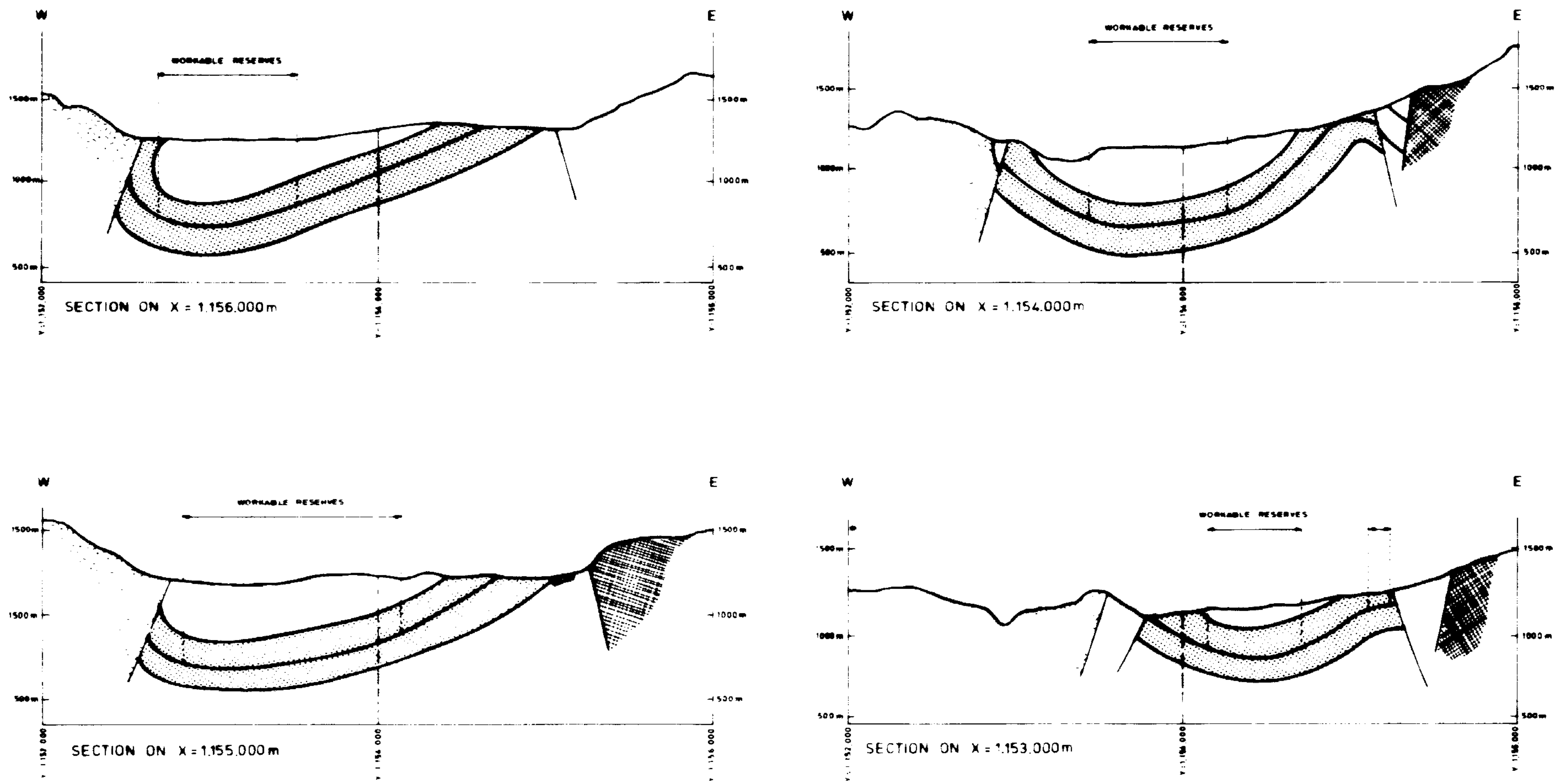
Figure 8

GEOLOGICAL CROSS - SECTIONS

AMAGÁ - FREDONIA AREA

SHEET 2

Scale : 1 2500



NOTE No vertical exaggeration – Looking north – For legend see plate 7

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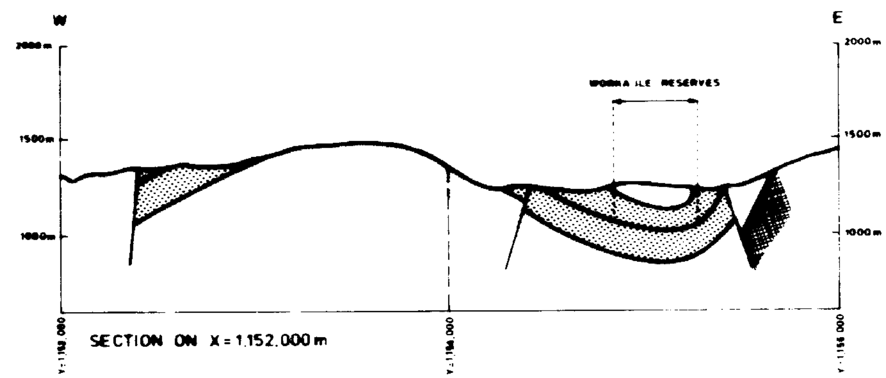
Figure 9

GEOLOGICAL CROSS – SECTIONS

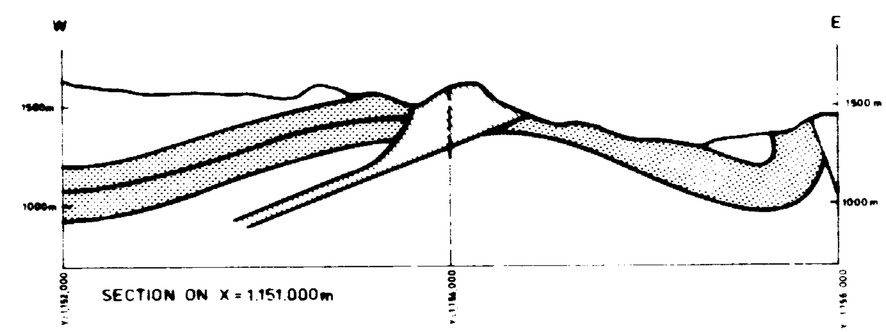
AMAGÁ – FREDONIA AR...

SHEET 3

Scale : 1 2500

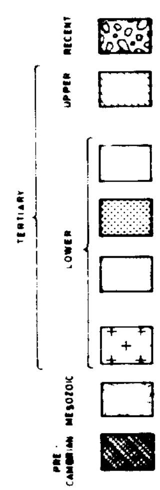


SECTION ON X = 1.152.000 m

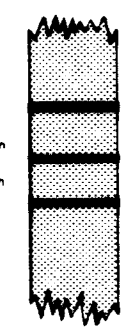


SECTION ON X = 1.151.000 m

GEOLOGY LEGEND FOR CROSS SECTIONS



- TERTIARY
  - RECENT: Alluvium
  - UPPER: Andesite
  - COAL MEASURES (LOWER)
    - Upp. formation — SANDSTONES & MUDSTONES WITH MINOR CONGLOMERATES & COAL SEAMS
    - Middle formation — CLAYSTONES & SANDSTONES WITH MINOR CONGLOMERATES & COAL SEAMS
    - Lower formation — CONGLOMERATES SANDSTONES & MUDSTONES WITH MINOR CONGLOMERATES
  - Granite
- MESOZOIC: Diorite
- PRE-CAMBRIAN: Slates with minor phylites and quartzites



Middle coal formation
Lower tertiary
Approx thickness 300m

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NOTE No vertical exaggeration - Looking north

The following thicknesses have been used for reserve calculation based on measurements taken from outcrops and mine workings around the periphery of the basin (see Table 5.5).

Table 5.5 - Thicknesses Used for Reserve Calculation

Layer	Thickness
	m
Seam 1	1.6
Interburden	14.0
Seam 2	1.3
Interburden	19.0
Seam 3	1.5

The volume of geological reserves for each of the three seams has been calculated for each 1 km block between sections by multiplying the average area of coal on the two sections by 1000 m (see Appendix 4, Table A4.1). A specific gravity of 1.4 has been used to obtain the tonnage.

The geological reserves total 110.7 million tonnes, which are located in three seams as shown in Table 5.6.

Table 5.6 - Location of Geological Reserves

Seam	Geological Reserves 10^6 tonnes	%
1	39.9	36
2	33.2	30
3	37.6	34
TOTAL	110.7	100

5.5.2 Exploitable Reserves

The geological reserves have been reduced by the following factors to obtain the tonnage of exploitable reserves:

- 15% reduction of area in order to protect Amaga and the mines of Carbones de San Fernando and Nechi.
- 20% reduction of remaining area on account of the steep dip and faulted nature of the seams at the basin edges.
- 10% reduction of the remaining reserves on account of geological disturbances.

The following factors have been used to determine the exploitable reserves:

- 65% recovery factor for Seam 1 to account for underground roadway and panel pillars and the railway which crosses the coalfield.
- 62% recovery factor for Seam 2 to account for underground roadway and panel pillars and the railway.
- 60% recovery factor for Seam 3 to account for underground roadway and panel pillars and the railway.

The exploitable reserves amount to 42.4 million tonnes, which are located in the three seams in the proportions shown in Table 5.7.

Table 5.7 - Location of Exploitable Reserves

Seam	Exploitable Reserves 10^6 tonnes	%
1	15.9	37
2	12.6	30
3	13.9	33
TOTAL	42.4	100

5.6 Design of New Mines

5.6.1 General

The proposal method of exploiting these reserves has been selected on the following criteria:

- The method used should be compatible with the level of technology attained in current practice (i.e. semi-mechanised longwall faces).
- It should employ the minimum amount of mechanisation compatible with the required continuity of production and magnitude of output to minimise capital costs.
- It should be labour intensive rather than capital intensive to provide employment in the area.
- Access to the mines should be as close to the railway and existing power lines as possible to minimise surface installation costs.

Because of the elongated distribution of the reserves, it is proposed to divide the area into three units, each capable of supporting a drift mine using longwall method of working with an output in excess of 500 000 tpa. A conceptual design and layout of the proposed new mines is shown in Figure 10. Room-and-pillar mining is not recommended since continuous operation would be required to achieve the output envisaged. The operation and maintenance of continous miners are not considered feasible at this stage of the coalfields development because of the low level of technology currently available.

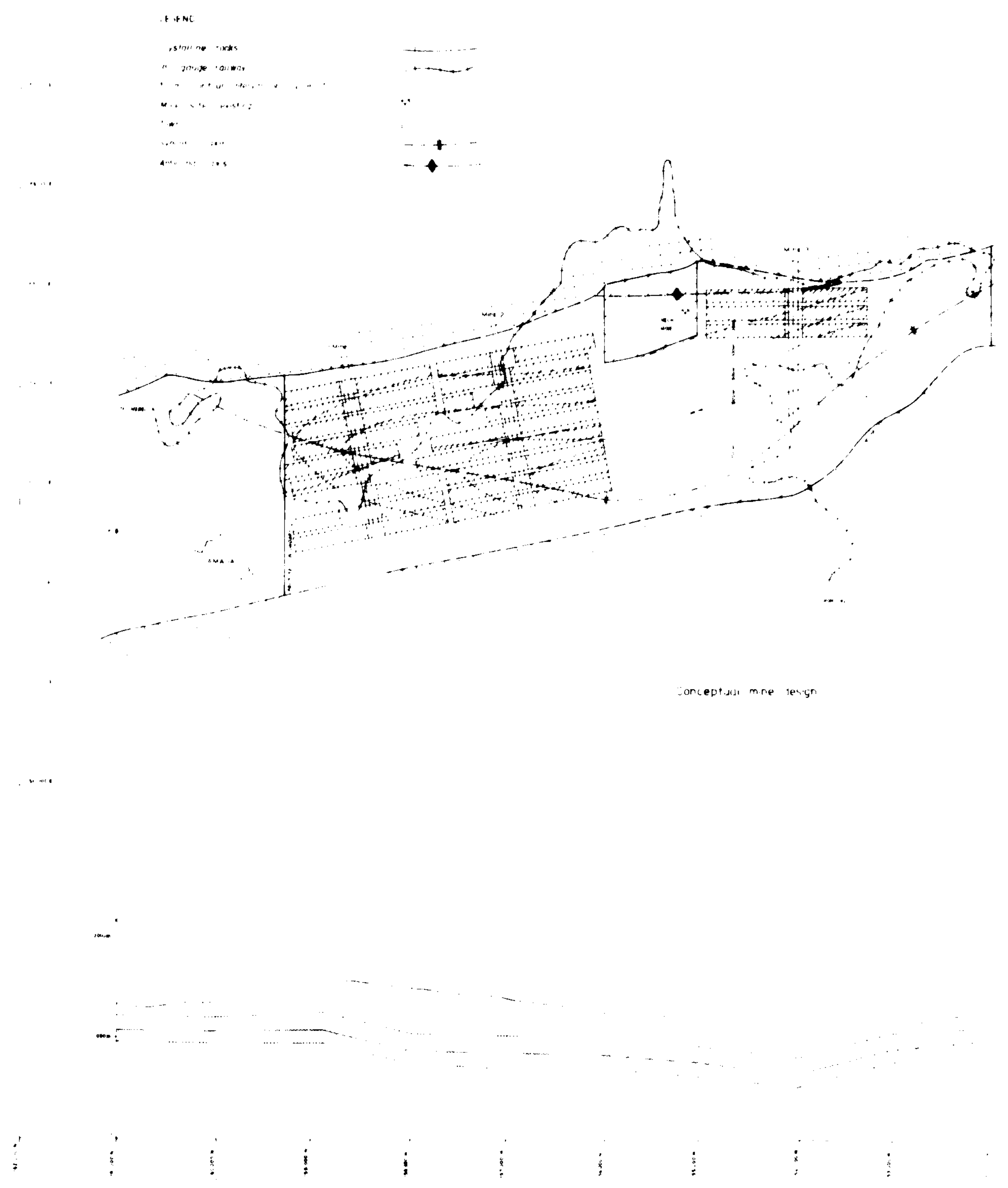
It must be noted that the conceptual design of the mine outlined here and the resulting costings are based on the very limited field data available at this time. They will be contigent on the results of the exploration and drilling programme which will be carried out in the feasibility study stage.

It is proposed that the three mines should be developed in sequence, or, depending on the requirements for the proposed coal chemical plants, the smaller mines in the northern and central areas established before the larger mine to the south. The obvious area for initial development is the northern part since it is nearest to the existing San Fernando and Nechi workings and the geology and working conditions in the seams are well known. The coal quality is also likely to be better than to the south where there is evidence of clay partings in one or more of the seam. This area, in fact, borders the area in which Carbones

Figure 10

AMAGÁ - FREDONIA AREA

CONCEPTUAL MINE DESIGN AND LONGITUDINAL PROFILE

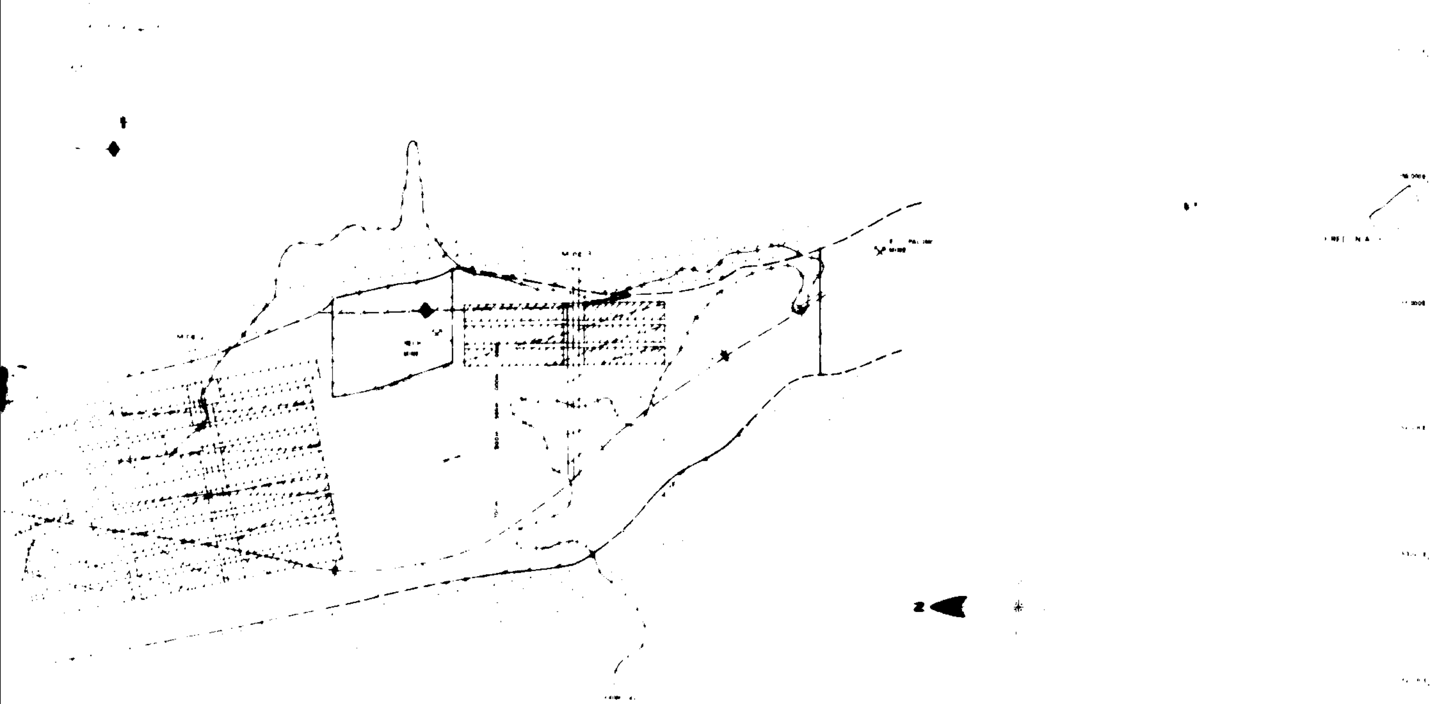


Longitudinal profile through X-X' showing the middle formation coal bearing str...

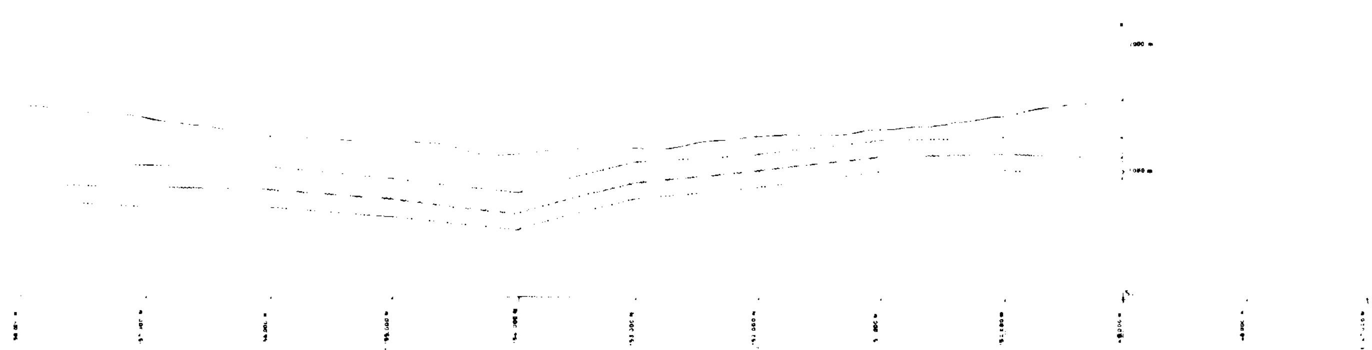
SECTION 1

AMAGÁ - FREDONIA AREA

CONCEPTUAL MINE DESIGN AND LONGITUDINAL PROFILE



Conceptual mine design



Longitudinal profile through X-X' showing the middle formation coal-bearing strata

SECTION 2

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San Fernando has plans to establish a new longwall face mine. Development in sequence would have the advantage that a greater degree of mechanisation could be employed in the later mines as the mining personnel gather more experience and expertise. The precise phasing of the production from the new mines will depend on the requirements of the chemical plant and possibly the market for coal in the Medellin area.

The range of depths of the workings is estimated to be between 100 m and 580 m. The recoverable reserves of the three proposed developments and the annual outputs envisaged are as shown in Table 5.8.

Table 5.8 - Estimate of Recoverable Reserves

	10^6 tonnes			
	Mine 1 (North)	Mine 2 (Central)	Mine 3 (South)	Total
Seam 1	3.7	4.1	8.8	15.9
Seam 2	2.9	3.3	6.4	12.6
Seam 3	3.2	3.6	7.1	12.9
TOTAL	9.8	11.0	21.6	42.4
Output (tonnes/year)	5×10^5	5×10^5	1×10^6	2×10^6
Mine Life (years)	20	22	22	21

Mines 1 and 2 will each have five equipped longwall faces of which one will be held in reserve. In each case initial production will be from Seam 1 which has sufficient exploitable reserves for 7-8 years.

Access to the seams will be by twin drifts driven on the dip of Seam 1, across the strike of the basin from the eastern margin of the basin. Longwall panels up to 800 m long will be driven along the strike on both sides of the drifts. The panels will be worked in advance and have face lengths of 150 m. The layout of the workings in Seam 1 for the northern and central mines is given on Figure 10. Seams 2 and 3 will be developed from inclines driven down from the workings in Seam 2. Panel layout in the lower seams will be similar to that in Seam 1. Their layout will be such that panels of the lower seams will lie within and parallel to the panel of the seam above in order to relieve the lithostatic stresses caused by the mining. Thus pillar size will increase and the face length decrease in each descending seam (see Figure 11). The seams will be worked in descending order from the surface and, after an area has been mined, more than one year will be allowed to lapse before any exploitation is commenced in panels immediately beneath it.

5.6.2 Access and Development

Access to the mines will be by twin drifts concrete lined for the first 30 m from the surface. One drift will act as the intake airway and will be equipped with the main haulage conveyor; the other, acting as the return airway, will be equipped with rails and hoists for the transport of men and materials. The drifts and development headings will be advanced by drilling and blasting using sheathed or equivalent sheathed explosives. Material will be loaded by electrically-operated shovel into mine tubs for haulage to the surface. All drifts and roadways will be lined with steel arches set on 1 m centres. These will be especially necessary in the drifts and longer panels to prevent closure of the roadways during mining.

5.6.3 Longwall Faces

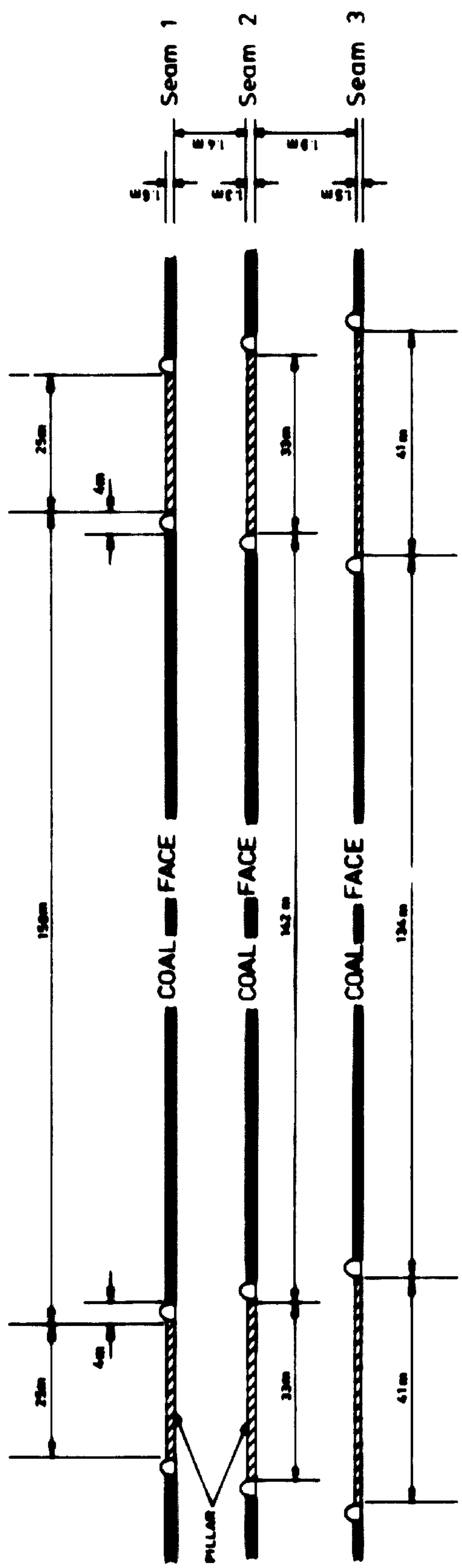
The semi-mechanised longwall faces will work on a 3 shift per day cycle. The face will be cut with a coal cutter and drilled with electrically operated drills. Only permitted (as approved for NSE and NCB mines, UK) explosives and permitted detonators will be used for blasting the coal on to an armoured face conveyor (AFC), extending the length of the face. The face will be cleared of broken coal manually.

The face will be supported by hydraulic props, suitable for a 1 m to 2 m seam and 1.25 m long link bars, set on 65 cm centres. Friction

Figure 11.

SECTION THROUGH PROPOSED MINE SHOWING COAL FACE AND PILLAR LAYOUT

Scale 1 1250



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chocks and timber props will be set alternately between every row of support at the waste edge ot aid caving.

5.6.4 Coal Transport

Coal from a longwall face will be transferred from the AFC at the gate-end to a stage loaded and thence by conveyors to the surface. Materials for the face will be transported by wagon using main and tail hoists along the in-bye roadway.

5.6.5 Ventilation and Lighting

A main fan will be located at the surface to provide mine ventilation. Headings will be ventilated by auxiliary fans. All electrical equipment will be flame-proofed for working gassy mines. Due attention will be paid to internationally accepted regulations regarding methane emissions and ventilation. All workings will be stone dusted for added protection against coal dust explosions.

The working faces and main drifts will be adequately lit and all underground personnel will be issued with standard miner's Ni-Cd battery lights. Personnel will also be equipped with suitable protective clothing, helmets, boots and respirstors.

5.6.6 Power

Power will be taken from the local Antioquia grid (13.2 kV). The total power consumption for Mines 1 and 2 will be some 7 million kWh per annum. The maximum power load will be 2.6 MVA.

5.6.7 Surface Stockpile and Treatment

Coal will be delivered either to a coal preparation plant,if so required,or to a surface bunker and stockpile,prior to its shipment to the coal chemical plant.

A coal preparation plant will not be required if the seams exploited in Mines 1 and 2 are similar in qualities to those currently worked in the northern part of the Amaga-Fredonia basin. However, seams further to the south, as seen in the Nechi and El Palomo mines, do contain clay partings which may require the coal from Mines 2 and 3 to be washed before use for some conversion purposes. The decision on whether a coal preparation plant is necessary and the type required will depend on the results of the drilling programme and should be the subject of any feasibility study which may follow the present study.

5.6.8 Surface Installations

Surface installations will include offices, workshop, stores, lamp room, baths, rescue station, dispensary, stone dust plant and explosives magazine.

5.6.9 Manpower

The total complement for mines 1 and 2 will be about 1160 men comprising some 1000 underground personnel working three 8 hour shifts and 160 day workers and staff.

5.6.10 Level of Technology

The level of technology to be employed in the first mining development is marginally more advanced than that used in the El Silencio-Villadiana mine belonging to Industrial Hullera. Friction props have been replaced with single hydraulic props, which are safer and cost marginally more at US$190 apiece. Friction chocks (US$600 each) will be used to promote caving and also make faces safer for working. A coal cutter will be used in conjunction with drilling and shotfiring to promote a cleaner cut and better roof condition, increase the size of coal broken and decrease explosives consumption. Rocker shovels will be used instead of manual loading for development ends.

This increased mechanisation is warranted to maintain a regular output from the faces and will improve safety and productivity. Maintenance of this machinery is considered to be well within the capability of existing maintenance staff in the Medellin coalfield.

A further improvement in working conditions and safety will also result from a double method of entry, as this provides the minimum number of drifts required to establish a workable ventilation system in the mine.

Every effort should be made to upgrade the level of mechanisation when further mines are brought into production. Experience has shown that productivity and safety increase as the degree of mechanisation advances.

5.6.11 Transportation of the Coal

Four altérnative methods of transport of the coal to the chemical plant can be considered. These are:

- Road
- Rail
- Slurry pipeline
- Aerial tramway

The appraisal of these methods will be a task for the mine feasibility study.

Because of the inadequacy of the existing roads in the Medellin mining area which already carry a heavy traffic of coal lorries, it is considered that major road improvements would be necessary if the coal were to be transported to the chemical plant by road. It is therefore believed, at this stage, that the existing railway, after its rehabilitation, could provide a more satisfactory method of transport for the coal. The other two transport methods, because of their complexity, have not been considered in this pre-feasibility study.

For the purpose of project evaluation, it is assumed that the railway will be rehabilitated and the coal will be transported from the mine to the chemical plant in 40 tonne capacity coal wagons using two unit-trains each carrying approximately 1700 tonnes per day.

6. MARKET REVIEW

6.1 Current and Future Pattern of Coal Utilisation in Colombia

The major coal consuming industries in Colombia are the cement, textile and iron and steel industries.

There are 17 companies producing cement, the demand for which has increased nearly threefold over the years 1956 to 1976; output in 1976 amounted to 3 662 000 tonnes. Demand undoubtedly will increase in the future with the increasing requirements for urban housing and the industrial development programme. The industry expects to be producing 9 million tonnes by 1985, by which time coal consumption will have risen from 754 000 tonnes per year to 2 million tpa. The increased coal consumption will not only be due to the increased cement production, but also to the replacement of the more expensive fuel oil at a number of plants by coal.

The three major textile manufacturers in Colombia are Coltejar, Fabricato and Tejicondor, all with headquarters in Medellin. Coltejar has factories in Medellin, Envigado and Rio Negro in Antioquia. Fabricato, the second largest textile firm has four factories, two at Valle de Abbura, one in Bogota (called Texmeralda) and one on the Rio Negro. Tejicondor is centred in Medellin. There are other smaller producers near Cali and at Barranquilla and Cartagena. The current coal demand by the textile industry's 19 plants is around 300 000 tpa. Coltejar plan a new factory at Rio Negro and this, together with the expansion of its other plants will boost its coal consumption to 265 000 tpa. Fabricato's coal usage is expected to increase from the current 90 000 tpa to 150 000 tpa and Tejicondor should, by 1985, require 60 000 tpa of coal. The total coal demand for textile manufacture by 1985 is estimated as 475 000 tpa,almost all in Antioquia; other forms of fuel will continue to be used in the factories in other parts of the country.

Colombia's iron and steel manufacture is centred in Acerias Paz del Rio S.A. The present output is only 330 000 tpa. Consumption in 1974 was only 29 kilo per capita against an average of 63 kg per capita in other Andean countries. The objective of the development plant for the Colombian iron and steel industry is to raise consumption to 62 kg/capita by 1985 which will entail an increase in raw steel production from the present level to 2.2 million tonnes per annum. Semi-integrated steel facilities are to be increased to produce 500,000 tpa of semi-finished steel products and two new cast iron foundries are also planned. Ingot output at Paz del Rio will go up to 1 million tpa and a new 250 000 tpa bar and rod mill will be built there.

At present the iron and steel industry is estimated to consume 900,000 tpa of coal. This will not increase in proportion to the expanded steel output,since it is planned, in order to overcome an expected shortage of scrap, to construct two sponge iron plants based on direct reduction of pelletised rich ore with natural gas. These plants are to be built at Cali and Barranquilla and will have a combined output of 674 000 tpa. Demand for coal, both for coke production and steam raising and heating,is forecast to amount to 1.6 million tpa by 1985.

The Colombian chemical industry is not a big user of coal. Present consumption is around 200 000 tpa. Future demand is uncertain, but the expected growth, coupled with some replacement of fuel oil by coal for process heating, will, it is estimated,raise coal consumption to 500 000 tpa without taking into consideration any direct conversion to chemical products.

There are numerous other industries made up of small units which use coal for which no specific current or future usage figures were available. Estimates have been made by industry observers and the averagee of these are included in Table 6.1.

In 1976, the coal consumed for electric power generation amounted to 385 000 tonnes. If the new thermal stations proposed for Carelca and Bolombolo are built, thie will increase to 875 000 tpa.

Finally, in considering the future demand for coal in Colombia, one must consider exports. In 1976, exports of coal from Colombia totalled 90 000 tonnes of which 40 000 tonnes was coking coal. These exports were mainly to Holland and the Argentine. All the Latin American countries plan major increases in steel production and it is estimated that this will result in a total coal consumption in excess of 20 million tpa and the importation of coal or its coke equivalent of 11-12 million tpa; Brazil alone, it is estimated, will require to import 8 million tpa by 1985 to meet its steel target of 32 million tpa.

Colombia appears to be well placed to secure a major share of this potentially lucrative market provided significant new mining areas can be developed, particularly coking coal deposits. Planning to this end has gone a certain way with the exploration and the projected development of the Boyaca-Cundinamarca and El Cerrejon fields and the plans to construct coking plants at Puerto Berrio and Cucuta or Pamplona.

Summarising, Table 6.1 gives the estimated domestic markets for Colombian coal in 1976 and 1985, excluding exports and any direct conversion to gas or chemicals.

Table 6.1 - Estimated Annual Domestic Markets for Colombian Coal in 1976 and 1985

	1976 Estimated Annual Coal Consumption	1985 Estimated Annual Coal Consumption
Leading Industries	tonnes	tonnes
Cement	850 000	2 000 000
Textiles	300 000	475 000
Iron and Steel	900 000	1 600 000
Electric Power	600 000	3 000 000
Chemicals	200 000	500 000
Total Leading Industries	2 850 000	7 575 000
Smaller Industries		
Paper	50 000	75 000
Food, drink, tobacco	200 000	190 000
Bricks, refractories	25 000	30 000
Furniture	20 000	30 000
Confections	30 000	40 000
China and glass	10 000	15 000
Mechanical shops and foundries	150 000	250 000
Leather and shoes	20 000	30 000
Domestic households	400 000	550 000
Total Smaller Industries	805 000	1 210 000
GRAND TOTAL ALL INDUSTRIES*	3 655 000	8 785 000

* Excluding exports

6.2 Current and Future Pattern of Coal Utilisation in Antioquia

Antioquia is one of the 22 departimentos of Colombia. Medellin, its capital, forms the northern apex of the industrial triangle whose other apices are Bogota in the south east and Cali in the south west. Within this area of 110 000 square kilometres about threequarters of the nation's business is conducted.

All the major textile firms, Coltejar, Fabricato and Tejicondor, have their headquarters in Medellin and this industry is the major coal consumer. Current usage is 265 000 tpa and, from the discussions with the senior personnel of these larger firms, an estimate of coal demand of 450 000 tpa by 1985 has been arrived at.

Cement making and grinding accounts for the next largest proportion of the coal consumed by Antioquian industry. There are four plants, two of which - Cementos El Cairo and Compania de Cemento Argos S.A. - currently use coal. Cementos de Nare and Cemento Blanco de Colombia, which produce clinker using fuel oil for firing, plan to covert to coal burning in the future. Current consumption was given as 170 000 tpa increasing, it is estimated, to as much as 435 000 tpa by 1985.

These two industries currently account for 70% of the coal consumed by Antioquian industry. The remaining 30% is used by a diversity of industries of which brewing and brick-making are the most important.

The only iron and steel producing plant is Simesa Siderurgia de Medellin S.A., the oldest steel plant in Colombia. This company makes reinforcing rods, mild steel and galvanised tubing and pipe-fittings and castings. It has recently obtained a licence from the Amsco Division of ABEX Corporation for making abrasion-resistant castings and balls for grinding mills. However, it produces its steel entirely from scrap and is therefore not a major coal user. It has plans to increase capacity in 1983/4 to 150 000 tpa with a consequent increase in coal consumption from 1 200 tpa to 2 400 tpa.

The only chemical producing firm of any size in Antioquia is Annidridos y Derividas de Colombia (Andercol) in Medellin. This firm operates a phthalic anhydride plant using as feedstock o-xylene from Ecopetrol. The phthalic anhydride is converted to phthalate plasticisers and alkyd resins. Andercol also makes a range of speciality solvents based on petroleum fractions. It is not a major coal user; present consumption is about 1 000 tpa for steam raising and there are no plans to increase it.

Table 6.2 summarises present and estimated future demand for coal by Medellin based industry.

Table 6.2 - Current and Probable Future Coal Demand by Medellin Industry and Exports

Industry	Demand 1976 tpa	Estimated Demand 1985 tpa
Textiles	265 000	450 000
Cement	170 000	435 000
Brewing	12 000	18 000
Brick-making	2 500	4 000
Iron and steel	1 200	2 400
Chemicals	1 000	1 000(1)
Other (paper, food, tobacco, furniture, confections, mechanical shops and foundries, leather goods and domestic usage)	50 000	75 000
Exports to Cali and Caldas	120 000	150 000
TOTAL	621 700	1 135 000

(1) The future chemical usage does not include any consumption of coal from the proposed new mines by new coal conversion plants. Nor does the estimated future usage include any demand for coal for the proposed thermal power plant at Bolombolo. Plans for this installation are, at present, very vague and there is considerable difference of opinion about its desirability. If it is built, it will increase future demand for coal by about 300 000 tpa, i.e. to 1 435 000 tpa.

6.3 The Colombian Chemical Industry

6.3.1 General

Table 6.3 lists the chemicals for which there was a production capacity in Colombia in 1974 greater than 5000 tpa, excluding petroleum fractions but including petrochemicals. The list also includes bulk polymers but not synthetic staple and filament. The figures are mainly taken from 'La Industria Quimica en el Area Andina' for 1974, which is the latest date for which reasonably complete statistics are available. As far as can be ascertained, there has been little change in capacity since then. 'NA' in this table signifies that the information is not available from the published statistics.

Table 6.3 - The Main Products of the Colombian Chemical Industry in 1974

Product	Capacity tpa	Production tpa	Imports tonnes*	Exports tonnes	Apparent Consumption tpa
Alkyd resins	10 000	7 200	nil	nil	7 200
Ammonia	121 500	109 000	14 500	nil	123 500
Ammonium nitrate	42 900	26 630	1 071	nil	27 701
Ammonium sulphate	79 000	50 000	14 550	nil	64 550
Benzene	43 000	31 000	nil	16 600	14 900
Caprolactam	16 500	12 000	nil	1 050	10 950
Carbon black	31 000	27 000	200	13 000	14 300
Chlorine	48 000	35 522	492	nil	36 014
Cyclohexane	20 000	NA	NA	NA	NA
Dichloroethane	50 000	NA	NA	NA	NA
Dodecyl benzene	15 000	nil	12 000	nil	12 000
Ethylene	20 000	8 500	1 000	nil	9 500
Herbicides (solid)	NA	9 267	NA	NA	NA
Herbicides (liquid)	NA	5 685	NA	NA	NA
Hydrochloric acid	NA	20 500	12	335	29 187
Nitric acid	89 500	65 000	7	nil	65 007

Table 6.3 continued

Product	Capacity tpa	Production tpa	Imports tonnes	Exports tonnes	Apparent Consumption tpa
Nylon 6	13 500	11 000	nil	nil	11 000
Oxygen	14 000	12 000	nil	nil	12 000
Phenol-formaldehyde resins	NA	4 185	190	961	3 414
Phthalic anhydride	9 000	3 330	2 000	nil	5 330
Phthalate plasticisers	14 300	7 850	140	nil	7 990
Polyethylene	15 000	8 300	22 100	nil	30 400
Propylene	10 000	NA	nil	nil	NA
Polyvinyl chloride	43 200	16 600	4 400	3 500	17 500
Sodium carbonate	300 000	178 853	nil	30 743	148 100
Sodium hydroxide	60 000	59 505	6 000	nil	65 505
Sodium sulphate	5 400	1 225	5 850	nil	7 025
Sulphuric acid	69 200	67 700	1 857	nil	69 557
Polyethylene terephthalate	20 500	16 700	nil	nil	16 700
Polystyrene	12 500	8 000	1 268	68	9 200
Superphosphate	15 000	nil	23 344	nil	23 344
Toluene	30 000	5 300	nil	nil	5 300
Urea	110 000	85 471	NA	nil	NA
Vinyl chloride	25 000	5 600	12 500	nil	18 100
o-Xylene	8 300	3 000	NA	nil	NA
Mixed xylenes	39 300	NA	nil	24 207	NA

From this table it will be seen that the Colombian chemical industry is concentrated in three sectors - heavy inorganics, petrochemicals and certain downstream products for plastics and man-made fibres and fertilisers. Unfortunately, it is precisely these sectors which are suffering from world-wide overcapacity, low plant utilisation and inadequate prices.

In contrast, Colombia's production of speciality organics - herbicides, insecticides and fungicides, antioxidants, surfactants, dyestuffs, pigments and dyestuff intermediates, explosives, pharmaceuticals, speciality solvents etc. is negligible. The country's requirements for all the innumerable high priced speciality chemicals needed by industry, agriculture and in the home are imported, generally as formulated proprietary products which do not show up in the chemical industry statistics.

The value of chemical imports greatly exceeds that of exports. In 1976, imports of chemical raw materials, semi-products and pharmaceuticals rose from $286 million in 1975 to $319 million, while exports of chemical products fell from $63 million to $58 million. Fertiliser exports suffered badly from both lower prices and a sharp drop in volume from 64 643 tonnes to 40 338 tonnes. Fertilizer imports also fell but not by as much as exports. One reason given for this poor performance of the industry was that the hopes of a deeper penetration of Colombian chemicals into the Andean pact markets did not materialise. This throws some doubt on the implementation of the Andean group's plans for an integrated petrochemical industry.

6.3.2 Petrochemicals

Under the Andean Group plan, each country in the group has been allocated certain products for the manufacture of which it will be primarily responsible for the whole of the group. The products which are earmarked for Colombia are listed in Table 6.4 together with present and planned future capacity for all petrochemicals.

This programme is well behind. The projected new plants to be completed in 1975 and 1976 are now operating but it appears that those due for completion in 1977 have not been started while the firms to be responsible for the last six items on the list and the locations of the plants, have not yet been decided.

Table 6.4 - Present and Future Capacity for Petrochemicals in Colombia

Product	Present Position				Projected New Capacity		Total Capacity tpa
	Firm	Location	Installed Capacity tpa	Date	tpa	Date	
Ethylene	Ecopetrol	Barranca-bermeja	16 000	1971	nil	-	16 000
Propylene	Ecopetrol	"	15 000	1971	nil	-	15 000
Benzene	Ecopetrol	"	12 000	1971	nil	-	12 000
Toluene	Ecopetrol	"	36 000	1971	nil	-	36 000
o-Xylene	Ecopetrol	"	8 300	1971	nil	-	8 300
Mixed xylenes	Ecopetrol	"	33 000	1971	nil	-	33 000
Cyclohexane	Ecopetrol	"	20 000	1971	nil	-	20 000
Dodecyl benzene	Ecopetrol	"	15 000	1971	nil	-	15 000
*Ld Poly ethylene	Polecolsa	"	15 000	1971	50 000	1978	65 000
Ethylene	Polecolsa	"	nil	-	100 000	1978	100 000
*Caprolactam	Monomeros	Barran-quilla	16 500	1971	40 000	1978	56 500
*Carbon black	Philips Petroquimica	Cali	16 000	1968	nil	-	16 000
*Carbon black	Cabot Colombia	Bogota	15 000	1966	nil	-	15 000
*Phthalic anhydride	Carboquimica	Bogota	7 200	1962	nil	-	7 200
"	Andercol	Medellin	1 000	1962	5 000	1975	6 000
*Polystyrene	Dow Colombia	Cartagena	12 500	1965	21 500	1978	32 500
*Dichloroethane	Petroquimica Colombia	Cartagena	50 000	1972	nil	-	50 000
*Vinyl chloride	"	Cartagena	16 000	1972	nil	-	16 000
*PVC Suspension	Petroquimica	Cartagena	31 000	1965	nil	-	31 000
*Vinyl chloride	Colcarburo	Cali	6 800	1967	2 900	1976	9 700
*PVC Suspension	Colcarburo	Cali	6 200	1967	2 600	1976	8 800
*Acrylic fibres	-	-	nil	-	10 000-12 000	?	10 000-12 000

Table 6.4 continued

Product	Present Position				Projected New Capacity		Total Capacity tpa
	Firm	Location	Installed Capacity tpa	Date	tpa	Date	
*Maleic anhydride	-	-	nil	-	9 000-10 000	?	9 000-10 000
*ABS/SAN resins	-	-	nil	-	7 500	?	7 500
*SBR rubber	-	-	nil	-	30 000	?	30 000
*Polybutadiene rubber	-	-	nil	-	10 000	?	10 000
*Dimethyl terephthalate/terephthalic acid	-	-	nil	-	135 000	?	135 000

* indicates petrochemical products for which Colombia will be primarily responsible.

At present, petrochemical production is mainly centred at the Ecopetrol complex at Barrancabermeja. The refinery on this site has a capacity of 38.5 million barrels per annum and the processes operated depend on whether the crude received is paraffinic or mixed.

In the case of the more paraffinic crudes, the oil is first fractionated at atmospheric pressure to yield refinery gas as overheads, motor spirit, naphtha, kerosine as side streams and a base product. The bottoms pass to a vacuum column and are split into gas oil as overheads, a number of lube oil stock sidestreams and a residue which is subjected to vis-breaking to yield additional gas oil and fuel oil. The naphtha fraction plus imported naphtha is desulphurised, platformed and the benzene, toluene and xylenes extracted using the Shell Oil 'Sulpholane' process. From the aromatic extract, pure benzene, toluene, o-xylene and mixed xylenes are produced by high efficiency fractional distillation. The gas oil fraction is catalytically cracked and the cracked products fractionated to give an ethane/ethylene cut, an LPG (C_3-C_4) cut, light cycle oil, fuel oil and an aromatic residue which is utilised as the feedstock for the manufacture of carbon black by Philips Petroquimica and Dow Colombia. The lube oil feedstocks are dearomatised by aqueous phenol extraction and then blended to produce a range of lubricating oils for sale. The residual aromatics and the cycle oil are blended with the fuel oil fraction.

On mixed crudes, operation at Barrancabermeja is similar, except that no lube oil fractions are taken. Most of the toluene produced is hydrodealkylated to benzene, some of which is hydrogenated to cyclohexane.

At the smaller refineries mentioned in Section 3.1, the processes are confined to atmospheric and vacuum distillation and no petrochemicals are made there.

There were plans to build a new refinery and petrochemical plant at Tumaco with a throughput of 75 million bbl/year and with substantially the same range of unit operations as at Barrancabermeja. It is, however, understood that, because of the reduction in Colombia's output of crude oil, this project, for which Foster-Wheeler was selected as main contractor, has been abandoned.

6.3.3 Fertilizers

Fertilizer production in Colombia is in the hands of Abonas Colombianos S.A. (Abecol) at Cartagena and Ferticol at Barrancabermeja. Both these firms make ammonia from natural gas and convert the bulk of it to nitric acid and urea. Abecol also produces compound NPK fertilizer, using imported phosphate rock or phosphoric acid. Ferticol, in addition to urea, make granular ammonium nitrate. The Monomeros caprolactam plant at Barranquilla produces ammonium sulphate as a by-product and converts this in a modified Dutch State Mines nitric phosphate unit into NPK fertilizer. For this purpose, nitric acid is produced on site using ammonia imported from Venezuela.

1974 capacity of these plants was:

Nitrogen fertilizers (urea and ammonium nitrate)	152 000 tpa
Compound fertilizers	340 000 tpa
Superphosphate	15 000 tpa

However, in recent years these capacities have never been attained. Abecol, particularly, has had a chequered history. This plant was reopened in September 1977 following a two month shutdown for repairs, but it was recently reported that, during the start-up, it was severely damaged by an explosion and its output for 1978 is likely to be severely affected.

The demand for fertilizers in Colombia is growing rapidly. Urea is replacing ammonium sulphate in the cultivation of rice, coffee, sugar and other main crops. According to the Colombian Institute for Industrial Development (Instituto Fomento Industrial) in its 1976/77 Report on the ammonia and urea project proposed for Guajira, the domestic demand for urea in 1978 is expected to be 242 000 tonnes against a production of 100 000 tonnes assuming that the Abecol plant operates at 80% of capacity, which is very unlikely. Future growth of urea demand is put at 7.5% per annum. Another estimate (UNIDO Report No. 1548-CO, 'Economic Pointers and Prosperity in Colombia: Statistical Appendix', 1977) gives the following data for fertilizer production and nutrient supply.

Table 6.5 - Fertiliser Production and Nutrient Supply in Colombia

	tonnes					
	1970	1971	1972	1973	1974+	1975*
Fertilizer Production						
Mixed fertilizers	221 000	264 000	284 000	363 000	410 000	440 000
Nitrogenous fertilizers (mainly ammonium nitrate and urea)	102 000	109 000	112 000	110 000	114 000	130 000
Phosphates (mainly Escorios Thomas)	54 000	58 000	42 000	70 000	70 000	130 000
Others	2 000	3 000	3 000	5 000	5 000	8 000
Imports for Direct Applications						
Mixed fertilizers	-	15 000	27 000	76 000	80 000	?
Urea	5 000	19 000	71 000	128 000	130 000	?
	% of total					
Imported Nutrient						
Nitrogen			45	58		
P_2O_5			98	87		
Potassium			100	100		

\+ preliminary   * projected

According to these estimates, the difference in total national production and projected demand (1975) could be supplied by 130 000 tonnes urea, 40 000 tonnes mixed fertilizers and 10 000 tonnes of potassium chloride or potassium sulphate.

The shortfall in fertilizer production is a serious drain on Colombia's balance of payments. In the first nine months of 1977, 31 475 tonnes of potassium salts, 27 700 tonnes of phosphate rock, 9 800 tonnes of phosphoric acid, 11 300 tonnes of ammonia, 4 736 tonnes of mixed fertilizers as well as an unspecified amount of urea were imported. The value of the recorded imports was $5.7 million.

There are plans to remedy the deficiency in fertilizer production. The Institute for Industrial Development has recommended the construction of a new natural gas-based $200 million ammonia/urea complex at either Barranquilla or near the Guajira gas field on the Caribbean coast. This would have a capacity of 1000 tonne/day of ammonia, most of which would be converted to urea (1 300 tonne/day). Empresa Colombiana de Minas (Ecominas) are seeking contractors to carry out a $3.2 million feasibility study (partly financed by a loan of $1.7 million from the Inter-American Development Bank) on the extraction and processing of the phosphate rock deposits at Pesca in the department of Boyaca and at Sardinata in Santander del Norte. The material from these indigenous deposits could feed a new $60 million compound fertilizer plant.

6.3.4 Coal Chemicals

The production and utilisation of coal chemicals in Colombia is very small. Colombia de Carburo y Derividos S.A. operates two plants, one at Zipaquira, Cundinarmarca making carbide from 18 000 tpa coking coal and the other on the Cauca making 8-9 000 tpa of PVC from the acetylene generated from the calcium carbide.

The only tar distilling plant is that operated by Carboquimica S.A. on the outskirts of Bogota. This firm processes the crude tar from the Paz del Rio steelworks. Its capacity of 10 000 tpa is too small for a normal continuous tar still and the unit operates on the continuous pot still principle. Crude tar is fed to a large cylindrical vessel heated by burning residual gases. The distillate produced is condensed in a water-cooled condenser and the oils and liquor separated in a decanter. The oils then pass to two flash stills, the second of which is equipped with a short fractionating column. Residual heavy oil is taken from the base of the first still, light oil (80-240°C boiling range) as overheads from the second still; creosote oil as sidestream and anthracene oil as the base product are also taken from the second still. The light oil is cooled in open pans to separate crude naphthalene which is upgraded to 78°C crystallising point by recrystallising from naphtha and the drain oil blended with the creosote and the anthracene oil to give wood preservation creosote and cresylic creosote. For the latter, 50 tonnes per annum are required to bring the phenols content to specifications; these cresols are imported.

The residual pitch from the continuous pot still is partly used with some of the anthracene to make pipe-coating enamels and black varnishes are also made from the pitch and heavy oil fluxed back with naphtha. The major part of the pitch is exported as an electrode binder.

At present this installation is only receiving between 5 000 and 6 000 tpa crude tar. The products are 160 tpa cresylic creosote, 600 tpa naphthalene, 600 tpa wood preservation oil, 300 tpa coal tar enamels, 15 tpa black varnish and 3 700 tpa pitch.

Carboquimica also receives the crude benzole from the Paz del Rio coke ovens, which it fractionates into technical benzole, technical toluol and naphthas. These are sold or used as solvents or, in the case of the heavy naphtha, sold as an insecticide vehicle.

Two grades of cresylic creosote are produced. The lighter grade commands a realisation of Ps35/kg ($951/tonne) and the darker grade sells at Ps22/Kg ($598/tonne). They are sold to formulators who make them into disinfectant emulsions for hospitals and household use and into cattle and sheep dips. About 300 tpa of naphthalene is sold to chemical firms such as Bayer Colombia and Ciba-Geigy at $220/tonne and the remainder converted into phthalic anhydride in a small oxidation plant. Ferrocarriles Nacionales is the main customer for the wood preservation oil. Four grades are made - 80/20 (80% creosote, 20% fuel oil), which sells at Ps50/US gallon ($330/tonne), 60/40 selling at Ps45/US gallon ($297/tonne), 50/50 selling at Ps40/US gallon ($264/tonne) and 100% creosote which has a realisation of Ps60/US gallon ($390/tonne).

The coal tar enamels produced conform to the AWWA C-27 specification. Some is supplied to Ecopetrol and the rest exported to Venezuela. The main buyer for the pitch is SICOR.

On the evidence of the available statistics the current demand for coal chemicals in Colombia is insignificant. Table 6.6 summarises the exports and imports for 1974 and, where available, for 1976. Future prospects for coal chemicals are discussed in the next section of this report.

Table 6.6 - Imports and Exports of Coal Tar Products

Product	Year	Imports tonnes	Exports tonnes
BTX and Naphthas	1973 1974	246 710	2 000 ?
Naphthalene	1974	1 000	nil
Naphthalene products	1973 1974 1976	40 0.1 0.01	nil nil nil
Phenol (mainly synthetic)	1974 1976	1 815 0.4	nil nil
Cresols	1974 1976	34 2	nil nil
Coal tar acids	1974	12	nil
Creosote oil	1974	44	nil
Other tar oils	1974	15	1 611
Pitch and pitch coke	1974 1976	0.05 9	4 838 ?
Bituminous paints	1976	56	nil

6.3.5 Other Chemicals

Other than petroleum products and petrochemicals, heavy inorganic chemicals and fertilizers, the chemicals which feature in the Colombian chemical industry statistics are mainly solvents. Table 6.7 lists these for 1974.

Table 6.7 - Colombian Production, Exports and Imports of Other Chemicals

Chemical	Capacity tpa	Production tpa	Imports tpa	Exports tpa	Apparent Consumption tpa
Acetic acid	1 500	1 200	nil	70	1 780
Acetone	nil	nil	2 964	nil	2 964
Chlorobenzene	nil	nil	153	nil	153
Ethyl acetate	1 300	1 300	nil	nil	1 300
Formaldehyde	2 000	1 525	48	474	1 099
Formic acid	nil	nil	348	nil	348
Hexachloro-cyclohexane	nil	nil	159	nil	159
Methanol	nil	nil	6 093	65	6 028
Nitrobenzene	nil	nil	991	nil	991
Pentachloro-phenol	nil	nil	80	nil	80
Trichloroethylene	nil	nil	950	nil	950

There are some surprising omissions from the list of chemical raw materials or intermediates recorded as produced or imported into Colombia. There is no mention of aniline or aniline derivatives, or of solvents like carbon tetrachloride, higher alcohols, ketones, ethers, glycols, pyridine bases, quinoline, tetrahydrofuran or dimethyl formamide. Ethylene oxide, aliphatic amines or diamines, aminoalcohols such as ethanolamine are not listed,nor are the intermediates for the production of the more common and widely used herbicides, insecticides, fungicides, antioxidants, surfactants or textile assistants. Bromine, iodine, hydrogen peroxide, phosphorus oxychloride, phosphorus penta-sulphide, sodium sulphite and titanium dioxide are other gaps in the inorganic sector. These and other chemicals, which are usual products or imports in industrially developed countries, presumably enter Colombia as formulated proprietary products which do not feature in the chemical industry statistics.

7. THE POTENTIAL UTILISATION OF ANTIOQUIAN COAL FOR THE PRODUCTION OF COAL BASED CHEMICALS

7.1 General

The market survey has established that the consumption of coal in Antioquia could possibly rise by some 400 000 tonnes/year between 1977 and 1985, excluding coal for the manufacture of chemicals or the generation of electric power.

The possibility of improving the output of the existing mines in the Medellin coalfield has been briefly reviewed. This output could poseibly be increased by some 300 000 tonnes/year in the short term and some 800 000 tonnes/year in the long term. Such an increaee in output, although sufficient to cater for predicted Antioquian demand for thermal coal in the medium term, would not be adequate to support in addition a commercielly viable coal chemicel plant.

The mining eurvey has identified the possibility of developing three new mines on the Amaga area. Two of these mines would have an estimated output of 500 000 tonnes/year and the third 1 million tonnes/year. The total output of this new mining development could reach 2 million tonnee/year. Such an output is sufficient to warrant the further examination of the possibility of establishing a coal based chemical industry in Antioquia.

Any development of a coal chemical industry should be based on the utilieation of coal from new captive mines, designed and operated specifically to serve the convereion plants, thus ensuring a constant supply of coal of assured quality. Only the certainty of a regular supply of coel, unaffected by variations in the supply/demand position in Medellin, would ensure the viability of such convereion plante and would attract the necessary finance.

The use of coal for the generetion of electric power is outside the terms of reference of this Study. Moreover, the Colombian government has stated its objective that electric power in Colombia should in the future be generated principally from the country's water resources. Although not in the remit of this Study, the use of coal from the new mines has been briefly considered in section 7.4.1 below in order to provide a comparison with the use of Antioquian coal to produce chemicals.

7.2 Routes to Coal Chemicals

The structure of coal is still imperfectly understood. The current and most plausible hypothesis is that its main constituents (macerals) have a three dimensional structure consisting of polynuclear groups joined together by methylene, conjugated diene and/or ether linkages. To produce commercially valuable chemicals requires a depolymerization by breaking the bridging groups and the decomposition of the 'monomer' aromatic or heterocyclic entities to small molecules. These objectives can be partly achieved by the following processes.

7.2.1 Carbonization

By heating coal in the absence of air to temperatures between 450°C and 1350°C, the bonds between the polynuclear units are disrupted and these units undergo a more or less complete decomposition into a variety of free radicles. The majority of these radicles recombine to yield char or coke, but a smaller fraction is stabilized by combination with smaller free radicles or by dimerization to yield gaseous and liquid products.

The extent of the decomposition of the 'monomer' units and the degree to which they form solid char or coke rather than smaller molecular weight, stable products, depends on the carbonization temperature and the time they are exposed to that temperature. In high temperature carbonization in coke ovens or continuous vertical retorts used for town gas production, not only is there considerable breakdown of the 'primary' products but also those reactions which would be expected to occur on thermodynamic grounds - aromatization of paraffinic and naphthenic structures, dealkylation of alkyl substituted ring compounds, hydrogenolysis of hydroxyl substituted ring compounds - proceed almost to completion. At the same time the conditions favour the polymerization of the initial free radicles formed to high moleculer weight, highly carbonaceous solid coke rather than stabilization by hydrogen transfer or dimerization to smaller volatile products. Thus the results of high temperature carbonization is to give a coke of low reactivity as the main product, an aqueous solution of inorganic salts and a relatively low yield of gaseous and organic liquid products. The tar produced is highly aromatic, contains only small amounts of paraffins and phenols and the molecules of which it is composed contain relatively few substituent groups and tend to have a condensed structure. From the light oil (or crude benzole) derived from the products of high temperature carbonization, pure benzene toluene and xylenes are readily produced as well as indenecoumarone resins and aromatic naphthas. From the higher boiling fractions of the tar, naphthalene, acenaphthene, fluorene, diphenyl, anthracene and phenathrene as well as higher polynuclear hydrocarbons like pyrene chrysene and fluoranthene can be isolated in pure form. Only the lower phenols - phenols and cresol isomers - can be regarded as products of high temperature carbonization and then only in very small amount.

However, a primary object of high temperature carbonization is to produce a low reactive coke in lump form and only coking coals or blends obtaining a major amount of coking coals, are suitable. Antioquian coals have no coking properties and are not suitable for the production of metallurgical coke or domestic coke by high temperature carbonization,and the chemicals produced from coal by this process need not be further considered in the context of the utilization of coal from Antioquian mines.

Low temperature carbonization at 450-500°C, whilst effecting depolymerization of the coal structure, leads to only a minor simplification of the 'monomer' structures and results in a relatively high yield of tar. This tar is still of relatively high molecular weight and chemically complex and the separation from it of individual chemicals of commercial interest in economic yield is not possible.

Medium temperature pyrolysis at temperatures in the range of 600-800°C under conditions which restrict the residence time in the reaction zone effects a depolymerization of the coal, a useful degree of decomposition of the monomer units to smaller radicles, but restricts the repolymerization of these radicles to high molecular weight products and the aromatization, hydrogenolysis and dealkylation reactions. The result is the production of a reactive char, ammoniacal liquor and, in considerably higher yield than in high temperature carbonization, a tar which contains relatively large amounts of paraffins, olefins and phenols.

This type of carbonization can be carried out with any type of coal and is usually carried out in a fluidized bed to yield the char as powder. This finely divided char is suitable, after quenching and stabilizing, as a pulverised fuel for boilers or furnaces, or for gasification. It is not however usable as a reductant in blast furnaces.

The tar can be hydrogenated to produce a synthetic crude oil from which the gasoline, diesel fuel and fuel oils can be produced by traditional refining methods. On distillation, the tar yields a light oil fraction which is too highly paraffinic to employ as a source of benzene, toluene and xylenes, but is useful as a gasoline blending agent or low boiling aromatic solvent. The higher boiling distillatate oils from the tar are rich in phenols which can be extracted and fractionated to give phenol, cresols, xylenols and a range of cresylic acids. Alternatively, only the lower boiling, more valuable phenols may be isolated, leaving the higher boiling members in the oil as cresylic creosote. The higher boiling fractions of the tar, with some residual phenols, can be blended to yield satisfactory wood preservation creosote. The pitch residue from medium temperature coal tar is not suitable for use as an electrode binder or for the production of needle pitch coke. Its main uses are as a binder in the making and maintenance of 'black-top' roads, as an impregnant for carbon bonded refractories, as a bituminous adhesive and sealant and for the manufacture of black varnishes and other coating compounds.

The aqueous liquor contains dissolved phenols and ammonium salts. The former are recovered by solvent extraction and the latter recovered as concentrated liquid ammonia or as ammonium sulphate.

There is one process which has recently been developed which can convert non-coking coals into metallurgical coke. This is the production of 'formed coke' which involves a two stage carbonization. The pulverised coal is first subjected to a medium temperature pyrolysis and the char is formed into conveniently shaped briquettes using the tar, after controlled air blowing, as the binder. The 'green' briquettes are finally calcined in a kiln to yield a low-volatile lump coke which is claimed to be suitable for metallurgical use.

7.2.2 Gasification

In this process the coal, frequently in pulverized form, is treated with steam and oxygen or air in controlled amount at medium high temperatures. This results in the initial depolymerization of the coal, the conversion of the 'monomer' and any decomposition products produced from the 'monomer', by a complex series of reactions to a gas consisting essentially of methane, hydrogen and carbon monoxide with some carbon dioxide and hydrogen sulphide. Little or no char or tar is produced as by-products and the composition of the gas can be varied within limits by varying the temperature, pressure and the steam/oxygen ratio. The raw gas can be adjusted in composition by various secondary reactions to give pure hydrogen or synthesis gas suitable for conversion to methanol, substitute natural gas (methane) or for Fischer-Tropsch synthesis to synthetic crude oil. The hydrogen with added nitrogen can be converted to ammonia and this can be combined with the CO_2 recovered from the raw gas to yield urea.

A new route to synthetic gasoline, which is creating considerable interest,starts with coal gasification and the conversion of the gas to methanol. This is partly dehydrated to give a mixture of dimethyl ether, unreacted methanol and water and this mixture is hydrogenated at high pressure over a zeolite catalyst. The products are mainly lower molecular weight paraffins and olefins which are converted to a high octane gasoline by conventional means.

7.2.3 Carbonization followed by Gasification

The process described in 7.2.1 and 7.2.2 can be combined. The coal is subjected to medium temperature pyrolysis and the char gasified with steam and oxygen containing gas to give synthesis gas for methanol, SNG, ammonia or Fischer-Tropsch synthesis. The range of products is therefore those described under the previous two sub-sections.

7.2.4 Solvent Extraction

Treatment of coal with an aromatic solvent at temperatures above 300°C leads to at least a partial depolymerization of the coal structure, yielding some polynuclear 'monomer' molecules which dissolve in the solvent and larger fragments which form a colloidal dispersion in the solution. There is little evidence that the monomer molecules or the colloidally dispersed coal are much altered. On removal of the solvent, a fusible product resembling a high softening point pitch is left as the product. Ash constituents including inorganic sulphur compounds are left undissolved and can be removed by filtration or centrifuging from the solution dispersion. The solvent refined coal can therefore be used as a clean boiler fuel.

The dispersed coal may be separated from the coal solution by fine filtration to yield an extract and a char. A process in the course of development by the British National Coal Board accomplishes this separation in an elegant fashion by employing a low boiling aromatic solvent, such as toluene, as the solvent at a pressure above its critical pressure. By reducing the pressure at the end of the extraction, the undissolved coal separates and the extract can be decanted from it.

Uses for the coal extract and the char are still being investigated and so far the process has only been operated on a small pilot plant.

7.2.5 Liquefaction/Hydrogenation

In this process the depolymerization action of an aromatic solvent is combined with hydrogenation of the dispersed and dissolved coal fragments at high temperature and pressure. This results in their decomposition, but the free radicles formed are stabilized by proton addition as well as undergoing hydrogenation. The product formed is thus mainly a mixture of paraffinic and naphthenic hydrocarbons with some aromatic hydrocarbons similar to crude petroleum. It can be refined in a similar way to yield gasoline, diesel oil, fuel oils etc.

In one process the hydrogen is partly supplied by the solvent which is dehydrogenated in the conversion step and catalytically rehydrogenated before recycle.

In the process as originally developed by Bergius and in the improved versions which are now under development, the hydroxyl substituents on the polynuclear aromatic elements of the coal molecule are hydrogenated and the syncrude product does not contain extractable amounts of phenols. There is the possibility that liquefaction hydrogenation could be carried out in two stages - a mild first stage to effect depolymerization and some simplification of the monomer structure but not sufficient to effect hydrogenolysis of the OH groups, followed by a more drastic hydrogenation with intermediate extraction of the more valuable phenols. No viable process along these lines has been developed.

7.2.6 Range of Potential Conversion Products from Antioquian Coal

These can be put in five groups:

Fuels: Substitute natural gas (SNG), liquefied petroleum gas (LPG), gasoline, diesel oil, fuel oil, coke or char.

Bulk Products: Ammonia, methanol, urea.

Tar Products: Light oil, phenol, cresols, xylenols, cresylic acids, creosote for wood preservation, cresylic creosote, road tars, pitch.

Carbon Products: Formed coke

Inorganic By-products: Ammonium sulphate, conc. aqueous ammonia, sodium sulphate (as byproduct in the recovery tar acids).
Sulphur (from the H_2S removed from raw gas).

7.3 Present and Future Markets for and Values of Coal Conversion Products in Antioquia

7.3.1 Substitute Natural Gas (SNG)

As indicated in sub-section 3.2, Colombia enjoys ample supplies of natural gas and, in fact, proposes to export large quantities in the future. The value of SNG produced in Antioquia can be equated to the cost of natural gas brought by pipeline from the northern gas fields.

The 1977 price of natural gas throughout Colombia was 38 pesos ($1.0) per 10^6 Btu. This is, however, an artificial price. By resolution No. 039 of 10th July, 1975, issued by the Price Commission for oil and natural gas, a price of $0.50/thousand cubic feet was set at the producing field for non-associated gas from the Texaco-Ecopetrol deposits, when supplied for thermal power generation in La Guajira, and $0.80/thousand cubic feet ($0.879/$10^6$ Btu) if supplied for other purposes. These prices are to be varied in step with the export price of fuel oil, fob Cartagena, for the preceding six months.

Although no pipeline is yet available between the gas fields and Medellin, an estimation of the transmission costs of natural gas from Balleria to Cartagena and thence to Medellin can be obtained from the data in the IFI Report 'Analysis of the Ammonia and Urea Project' by Jose A. Bazake, p.17. The cost of transmission for the 394 km between Balleria and Cartagena is based on the cost of the Promigas pipeline recently completed between these locations. It is $0.395 /thousand cubic feet and assuming the same tariff applies for any new pipeline between Cartagena and Medellin, a total transmission cost of $1.095 thousand cubic feet could be incurred and the sales price for natural gas in Antioquia could be $1.895/ thousand cubic feet or $2.08/$10^6$ Btu.

7.3.2 Liquid Fuels

Colombia is at present, and is likely to continue to be in the future, a net importer of crude oil, diesel fuel and gasoline, while remaining a large exporter of fuel oil. For crude oil, diesel fuel and gasoline, the landed prices at Barranquilla or Cartagena will be close to the general Caribbean prices, i.e. about $13/bbl for crude oil,$0.40/US gallon for diesel fuel and $0.417/US gallon for 95 octane motor spirit. In the case of crude oil, this must be transported by pipeline to Barrancabermeja at a cost of approximately $0.50/bbl. Syncrude produced in Antioquia would have to be brought to Barrancabermeja for processing, in this case, either by road or rail tanker at a cost of $0.035/tonne km. Thus the notional value of syncrude at present in Antioquia is estimated as $12.20/bbl.

Light oil from medium temperature carbonisation is of relatively high aromatic content and improves the octane rating of gasoline with which it is blended. It must, however, be refined to remove sulphur and unsaturated compounds which involves a loss of about 10%. The cost of refining is about equivalent to the premium over petroleum motor spirit and, thus, the value of light oil can be taken as 90% of the value of gasoline in Antioquia which is $169.5/tonne. The value of light oil produced in Antioquia is therefore assessed as $152.5/tonne.

In the case of fuel oil, any amount produced in Antioquia as a by-product of coal conversion processes would simply increase the amount to be exported and hence a maximum value of $10.60/bbl ($75/tonne), the present fob export price of fuel oil, can be taken for this product. The actual selling price for fuel in Medellin in mid 1977 was around $45/tonne.

7.3.3 Coke or Char

There is little demand for domestic coke or smokeless fuel in Colombia and,considering the availability of most convenient cleaner fuels such as LPG and, in the future, natural gas, it seems unlikely that any demand will materialise. The calorific value of domestic coke is generally in the region of 30 mJ/kg, similar to that of Antioquian coal and, as a heating medium, coke or char from coal conversion processes involving medium temperature carbonisation could not be given a value much higher than coal.

7.3.4 Urea

Colombia's current production capacity for urea is 110 000 tonnes/year but, in recent years, actual production has been well below this figure and, with the probable disruption in output from Abecol for much of 1978 as a result of a recent explosion, domestic output is unlikely to be more than 50 000 tonnes in that year. Imports, according to a recent announcement by the Colombia Ministry of Agriculture will total 265 000 tonnes from US, South Korea, Venezuela and Holland. The domestic demand for urea is thus around 310 000-320 000 tonnes which represents a sharp increase in the forecast in the IFI Report mentioned earlier. This estimates the 1978 domestic demand as 242 000 tonnes and a growth rate of 7.5% per annum. Actual growth rate between 1976 and 1978 appears to be nearer the 21% which was that reported for the Andean group as a whole in 1974. While it would be unrealistic to expect this high increase in domestic demand to continue, an annual rise of 10% between 1978 and 1982 is regarded as possible leading to the conclusion that, by 1982, consumption in Colombia will be of the order of 454 000 tonnes/year. This will require, if no new plants are constructed in Colombia, an importation of some 350 000 tonnes/year.

It is not possible to establish the cost price of urea made from natural gas in the existing Colombian plants. Their capital cost, the capital recovery charges and their current outputs are all unknown. Since it appears that a large part of the domestic demand will have to be met by imports, the cost of urea imported from the US Gulf Coast is, probably, the best value to take for urea in Colombia. The present spot price for bulk urea FOB Gulf Coast is $125/tonne. This is a manufacturing 'plant-gate' price to which must be added transport from plant to docks ($10/tonne), packaging ($8/tonne) and loading ($2/tonne) giving a price on board of $145/tonne. The cif, tax-paid delivered price at Barranquilla can be derived as shown in Appendix XIV of the IFI report thus:

	$/tonne
FOB Cost	145
Ocean Freight	20
Consular Fee (1% FOB)	1.45
Insurance (0.21% FOB)	0.30
Cif Barranquilla	166.75
Proexpo and Fedecafe taxes (6.5% cif)	10.84
Harbour Dues (2% cif)	3.33
Letter of Credit (1.5% cif)	2.50
Cif taxed Barranquilla	183.42
Losses in transit (1% cif, taxed)	1.83
Delays in unloading	1.00
Cost of unloading	2.00
Cost in Store at Barranquilla	188.25

In Antioquia, the July 1977 price for urea was $203/tonne sold to farmers. Allowing for transport costs, this corresponds to a price landed Colombian port of around $183/tonne. In 1977 the National Federation of Coffee sold urea to its members at the subsidised price of $183/tonne.

Since any urea produced in Antioquia would principally replace imported product, the value of urea can be taken as the price of urea landed Colombian port, $185/tonne approximately, or $205/tonne,delivered to Antioquia.

7.3.5 Methanol

Although no production of methanol is recorded in the Colombian statistics for 1974, it is understood that a relatively small amount is recovered in the manufacture of polyester fibre. On the basis of a fibre production of 6500 tpa, this recovery is estimated at 1 900 tpa. In addition, 2 444 tonnes were imported in 1976, indicating a total domestic demand of around 4 300 tpa. Under the Andean group plan for synthetic fibres, Colombia is scheduled to undertake the production of 135 000 tpa of dimethyl terephthalate and/or terephthalic acid. It is not clear whether the conversion of these intermediates into polyester is to be carried out in Colombia; polyester production is not amongst the activities earmarked for Colombia. If the intermediate chosen is dimethyl terephthalate and this is exported as such, an additional demand for methanol amounting to 43 000 tpa would be created.

The only obvious market for the remainder of any coal derived methanol would be as an automotive fuel. It has been demonstrated that, with minor adjustments, cars can run on an 80/20 gasoline/methanol mixture although there are certain disadvantages with cold starting and vapour locking. However, the calorific value of methanol, on a volume basis, is only about half that of gasoline and, thus, the value as a petrol blending agent can only be regarded as about half that of petrol i.e. $85/tonne.

The use of methanol for making synthetic gasoline by the Mobil process is even less attractive on the basis of the details recently disclosed by A.J. Silveski at the Third International Conference on Coal Gasification and Liquefaction held in August, 1977 at the University of Pittsburgh. He put the cost of gasoline at 2.4 times the cost of methanol plus 5%, which on the basis of a gasoline value of $169.5/tonne would value methanol at only $67.3/tonne.

The highest value that could be given to methanol produced as a main product from Antioquian coal would be that about 50 000 tpa might be valued at the CIF price of imported methanol which, on the basis of the US FOB Gulf price of $147/tonne, is $188/tonne with the remainder being worth about $80/tonne for use in Colombia or $127/tonne for export.

7.3.6 Tar Acids

Whereas at one time all the phenol used by industry was derived from coal tar, now it is almost all derived from petroleum. It is however one of the petrochemicals which is not produced in Colombia. The country's present needs are small; in 1974 imports amounted to 2 200 tonnes in 1976 and only half a tonne was reported as coming into the country. The main outlets for phenol are for phenolic resins (40%) caprolactam (15%), bisphenol A (15%), adipic acid (3%), miscellaneous (24%). In Colombia, the 15 000 tpa Nylon 6 capacity employs caprolactam made from benzene via cyclohexane and the phenol-formaldehyde resins (4 185 tonnes produced in 1974) are based on imported phenol. Phenol however is a versatile chemical and is the raw material for many speciality chemicals such as salicylic acid, non ionic detergents of the polyethoxylated alkyl phenol type, antioxidants such as 2,6 Ditertiary butyl phenol, herbicides such as 2,4-Dichlorophenoxy acetic acid, explosives such as picric acid as well as disinfectants, dyestuffs intermediates, and pharmaceuticals. As the Colombian economy grows and the desire to replace imported speciality organic chemicals by indigenous products is fulfilled, the demand for phenol is bound to increase and, it is believed, to an extent which will take up the relatively small volume that can be produced from medium temperature tar. The present export price of phenol from the USA is $463/tonne FOB which, when import taxes, freight and other charges are allowed for, but assuming no custom duty, would be $562/tonne, delivsred to Medellin. This is the value taken for phenol produced in Antioquia.

O-cresol is not at present a product of the Colombian chemical industry and the amount imported in 1976 was only 2.6 tonnes. The main outlet for this crssol isomer is for the manufacture of the herbicide MCPA (2-methyl, 4-chloro phsnoxy acetic acid) which is the main agent used for controlling weeds in cereal crops in Europe. It is not possible to check whether MCPA preparations are imported into Colombia; if so, the amount is small since total herbicide imports in 1976 amounted to 116 tonnss. It is believed - belief reinforced by the opinions of the Colombian industrialists with whom the subject was discussed - that the avsilability of indigenous o-cresol would be followed by the establishment of production of its useful derivatives. The maximum value which could be attributed to o-cresol would be its costs imported from the USA and delivered (tax-paid, but not subject to duty) to Medellin. Thia is $1165/tonne. Its minimum value would be based on the assumption that it had to be exported at the ruling US FOB export price of $1012.5/tonne less transport from Medellin to a Caribbean port i.e. $991/tonne.

Mixtures of meta and para cresol are in good demand worldwide. Unlike petrochemicals, the substituted phenols derived from coal tar are becoming scarcer as the amount of crude tar available dwindles. There is at present a tight market for these products with prices increasing rather than decreasing. The mixed isomers have two main outlets for the production of phenoplast adhesives for plywood and the manufacture of amylphosphate plasticiers. They may be separated by reacting with isobutane and separating the dibutyl derivatives - 2,6 ditertiary butyl - 4-methyl phenol and the 2,4-ditertiary - 5-methyl phenol - by vacuum fractionation. The dibutyl derivatives of the para isomer, also known as butylated hydroxy toluene or BHT, is the most widely used antioxidant for butter, lard and other animal fats. The meta isomer is the raw material for insecticide 'Sumithion'. In addition to these major outlets, the mixture and the separate isomers have a variety of minor uses in the production of surfactants, antioxidants, drugs, tanning agents, froth flotation and metal degreasing agents.

Currently there is no domestic production of meta/para cresol in Colombia and imports are negligible although current demand for phenoplasts is put at 3 500 tonnes/annum. Like o-cresol, meta/para cresol, or the individual isomers are amongst the most widely used intermediates in the manufacture of speciality chemicals and the maximum and minimum values of metal/para cresol in Antioquia can be derived, in the same way as for ortho-cresol from the mid-1972 US FOB price of $0.44/lb. These values are $1192/tonne maximum and $948/tonne minimum.

Higher boiling fractions of tar acids are variously termed xylenols or cresylic acids. Again their major outlets are for the production of plywood adhesives and flame resistant plasticisers. Halogenated xylenols are amongst the most widely used fungicides and cresylic acids are the basis of disinfectants, froth flotation agents, resin solvents and synthetic tanning agents. They are not recorded as being produced in Colombia nor is there any mention of them as such in the chemical industry import statistics. Their value in Antioquia would depend on whether the manufacture of speciality chemicals for internal use or for export would, as is believed, rapidly follow their availability or whether they had to be exported. Based on the current US FOB export price of $924/tonne, their maximum and minimum values in Antioquia are estimated as $1100/tonne and $915/tonne.

7.3.7 Creosote

The major outlet for creosote is as a wood preservative particularly for heavy duty use for the treatment by pressure impregnation of railway sleepers, telegraph and electricity transmission poles, marine piling fencing and farm buildings. Its effectiveness is this sphere is backed by more than a hundred years of service records and the amount used worldwide is not far short of a million tonnes. The only production in Colombia, the 600 tpa made by Carboquimica SA, is taken up almost wholly by the Colombian National Railway for the preservation of sleepers. For the treatment of poles, Boliden K33, a copper chrome arsenic preparation is mainly used. This is imported from the Osmose Co. of Buffalo, New York as a concentrate costing $0.72/lb FOB New Orleans, which when it has paid the freight, harbour charges, import taxes, a customs duty of $48/tonne and the freight to Bogota or Medellin costs $0.85/lb. The cost of treating poles with this material works out slightly more expensive than using creosote at $330/tonne.

Both Servicios y Equipos de Colombia SA and Immunizidora de Maderas Ltda the two leading wood-preserving companies, claim that they would prefer to use creosote if they could obtain enough of satisfactory quality. It appears that, some years ago, they used a creosote type oil from Paz de Rio, but abandoned this when some of the treated poles failed within 5 years because of wetrot attack at the ground line. There is evidence, however, that this material did not conform to the specification for a wood preservation oil, and that it lacked both toxicity and permanence. Anticipating the development in telephonic communications and rural electrification, the view of these companies is that the future demand for satisfactory wood preservation creosote would grow to as much as 57,000 tpa without considering the potential markets for treatment of fencing and farm buildings, which have not been exploited at all. This estimate of a large future market for wood preservation creosote is confirmed by Ferrocarriles Nacionales who have approached Carboquimica for 6000 tpa, a tenfold increase on their present offtake.

It therefore seems certain that there will be a market for all the wood preservation creosote that can be produced at a realisation equivalent to the present Colombian price of $330/tonne.

The other main outlets for creosote are as a fluxing oil, as a feedstock for carbon black manufacture and as cresylic creosote. Some of the medium temperature creosote derived from coal carbonisation in Antioquia may be used as fluxing oil to produce road binders but the outlet for carbon black production is not likely to be either an important or attractive one. Ecopetrol's refinery operations at Barrancabermeja provide ample supplies of aromatic residues for the Colombian carbon black industry and the realisation is not more than $150/tonne. In contrast, cresylic creosote in Colombia is priced at $800 and $950/tonne and this is the other market to which the creosote from medium temperature carbonisation of coal should be directed. Cresylic creosotes have two main uses. The larger one is for the manufacture of disinfectant emulsions for domestic, industrial and agricultural use, the smaller is for controlling over-wintering pests on fruit trees. At present, the only production amounts to the 160 tonnes/year made by Carboquimica SA,which is almost entirely used for domestic and industrial disinfectants. The most extensive agricultural market for sheep and cattle dips has not apparently been penetrated, probably because Colombia's main livestock industry is the rearing of cattle which are not normally treated with cresylic emulsions. There is however a considerable export trade between Europe and Latin American countries such as Brazil, Argentina, Patagonia and Uruguay for cresylic creosote and the view of the sales executives of Carboquimica is that this market was capable of, at least, a tenfold expansion if suitable material were available. A reasonable price to put on cresylic creosote made in Antioquia would be $819/tonne, the present realisation by Carboquimica for their darker and cheaper grade.

7.3.8 **Pitch and Road Binders**

The main use for coal tar pitch, at present, is as binder for the Söderberg or prebaked electrodes used in the smelting of aluminium and for the graphitized electrodes employed in electric arc steel furnaces. Other major outlets are for the briquetting of coal dust, as the water-proof adhesive in the construction of membrane roofing and as a road binder. It also has outlets in the production of heavy-duty anti-corrosion coatings such as black varnishes, pipeline enamels, tar epoxy and tar polymethane coatings. Other uses are for the impregnation of fibre pipelines, in the manufacture of pitch-fibre pipes and of refractories in the production of carbon bonded refractories for blast furnaces and steel making converters.

However, for most of these uses, the relevant specifications rule out medium temperature pitch and, for this type of pitch with its relatively low C/H ratio, the developed uses are for road binders, for impregnation and for anti-corrosion paints. In 1976, medium temperature pitch production in Great Britain amounted to 65 000 tonnes which was used for the following purposes: pitch fibre pipes 7.5%, coating compounds and refractories 18%, road binders 74.5%.

In road construction and maintenance, pitch is used in the form of pitch/bitumen for surfacing main roads and, blended with tar heavy oil, as road tar. This latter is used, either alone or as a mixture with cut-back bitumen, as the binder in premixed macadams or for the repair and maintenance of road surfaces by surface dressing.

It has been found that the polishing under traffic, which causes asphalt road surfaces in which petroleum bitumen is the binder to become prone to skidding, can be prevented by blending 20% of medium temperature pitch with the bitumen, and pitch/bitumen is now the preferred binder for such surfacings. The use of blends of 50% medium temperature road tar with 50% of cut-back bitumen for surface dressing follows research over the past decades. This has demonstrated that such mixtures combined the good melting properties and resistance to softening in contact with petroleum oils and to stripping by water which are characteristic properties of road tar, with the superior weathering properties of bitumen. Of the tar binders used for surface dressing in Great Britain in 1977, over 75% was in the form of tar/bitumen blends.

Both pitch/bitumen and tar/bitumen blends would be ideal binders for the construction and maintenance of roads in Colombia. Considering the vast amount of road construction and improvement which is necessary in Colombia if its transport system is to be made adequate for its potential industrial development, there should be no lack of demand for road tars in the immediate and more distant future.

At present, such surfacing and maintenance of roads as occurs in Colombia is done with bitumen produced at the smaller refineries. Ecopetrol's main refinery at Barrancabermeja does not make bitumen but could, if necessary, product 18 000 tpa at the expense of fuel oil. There was in 1976 a small net import of bitumen of 45 tonnes sold at an FOB price of $129/tonne. This is considered to be the appropriate value to give to coal tar pitch or road tar produced in Antioquia. The US FOB price for roofing pitch is $110/tonne which would equate to $196/tonne landed at a Colombian Caribbean port.

7.3.9 Surface Coatings

Black varnish essentially consists of coal tar pitch fluxed back with heavy oil to about 55-60°C softening point and this base is thinned with heavy naphtha to brushing or spraying consistency. Black varnishes are mainly used industrially to protect steel structures against corrosion, as antifouling coatings for ship's bottoms and for painting outdoor wooden buildings. Their current usage in Colombia is small; in 1976 56 tonnes were imported at a CIF value of $110/tonne.

Pipe coating enamels consist of a mixture of coal tar pitch and heavy oil in which bituminous coal is dispersed at 310-320°C to give a modulate to which 35% of powdered talc or slate flour is added as a filler. Almost all pipe coating enamels are made from coke oven pitch and heavy oil and there is some doubt whether satisfactory products could be formulated on the basis of medium temperature tar products. These enamels are the preferred materials for coating the outside surfaces of underground oil and gas pipelines and, although at present, production in Colombia is restricted to the 300 tpa produced by Carboquimca, the ambitious plan for a natural gas distribution network in Colombia as well as oil and gas distribution developments in other Latin American countries should ensure a much larger market in the future. The present realization varies from $300/tonne for home sales to $435/tonne for export and a value of $350/tonne for future production is regarded as realistic. This corresponds to a value for pipe coating enamel modulate of around $220/tonne.

7.3.10 Formed Coke and Pitch Coke

The ratio between the price of coking coal and the average realisation for metallurgical coal in the US is 1:1.88. Coking coal in Boyaca was quoted at $40/tonne at the end of July, 1977 so that the value of coke at the Paz del Rio steelworks, assuming the same ratio holds, would be $75.2/tonne. The value at an Antioquian production plant, when the $15.6/tonne carriage to Boyaca is deducted, would be approximately $60/tonne. This is of the same order as the FOB export price of coke from Colombia. In 1976, 29 366 tonnes of coke and semi-coke were exported with a value of around $/tonne 60.

There is no production of pitch coke recorded in the Colombian statistics for 1974-1976. In 1976, 9 tonnes were imported at a cif value of $457/tonne.

7.3.11 Inorganic By Products

These arise in two major ways from medium temperature carbonization. The aqueous liquor, separated from the tar, contains dissolved ammonia and ammonium salts and the free and fixed ammonia can be recovered in the conventional fashion either as concentrated ammonia solution or as ammonium sulphate. When the phenols are extracted from tar middle oil with caustic soda and the sodium phosphate neutralized with sulphuric acid to regenerate the crude tar acids, a solution of sodium sulphate is produced. This, after solvent extraction to remove entrained tar acids,can be evaporated to yield a concentrated solution which has been found suitable for use in paper manufacture or crystalline Glauber salt which can be sold to the glass or paper industries.

There is a market for sodium sulphate in Colombia. Production in 1974 was just over 1 000 tonnes but imports were nearly 6 000 tonnes. Most of the statistics are not yet available; current demand is believed to be around 10 000 tpa with a value, based on the present US FOB price of $55/tonne, of $84.5/tonne in Colombia.

Ammonia sulphate is also a net import, averaging about 15 000 tpa to supplement Colombian production of around 50 000 tpa. The 1977 cif value value of imported material less customs duty was $95/tonne. On the other hand, concentrated ammonia liquid is a net export from Colombia. 6 165 tonnes of ammonia as a 20-30% solution was exported in 1976 at an average FOB price of £125/tonne ammonia content. This would correspond to a value at an Antioquian production site of $103.5/tonne of ammonia or about $30/tonne of concentrated solution.

In addition to these tar products, some sulphur is recovered on cleaning the raw gas from gasification processes. The value of this can, as before, be calculated from the US Gulf FOB price of $61.5/tonne, as $94.5/tonne bonded, tax paid, in Colombia.

7.4 Review of Process Routes for the Conversion of Antioquian Coal

7.4.1 Electric Power Generation

This is the major use for coal in industrialised countries, but in Colombia, would be contrary to the government's overall energy policy. This is to exploit the country's hydroelectric resources as the main method of power generation and to discourage the use of fossil fuels for this purpose. Antioquia is, at present, almost wholly dependent for its 774 MW capacity on the seven Medellin hydroelectric installations, the supply from which has provsd very erratic in recent years. Medellin industry would welcome a more dependable supply.

Figures relating to the cost of generating electric power via the conventional steam cycle route using pulverised coal firing with no stack gas scrubbing have been obtained from a study undertaken by International Engineering Co. of Vancouver, for the British Colombia Hydro and Power Authority in 1976 and extrapolated to 1977 conditions. For coal delivered to the generating station at $16/tonne, the generating costs would be approximately:

Generation Capacity	Annual Coal Consumption	Generating Cost
MW	tonnes	$/MWh
500	700 000	29
250	350 000	34

Thus the estimated cost for electric power from coal from the new mines in Antioquia in a 250 MW station (this is the size of the new hydroelectric station planned), would be about $0.034/kWh. The mid-1977 price of electricity in Medellin is Ps0.45/kWh ($0.0122/kWh) increasing by 2% per month to a maximum of Ps1.0/kWh and this includes both transmission and generating costs.

The conclusion is that electric power generated from Antioquian coal cannot compete on price with hydroelectric power. This method of using coal from the new mines is not a commercially viable option.

Any decision to use this coal for power generation in order to ensure greater continuity of supply would therefore have to be made by the Colombian authorities and possibly subsidised in some manner.

7.4.2 Underground Gasification (Process Option 1)

This is theoretically the cheapest method for converting coal to a gaseous fuel. It has been used in an experimental manner in Russia and the USA and, given certain geological and stratigraphic conditions - thick seams between impervious formations and with shallow dips - would appear to offer a cheap method of generating electric power by using the low Btu gas produced in gas turbines or by a combination of gas turbines and steam turbines. The necessary conditions do not, however, exist in the Medellin coalfield nor is there likely to be the demand for power from the very large generating installations, involving very high capital investment, which would be necessary for the economic exploitation of coal in this fashion.

7.4.3 High Temperature Carbonisation (Process Option 2)

Carbonisation in coke ovens or continuous vertical retorts for the production of metallurgical or domestic coke represents a major outlet for coal in most industrialised countries. For these purposes, the coal must have certain properties which, unfortunately, only a very minor proportion of the output from the Antioquian mines possesses. The coal which it is expected would be the product of any mines in the Amaga-Fredonia region would be sub-bituminous high-volatile coal entirely unsuited for use in high temperature carbonisation processes. This process option is not therefore feasible.

7.4.4 Gasification for the Production of Substitute Natural Gas (SNG)

The basis of this process is the complete gasification of the coal in a static bed or fluidised bed gasifier with steam and oxygen to yield a gas consisting mainly of hydrogen, carbon monoxide and methane. This gas is first treated to remove the small amounts of CO_2 and H_2S which it contains and then a portion is subjected to the 'shift' reaction, i.e. reacted with steam to convert the CO to CO_2 and hydrogen. The proportion of the cleaned raw gas shifted is calculated to give, after removal of the CO_2 formed in the shift reaction, a gas with a $CO:H_2$ ratio of 1:3 by volume. This synthesis gas is then reacted under pressure over a nickel-containing catalyst which converts it to methane.

For the initial gasification,there are a large number of processes. Some, like the Lurgi, Koppers-Totzek and Winkler gasifiers,have been in use on a commercial scale for many years; others, like the'Bi-Gas' process of Bituminous Coal Research Inc., the 'CO_2-Acceptor' process of Consolidation Coal Co., the 'Hygas' process of the Institute of Gas Technology and the US Bureau of Mines 'Synthane' process have been developed to the large pilot plant or demonstration plant stage. Several processes are also available for the methanation stage such as the Lurgi process, the British Gas Corporation's 'Catalytic Rich Gas Recycle' process and the UOP process. They all use a nickel based catalyst and, like the newer gasification processes, have not yet been carried out on a full commercial scale.

Capital and processing costs have been published recently for a number of these processes. These have almost invariably been on a scale of 25 000 tonnes/day of coal (8.25-8.5 million tonnes per year) to produce 250 million cu.ft. per day of gas. A recent analysis by R.L. Dickenson of Standard Research Institute (American Chemical Society, Division of Fuel Chemistry, Preprints of Papers presented at Chicago, Illinois on August 29th to September 2nd 1977, 22, No. 7, 1.) estimates the capital cost of such a plant as between \$762 million and \$846 million and the cost of gas from coal at \$7.00 per tonne as between \$4.00 and \$5.26/10^6 Btu to give a 15% DCF rate of return. An earlier analysis by R. Detman of F. Braun and Co. estimated the cost of SNG on this same scale from Montana lignite as \$4.25-\$4.34/10^6 Btu, amortising the plant on straight line depreciation at 12.5% over 20 years. These capital costs and product prices are confirmed by the figures published for the study which C.E. Lummus undertook for the plant which American Natural Gas Co. propose to build at Beulah, N. Dakota to produce SNG from lignite (costs at $8/tonne) on a 25 000 tonnes/day scale. The estimate of the capital cost was $780 million and the price of gas, in 1975, estimated at $\$4/10^6$ Btu.

On the much smaller scale which could be envisaged in Antioquia and with coal at double the price, the cost of SNG would be of a considerably higher order, probably, it is estimated, in the range of $\$8-\$10/10^6$ Btu. This is very much greater than the price of natural gas piped from the northern gas fields to Antioquia, as assessed in section 7.3.1. The obvious conclusion is that the conversion of Antioquian coal to substitute natural gas would be hopelessly uneconomic.

7.4.5 Liquefaction/Hydrogenation for Producing Synthetic Crude Oil (Syncrude) (Process Option 4)

Processes for carrying out the hydrogenation of coal to yield substitute petroleum fuels are well known and have been operated to a considerable extent in Germany and, to a lesser extent in Great Britain and the USA, particularly during and just after World War II. Interest in this type of process has recently been revived and a number of new methods of procedure developed. These are claimed to possess some advantages over the original Bergius and Pott-Broche processes, but it is sometimes difficult to see where these alleged advantages lie.

The basis of the process is to dissolve or suspend the powdered coal in an aromatic solvent and catalytically hydrogenate the solution or slurry at elevated temperatures and pressures. The yield of 'syncrude' by all the processes is much the same - between 3 and 4 barrels per tonne of coal processed. Again the recent capital and operating costs refer to plant handling 25 000 - 30 000 tonnes/coal per day. Dickenson, in his analysis of the economics of coal conversion processes referred to in the last option, estimates the total investment involved in building such a plant as between $1.3125 billion and $1.375 billion and the product on a 15% DCF rate of return, to sell at $21.00 to $26.25 per barrel. A more recent analysis by E.W. Neben of Fluor Engineers and Constructors of the economics of the 'H Coal' or similar processes is that the selling price of syncrude would have to be \$24-35/bbl to give a 14% return on investment. On the vastly smaller scale which could be envisaged in Antioquia, and employing coal at around \$20/tonne, the cost of syncrude is estimated at approximately treble - somewhere between \$60 and \$70 per barrel. Costs recently published for the 600 tonne/day plant being erected at Catlettsburg, Kentucky to demonstrate the 'H-Coal' process, one of the more advanced second generation coal liquefaction/hydrogenation processes, quoted the cost of construction as \$108 million and the annual operating cost, not including the cost of the coal or capital recovery on the plant, as \$35 million for the production of 1 800 barrels per day. This works out at \$55 per barrel without including raw material costs or plant pay-off. The notional value of syncrude in Antioquia was assessed at \$12.20/bbl in section 7.3.2.

Consequently the cost of syncrude produced from Antioquian coal would be very much higher than imported crude petroleum in the foreseeable future. This potential use of Antioquian coal can therefore be dismissed.

7.4.6 <u>Fischer-Tropsch Synthesis</u> (Process Option 5)

This is the only process for converting coal into liquid fuels currently in commercial operation. The researches of Fischer and Tropsch into the hydrogenation of carbon monoxide to liquid hydrocarbons were developed to a commercial process by Ruhrchemie who erected the first plant in 1933. By 1939 nine plants were in operation in Germany, one of which was still operating in 1962. Since the early 1950s the development of this process has been mainly centred in South Africa where the South African Coal Oil and Gas Corporation (SASOL) built a large unit in 1955. They have recently announced that a much larger unit, which is designed to produce 1.5 million tonnes of gasoline and corresponding large amounts of diesel oil and fuel oils is under construction. Some idea of the size of this new unit can be gained from the statement that it will be based on 1.165 million m^3 of synthesis gas per hour produced from a battery of 36 Lurgi gasifiers.

The process, like those considered for other options, starts with the complete gasification of cleaned coal with steam and oxygen, followed by the shifting of part of the cleaned raw gas to give a synthesis gas with a $CO:H_2$ ratio of 1:1.5 which is reacted over catalysts, partly in a fixed bed reactor at 210°C and 360 psi, and partly in a fluidised bed reactor at 310–330°C and 330 psi. The products are separated into gas, hydrocarbon liquid ('kogasin') and aqueous liquor. This latter contains water soluble aliphatic acids ketones and alcohols which are recovered and separated. The kogasin is refined to gasoline, diesel fuel and fuel oils, lube oils and waxes by conventional techniques.

This process appears to be reasonably attractive as a method of converting coal into automotive fuels and fuel oils when carried out on a large scale with cheap coal. P. Rousseau in his 1975 Robens Coal Science Lecture, disclosed that although the South African version of the Fischer-Tropsch process was more expensive than coal liquefaction/hydrogenation as a method of making syncrude, it was the only process that was commercially proved. On the scale of SASOL 1, it made a marginal profit with coal at $5/tonne, but if the coal is priced at $10–$15/tonne, then Fischer-Tropsch derived fuels can only compete with imported petroleum fuels if they are subject to a lower level of tax, the resultant loss of revenue to the government being regarded as the cost of national self-sufficiency. A recent paper by J.B. O'Hara, N.E. Mentz and R.V. Teeple of the Ralph H. Parsons Co. (American Chemical Society, Division of Fuel Chemistry, Preprints of Papers presented at Chicago, August 29th - September 2nd, 22, No. 7, 20.) gives an analysis of the economics of the conversion of 40 000 tonnes/day of coal to 260 million ft^3 of gas, and 50 000 barrels/day of liquid fuels in an improved version of Fischer-Tropsch. Capital costs, they estimate would be $1.245 billion not including the coal preparation plant; the average selling price of the products based on a 12% DCF return on a 65/35 debt/equity funded investment would be $\$2.55/10^6$ Btu (equivalent to $15.25 barrel). This comparatively attractive price is, however, dependent on having large captive mines producing coal at $7.65/tonne.

The conclusion is that Fischer-Tropsch synthesis can only be regarded as an economic outlet for coal if it is conducted on a scale much larger than could be contemplated in Antioquia and if the coal were much cheaper than that likely to come from any new mines in the Medellin coalfield.

7.4.7 Medium Temperature Pyrolysis and Urea Production (Option 6)

The basis of the scheme is to subject the coal first to carbonisation at around 750°C to give a gas, a reactive char and a medium temperature tar. The tar would be distilled to yield a number of saleable tar products. The char would be gasified to yield a synthesis of gas which, by shifting and CO_2 removal would be converted to hydrogen. This would be mixed with nitrogen from an air separation unit and the 3:1 H_2:N_2 mixture converted to ammonia by conventional technology and the ammonia combined with the CO_2 extracted from the shifted gas stream to yield urea.

This type of 'Coalplex' would provide a range of coal chemicals, on which the manufacture of some of the speciality chemicals currently imported into Colombia could be based, and at the same time, satisfy the needs of Antioquia and neighbouring provinces for urea.

The present day standard synthetic ammonia plant produces 1 000 tonne/day and almost all the up-to-date information in investment and operating costs of ammonia and urea plants relate to this scale of production. It is on this scale - the production of 580 000 tonnes/year of urea from just over 1 million tonnes/year of run-of-mine coal that this process option was considered.

Preliminary cost calculations indicated a possible cost of urea by this route less than the value of urea in Colombia calculated in section 7.3.4. This process option was therefore selected for further study. Its technical aspects are described in Section 8 and its economics in Section 10.

7.4.8 Medium Temperature Pyrolysis and Methanol Production (Process Option 7)

This process route is a variation of process option 6. The same medium temperature carbonisation system would be used with the same yields of gas, char and tar. The char would be gasified as for the previous option, but only about 17% would be subject to the shift reaction to give a final 2:1 H_2:CO ratio. Capital costs would therefore be lower because of the smaller size of the shift and CO_2-removal reactors and because no urea synthesis unit is required. Operating costs would also be reduced by the omission of the urea plant. The total depreciable investment is calculated at around $270 million for a complex producing 80 000 tonne/year of tar and 330 000 tonne/year of methanol from 950 000 tonne/year of coal. Production costs, including capital recovery, are estimated at around $60 million per year for a coal price of $16/tonne. The cost of methanol based on these figures works out between $160 and $200/tonne depending on the pattern chosen for exploitation of the tar.

As discussed in section 7.3.5 the highest value that could be given to methanol as the main product from a coal conversion plant in Antioquia would be around $96/tonne which is well below the estimated cost of production. This process option can therefore be ruled out.

7.4.9 Complete Gasification of the Coal and Urea Production (Process Option 8)

This process route is a simpler version of process option 6 in which the medium temperature pyrolysis is omitted. It has the advantage that the yield of urea is higher per tonne of coal processed. It has the disadvantage that no tar chemicals are produced and therefore the possibility of establishing a speciality chemical industry in Medellin is ruled out.

A preliminary economic evaluation suggested that, based on an annual production of 580 000 tonnes/year of urea, the cost of urea by this route would be less than the value of urea in Colombia, calculated in Section 7.3.4. This process option was therefore selected for further study. Its technical aspects are described in Section 8 and its economics in Section 10.

7.4.10 Complete Gasification of the Coal and Methanol Production (Process Option 9)

This route is related to process option 8. To produce the 2:1 H_2:CO ratio gas, it is necessary to submit only 23.6% of the clean raw gas to the shift reaction. The capital requirements are reduced by the omission of the urea synthesis plant and the smaller size of the shift converter and the CO_2 removal plant. Energy requirements are less than for option 8, the energy required for the urea plant more than makes up for the smaller amount recovered from the shift unit. A consumption of 845 000 tonnes coal is calculated to yield 590 000 tonnes of methanol. This agrees with the figures quoted by W.C. Morel and Y.J. Yim (American Chemical Society, Reprints of Papers presented to the Division of Fuel Chemistry, at Chicago on August 29th to September 2nd, 22, 95, 1977.).

The total investment is calculated at around $240 million and operating costs excluding capital recovery and cost of coal at around $26 million per annum. The cost of methanol based on these figures can be calculated at around $120/tonne for a coal price of $16/tonne. This is about the value of methanol in Antioquia if the methanol surplus to Colombia's internal requirements were exported at the US FOB export price. On this basis a nil profit would be achieved. If the bulk of the methanol can only be disposed of as a petrol blending agent at a realisation of $90/tonne, then this option is uneconomic.

7.4.11 Formed Coke Production (Process Option 10)

A number of processes have been proposed for producing metallurgical coke from non-coking coals, but none is in commercial operation. They are based on briquetting a mixture of pulverised coal and recycle coke breeze with a pitch binder and calcining the 'green' briquettes,

One process which has received some publicity and from which some cost figures may be derived, is that developed by the FMC Corporation. This has been operated for some years on 1 250-300 tonne/day scale at Kemmerer, Wyoming using a sub-bituminous 'B' coal, whose characteristics (volatile matter and fixed carbon on dry coal, 44.2% and 52.9% respectively) are not far removed from the average Amaga-Angelopolis coal. This plant produces sufficient formed coke for FMC's commercial operations in phosphorus production. Trials of the product in blast furnaces have also been carried out.

The process involves a low temperature pyrolysis to give a char and a tar as in the first stage of options 6 and 7, but instead of the tar being distilled, it is air blown to produce the binder for briquetting the char mixed with a certain amount of coal and recycle coke. The briquettes are finally calcined to reduce their volatile matter content to a low level. Volatiles evolved during the calcination are partly used in situ to supply the heat for the process and partly recovered and recycled to the pitch air-blowing reactor. The yield of coke from the coal on a daf basis is reported to be 56.5%. Relating this to Antioquian coal, the production of 500 000 tonne/year of formed coke would require 1.02 million tonnes coal.

The capital costs of the pyrolysis, briquetting and calcination plant and all the ancillary plant is estimated at around $85 million for a plant to make 500 000 tonne/year formed coke. Operating costs are estimated at around $23 million, excluding capital recovery, for a coal price of $16/tonne. The resulting cost for the formed coke is of the order of $70/tonne.

This calculated cost for the formed coke agrees well with that estimated from the data given by P.F. Gill in a paper to the ILAFA Coal Congress held in Mexico City in July, 1976. This paper, entitled 'Future Location of Coke Making: The Role of the Coalplex' gave production costs for a 5 million tonne/year plant. Allowing for 10% inflation since then and applying the accepted scale-down factors for operating and capital costs, the expected cost of the formed coke produced on a 500 000 tonne per year scale works out at $71/tonne.

On this analysis the cost of producing formed coke in Antioquia is higher than the value of the coke assessed in section 7.3.10 at around $60/tonne. It is concluded therefore, that formed coke production from Antioquian coal will not be economical at the scale of operation considered.

It is tempting to suggest that the economics of formed coke production would be made more attractive if the tar from the pyrolysis step were processed to recover phenol cresols and cresylic acids etc., and only the pitch fraction used as a binder. However, the available information indicates that the pitch would not provide sufficient binder to enable satisfactory briquettes to be produced.

8. THE PRODUCTION OF UREA FROM ANTIOQUIAN COAL

8.1 Introduction

Two potential conversion routes have been identified which could lead to the commercially viable production of chemicals based on coal from the new proposed mines in the Amaga-Fredonia area. Both these routes lead to the manufacture of urea. A large demand for this product is predicted in Colombia and the present Colombian urea production facilities are not capable of meeting this demand.

One route proposed, the complete gasification of the coal followed by ammonia and urea synthesis, is a conventional route for which there has been a number of commercial applications in the world. Its sole product is urea.

In the other route proposed, medium temperature pyrolysis of the coal followed by gasification of the char and ammonia and urea synthesis, the volatiles in the coal are removed to a substantial degree before the remaining char is gasified to produce urea. The recovered volatiles are subsequently treated to produce a number of chemicals. This route, therefore, presents the advantage of extracting a wider spectrum of products from the coal. The range of chemical products produced can be varied to some degree to suit the requirements of the market. In addition to urea it could include wood preservation creosote, for which there is a large potential market in Colombia, and a range of chemicals on which a new speciality chemicals industry could be based.

8.2 Status of Coal Gasification for Ammonia and Urea Synthesis

The synthetic ammonia industry was founded on coal as the feedstock for the production of the key intermediate, hydrogen. After World War II, however, coal was largely displaced by natural gas and naphtha which, because of their inherently higher hydrogen content and greater convenience, were more attractive, as well as more economic, feedstocks. Despite this, a number of coal-based ammonia plants have been built since 1950. The majority are quite small, but several rank as present day 'standard' plants, i.e. they produce about 1000 tonnes ammonia per stream day.

Of the existing coal-based plants, four are based on the Winkler fluidised bed gasifier. The largest, located in India, produces about 300 tonnes ammonia per day. Two plants are based on the conventional Lurgi moving-bed, dry-bottom gasifier. The larger of these plants, in Korea, produces 150 tonnes ammonia per day. Ten plants are based on the Koppers-Totzek entrainment gasifier. While the smallest of these plants produces only 100 tonnes ammonia per day, there are three 'standard' plants; two located in India, the third in South Africa.

The Winkler and Koppers-Totzek gasifiers are operated at relatively low pressure (less than 3 bar),but at different temperatures. In the Winkler gasifier, the temperature is carefully controlled so that the ash sinters to form particles of density greater than the average bed density so that ash accumulates at the base of the fluidised bed whence it can be withdrawn continuously with little carbon loss. In the Koppers-Totzek gasifier, the temperature is maintained above the ash fusion temperature and about two-thirds of the ash forms molten slag which drains from the base of the gasifier, while the remainder is entrained by the product gas. The higher temperature increases the rate of gasification, but also shifts the equilibrium so that virtually no methane is produced and tar evolved from the coal is completely gasified.

The Winkler and Koppers-Totzek gasifiers produce raw synthesis gas with hydrogen, carbon monoxide and carbon dioxide as the principal components. After cooling and the removal of entrained fine ash particles, it is compressed and purified by absorption processes. The carbon monoxide is largely converted to hydrogen by reaction with steam (the 'shift' reaction). After further purification, the gas, which has been converted to fairly pure hydrogen, is mixed with nitrogen in the correct proportion and the mixture is converted to ammonia over a highly selective catalyst. This reaction is favoured by high pressure and modern ammonia synthesis plants operate at pressures up to 300 bar in the synthesis stage.

Because it involves pyrolysis as well as gasification, the conventional Lurgi gasifier produces tar as a by-product and yields gas having a considerable methane component (ca. 10%). In the newer slagging version, tar and methane are still produced, but the carbon monoxide content of the raw gas is much higher. Both forms of Lurgi gasifier operate at moderate pressure (20-30 bar). This is a considerable advantage for the gas purification stages and also reduces the compressor duty at the synthesis stage. Methane is inert in ammonia synthesis, but can be converted to hydrogen by reforming to synthesis gas with steam and subsequent 'shifting' of the carbon monoxide to produce more hydrogen. The actual synthesis of ammonia is virtually identical to the description given above.

The chief attractions of the Koppers-Totzek gasification process with regard to ammonia synthesis are consequences of the combination of co-current gasification at a relatively high temperature. With no by-product tar, and no necessity to reform methane, this gasification process is optimised for the production of synthesis gas. However, although Koppers-Totzek gasification has clearly been preferred in the past, it is beginning to lose favour for ammonia synthesis. Its principal defects are the rather low thermal efficiency and the high oxygen demand. Present collaboration between Koppers and Shell is directed toward the development of a pressurised version of this entrainment gasifier. This should facilitate gas purification and improve the economics. The Shell-Koppers pressurised gasifier has been operated successfully at the small pilot plant scale. A demonstration plant is now being built in Hamburg, West Germany, and is due for completion in 1978.

Another new contender is the Texaco coal gasifier which has been developed from Texaco's well proven partial oxidation oil gasifier. In this gasifier, fine coal is injected into the gasifier in the form of a paste with water. The Texaco coal gasifier has been operated successfully at the demonstration plant scale and the detailed design of a commercial scale plant is now being developed. A number of economic advantages are claimed for this gasifier. In the USA, the Tennessee Valley Authority has selected the Texaco gasifier for the retrofitting of their natural gas based ammonia to coal plant. W. R. Grace has also selected this gasifier for their major feasibility study funded by ERDA of a 1200 tonne/day ammonia from coal complex in Western Kentucky. This would be partly owned by W. R. Grace and is scheduled to be operational by the early 1980s.

8.3 Status of Medium Temperature Pyrolysis and Char Gasification

The existing commercial medium temperature carbonisation processes are specifically designed to produce solid smokeless fuel in lump form as the major product. The carbonisation of the lump coal takes place in batch reactors.

The use of a fluidised bed instead of a fixed bed for the pyrolysis of coal reduces the contact time of primary decomposition products with the hot char. This reduces secondary decomposition, leading to a higher yield of tar and a lower yield of gaseous products. Thus for the carbonisation of coal specifically for the production of tar, a fluidised bed process is to be preferred.

Existing commercial fluidised bed carbonisation processes are all low temperature processes developed for the manufacture of smokeless fuels. They produce a low temperature tar which is useless as a chemical feedstock because of its complex and unstable nature.

A number of medium temperature fluidised bed carbonisation processes are in development in the USA for the conversion of coal to cleaner and more readily handled fuels. The oldestand most highly developed of these is the COED process (Char Oil Energy Development), on which research was started by FMC in 1962.

FMC's early interest in coal carbonisation related to the manufacture of smokeless fuels,and later the development of the FMC formed coke process. The aim of the COED development, which was supported by a grant from the US Office of Coal Research (OCR), was initially to produce a sulphur-free char suitable as a clean fuel for electricity generation. The process is based on the multi-stage fluidised bed pyrolysis of coal at medium temperature and produces a medium temperature tar (between 10 and 15% on the coal), gas and char (about 50% on the coal). The char can be used as fuel (however, not sulphur-free as expected), calcined to a metallurgical coke, or gasified. The tar can be hydrogenated to yield a syncrude from which a range of fuels including high octane gasoline, diesel fuel and fuel oils can be made, the hydrogen being provided by gasification of some of the char. Products from the 40 tonne coal/day COED pilot plant at Princeton have been extensively tested. The fuel oil has been successfully used by the US Navy. The kerosine fraction has been used to power full scale jet engines and gas turbines.

Further development in the COED programme has been concerned with the gasification of the char produced in the pyrolysis process. Various gasification processes were considered and the Kellogg molten salt gasifier was proposed for this application in an OCR sponsored study in 1972. However, this process was supplanted in the FMC development programme by the COGAS process.

The COGAS Development Company was formed in 1972 by a consortium of American companies headed by FMC. Its purpose was to study the gasification of COED char and to investigate the conversion of this gas, alone or combined with pyrolysis gas, to substitute natural gas.

The research and testing facilities at the National Coal Board's Coal Utilisation Research Laboratories (formerly BCURA) at Leatherhead, England, were used for this purpose. Char from the Princeton COED pilot plant was shipped to Leatherhead and gasified in a 50 tonnes char/day low pressure steam gasifier.

Results of the successful 18 months COGAS programme at Leatherhead have been so promising that the COGAS process is one of the two SNG-from-coal processes selected for development to demonstration plant scale by ERDA. This commitment is now in the form of a contract to prepare the conceptual design of the plant. The next phase of the development, if sanctioned, will be the detailed design of the plant. This is presently expected to be placed at the end of 1978, to be followed by the construction of the demonstration plant, probably in 1980 and 1981. If the development goes ahead as planned, plant operation could start in 1982. The designed throughput of the demonstration plant is put at 2200 tonnes/day coal and the cost of the complete programme is put at $334 million.

The COGAS process is essentially the combination into an integrated process of COED pyrolysis with char gasification. Its prime objective is the production of substitute natural gas. Hot char from the pyrolysis is introduced directly into a low pressure gasifier where it is reacted with steam to produce primarily hydrogen and carbon monoxide. Heat required for the reaction is produced by the combustion of part of the char with air outside the gasification stream, the hot char being then returned to the gasifier. Thus the gasification reaction does not require oxygen to support it, and air is only used externally to the gasifier for the combustion of the char. The gases produced are primarily intended for conversion to substitute natural gas. However, they can readily be adjusted to produce synthesis gas for other purposes such as methanol and ammonia synthesis.

An advantage of the COGAS process is claimed to be its flexibility. Thus the yield of tar can be varied from 12-15% down to less than 2% depending on the pyrolysis temperature used, and the process can handle a wide range of coals. A further advantage is that it does not require oxygen for its operation. Finally the gasification stage is designed specifically to handle hot, highly reactive char.

Another development of the FMC medium temperature carbonisation technology is the manufacture of metallurgical formed coke. In this application, coal is converted to char in a COED pyrolysis stage with co-production of tar. Tar recovered from the process is used as binder to briquette the char. The briquettes are then subjected to high temperature carbonisation to convert the briquettes to formed coke. This combination constitutes the FMC Formed Coke process. FMC has operated a 250-300 tonne/day formed coke plant in Wyoming since 1960, using a sub-bituminous B coal. This plant produces sufficient formed coke for FMC's commercial operations in phosphorus production in Idaho.

The above review of the status of COED medium temperature process process and its applications indicates that the process, although not used yet at a commercial scale, is well substantiated and can be considered as fully developed.

There are only two other processes for the medium temperature carbonisation of finely divided coal to produce char. These are the Garrett process and the Toscoal process. Neither of these are in an advanced state of development, and neither of these has been selected by any of the US agencies for further development. There are very few details available concerning these processes.

The Garrett process, developed by the Garrett Research and Development Company, is said to be based on the rapid carbonisation of coal by contacting ground coal with hot recycle char. The heat is supplied by the partial combustion of part of the char in a separate vessel. Like the COED process, it yields, gas, tar and char, and the same options are open for the conversion and utilisation of these products. The process is alleged to have been tested on a small scale pilot plant. Its present status of development is unknown.

The Toscoal process is based on The Oil Shale Company's successful shale oil retorting process. It involves the pyrolysis of pulverised coal to medium calorific value gas, medium temperature tar and a char, using a pebble bed heater. The heat transfer medium is heated externally by combustion of part of the char. It has apparently been operated for a short time at a 25 tonne/day scale, probably using existing shale oil retorts. This process has not attracted any US agency money or industrial support.

For the gasification of the char produced in the pyrolysis process, a number of routes are available. If the char is produced by the COED or similar process, it is delivered from the process at carbonisation temperature (700-750°C) and at low pressure. Because of the reactivity of the char, and also for heat economy, it is desirable to feed the char directly to the gasifier, without cooling. Such a feed would cause problems with the usual lock hopper systems feeding pressurised gasifiers. Thus preference must be given in the first instance to low pressure gasification routes capable of operating with hot char.

A prime contender for this duty, would be the COGAS process since this is a combination of the COED process with an integrated gasification section specifically designed to handle the hot COED char. As indicated earlier, a large demonstration plant is being considered to prove this route, the scale of operation being similar to that considered for the proposed plant in Antioquia. If the COGAS development programme proceeds to schedule, commercial scale operating data from the demonstration plant should be available in the course of 1982.

As already mentioned, an early version of the COED/gasification route considered the use of the Kellogg molten salt gasifier for the gasification of COED char. This gasifier was proposed for this application by the American Oil Company in their economic evaluation of the COED process combined with char gasification, prepared in 1972 for OCR. In this process, like in the COGAS process, char is gasified with steam and in the absence of oxygen or air. Reaction heat is provided by a bath of molten salt (sodium carbonate). This is heated externally to the gasification stream by the combustion with air of ungasified char mixed with the molten salt withdrawn from the gasification section of the process. An attraction of the process is that its low pressure operation would be appropriate to the gasification of hot char. Another advantage of the process is that, like the COGAS process, it does not require oxygen for its operation. This gasification has, however, only been operated on a bench scale and there are no plans for its further development for this application, as it has now been superseded by the COGAS route.

The gasification of the char by any of the routes outlined in Section 8.2 is not likely to be feasible or economically viable because of the nature and conditions of the char input.

As outlined in Section 8.2, the Lurgi gasifier itself involves both pyrolysis and gasification and produces tar as a by-product. It can therefore be considered in its own right as a combination of medium temperature pyrolysis and moving bed gasification. Its tar yield is, however, considerably lower than that of the COED/COGAS process and in comparison with these processes, it must be considered very much as a second choice.

8.4 Selection of Model Processes

It was necessary to select specific process routes in order to undertake the appraisal of the two schemes under consideration. The processes selected had to meet the following criteria:

- They had to be representative of the technology likely to be used if the plant were to be built.
- They had to have adequate data available on yields, product composition and other essential process information relating to coals similar in nature to Antioquian coal.

- They had to have adequate information available on capital costs and operating data.

Model process routes were selected with these requirements in mind. The model routes chosen are not necessarily the optimum process routes, nor even, in the case of the gasification of char produced by medium temperature carbonisation, a route which would be considered for commercial application, because of its incomplete state of development. However, it is believed that the model processes selected are reasonably representative of the technology that would ultimately be used and therefore sufficient to provide meaningful economic appraisal data. The determination of the optimum route for any one scheme would be a major task for a detailed feasibility study.

Because Antioquian coals have not previously been utilised as proposed, part of the appraisal has been to locate suitable data for the utilisation of similar coals. This has, fortunately, been possible in all cases considered. However, it must be emphasised that large scale testing of Antioquian coals would be essential to confirm that the parallels drawn in this appraisal are really valid. Where assumptions and interpretations of information were made, the aim has been to be conservative so that the final economic assessment is not overly optimistic.

The model processes and data sources used are described below. Because the processes for the economic appraisal are generally unlikely to be those that would be later implemented, detailed process descriptions have not been undertaken. However, a brief outline of the processes used for the appraisal is given, illustrated by block flow diagrams indicating the mass balance of the primary products. The tar processing plant is described in somewhat greater detail because the processes proposed are less liable to change.

8.5 Selection of Plant Capacity

In the selection of plant capacity, three main factors have been taken into account. These are:

- Optimum size of process units.
- Availability of feedstock.
- Size of potential market.

Economy of scale dictates that present day synthetic ammonia plants have generally a capacity of 1000 tonnes/day ammonia. Because of this, most of the up-to-date published information about investment and operating costs relate to plants of this size. One or two 1500 tonnes/day plants are in existence, but these are still the exception. Coal requirements of a 1000 tonne/day ammonia plant are of the order of 1 million tonnes/year.

The mining survey has established that up to 2 million tonnes/year of coal could be produced from the new mines proposed. However, predictions of future local coal demand suggest that some of this output should be reserved to satisfy this demand. An allocation of around 1 million tonnes/year of coal for the ammonia plant appears sensible.

Based on these considerations, a capacity corresponding to 1000 tonne/day of ammonia has been selected. No substantial market for ammonia in Antioquia has been identified. It has therefore been assumed that the total make of ammonia would be converted to urea. The annual production of the plant would be around 579 000 tonnes/year of urea, based on 330 days operation at 100% output. Predictions of future urea demand in Colombia indicate that such an output of urea could be absorbed by the Colombia market. This topic is considered in further detail in Section 12.1.

8.6 Scheme 1 - Medium Temperature Carbonisation and Char Gasification to Produce Ammonia for Conversion to Urea

8.6.1 General Process Route

Coal is subjected to pyrolysis at 700-750°C to give a gas used internally as fuel in the process, a reactive char, a medium temperature tar and an aqueous liquor. The char is gasified to yield a gas which, after treatment and removal of carbon dioxide and sulphur compounds, provides the hydrogen for ammonia production. An air separation plant provides the nitrogen necessary for the ammonia synthesis. The ammonia is finally combined with the recovered CO_2 to yield urea. The sulphur compounds from the gas are recovered to produce elemental sulphur.

The aqueous liquor containing dissolved phenols, ammonia and ammonium salts is treated for the recovery of these products, in order to improve the economics of the process, and to reduce the phenol and ammonia contents of the final effluent to levels acceptable to the environment.

The crude medium temperature tar is distilled to yield light oil, middle oil, heavy oil and pitch. The middle oil fraction is rich in phenols (tar acids) and these are extracted with caustic soda. The tar acids, together with part of the phenols extracted from the liquor, are fractionated to yield phenol, cresols and a range of cresylic acids. The dephenolated middle oil, the heavy oil and pitch are blended with, where required, some of the cresylic acids or light oil to produce wood preservation creosote, cresylic creosote and coating compounds.

8.6.2 Model Processes Selected and Data Sources

For both the pyrolysis and the gasification stages, the preferred process, on present knowledge, would probably be an adaptation of the COCAS process. However, data for the evaluation of this route is incomplete, particularly on the cost side. As a result earlier better documented versions of the process route were selected as the model processes.

For the pyrolysis stage, the COED fluidised bed pyrolysis process was selected. This is, to a large extent, identical with the pyrolysis stage of the COGAS process which is derived from it. The COGAS process in its present configuration does not use oxygen in the last pyrolysis stage, unlike the COED process. However, the cost effect of this is likely to be small, in view of the fact that an air separation plant is required in any case for the ammonia synthesis plant.

For the gasification stage the Kellogg molten salt gasification process was selected as the model process. This process is an early gasification process evaluated for application with hot reactive char from the COED process. Although the molten salt gasifier is very different in concept with the gasification stage of the COGAS process, the two processes have some similar operating characteristics. They are both conceived to handle hot char, they both employ low pressure steam gasification in the absence of oxygen or air, they are both heated externally to the gasification stream by the combustion of some of the char. Neither of them requires any oxygen from an air separation plant.

The basic concept is a plant to produce 1000 tonnes/day of ammonia resulting in an annual urea production of about 579 000 tonnes/year. It has been assumed that the as-mined coal would have a moisture content equivalent to the capacity moisture content found for coal sample No.1, i.e.19.3% (see Appendix 3, Table A3.7). This would produce about 80 000 tonnes/year of medium temperature tar, fuel gas for some of the plant's energy requirement, and about 364 000 tonnes char/year. The highest operating temperature in the pyrolysis process would be about 765°C. The yields of these products are based on data published in Office of Coal Research R&D Report No.73 - Interim Report No.1 (prepared by the FMC Corporation) covering pilot plant operations on a scale of 36 tonnes coal/day with a sub-bituminous B coal (Big Horn strip mine, Monarch seam, Sheridan Wyoming) between 1971 and 1972. Analytical data for this coal and the averaged analytical data for bulk samples 1, 2, 4, 5, 6, 7 Antioquia coals were compared. The higher carbon content and lower oxygen content of the Antioquia coals show that they are of somewhat higher rank than the Wyoming coal. It has been assumed, however, that the coals are sufficiently similar to justify basing the study on the data for the Wyoming coal tests in the COED pilot plant.

The American Oil Company, in their economic evaluation of the COED process plus char gasification prepared for the OCR in 1972 (OCR R&D Report No.72), evaluated the air blown version of the Kellogg molten salt process. The American Oil Company design study related to the production of substitute natural gas (SNG) by this process combination. In the present study, the synthesis gas is shifted to produce hydrogen for the ammonia plant. The necessary adjustments have been made to the conceptual design to meet that requirement.

The design of the gasification section is a modification - for low-pressure operation - of a conceptual commercial design proposed by Kellogg in OCR R&D Report No.38 (1970).

The unit processes in the scheme following the gasification stage are all well known and in full commercial operation. The gasification stage produces more than 500 000 tonnes/year of raw synthesis gas. The Rectisol process is nominated for gas cleaning prior to and after the shift converter stage. The annual production of pure hydrogen is just less than 60 000 tonnes. This is converted to ammonia in a conventional syntheis unit (Kellogg, Snamprogetti or ICI). Nitrogen for ammonia synthesis is produced by an air separation plant processing just over 1000 tons air/day. The oxygen produced by the air separation plant, 81 000 tonnes/year, represents about 9000 tonnes/year in excess of the demand for the COED pyrolysis stage. Thus, a valuable co-product is available for sale to local industry.

The ammonia is converted to urea by a conventional process (e.g. Snamprogetti or Stamicarbon). The pure carbon dioxide required is provided from the second stage Rectisol unit (i.e. after the shift stage) The total make of ammonia is converted to urea, so that the annual production of urea is about 580 000 tonnes.

The nature of the tar and the yield of the various fractions likely to be obtained on its processing are based on an analysis obtained from the COGAS Development Co. and assays of medium temperature tars produced from low rank bituminous coals publisned by the British Coal Tar Research Association. It is known that the chemical nature of a coal tar (though not the yield) depends mainly on the temperature of carbonisation and is little affected by the nature of the coal.

The process selected for the recovery of tar acids and ammonia from the crude carbonisation liquor is the modified Lurgi 'Phenosolvan' process currently employed on a comparable scale by Coalite and Chemical Products Ltd. of Bolsover, England.

For the tar distillation unit, the atmospheric pressure: vacuum system developed by Koppers-Teerverwertung of Essen has been selected in view of the probably restricted thermal stability of the tar.

For the extraction of tar acids from middle oil, the system currently used by Croda Hydrocarbons, Knottingly, England, has been selected. In this system the phenol-bearing oil is extracted with 10% caustic soda solution and the crude phenate, after purification, neutralised with sulphuric acid. This method has been selected rather than the more usual lime recausticisation method on environmental grounds, since it does not involve the production and disposal of 'lime mud'.

The fractionation of the tar acids is a well developed process as used by the British Steel Corporation in the UK, the Allied Tar Acid Refiners in South Africa and a number of other producers.

8.6.3 Process Description

The block flow diagram for the process is shown on Figure 12. This gives the overall material balance for the primary products.

Coal delivered from the mine is reduced to minus 1/8 inch (3.2 mm) size in the coal preparation section and subsequently dried. The coal is then led to a COED four stage pyrolysis unit. This consists of four fluidised medium temperature carbonisation reactors where the coal is pyrolised at successively increasing temperatures. Heat for the process is generated by burning char in the fourth stage and by using the hot gases and hot char to supply the heat for the other stages. Some oxygen from the air separation plant, used to produce the nitrogen for the ammonia synthesis plant, is fed to the last stage of the pyrolysis. Fuel gas produced in the pyrolysis is used to provide heat for the coal drier and first stage pyrolysis and the surplus is used in utilities generation. Pyrolysis tar is filtered and fed to a tar refinery, where it is refined into a number of products and chemicals. Aqueous liquor produced as the result of the pyrolysis gas clean-up is circulated to a phenol and ammonia recovery unit where these by-products are extracted.

Char from pyrolysis is gasified by reacting with steam in a bath of molten sodium carbonate in the gasifiers. The Kellogg molten salt gasifier is an integral gasifier/combustor. This is a divided vessel where the gasification process is isolated from the combustion process. Air is used to generate heat by combusting part of the char, dispersed in the salt, and the flue gas leaves the combustor separate to the gasification stream. The concentration of ash in the gasifier/combustor is

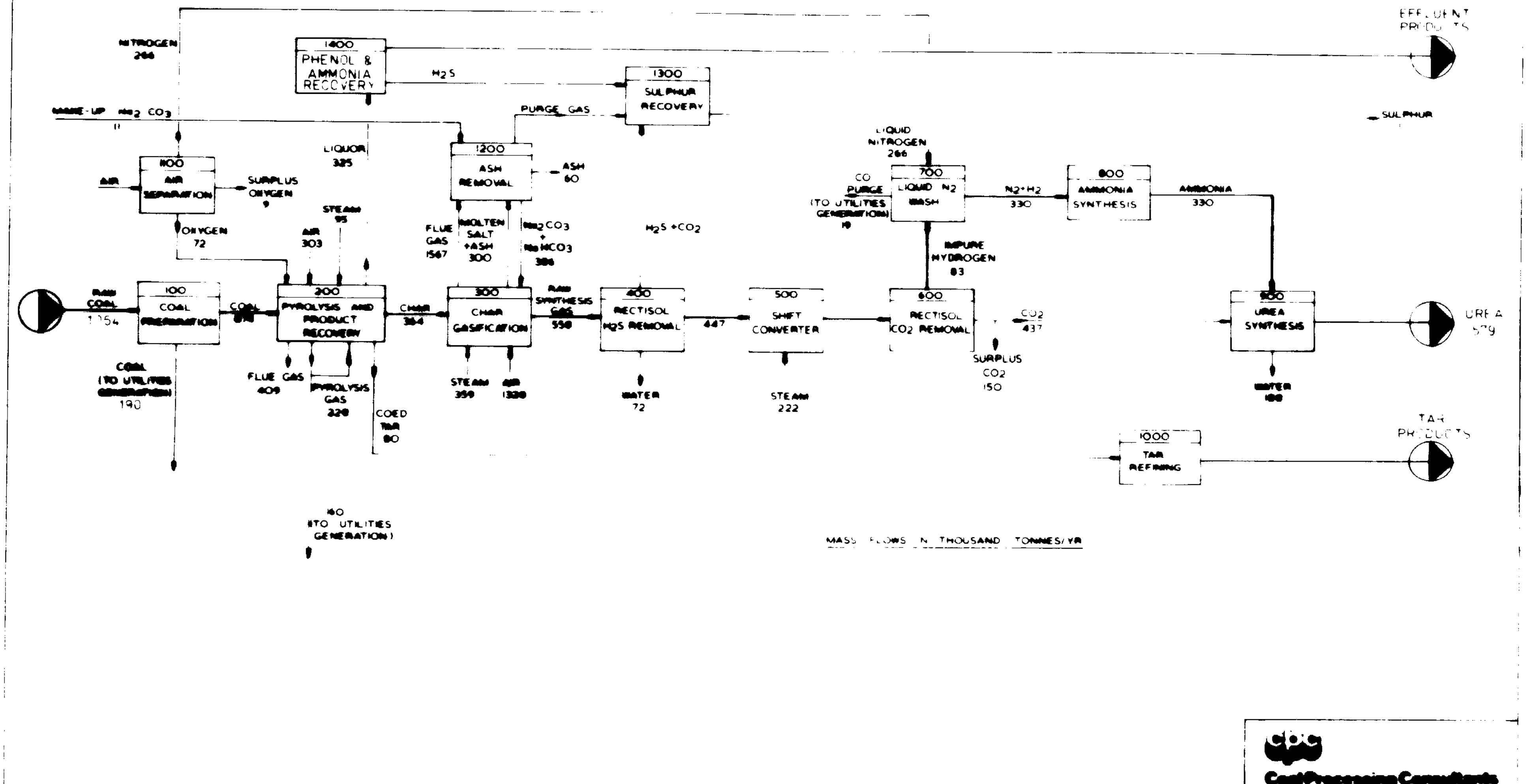

Figure 12

BLOCK FLOWSHEET - COED PLUS MOLTEN SALT GASIFICATION FOR UREA SYNTHESIS controlled by withdrawing part of the molten salt, calcining residual carbon, separating the ash and recycling the molten salt together with make-up salt to the gasifier/combustor.

The raw synthesis gas from the char gasification is compressed and fed to a Rectisol unit where H_2S and some CO_2 are removed. This gas is shifted to convert most of the CO to H_2 and CO_2. CO_2 is removed in a second Rectisol stage to give a gas consisting of hydrogen, together with small quantities of other gases. These other gases (mainly CO) are removed in a liquid nitrogen wash and are used as a fuel for utilities generation. The nitrogen is supplied by a cryogenic air separation plant. Gas streams containing sulphur compounds are fed to a Claus plant where they are converted to elemental sulphur.

The purified hydrogen and the nitrogen introduced in the liquid nitrogen wash is compressed and fed to a conventional high pressure ammonia synthesis loop. The ammonia produced is reacted with CO_2 from the second stage Rectisol unit to produce urea which is packaged for sale.

The necessary utilities are produced in an integrated utilities plant using coal, surplus pyrolysis gas and a CO purge gas as the fuel. The utilities plant includes electric power generation and steam generation. A pumping station is also included for pumping the plant's water requirements from a nearby river.

8.6.4 Tar and Effluent Processing

Aqueous liquor from the pyrolysis section is treated in a phenol and ammonia recovery unit. Phenols and a concentrated ammonia liquor are recovered for marketing. Instead of the ammonia liquor, ammonium sulphate can be produced. Filtered pyrolysis tar is refined into a range of products in a number of process units. The products of tar processing are either marketed as they are, or blended to produce a range of products. The pattern of products can be varied by appropriate blending and suited to the market requirements. The recovery and refining process are described below.

1. Recovery of Phenols and Ammonia from Crude Liquor

The crude liquor from storage is extracted with about one seventh of its seight of butyl acetate, some of which has previously been used to wash the sodium sulphate solution obtained on springing the phenols from tar middle oil. The extraction is carried out in 5 pairs of ring-packed towers in parallel. Each pair of towers is in series and the flow of liquor and extractant is countercurrent. The extract from the second tower of each pair passes to the extract storage tank from which it is pumped to the 6th plate of a twelve-plate fractionating column via a steam preheater. Recovered butyl acetate is taken as overheads and returned to the butyl acetate storage tank, while the recovered phenols pass from the base of the extract still as feed to a second twelve-plate fractionating column where they are split into monohydric phenols (0-250°C boiling range) as overheads and a higher boiling cresylic acid fraction rich in dihydric phenols.

The raffinate flowing from the base of the first of each pair of columns passes to raffinate storage and, in order to recover the dissolved butyl acetate, is steamed in a packed column to give about 1.5% distillate. This on cooling separates into a rich butyl acetate upper layer, which is returned to extract storage, and a lower layer which passes to raffinate storage. The dephenolated liquor from the base of the raffinate stripper passes directly to the ammonia recovery still.

In order to minimise the loss of butyl acetate, the extract and butyl acetate storage tanks, the raffinate stripped decanter and the vacuum pump seal on the extract still are vented to a small packed water scrubber, the effluent from which is added to the raffinate stripper decanter.

Figure 13 is a quantitative flowsheet of this part of the complex, based on a crude liquor flow of 325,000 tpa, a phenol content of crude liquor of 1.35% by weight and fixed and free ammonia contents

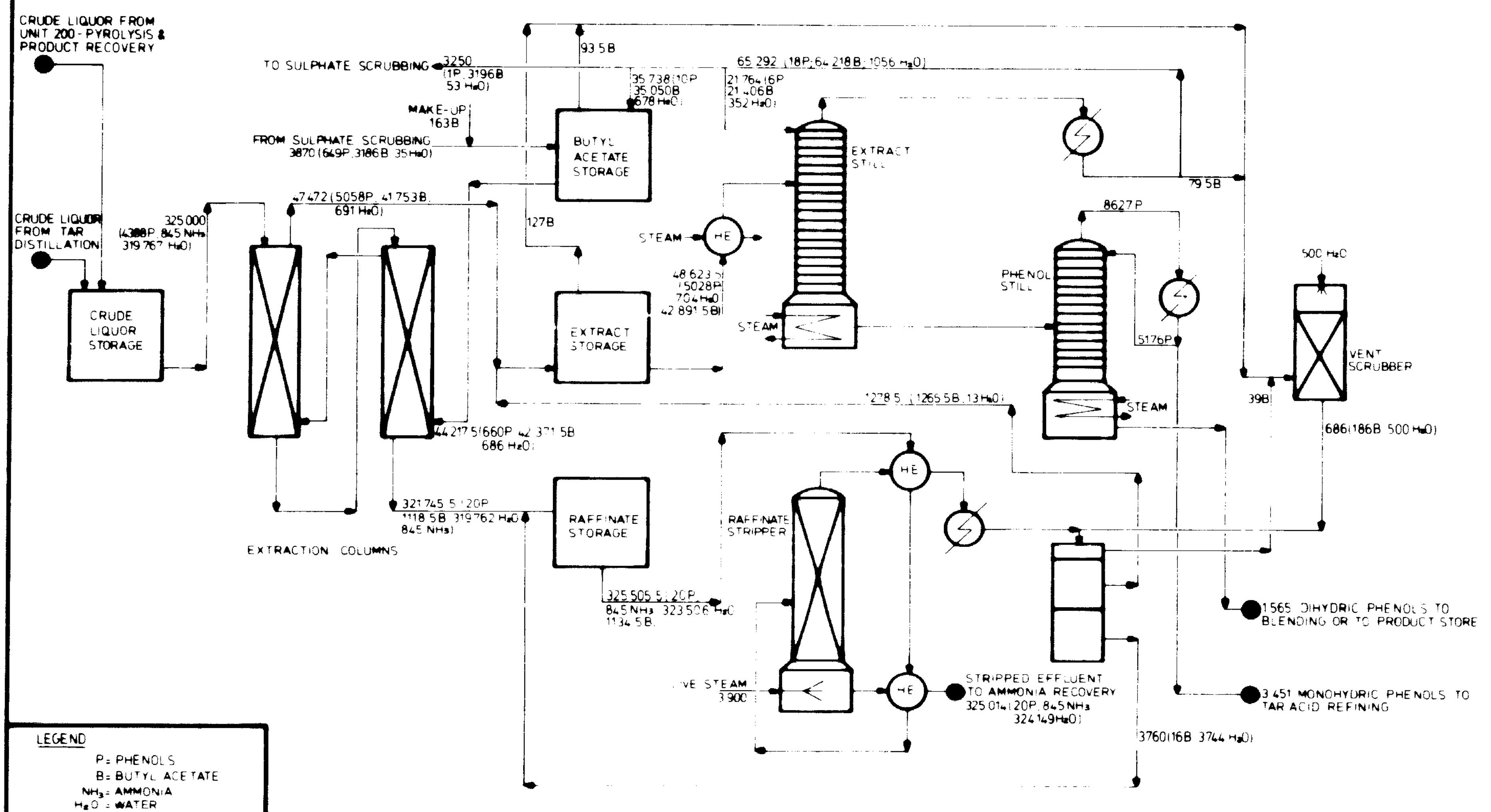

FIG. 13 FLOWSHEET UNIT 1400 - RECOVERY OF PHENOLS FROM LIQUOR

(ALL FIGURES ARE IN TONNES/YEAR)

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of 0.14% and 0.12% by weight respectively. Figure 14 illustrates the ammonia recovery section, which follows the well known process applied at coke ovens or town gas works. In the flowsheet, the product is concentrated aqueous ammonia, but as an alternative, the vapour from the ammonia still dephlegmator can be introduced into a saturator with the appropriate amount of sulphuric acid to produce ammonium sulphate as in the 'direct' coke oven by-product recovery process. Output of ammonium sulphate in the scheme under consideration would be 3020 tpa for the consumption of 2875 tpa 60 Be acid.

2. Tar Distillation

The crude tar separated from the liquor is expected to contain 5% of entrained and dissolved liquor. Figure 15 illustrates the distillation of 80 000 tpa of crude tar which, it is estimated, will be produced in the plant. The process is quite simple. The crude wet tar is first heated to about 150°C by heat exchange with middle and heavy oil vapours and passage through a waste heat coil in the helical coil heater. The hot crude tar is injected into the baffled dehydrator where most of the liquor and light oils flash off. These are condensed and separated in a decanter. A portion of the light oils is passed back to the dehydrator to assist vaporisation and the remainder furnishes reflux for the atmospheric pressure fractionating column. The separated liquor is returned to the crude liquor storage tank.

The dehydrated tar, after heat exchange with the hot pitch, is raised to 300°C in the main heating coil in the furnace and injected into the atmospheric pressure fractionating column, from which residual light oil and liquor is taken off as a small overhead stream, middle oil as a side stream and base tar (heavy oil plus pitch) as a bottom product. The middle oil is fed to a small stripping column from the base of which a close cut middle oil,

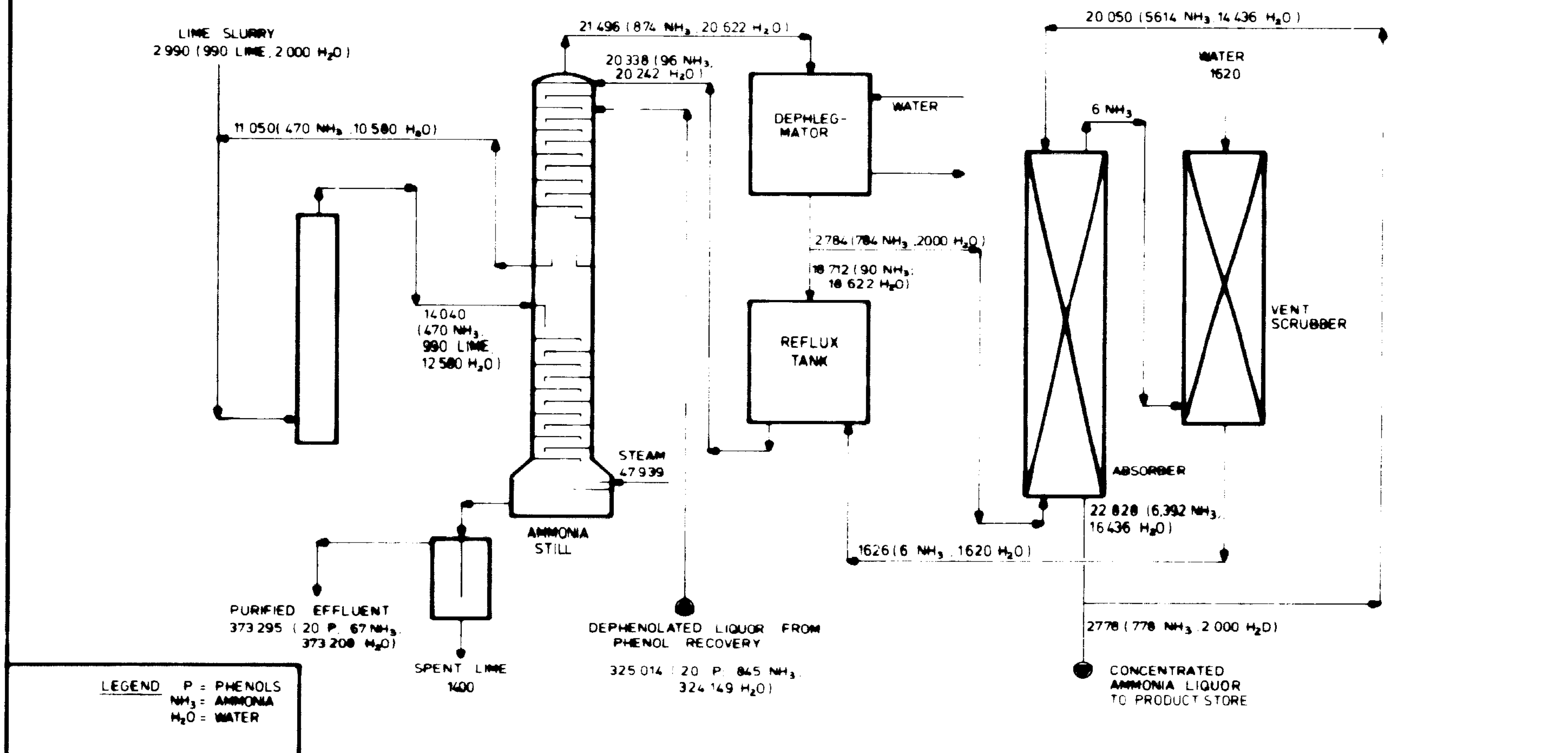

FIG. 14 FLOWSHEET UNIT 1400 - RECOVERY OF AMMONIA FROM LIQUOR

(ALL FIGURES IN TONNES / YEAR)

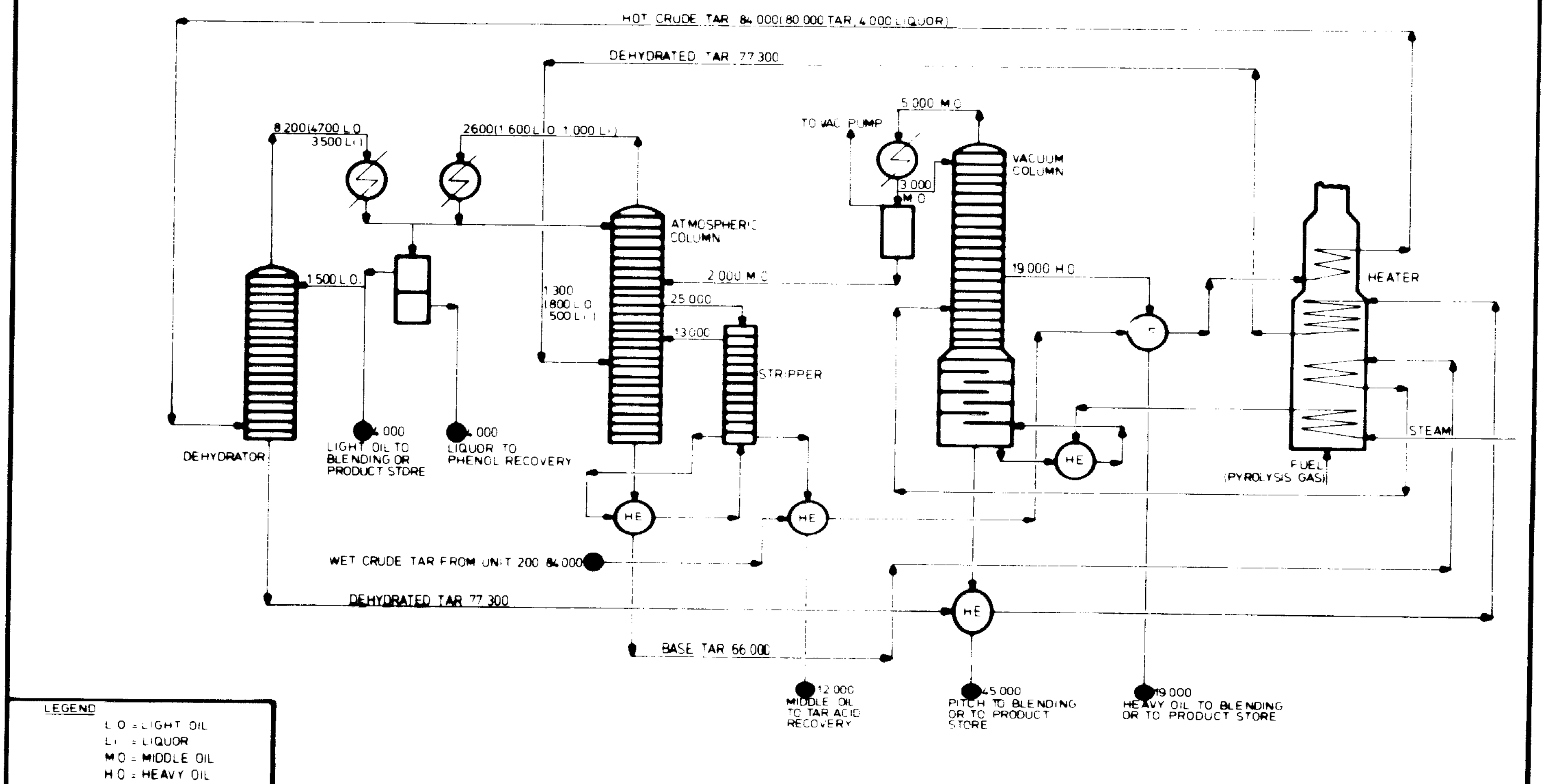

FIG.15 FLOWSHEET UNIT 1000 - TAR DISTILLATION

(ALL FIGURES ARE IN TONNES/YEAR)

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expected to contain 41.5% of tar acids, is removed. The light oil and liquor overheads are cooled and the condensate added to the dehydrator decanter from which the make of light oil and liquor are taken.

The base tar is pumped through a small auxiliary coil in the furnace and reheated to 300°C before entering the vacuum fractionating column as feed. An overhead fraction from this column is taken and passed back to the atmospheric pressure column as reflux for the lower half. Heavy oil is removed as a side stream and pitch as the residual product.

3. Recovery of Tar Acids from Middle Oil

This follows conventional practice except that sulphuric acid rather than CO_2 is used for decomposing the sodium phenate. In the normal practice, using flue gas for springing the phenate, the sodium carbonate/bicarbonate solution is recausticised by the addition of quicklime. This, however, results in a precipitate of calcium carbonate or 'lime mud' the disposal of which presents an increasingly serious problem. Of the methods adopted to solve this problem the use of sulphuric acid as the neutralising agent, when, as in Colombia, there is a market for sodium sulphate as an aqueous solution or the crystalline decahydrate, appears to be the most attractive.

Figure 16 illustrates the process. The middle oil is first extracted with a small excess of 10% aqueous caustic soda (this contains some sodium phenate since the 'phenol-water' fraction from the flash distillation of the crude wet tar acids is used to dilute the caustic soda), the crude phenate separated from the washed middle oil in a separator and the phenate freed from some coextracted neutrals and unreacted phenols and bases by steaming. The purified phenate is then treated with an equivalent amount of concentrated sulphuric acid to yield the crude tar acids and a solution of sodium sulphate, in which a small amount of phenols are dissolved, as separate layers. These are separated in a decanter and the

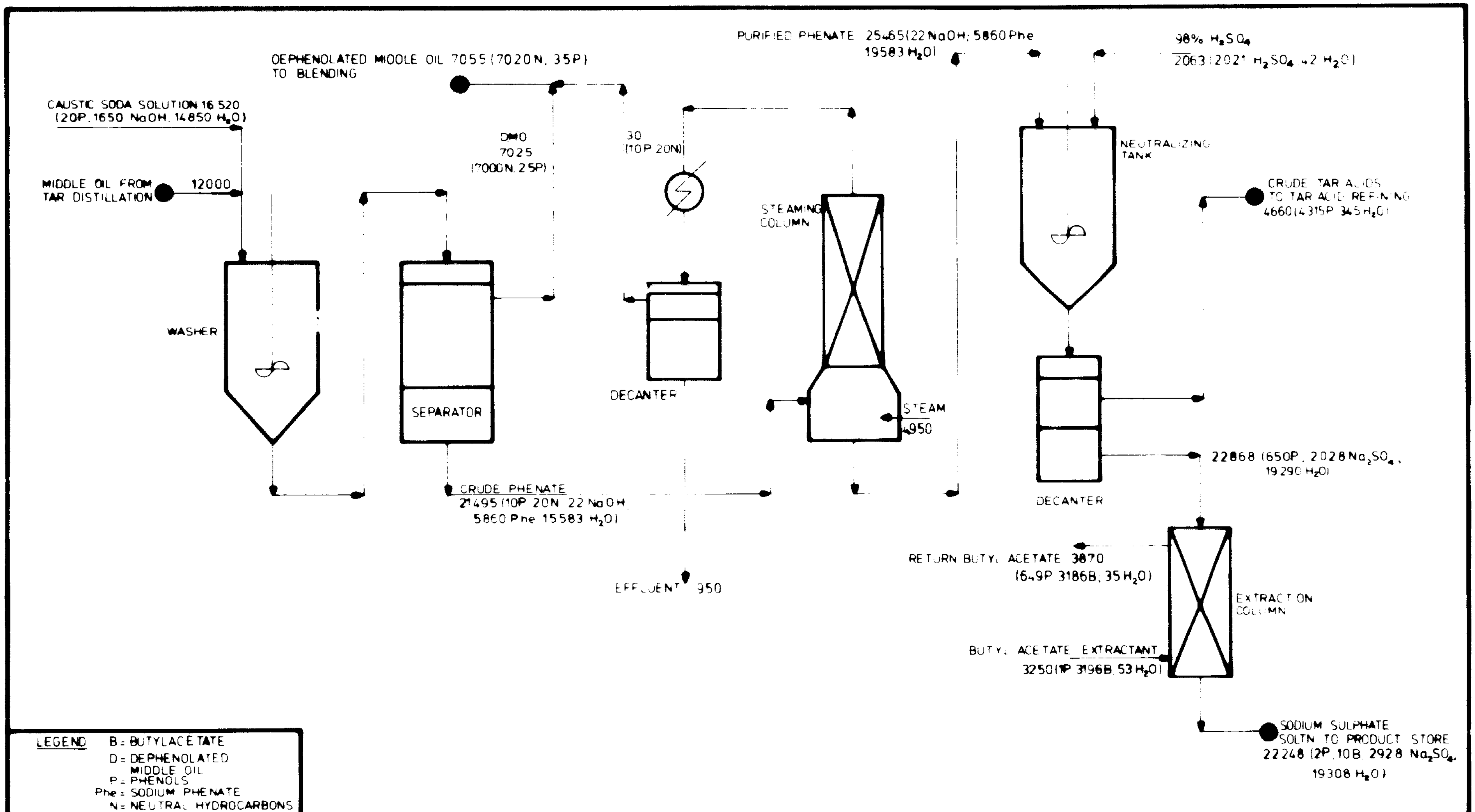

FIG. 16 FLOWSHEET UNIT 1000 - RECOVERY OF TAR ACIDS FROM MIDDLE OIL

(ALL FIGURES ARE IN TONNES/YEAR)

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sodium sulphate freed from phenols by extracting with butyl acetate. The treated sulphate solution can be evaporated to yield a saleable Glauber's salt or a solution which has been found suitable for use in the paper industry.

For the initial extraction of phenol bearing tar oils, many types of contacters are in use, ranging from pulsed or unpulsed columns, disc contacters, Colby 'raining bucket' extracters and simple stirred tanks. The type of mixer which give sufficiently good contact between the phases to ensure rapid and complete extraction of the phenols without causing undesirable emulsions, depends on the nature of the tar. In the flowsheet, a simple stirred mixing vessel is depicted.

4. Fractionation of Tar Acids

The crude wet tar acids extracted from the tar middle oil are mixed with monohydric phenols from the liquor and subjected to a preliminary flash distillation in a packed or valve tray column to yield an aqueous solution of phenol ('phenol-water') as a small overhead fraction, once-run tar acid as a side stream and a residue of phenolic pitch which is usually used as fuel. The once-run tar acids may be passed as vapour directly to the phenol still or may be condensed and stored until required. Specification grade phenol is taken as distillate from the phenol still and o-cresol as the distillate from the o-cresol still. The residue from this second of the two continuous stills is stored until required and fractionated in a batch still to give m/p-cresol mixtures and various grades of cresylic acid. To avoid atmospheric pollution and minimise loss of phenols, the vacuum pump delivery as well as the storage tanks are vented to a small caustic scrubber, the effluent of which is added to the caustic dilution tank.

The calandria in the reboilers of the stills in a tar acid refinery corrode rapidly unless made of stainless steel and, to prevent discolouration of the distilled phenols (an important sales point), the condensers, run-down lines and intermediate storage tanks must be fabricated in stainless steel or a non-ferrous metal like nickel or tin. There is also a choice between operating at atmospheric pressure with circulating hot oil heating or under reduced pressure with high pressure steam or hot oil as the heating medium.

The process is depicted in Figure 17. The design of the plant for the purpose of its evaluation is based on the use of vacuum stills with cast iron shells and stainless steel valve trays, stainless steel reboilers and calandria heated by circulating hot oil. The condensers, run-down lines and intermediate storage tanks are also in stainless steel.

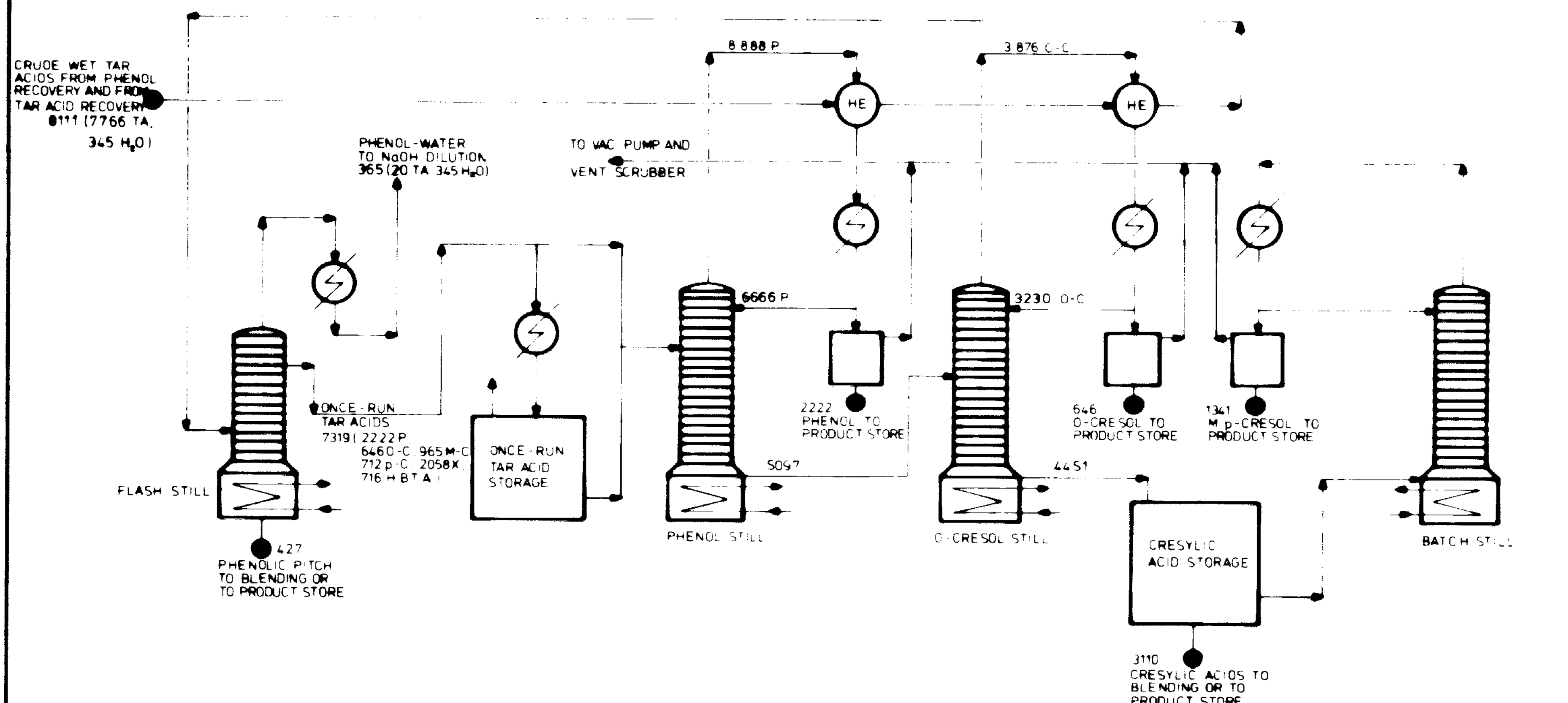
8.6.5 The Products of Tar and Effluent Processing

The primary products derived from the 80 000 tpa crude tar and 325 000 tpa crude liquor which it is estimated the scheme outlined above would produce are listed in Table 8.1 below.

Table 8.1 - Primary Products of Tar and Effluent Processing

Product	Output
	Tonnes/year
Concentrated ammonia liquor[(1)]	2 828
Sodium sulphate decahydrate (Glauber's salt)	6 640
Phenol	2 222
o-Cresol	646
m/p-Cresol	1 341
Cresylic acids (including a dihydric phenol concentrate)	4 675
Light oil	4 000
Dephenolated middle oil	7 055
Heavy oil	19 000
Pitch	45 000
TOTAL	93 407

(1) This can be replaced by ammonium sulphate at 3020 tonnes/year



LEGEND
TA = TAR ACIDS
P = PHENOL
O-C = O-CRESOL
M-C = M-CRESOL
p-C = p-CRESOL
X = XYLENOLS
HBTA = HIGH BOILING TAR ACIDS

FIG. 17 FLOWSHEET UNIT 1000 - TAR ACID REFINING

(ALL FIGURES ARE IN TONNES/YEAR)

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The last five items in this table can be blended in a variety of ways to yield saleable products and the product disposal pattern selected would materially affect the revenue derived from these by-products.

The simplest and least lucrative disposal pattern would be to sell the light oil as a petrol blending agent or solvent, and blend the residual oils and pitch for sale as a liquid fuel oil. The products under this first pattern are listed in Table 8.2 below.

Table 8.2 - Disposal Pattern 1 for Products of Tar and Effluent Processing

Product	Output tonnes/year	Product Value Assumed $/t	Production Value $/year
Concentrated liquid ammonia	2 828	30	84 840
Glauber's salt	6 640	84.5	561 080
Phenol	2 222	562	1 248 764
o-Cresol	646	1050	678 300
m/p-Cresol	1 341	1050	1 408 050
Cresylic acids	4 675	1000	4 675 000
Light oil	4 000	152.5	610 000
Fuel oil	71 055	75	5 329 125
TOTAL	93 407		14 595 159

The market survey identified the most valuable bulk tar products as cresylic creosote at $819/tonne and wood preservation creosote at $330/tonne (see Section 7.3). The most attractive tar products disposal pattern would be to maximise these products. The resulting pattern is given in Table 8.3.

Table 8.3 - Disposal Pattern 2 for Products of Tar and Effluent Processing

Product	Output tonnes/year	Product Value Assumed $/t	Production Value $/year
Concentrated ammonia liquor	2 828	30	84 840
Glauber's salt	6 640	84.5	561 080
Phenol	2 222	562	1 248 764
o-Cresol	646	1050	678 300
m/p-Cresol	1 341	1050	1 408 050
Cresylic acids	1 663	1000	1 663 000
Light oil	2 732	152.5	416 630
Cresylic creosote	10 040	819	8 222 760
Wood preservation creosote	25 370	330	8 372 100
Pitch	39 925	129	5 150 325
TOTAL	93,407		27 805 849

The actual disposal pattern selected will obviously be chosen to suit the potential markets. A third specimen product pattern can be worked out on the assumptions, for example, that the possible market for cresylic creosote would be 3000 tpa, that for wood preservation creosote would reach 10 000 tpa, that markets for pipe coating enamels and black varnishes could be established and that there would be an almost unlimited demand for road tar. The products produced in this pattern are listed in Table 8.4.

Table 8.4 - Disposal Pattern 3 for Products of Tar and Effluent Processing

Product	Output tonnes/year	Product Value Assumed $/t	Production Value $/year
Concentrated ammonia liquor	2 828	30	84 840
Clauber's salt	6 640	84.5	561 080
Phenol	2 222	562	1 248 764
o-Cresol	646	1050	678 300
m/p-Cresol	1 341	1050	1 408 050
Cresylic acids	3 475	1000	3 475 000
Cresylic creosote	3 000	819	2 457 000
Wood preservation creosote	10 000	330	3 300 000
Pipe coating enamel modulate (1)	555	220	122 100
Black varnish	1 000	125	125 000
Road tar	54 900	) 129	7 959 300
Pitch	6 800	)	
TOTAL	93 407		21 419 434

(1) This will give 1000 tonnes/year of enamel when combined with 185 tonnes/year of coal and 260 tonnes /year of talc or slate flour.

8.6.6 Manpower Requirements

Four shift operation of the complex would be necessary, with the exception of product dispatch. Manning requirements for the process plants have been assessed, allowing for a modest increase over US and Western European practice. Maintenance staff have been allowed for at 110% of the operating staff, in accordance with current Colombian practice. Appropriate additions have been made for general plant services, supervision and administration.

The total workforce of the complex is estimated at about 850 people of which around 600 would be operators, labour and maintenance fitters, and 250 would be salaried staff.

8.7 Scheme 2 - Total Gasification of Coal to Produce Ammonia for Conversion to Urea

8.7.1 General Process Route

Coal is reacted with oxygen and steam at high temperature to yield a gas which, after treatment and removal of carbon dioxide and sulphur compounds, provides the hydrogen for ammonia production. An air separation plant provides the oxygen for gasification and the nitrogen for ammonia production. The ammonia is finally combined with the recovered CO_2 to yield urea. The sulphur compounds from the gas are recovered to produce elemental sulphur.

8.7.2 Model Processes Selected and Data Sources

A number of gasification processes could be used for the production of the synthesis gas, some of which have been used commercially for this purpose.

The newly developed Texaco gasifier is claimed to have economic advantages over its competitors. It has been successfully proven at the demonstration plant scale. The Texaco process is the route which has been chosen for several recently planned commercial facilities in the USA for the production of ammonia from coal.

The gasification process which has been the most widely used to date is the Koppers-Totzek process, and this is the model process which has been selected for this scheme. This selection was made, because the process is the most widely used and because adequate published data is available.

The basic concept is a plant to produce 1000 tonnes/day ammonia resulting in an annual urea production of about 579 000 tonnes. It has been assumed that the as-mined coal would have a moisture content equivalent to the capacity moisture content found for coal sample No.1, i.e. 19.3% (see Appendix 3, Table A3.7).

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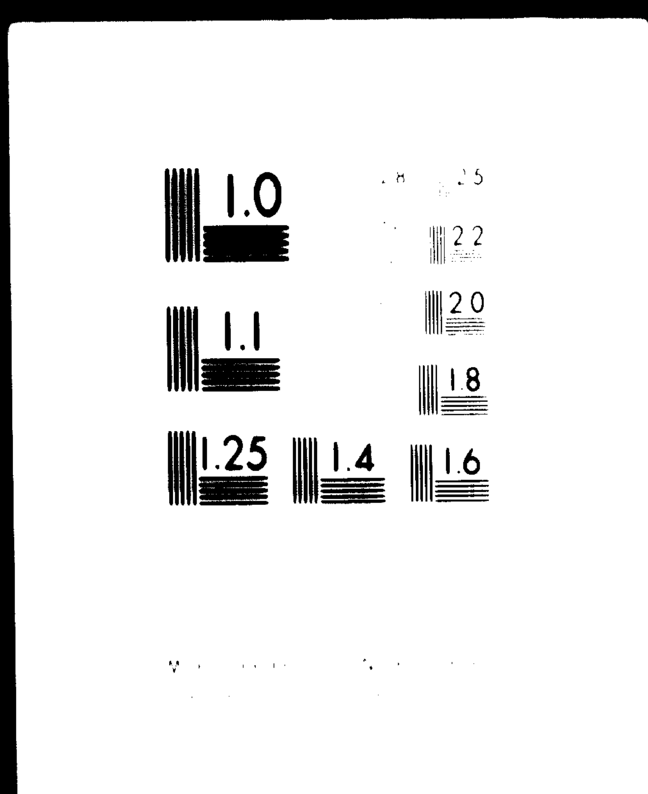

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The principal reference source was a paper by Wintrell of Koppers (USA) to the American Institute of Chemical Engineers in 1974[1] which gives some data for a 1000 tonne/day plant operating, unfortunately, with a bituminous coal. However, this was supplemented by information given in a paper published in the Proceedings of the 1973 Symposium on Clean Fuels from Coal of which Wintrell was a co-author[2]. This earlier paper gives gasifier data for three US coals - a Western coal, an Illinois coal and an Eastern coal - and shows how synthesis gas of roughly similar composition could be produced from these different coals by varying the proportions of oxygen and steam used for gasification. The western coal's analysis was virtually identical with the averaged analysis for Antioquian coals. This permitted a fairly reliable estimate for oxygen and steam requirements in the present study.

The major process quantities are shown on the flowsheet in Figure 18.

Scheme 2 has a lower specific coal requirement per tonne of urea than Scheme 1, but this ignores the substantial output of by-product chemicals. Scheme 2 has a high oxygen requirement, hence requires a large air separation plant. As a consequence, Scheme 2 produces a large excess of nitrogen. Finally, Scheme 2 has a much higher coal requirement for energy generation that Scheme 1 denoting a less energy efficient process route.

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(1) The K-T Process: Koppers commercially-proven coal and multifuel gasifier for synthetic gas production in the chemical and fertiliser industries. R. Wintrell. Paper presented at National Meeting of the A.I.Chem.E., Salt Lake City, Utah, August 1974.

(2) Production of gas from coal by the Koppers-Totzek process. Farnsworth, Leonard, Mitsak and Wintrell. Paper presented to the 1973 Symposium on Clean Fuels from Coal, organised by the Institute of Gas Technology, Chicago.

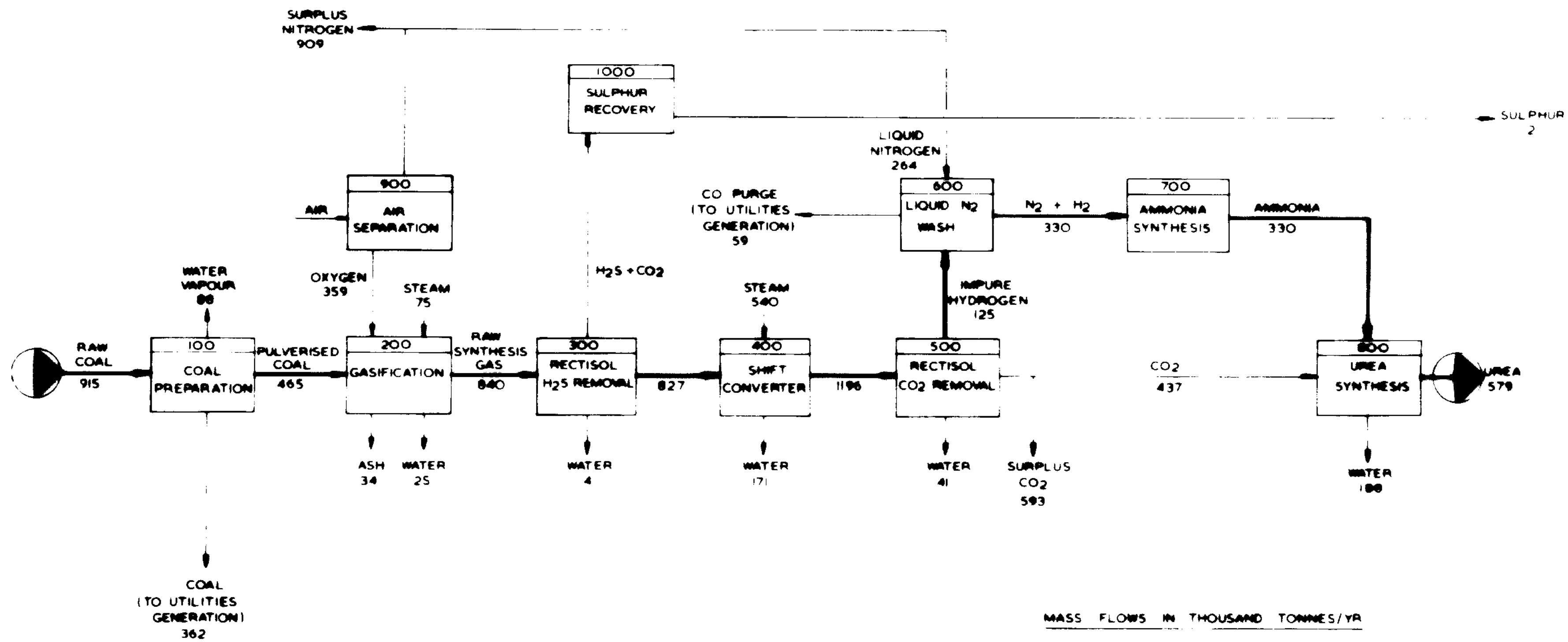


Figure 8 BLOCK FLOWSHEET – KOPPERS-TOTZEK GASIFICATION FOR UREA SYNTHESIS

Coal Processing Consultants
Date April 1978 Project SD 5527

8.7.3 Process Description

Coal delivered from the mine is pulverised and dried in the coal preparation section. The ground coal is injected with steam and oxygen into the Koppers-Totzek gasifiers. The Koppers-Totzek gasifier is a high-speed entrained gasifier operating at atmospheric pressure and high temperature, above the ash fusion point of the coal. At this high temperature, methane and other volatiles from coal are cracked and most of the gas consists of CO and H_2. There are no tars and little methane produced. The high temperature of the gasifier causes slagging of the ash and some 50% of the ash is removed in this form. The remaining 50% of the ash is fine fly ash which is removed in the gas cleaning systems. The oxygen for gasification is produced by a cryogenic air separation plant which also produces the nitrogen required for ammonia production.

The hot raw synthesis gas from the gasifiers is quenched to below the ash fusion point and then cooled in a waste heat boiler. A number of gas cooling stages lowers the temperature of the gas to about $40^{o}C$ during which most of the dust is removed. Any remaining dust is removed in an electrostatic precipitator. The gas is then compressed to about 35 bar and fed to a Rectisol unit where H_2S and some CO_2 are removed. After shifting to convert most of the CO in the gas stream to H_2 and CO_2, the gas is passed to the second stage of the Rectisol plant where the bulk of the CO_2 is removed. The resulting gas consists of hydrogen, CO and small quantities of other gases. The CO and the other gases are removed in a liquid nitrogen wash and are used as fuel for utilities generation. H_2S from the Rectisol plant is fed to a Claus plant where it is converted to elemental sulphur.

The mixture of purified hydrogen and nitrogen from the nitrogen wash is compressed and fed to a conventional high pressure ammonia synthesis loop. The ammonia produced is reacted with the CO_2 removed in the second stage of the Rectisol plant to form urea which is packaged for sale.

The necessary utilities are produced in an integrated utilities plant using coal and CO purge gas as the fuel. This utilities plant includes electric power generation and steam generation. A pumping station is also included for pumping the plant's water requirements from a nearby river.

8.7.4 Manpower Requirements

Four shift operation of the complex would be necessary, with the exception of product despatch. Manning requirements for the process plants have been assessed, allowing for a modest increase over US and Western European practice. Maintenance staff has been allowed for at 110% of the operating staff, in accordance with current Colombian practice. Appropriate additions have been made for general plant services, supervision and administration.

The total workforce of the complex is estimated at about 700 people of which around 480 would be operators, labour and maintenance fitters, and 220 would be salaried staff.

8.8 Environmental Impact

The various processes are designed to reduce the levels of major gaseous pollutants to generally acceptable levels. Sulphur produced in the gasification trains is removed and converted to solid sulphur. The main sulphur pollution would be from combustion equipment burning coal to generate utilities. This should not cause any problems in the Antioquian situation because the coal used is a low sulphur coal.

The liquid effluent from the Koppers-Totzek or the Texaco gasification processes is a fairly simple effluent containing mainly cyanide. Most of the components can be removed by steam stripping and the remaining liquid is easily treated biologically.

The main environmental problem arises from the large volume of liquid effluent produced as the result of the pyrolysis of coal.

In the raw state, this effluent is contaminated with phenolic compounds and ammonia salts including chloride, cyanate, cyanide, sulphite, sulphide and thiosulphate. To purify this for discharge to sewers or water courses requires some suitable combination of solvent extraction, p[illegible]ding, aeration and biological treatment depending on the ultimate quality required. In the scheme proposed, the aqueous effluent is treated for removal of phenols by extraction with butyl acetate and for the removal of 'free' and 'fixed' ammonia by lime neutralisation and steaming. This, it is estimated, will yield a final effluent containing about 60-65 ppm phenols and [illegible]00 ppm ammonia, which diluted in the return cooling water could be discharged into a river provided the flow is adequate to ensure proper dilution. Ammonium cyanide and sulphide in the liquor are decomposed in the ammonia still and pass as vapours from the dephlegmator to the flue gas treatment unit where H_2S is removed as sulphur. The vapours are then scrubbed to remove acidic gases for stack discharge. The other ammonium salts appear as calcium salts in the spent lime and around 1400 tonnes/year of this must be dumped.

In tar processing, liquor disposal is normally a major environmental hazard, but in the plant suggested, effluent entrained in the crude tar is recycled to the main bulk of liquor and treated to render it fit for discharge. The other two main environmental problems normally associated with tar distillation - escape of phenol vapours from the springing towers and disposal of lime mud - are avoided in the design put forward by the use of sulphuric acid instead of carbon dioxide for neutralising the phenate solution.

If a Lurgi based gasification process were to be used, the liquid effluent from the gasification train would bear some resemblance to the pyrolysis liquor discussed above. This would require a fair degree of treatment, including biological treatment. The final effluent could contain 60-100 ppm phenols which again would require discharge into a river of adequate flow to ensure its dilution.

It is believed, therefore, that provided the coal processing complex is correctly designed and operated and provided the effluent outfall is correctly sited in a river with adequate flow, a coal based chemical plant of the nature studied in this report should not cause unacceptable air or river pollution.

9. PROGRAMME AND TIMESCALE OF DEVELOPMENT

9.1 General

It is recommended that the development of the proposed new coal mines and urea plant should proceed in a number of successive stages. These are described briefly below and are summarised together with their timescale in Figure 19. It is estimated that the total development time for the project would be appoximately nine years.

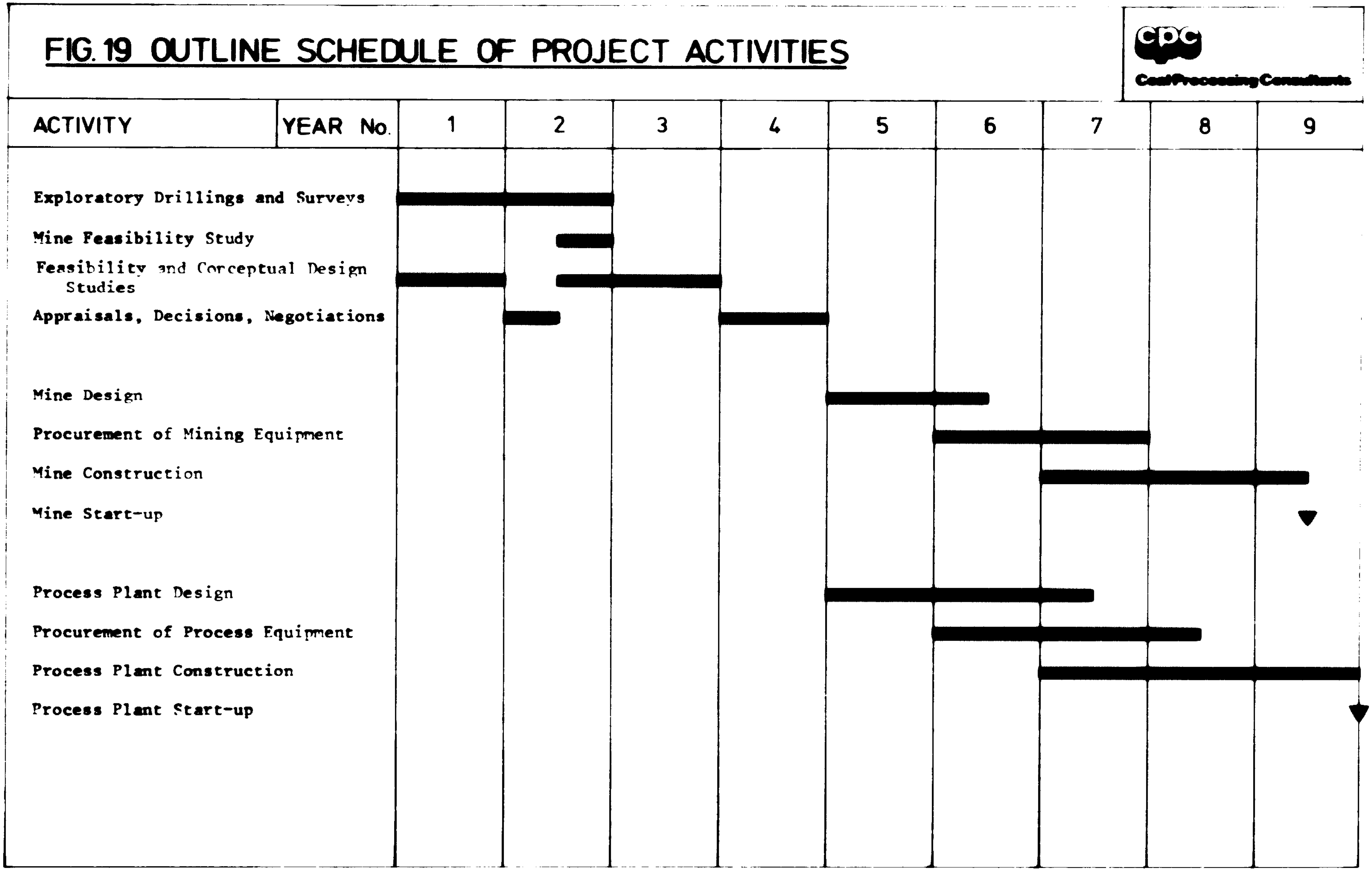
9.2 Mining Investigation

The first phase of the development will be a detailed mining investigation. This will include principally a detailed field survey, an exploratory drilling programme, topographical, hydrological and transport surveys, and preparation of detailed analytical data on the coal quality. The purpose of this investigation will be to make available the data necessary for a feasbility study of the proposed mining development.

It is recommended that a competent mining consultancy organisation should be entrusted with the planning, supervision and coordination of the investigation work. The topographical surveys and drilling work would be carried out by local contractors under the supervision of the Consultant. The geological, hydrological and transport surveys and the assessment of the data would be carried out directly by the Consultant. The Consultant would supply one exploration or mine geologist for the duration of the project. Specialists in the fields of topographic surveying, hydrology, geotechnical work, drilling and transportation studies would also be allocated to the project as necessary. Samples of coal and rock would be sent out to a suitable laboratory for testing.

Terms of reference for the supervision of the mining investigation are presented in Section 14.1. The duration of the mining investigation will depend on the availability of diamond drilling

FIG. 19 OUTLINE SCHEDULE OF PROJECT ACTIVITIES



rigs in the Medellin coalfield. Assuming that two rigs are made available with suitably experienced operators and adequate spares and diamond bits, it is estimated that the mining investigation phase could take 24 months.

The cost of the exploration drilling is estimated at approximately $660 000 on the basis of 600 m at $110/m. The cost of the surveys is estimated at approximately $250 000.

9.3 Mine Feasibility Study

A mine feasibility study will follow the mining investigation. It will collate all the required data enabling the selection of suitable areas of reserves for mining. Alternative methods of mining and transport will be assessed. Mine layouts with capital and production costs will be detailed for the major economically viable alternative mining schemes. The economics of the various mining schemes will be assessed for varying rates of production. Recommendations will be made as to the most viable mining scheme and method of transportation. Terms of reference for the mine feasibility study are presented in Section 14.2.

The work would be undertaken by the Mining Consultant responsible for the mining investigation. A team of consultants and engineers would carry out a local investigation in the Medellin area, lasting four to five weeks. The team would include a senior mining consultant, a senior mining engineer, a senior coal geologist, a mechanical/electrical engineer and a coal preparation engineer if coal beneficiation appeared necessary in the light of the investigation work. Subsequently the team would collate and analyse the data gathered and together with other specialists and support staff would undertake the necessary assessments and prepare the necessary recommendations, as outlined above.

The duration of the mine feasibility study is assessed at approximately six months, to run concurrently with the end of the mining investigation.

The cost of the mine feasibility study is estimated at approximately $250 000.

9.4 Process Plant Feasbility Study

In parallel with mining investigations, it is recommended that further studies should be undertaken in relation to the urea plant with the objectives of confirming the long term supplies for coal and markets for products,selecting a location for the plant, establishing the process route and sources of technology and providing up-dated capital and operating cost estimates.

The work will include a review of the known coal sources in Antioquia and a more detailed evaluation of the probable usages by other industries. Recommendations will be made regarding the desirability of conducting further mining studies, in order that the process plant developers may be certain that there are assured long term supplies of coal.

The studies will involve an assessment of markets for urea in the various parts of Colombia and other Latin American countries, taking into account the availability of other sources of fertilisers. The market survey will also consider potential chemicals derived from coal pyrolysis with the accent on the development potential in Colombia for downstream processing of these chemicals. An optimum product mix will be established to suit Colombian conditions.

A detailed appraisal will be undertaken of possible sites for the process plant. Consideration will be given to the availability of transport facilities, water, land, power, labour and their cost. The most appropriate location for the plant will be identified.

A coal analysis, which is typical of the local Antioquian coals, will be used as the design basis. Discussions will be held with developers and suppliers of plant involved in the alternative process schemes. Anticipated yields of the products, which can be made from the reference coal, will be assessed. The most appropriate process scheme will be selected, taking into account the market opportunities for the available product ranges, the state of development of the technology and the anticipated capital and operating costs. Some testwork, using the suppliers pilot plant facilities, may be required in the selection of the process scheme.

Terms of reference for the process plant feasibility study are presented in Section 14.3.

It is recommended that the process plant feasibility study should be entrusted to a competent Consultancy Organisation knowledgeable in this field of coal conversion and unbiased in its approach to the owners of process technology. The Consultant would collaborate with the owners of specific process technology who would make available their pilot plant testing facilites. Some local investigation work would be sub-contracted to local organisations, but the control and supervision of all study work would be the responsibility of the Consultant.

The duration of the process plant feasibility study is assessed at approximately 12 months. The cost of the study is estimated at around $500 000, the precise cost depending on the amount of pilot plant testwork, which is required.

9.5 Process Plant Conceptual Design Study

Following final selection of the mining area to be developed, plant location and product range, the design of the urea plant will be developed in sufficient detail to enable definitive capital and operating cost estimates to be prepared. All necessary pilot plant testwork will be conducted to confirm the suitability of the chosen route for the processing of Antioquian coals. On completion of this work, all necessary data should be available for the sponsors to make a final decision on the project and arrange financing.

The work should desirably be coordinated by a Specialist Consultant utilising the services of the local organisations together with the suppliers of the process technology.

The duration of the conceptual design study is assessed at approximately 18 months. The cost of the work is estimated at around $2.0 million, the precise cost depending on the process route adopted and extent of the pilot plant work.

9.6 Appraisal Phases

During these phases, the results of the studies must be reviewed by potential sponsors, owners and Government. The effects of project implementation must be studied in respect to regional and national economic strategy. Project financing must be organised. Enquiries for the following phases of project implementation must be issued, bids must be received and evaluated. Decisions must be made at appropriate levels on all aspects of the project.

Periods of six and twelve months are included in the programme for these activities. A total cost of $120 000 has been included in the estimates for this work allowing $20 000 for the mining project and $100 000 for the process plant project.

9.7 Mine Design and Construction

After the decision to proceed has been made, the mining development can proceed to its implementation stage.

The first phase will be preparation of a detailed project brief. This will incorporate all the data required for the detailing of the selected project, as well as the engineering design work necessary for the accurate assessment of capital and production costs. The requirements for plant and equipment, manpower and management, infrastructure and services, as well as costs, will be defined and a detailed implementation plan prepared.

Following this, the specification of equipment and work required will then be prepared. Quotations will be obtained, tenders evaluated and the necessary contract documents prepared. The equipment and materials will be purchased and fabricated, in accordance with the specifications, prepared and transported to the mine site. Construction on the mine and the transportation system will be carried out by contractors.

Further work will include the assessment of manpower requirements, recruitment and training of personnel at all levels, both in Colombia and overseas, the establishment of a management organisation and appropriate administrative and control systems for the mines, associated engineering services, transport, handling and required infrastructure.

It is recommended that the overall control of the mining project should be undertaken by an appropriate mining consultancy or engineering organisation, in order to ensure proper continuity and coordination of the project and proper transfer of modern mining technology and management. The Consultant/Engineer would prepare the project implementation brief and the specification of equipment and work . The Consultant/Engineer would further organise and supervise the procurement activities and the construction work. The Consultant/Engineer would also plan and assist in the training programme and the setting up of the mine organisation.

The overall duration of the design and construction phase of the mine is estimated at around a minimum of 3½ years. The outline schedule in Figure 19 is based, however, on a period of around 4½ years to suit the process plant development.

9.8 Process Plant Design and Construction

After the decision to proceed has been made and the necessary contracts placed, the process plant development can proceed to its implementation stage.

First, the detailed design of the plant will be completed. This will involve the design of all process plant equipment, pipework, handling systems, control systems, electrical systems, civil and building work, steelwork, refractories, thermal and acoustic insulation.

The procurement phase of the project covers the manufacture of all equipment and materials required for the plant to the specifications laid down, and the transport of all the hardware to the plant site.

The construction phase of the plant covers all site construction and erection work and the testing of the plant before start-up.

Further work will include the assessment of manpower requirements, recruitment and training of personnel at all levels, both in Colombia and overseas, the establishment of a management organisation and appropriate administrative and control systems for the process plant and its related services.

The involvement in the implementation stage of the project of a major engineering contracting organisation is considered essential to ensure the overall control of the project.

Because of the size and diversity of the project, a number of areas of work would be sub-contracted out to appropriate organisations. However, the overall control would remain the responsibility of the main contractor. Some aspects of the project could be handled in Colombia, specifically in the areas of civil engineering, building work and certain aspects of the construction work. However, the bulk of the design work, the equipment and materials and the construction supervision would have to be provided from abroad.

The total duration of the design, procurement and construction phases of the project is estimated to be around five years under Colombian conditions.

10. ECONOMIC EVALUATION

10.1 General

All costs are calculated in US dollars and related to mid-1977 conditions. No allowance is made for forward inflation. Where costs in Colombian currency are utilised, these are converted to US dollars at the conversion rate of Pesos 36.80 to the dollar (cross-rate of exchange in August, 1977, as published in the Financial Times). Where costs in British currency are utilised, these are converted to US dollars at the mid-1977 conversion rate of $1.72 to the pound sterling.

10.2 Basis of Capital Costs

The capital costs for the mine are estimated from in-house data derived from similar projects in developing countries, together with local cost data obtained in the Medellin area.

The capital cost estimates for the process plant are built-up from a combination of in-house data derived from other projects together with the most recent reliable published information originating from either the company which developed the process or chemical engineering construction companies active in the particular field.

Where capital cost information relates to pre-1977 conditions, this is escalated to mid-1977 conditions using appropriate indices. Where US capital cost information is used, this is escalated to mid-1977 conditions using indices generated for ERDA by TRW Systems and Energy (Paper on Coal Conversion Plant Cost Escalation, by Cohen and Hayoz, ACX, Divn. Fuel Chem., Preprints, 22, (7), 12th September 1977).

All capital costs are adjusted to take account of Colombian conditions by the use of appropriate uplift factors.

The Colombian industry does not have, at the present, the capacity to produce the equipment necessary for a large industrial development of the nature envisaged. It is therefore assumed that all equipment and specialised materials would be imported. The cost of all equipment priced on a UK or US basis is increased by a factor of 30% to take account of the cost of freight, Colombian import taxes and duties, and other import on-costs. The assessment of this factor is given in Table 10.1.

Table 10.1 - Cost of Equipment and Materials Imported into Colombia

All costs relate to a FOB price of 100 units.

Cost Item	Cost
FOB price	100.0
Ocean freight, Insurance) Handling charges) at 10%	10.0
Consular Fees at 1%	1.0
CIF Cost	111.0
Import duty at 5%	5.5
Proexpo and Fedecafe Taxes at 6.5%	7.2
Port Taxes at 2%	2.2
Opening Current Account at 1.5%	1.7
Free Zone Tax at 0.4%	0.4
Freight, Insurance, Handling from Colombian Port to Site at 1.8%	2.0
TOTAL	130.0

A number of the taxes and duties indicated are negotiable, depending on how the importance of the project is viewed by the Colombian authorities. Thus the import duty can vary from 5% to 30%. For a project of the magnitude and importance considered, the lower figure of 5% has been assumed. The import duty can even be reduced to 0 in some special instances. The Proexpo and Fedecafe taxes can also, apparently, be waived in certain instances. The port taxes are variable and the 2% figure assumed is an average. There is no sales tax levied on imports of heavy machinery for the basic industries. These include the mining and bulk chemicals manufacturing industries.

Where global plant costs were estimated on a UK or US basis, a global uplift factor is utilised to take account of the cost of importing the materials, the cost of providing expatriate site supervision, the lack of skilled labour and mechanised resources in Colombia and the longer construction period resulting from these factors and from the long transport distances. Based on in-house data relating to large industrial projects in both industrialised and developing countries, this global factor is assessed at around 25% for plant costs calculated on a US basis and 40% for plant costs calculated on a UK basis.

All estimates of capital cost include an estimating contingency of 20%. In addition, the cost estimates for certain process stages of Scheme 1 include appropriate contingencies to take some account of the developmental nature of these stages.

Further allowances are made in the capital cost estimates to cover the cost of the initial set of spares supplied with the equipment and to allow for administrative overheads and pre-operational expenses.

The allowances for spares are:

- For the mines 8% of the equipment cost delivered to the mine.
- For the coal wagons 5% of the cost of the wagons delivered to the mines.
- For the process plant 5% of the total installed cost.

The allowance for administrative overheads and pre-operational expenses is taken as 3% of the total installed costs in all cases.

10.3 Basis of Operating Costs

10.3.1 General

The operating costs are calculated on the basis of Colombian costs for labour, materials, chemicals and transport. Normal allowances are made to account for the usage of spares, plant insurance and overheads.

10.3.2 Labour Costs

A review was made of labour cost data obtained in Colombia. Labour costs in Colombia vary very considerably with the type and location of the job and the size of the firm. Unions are company unions whose militancy and success rate differ. Social benefits paid by the employer vary between 60% and 130% of the wages or salaries. In the chemical, petrochemical and fertiliser industries, the average labour costs in 1975/76 including social benefits were as shown in Table 10.2 below.

Table 10.2 - Average Labour Cost in Colombia 1975/76

Industry	Year	Labour Cost (inc. Social Benefits) $/year	
		Operator Category (1)	Staff Category (2)
Oil and coal based chemical industry	1975	2044	5560
General chemical industry	1975	2005	5270
Fertiliser industry	1976	2123	7990

(1) The operator category includes labourers, operators and maintenance fitters.

(2) The staff category includes skilled tradesmen, foremen, engineers and all administration staff.

From 1976 to mid-1977 it is estimated that the total cost of operators rose by 50%, and the total cost of staff by 30%.

Local sources indicated labour costs at mid-1977 as shown in Table 10.3.

Table 10.3 - Labour Costs in Colombia at mid-1977
(according to local sources)

Category	Labour Costs (inc. Social Benefits
	$/year
Labourer	2 300
Skilled Labourer	4 500
Foreman	7 500
Bilingual Secretary	7 800
Qualified Engineer	10 000
Manager or Director	25 000

Until recently, few of the mines were unionised. In the smaller mines where labour was unorganised or employed on a contract basis, the average labour cost including social benefits was in range $1500-1800/year. Since the El Silencio-Villadiana disaster in July 1977, the situation has changed and it was generally agreed in Medellin in August 1977 that the going rate in the near future including social benefits would be around Ps 240 per shift, corresponding to about $2200/year including bonuses.

On the basis of the foregoing information, the following labour costs are used to assess the operating costs of the new mines and the coal processing plant.

Table 10.4 - Labour Costs used for Economic Appraisal

Category	Labour Cost (inc. Social Benefits)
	$/year
Mine	
Miners and labourers	2 200
Staff	7 500
Process Plant	
Operators and fitters	3 200
Staff	10 000

10.3.3 Cost of Coal

The cost of coal used for assessing the process plant operating costs is the price of coal calculated for the operation of the new mines (see Section 10.5.6). This price also includes the cost of the transport by rail of the coal from the mine to the process plant.

10.3.4 Cost of Chemicals and Packaging

The cost of catalysts and chemicals is based on 1977 US prices increased by 40% to cover import costs into Colombia.

Packaging for urea is taken at $8/tonne. No packaging is allowed for any by-products which are assumed disposed of in bulk.

10.3.5 Cost of Utilities

Electric power to the mine is assumed taken from the local Antioquian grid. The cost of electricity is allowed at $0.0122/kWh (Ps0.45/kWh), the mid-1977 cost of electricity in Medellin.

The process plant includes its own generation facilities for electric power and steam. It also includes its own river water pumping station. Allowance is made in the capital cost estimate of the process plant for a total water pipeline length of 1 km. Fuel for utilities generation is principally coal which is included in the coal usage of the plant. The remainder of the energy used is provided by the gases generated in the processes. Thus no additional allowance is made for the cost of utilities to the process plant.

10.3.6 Cost of Waste Disposal

Ash generated in the process plant is assumed transported by lorry to a suitable dumping area. Ash transport costs are allowed at \$0.04/t km (Ps1.5/t km) for a distance of 10 km and a cost \$1/tonne for loading and unloading, thus giving a total transport cost of \$1.4/tonne ash. No charge is assumed for the use of the dumping ground and no credit value is allowed for the ash.

Liquid effluent is treated in the process plant and pumped to the river. These costs are included in the costs for the plant and no additional allowance for effluent disposal are made.

10.3.7 Materials, Spares and Insurance

The cost for materials and spares usage for the mines is calculated on the basis of in-house data adjusted to Colombian conditions.

For the process plant, the total yearly cost of spares usage and plant insurance is taken as 3.5% of the installed plant cost in Colombia.

10.3.8 Indirect Costs

An indirect costs allowance is made to cover the costs of overheads, administration, sales and general expenses. For the mine, this allowance is taken as 40% of the total direct production costs. For the process plant an allowance of 50% of the plant wages bill is used.

10.3.9 Replacement Capital

For the mines, a constant annual payment is assumed for the funding of replacement capital. This is allowed for at 5% of the total cost of the equipment delivered to the mine.

No allowance for replacement capital is made for the process plant or the transport system.

10.4 Basis of Financial Evaluation

10.4.1 Evaluation Method

For the evaluation of the project a variation of the Discounted Cash Flow (DCF) method is used called the Comprehensive Cost method. In this method, a yearly charge is calculated which is added to the operating costs and represents the additional income that has to be earned over and above the operating costs to provide for the net expenditure on fixed assets and their financing. The ratio of this capital recovery charge to the capital itself is known as the capital recovery factor.

Thus $T = P + rC$ where
- T = annual comprehensive cost
- P = annual operating cost
- C = capital cost
- r = capital recovery factor

The comprehensive cost per unit output represents a good approximation of the product cost. Thus

$$t = \frac{T}{U}$$

where
- t = product cost
- T = annual comprehensive cost
- U = annual output

The capital recovery charge for a project can be calculated by substituting the cash flow resulting from this regular capital recovery to the actual project cash flow, such that both cash flows have identical Net Present Values (NPV), when discounted at the same rate. The discounting rate used for the evaluation is the minimum return on capital required for the project. The regular capital recovery cash flow takes into account the build-up of output through time and delayed profits tax payments. The actual project cash flow takes account of all expenditure on fixed assets, their phasing, their financing and the associated tax implications, relief of tax payments on interest paid and on depreciation allowances.

The method is illustrated in Appendix 5, Table A5.1 and A5.2 which give the calculation of the recovery factors for the mine and the process plant respectively. This calculation is based on the assumptions used in the build-up of the financial model utilised for the evaluation (see Section 9.4.2 below).

An extension of this method considers also the capital recovery charges for working capital. Thus the comprehensive cost T can be calculated as follows:

$$T = P + rC + r_w W$$

where r_w = working capital recovery factor

W = working capital

r_w can be calculated in a similar way to the capital recovery factor r.

The working capital is a function of both annual operating cost P, and capital cost C. Thus the comprehensive cost T can be expressed as:

$$T = f(P + rC)$$

where f is a factor which takes account of the cost of working capital.

The capital recovery factor r is a function of the financing conditions assumed for the project, the local taxation requirements, the phasing of expenditure on fixed assets and the build-up of output. As long as these conditions do not vary, then the capital recovery factor remains a constant and, once calculated, can be used for the comparison of a number of alternative schemes, although these schemes may have quite different costs and operating characteristics.

In the same way,the working capital factor f remains a constant provided the financing, taxation and capital build-up assumptions used for its calculation remain unchanged. This factor has, moreover, a limited effect on the total comprehensive cost and varies little from project to project. From the study of other projects, this factor is typically in the range of 1.03 to 1.04. A factor f = 1.04 is therefore adopted for this study.

The product costs resulting from the calculation method outlined above can be taken as the target products costs which would ensure that the miminum required return on capital for the project is achieved. The target product costs calculated for the various scheme alternatives are then compared with each other and with the actual potential selling price of the product on the market. The differences between these values give a measure of the possible profitability of the schemes.

10.4.2 Assumptions used for Project Evaluation

The total project expenditure is financed on the basis of 50% equity and 50% loan.

Loans bear an interest rate of 7.5% on average annual basis (cf. World Bank, Venezuela 1977).

Loans are repaid over 12 years in equal instalments, starting in the first year of plant production.

The project life is 20 years.

The minimum return on equity required is 12% after deduction of tax. A DCF rate of 12% is therefore used for the calculation of the capital recovery factors.

The rate of profit tax is taken as 40%[1], payable one year in arrears. Municipal taxes[2] are ignored for the purpose of the evaluation.

The depreciation allowance for tax purposes is calculated on the diminishing balance method at 15% of the value of fixed assets[3]. The useful plant life, for the purpose of depreciation, is taken as 20 years. Fixed assets, for the purpose of depreciation, are assumed not to include the cost of surveys, feasibility studies, pre-operational expenses and first stock of spares.

The residual value of the works is assumed to be nil.

The output build-up for the process plant is taken as follows:

1st year of operation	70%
2nd year of operation	85%
3rd year of operation	95%
4th year of operation	100%

The output build-up of the mine is taken to match the process plant output build-up, i.e. it is assumed that the mine will not be operated in the build-up years to produce excess coal for marketing.

10.4.3 Phasing of Capital Expenditure

The phasing of capital expenditure is based on the outline schedule of project activities shown in Figure 19.

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(1) This corresponds to the 1977 Colombian rate of corporation tax paid to the Federal Government.

(2) Municipal taxes include a land tax at Ps11/Ps1000 value of land, an industry and commerce tax at Ps4/Ps1000 gross earnings, a transport tax which in Medellin is at Ps10/tonne.

(3) The Colombian government allows a depreciation rate on the diminishing balance method twice the rate that would be applied with the straight line method. An additional allowance up to 50% is permitted where the equipment is used on shifts.

Major capital expenditure on mine, process plant and transport system is allocated in accordance with typical S curve cumulative cash flows for similar applications.

The allocations used are shown in Table 10.5 below.

Table 10.5 - Assumed Phasing of Capital Expenditure

Year No.	1	2	3	4	5	6	7	8	9
Allocation of Expenditure									
Mining Investigation	50%	50%							
Mine Feasibility Study		100%							
Process Plant Conceptual Design		50%	50%						
Appraisal Phase				100%					
Mine Design and Construction					10%	35%	35%	17.5%	2.5%
Process Plant Design and Construction					5%	25%	40%	22%	8%
Transport System						20%	60%	20%	

It has been assumed, for the purpose of the appraisal, that all phases of capital expenditure on the project are financed at 50% equity and 50% loan. The capital recovery factors, calculated in Table A5.1 and A5.2 of Appendix 5, are computed on the basis of equity expenditure only. The phasing of expenditure on fixed assets is adjusted to suit.

10.5 Evaluation of New Mines

10.5.1 Capital Cost of New Mines 1 and 2

The preliminary capital cost for Mines 1 and 2 has been calculated and is summarised in Table 10.6 below.

Table 10.6 - Estimated Capital Cost for New Mines 1 and 2
Combined Output 1 million tonnes/year

Cost Item	Cost million $	
Preliminary Work		
Mining Investigation	0.91	
Mine Feasibility Study	0.25	
Appraisal Phase	0.02	
TOTAL		1.18
Installed Cost		
8 faces at $0.62 million each	4.96	
Underground Equipment	4.28	
Surface Equipment	1.26	
Equipment Cost FOB Port of Origin	10.50	
Freight, Handling, Import Costs at 30%	3.15	
Equipment Cost, Mine Site	13.65	
Surface Installations and Buildings	1.08	
Underground Development Costs	0.84	
Total Direct Costs	15.57	
Engineering, Procurement and Construction Management at 15% of Equipment Cost (Origin)	1.58	
Total before Contingency	17.15	
Contingency	3.43	
TOTAL		20.58
Additional Costs		
Spares	1.09	
Pre-operational Expenses	0.62	
TOTAL		1.71
TOTAL CAPITAL COST OF MINES 1 AND 2		23.47

The above estimates does not include the cost of working capital, replacement capital, land, coal transportation system, power line to the mine site, roads to the mine site, legal fees, permits and licences, local taxes and dues, finance charges.

The unit capital cost is \$23.47 per annual tonne of coal output. This is comparable with the cost of similarly sized drift mines in developing countries.

10.5.2 Operating Cost of New Mines 1 and 2

The operating cost for mines 1 and 2 (excluding capital recovery) has been calculated as shown in Table 10.7 below.

Table 10.7 - Estimated Operating Cost for New Mines 1 and 2

Combined Output 1 million tonnes/year

Cost Item	Annual Cost	%
	million \$/year	
Direct Costs		
Wages and Salaries		
Miners/labour 1030 at \$2200/year; Staff 130 at \$7500/year	3.24	34.1
Power	0.08	0.8
Materials and Spares	2.98	31.4
TOTAL DIRECT COSTS	6.30	66.3
Additional Costs		
Overheads, Administration, General Expenses	2.50	26.3
Allowance for Replacement Capital	0.70	7.4
TOTAL OPERATING COST FOR MINES 1 AND 2	9.50	100.0

10.5.3 Capital and Operating Costs of Coal Preparation Plant

The capital and operating costs of a coal preparation plant vary widely depending on the complexity of the circuits, the washability of the coal and the throughput required. Insufficient data is available to make anything but very preliminary estimates of the costs in this report.

The capital costs can vary from $10 000 to $30 000 per tonne of hourly throughput. For the purposes of this report, the total installed cost of the preparation plant (if found to be required) is estimated at $3.6 million, based on a unit capital cost of $15 000 per tonne of hourly throughput.

The operating cost is estimated to be $1.00 per tonne of r.o.m. coal, excluding capital recovery.

10.5.4 Capital and Operating Cost of Coal Transportation System

The transportation system for the coal is assumed at this stage based on the use of the existing railway, after its rehabilitation. It is further assumed that the capital costs of the rehabilitation and equipping of the railway will be borne by the Colombian National Railway Company, Ferrocarriles Nacionales de Colombia. As there is a shortage of rolling stock in Colombia, however, it is assumed, for the purpose of this evaluation, that the mines will be required to purchase the coal wagons.

The capital cost of the transportation system attributable to the mine is calculated in Table 10.8.

It is assumed that the railway will be operated by Ferrocarriles Nacionales de Colombia. The transportation charge of Ferrocarriles is calculated in Table 10.9, based on information provided by the railway company.

The transport cost for coal is calculated in Table 10.10 for a coal output of 1 million tonnes/year and assuming a transport distance of 60 km. This is equivalent to a plant location near Medellin or on the Rio Cauca near Bolombolo. This cost does not include capital recovery on the cost of the coal wagons and sidings.

Table 10.8 - Estimated Capital Cost of Coal Transportation System attributable to the Mines

Cost Item	Cost
	million $
45 Coal Wagons, 40 tonne capacity at $34 000 each	1.53
Freight, Handling, Import Costs at 30%	0.46
Equipment Cost, Mine Site	1.99
Procurement, 2% of Equipment Cost	0.03
Spur lines/Siding at Mine and Plant, 2km at $270 000/km	0.54
Total before Contingency	2.56
Contingency	0.50
Total Installed Cost	3.06
Spares	0.10
Administrative Overheads	0.09
TOTAL CAPITAL COST OF TRANSPORTATION SYSTEM	3.25

Table 10.9 - Estimated Transport Charge for Coal by Ferrocarriles Nacionales de Colombia

Cost Item	Charge	
	Ps/tonne km	$/tonne km
Basic Freight Charge	1.0	
Surcharge for Empty Journey Return at 30%	0.3	
Sub-total	1.3	
Surcharge for Difficult Terrain at 55%	0.7	
Total Normal Charge	2.0	
Reduction for Regular Bulk Transport of 1 million tonnes/year at 25% (negotiable)	0.5	
Total Bulk Charge	1.5	
Reduction Assumed for Use of Own Coal Wagons	0.2	
TOTAL TRANSPORT CHARGE FOR COAL	1.3	0.035

Table 10.10 - Estimated Transport Cost for Coal (60 km)

Cost Item	Annual Cost
	million $/year
Transport Charge, 60 km at $0.035/ tonne km	2.10
Loading and Unloading at $1.0/tonne	1.00
Spares and Maintenance Costs at 5% of Equipment at Mine	0.10
TOTAL TRANSPORT COST OF COAL	3.20

This cost can be compared with the mid-1977 charges made by the road haulers for coal transport. This would be of the order of $2.50/tonne for the distance considered.

10.5.5 Production Cost of Coal from New Mines 1 and 2

The total capital and operating costs for the mines and the transport system are calculated in Tables 10.11 and 10.12 below. In the present evaluation, it is assumed that a coal preparation plant will not be required.

Table 10.11 - Estimated Capital Cost for New Mines 1 and 2 and Coal Transportation System

Cost Item	Cost
	million $
Capital Cost of Mines (as Table 10.6)	23.47
Capital Cost of Transportation System (as Table 10.8)	3.25
TOTAL CAPITAL COST OF MINES AND TRANSPORTATION SYSTEM	26.72

Table 10.12 - Estimated Operating Cost for New Mines 1 and 2 and Coal Transportation System

Cost Item	Annual Cost million $/year
Operating Cost of Mines (as Table 10.7)	9.50
Operating Cost of Transportation System (as Table 10.10)	3.20
TOTAL OPERATING COST OF MINES AND TRANSPORTATION SYSTEM	12.70

The capital recovery factor for the mine and transportation system, based on the assumptions indicated above in Section 10.4.2 and 10.4.3, is calculated in Appendix 5, Table A5.1. It has a value r = 20.6%.

The cost of coal, including a return on equity of 12% after tax, and a non tax deductable royalty of 10% on the gross value of sales[(1)] can be calculated as follows:

$$t = \frac{f(P + rC)}{U} \times (1 + Z)$$

where t = cost of coal delivered to the plant
- f = working capital factor taken as 1.04
- P = operating cost takes as 12.70×10^6 $/year (Table 10.12)
- r = capital recovery factor taken as 0.206
- C = capital cost taken as 26.72×10^6 $ (Table 10.11)
- Z = royalty taken as 0.10
- U = output of mine taken as 1×10^6 tonnes coal/year

The cost of coal delivered to the plan is thus t = $20.8/tonne

This can be considered as a maximum figure for the evaluation.

(1) As charged by the Federal Government elsewhere in Colombia.

10.5.6 Variations in Production Cost of Coal

A minimum production cost of coal can be calculated assuming:

- no import duty on machinery
- no Proexpo or Fedecafe tax
- no purchase by the mine of coal wagons
- no royalty payments on the coal

The estimates in Table 10.6 - 10.10 are adjusted to suit and give the costs shown in Tables 10.13 and 10.14.

Table 10.13 - Estimated Minimum Capital Cost for New Mines 1 and 2 and Coal Transportation System

Cost Item	Cost
	million $
Capital Cost of Mines (as Table 10.6 modified)	21.71
Capital Cost of Transportation System (as Table 10.8 modified)	0.67
TOTAL MINIMUM CAPITAL COST OF MINES AND TRANSPORTATION SYSTEM	22.38

Table 10.14 - Estimated Minimum Operating Cost for New Mines 1 and 2 and Coal Transportation System

Cost Item	Annual Cost
	million $/year
Operating Cost of Mines (as Table 10.7)	9.50
Operating Cost of Transportation System	3.46
TOTAL MINIMUM OPERATING COST OF MINES AND TRANSPORTATION SYSTEM	12.96

Using the same capital recover factor as previously, the production cost of coal is calculated as follows:

$$t = \frac{f(P + rC)}{U}$$

where P = operating cost taken as 12.96 x 10^6 \$/year (Table 10.14)

C = capital cost taken as 22.38 x 10^6 \$ (Table 10.13)

the other factors remain unchanged.

The minimum production cost of coal is thus t = <u>$18.3/tonne</u>

The cost of the coal from the new mines is likely to be in the range of $18.3 - 20.8/tonne. For the evaluation of the chemical plant, a median coal cost of $20.0/tonne is assumed.

This cost can be compared with the sales price of coal in Medellin, which was $9.51/tonne prior to the El Silencio-Villadiana disaster, and is likely to stabilise at around $15/tonne after the disaster (see Section 4.14). The cost of coal from the new mine can be considered as comparable to existing production costs, if account is taken of the probable errors associated with the preliminary estimates presented in this report, and of the fact that Antioquian coal, even after the mine disaster, is still underpriced.

10.6 Evaluation of Ammonia/Urea Plant
Scheme 1 - Manufacture of Urea and Tar Products

10.6.1 Capital Cost of Ammonia/Urea Plant - Scheme 1

The preliminary capital cost for the Scheme 1 plant has been calculated and is summarised in Table 10.15.

Table 10.15 - Estimated Capital Cost for Ammonia/Urea Plant - Scheme 1 Output 579 000 tonnes/year Urea

Cost Item	Cost	
	million $	
Preliminary Work		
Process Plant Feasbility Study	2.50	
Appraisal Phase	0.10	
TOTAL		2.60
Installed Cost		
Ammonia Plant (US basis)	109.50	
Urea Plant (US basis)	20.00	
Utilities and General Services (US basis)	60.50	
Sub-total	190.00	
Increase for Colombian Conditions at 25%	47.50	
Tar and Phenol/Ammonia Recovery Plants (on UK basis)	6.80	
Increase for Colombian Conditions at 40%	2.70	
Colombian Erected Cost	247.00	
Contingency	49.00	
TOTAL		296.40
Additional Costs		
Spares	14.80	
Pre-operational Expenses	8.90	
TOTAL		23.70
TOTAL CAPITAL COST OF AMMONIA/UREA PLANT - SCHEME 1		322.70 Rounded off to 320.00

The above estimate does not include the cost of working capital, replacement capital, land, coal transportation system, roads to the plant site, legal fees, permits and licences, local taxes and dues, finance charges.

10.6.2 Operating Cost for Ammonia/Urea Plant - Scheme 1

The operating cost for the Scheme 1 plant has been calculated as shown in Table 10.16 below, allowing for a production of tar products in accordance with Disposal Pattern 2 defined in Section 8.

Table 10.16 - Estimated Operating Costs for Ammonia/Urea Plant - Scheme 1 Output 579 000 tonnes/year Urea

Cost Item	Annual Cost	%
	million $/year	
Direct Costs		
Wages and Salaries		
Operators/labour 600 at $3200/year) Staff 240 at $10 000/year)	4.42	9.6
Products and Materials		
Coal 1.064 x 10^6 tonnes/year at $20/t	21.28	46.1
Chemicals and Catalysts	2.30	5.0
Packaging at $8/tonne urea	4.60	10.0
Ash Disposal, 60 000 tonnes/year at $1.4/tonne	0.09	0.2
Maintenance Materials and Plant Insurance	11.20	24.3
TOTAL DIRECT COSTS	43.89	95.2
Additional Costs		
Overheads, Administration, Sales, General Expenses	2.21	4.8
TOTAL OPERATING COSTS	46.10	100.0
By-Product Credits		
Sulphur 1000 tonnes/year at $94.5/tonne[1] (0.10)		
Oxygen 9000 tonnes/year at $420/tonne[2] (3.78)		
Tar Products, as Disposal Pattern 2[3] (27.81)		
TOTAL CREDITS[4]	(31.69)	(68.7)
EFFECTIVE OPERATING COST OF AMMONIA/UREA PLANT - SCHEME 1, PATTERN 2	14.41	31.3

Notes

(1) The value of sulphur is taken as defined in Section 7.3.11.

(2) The value of oxygen is taken as Ps22/m^3, the bulk selling price of oxygen by AGA-FANO Ltda in Medellin. At present AGA-FANO only have a 100 m^3/hour tonnage oxygen plant and this does not satisfy the local demand.

(3) The value of the tar products for disposal pattern 2 is given in Table 8.3.

(4) No credit is allowed for the excess CO_2 produced.

10.6.3 Production Cost of Urea from Scheme 1 plant

The capital recovery factor for the ammonia/urea plant has been calculated in Appendix 5, Table A5.2, based on the assumptions indicated above in Sections 10.4.2 and 10.4.3. It has a value $r = 19.2\%$.

The production of urea, including a return on equity of 12% after tax, can be calculated as follows:

$$t = \frac{f(P + rC)}{U}$$

where t = cost of urea

f = working capital factor taken as 1.04

P = operating cost taken as 14.40×10^6 \$/year (Table 10.16)

r = capital recovery factor taken as 0.192

C = capital cost taken as 320×10^6 \$ (Table 10.15)

U = output of plant taken as 0.579×10^6 tonnes/urea/year.

Thus the cost of urea ex plant is calculated at $136/tonne

10.6.4 Variations in Production Cost of Urea from Scheme 1 Plant

.1 Effect of Disposal Pattern of Tar Products

If the tar products are produced in accordance with Disposal Pattern 3, defined in Section 8.6.6, the operating costs in Table 10.16 must be adjusted as follows:

- The tar products credit is 21.42×10^6 \$/year as calculated in Table 8.4.
- The total credits is 25.30×10^6 \$/year
- The effective operating cost of the plant is 20.8×10^6 \$/year

Using the same capital recovery factor as previously, the production cost of urea is calculated as $148/tonne.

.2 Effect of Coal Cost from New Mines

If the cost of coal is reduced to the minimum cost of $18.30/tonne calculated for the new mines, both the annual coal cost and the effective operating cost of the plant are reduced by 1.81×10^6 \$/year. The cost of urea is reduced by $3.2/tonne to approximately $133/tonne.

If the cost of coal is increased to the maximum cost of $20.8/tonne calculated for the new mines, the cost of urea is increased by $1.5/tonne to approximately $138/tonne.

.3 Effect of Plant Location

Provided the urea plant is located along the railway line, the cost of coal varies with the distance between the plant and the mine at the rate of $0.035/tonne per km and the price of urea at the rate of $0.067/tonne per km. Thus for a distance between the plant and the mine of 120 km, the cost of urea is increased by $4/tonne to approximately $140/tonne.

.4 Effect of Coal Source

If coal at $10/tonne were available (urea plant located next to opencast mine for example), the annual coal cost would be reduced by 10.64×10^6 \$/year and the urea price would be reduced by $19/tonne to approximately $117/tonne. If the plant were located near the coast, the probable cost of urea transported to Medellin would be around $137/tonne.

If coal at $30/tonne were used (coal imported from coalfield outside Antioquia for example), the urea price would be increased by $19/tonne to approximately $155/tonne.

.5 Effect of Process Route

If a conventional Lurgi process were used for the pyrolysis and gasification of coal, preliminary indications are that the capital cost of the plant would remain unchanged. The total coal usage would be reduced by some 20-25%. The tar output would be reduced to some 20 000 - 25 000 tonnes/year of tar of similar quality. The following changes to the operating costs would be expected:

- Reduction in annual coal cost of around 5×10^6 $/year.
- Reduction in credit for tar products of around 20×10^6 $/year.

The operating costs would be around 30×10^6 $/year and the resulting cost of urea would be around $160-165/tonne

Newer versions of the Lurgi process would be expected to reduce this cost.

10.7 Evaluation of Ammonia/Urea Plant Scheme 2 - Manufacture of Urea Only

10.7.1 Capital Cost of Ammonia/Urea Plant - Scheme 2

The preliminary capital cost for the Scheme 2 plant has been calculated and is summarised in Table 10.17 below.

Table 10.17 - Estimated Capital Cost of Ammonia/Urea Plant - Scheme 2 Output 579 000 tonnes/year of Urea

Cost Item	Cost	
	million $	
Preliminary Work		
Process Plant Feasibility Study	2.50	
Appraisal Phase	0.10	
TOTAL		2.60
Installed Cost		
Ammonia Plant (US basis)	140.00	
Urea Plant (US basis)	20.00	
General Services (US basis)	36.50	
Sub-Total	196.50	
Increase for Colombian Conditions at 25%	49.10	
TotalColombian Erection Cost before Contingency	245.60	
Contingency	49.10	
TOTAL		294.70
Additional Costs		
Spares	14.70	
Pre-operational Expenses	8.80	
TOTAL		23.50
TOTAL CAPITAL COST OF AMMONIA/UREA PLANT - SCHEME 2		320.80 Rounded off to 320.00

The above estimate does not include the cost of working capital, replacement capital, land, coal transportation system, roads to the plant site, legal fees, permits and licences, local taxes and dues, finance charges.

10.7.2 Operating Cost for Ammonia/Urea Plant - Scheme 2

The operating cost for the Scheme 2 plant has been calculated as shown in Table 10.18 below.

Table 10.18 - Estimated Operating Costs for Ammonia/Urea Plant - Scheme 2 Output 579 000 tonnes/year of Urea

Cost Item	Annual Cost	%
Direct Costs	million $/year	
Wages and Salaries		
Operators/labour 480 at $3200/year) Staff 220 at $10 000/year)	3.74	9.3
Products and Materials		
Coal 0.915 x 10^6 tonnes/year at $20/t	18.30	45.5
Chemicals and Catalysts	0.47	1.2
Packaging at $8/tonne urea	4.60	11.4
Ash Disposal, 34 000 tonnes/year at $1.4/tonne	0.05	0.1
Maintenance Materials and Plant Insurance	11.20	27.9
TOTAL DIRECT COSTS	38.36	95.4
Additional Costs		
Overheads, Administration, Sales, General Expenses	1.87	4.6
TOTAL OPERATING COSTS	40.23	100.0
By-Product Credits (1)		
Sulphur 2000 tonnes/year at $94.5/tonne	(0.19)	(0.5)
EFFECTIVE OPERATING COST OF AMMONIA/UREA PLANT - SCHEME 2	40.04	99.5

(1) No credit is allowed for the excess CO_2 and nitrogen produced.

10.7.3 Production Cost of Urea from Scheme 2 Plant

The capital recovery factor calculated for Scheme 1 is still applicable. Its value is r = 19.2%.

The production cost of urea, including a return on equity of 12% after tax, can be calculated as follows:

$$t = \frac{f(P + rC)}{U}$$

where t = cost of urea

f = working capital factor taken as 1.04

P = operating cost taken as 40 x 10^6 \$/year (Table 10.18)

r = capital recovery factor taken as 0.192

C = capital cost taken as 320 x 10^6 \$ (Table 10.17)

U = output of plant taken at 0.579 x 10^6 tonnes/year urea.

Thus the cost of urea ex plant is calculated at $182/tonne.

10.7.4 Variations in Production Cost of Urea from Scheme 1 Plant

.1 Effect of Coal Cost from New Mines

If the cost of coal is reduced to the minimum cost of $18.30/tonne calculated for the new mines, the annual coal cost is reduced by 1.6 x 10^6 \$/year. The cost of urea is reduced by $2.9/tonne to approximately $179/tonne.

If the cost of coal is increased to the maximum cost of $20.8/tonne calculated for the new mines, the cost of urea is increased by $1.3/tonne to approximately $183/tonne.

.2 Effect of Plant Location

Provided the urea plant is located along the railway line, the cost of coal varies with the distance between the plant and the mine at the rate of $0.035/tonne per km and the price of urea at the rate of $0.058/tonne per km. Thus for a distance between the plant and the mine of 120 km, the cost of urea is increased by $3/tonne to approximately $185/tonne.

.3 Effect of Coal Source

If coal at $10/tonne were available (urea plant located next to opencast mine for example), the annual coal cost would be reduced by 9.15×10^6 \$/year and the urea price would be reduced by $16/tonne to approximately $166/tonne. If the plant were located near the coast, the probable cost of urea transported to Medellin would be around $186/tonne.

If coal at $30/tonne were used (coal imported from coalfield outside Antioquia for example), the urea price would be increased by $16/tonne to approximately $198/tonne.

.4 Effect of Process Route

If the Texaco process were to be used for the total gasification of coal, preliminary indications are that the capital cost of the plant would be reduced by some $50 million (under Colombian conditions) and the total coal usage would be reduced by some 15-20%. The urea price would be expected to be reduced by some $22/tonne to around $160/tonne.

10.8 Evaluation of Urea Production from Natural Gas

The appraisal undertaken in 1976/77 by the Instituto Fomento Industrial (IFI) of the ammonia/urea project planned in the Barranquilla/Guajira area has been adjusted to provide comparative figures for the production of urea from Colombian natural gas both in the Barranquilla area and the Antioquia area. The following adjustments have been made:

- The natural gas price for the Barranquilla area is taken as $\$0.90/10^6$ Btu at mid-1977, based on the 1976 price of $\$0.879/10^6$ Btu increased by an inflation allowance.

- The price of natural gas brought by pipeline to Antioquia is taken as $\$2.10/10^6$ Btu, based on the calculation presented in Section 7.3.1.

- Capital costs are increased by 5% to allow for inflation from end 1976 to mid-1977.

- Capital costs are increased by $8 million to allow for a urea plant with an output of 579 000 tonnes/year (as in Schemes 1 and 2) instead of 380 000 tonnes/year (as in IFI Report).

- The cost for equipment and construction in Antioquia is taken as 1.5% higher than in Barranquilla because of additional transport costs.

- Wages and salaries are deflated by a factor of 0.70 to allow for the difference in wage levels between the IFI Report (1982 wage levels) and the present appraisal (mid-1977)[(1)].

- The cost of utilities is calculated from Appendix X of the IFI Report for natural gas prices of $\$0.9/10^6$ Btu and $\$2.1/10^6$ Btu respectively, adjusted for outputs of 330 000 tonnes/year ammonia and 579 000 tonnes/year urea.

- The allowances for contingency, spares, pre-operational expenses, maintenance materials, plant insurance and operating cost overheads are as defined in Sections 10.1 and 10.2.

- The timescale for plant construction (see Section 9), the capacity build-up and the financial assumptions (see Section 10.3) are taken as for Schemes 1 and 2, hence the capital recovery factor is taken as 19.2%.

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(1) Staff costs assumed: 1982 level - Ps40 000/month i.e. $13 044/yr.
1977 level - $10 000/year. Factor 0.767
Operator costs assumed: 1982 level - Ps15 000/month, i.e. $4891/year.
1977 level - $3200/year. Factor 0.654

From Appendices I, VIII and X of the IFI Report, the capital and operating costs for the plant can be calculated with the appropriate adjustments as indicated in Tables 10.19 and 10.20 below.

Table 10.19 - Estimated Capital Cost for Ammonia/Urea Plant based on Natural Gas Output 579 000 tonnes/year of Urea

Cost Item	Cost - million $	
	Barranquilla Location	Antioquian Location
Administration, Engineering, Taxes	31.2	31.2
Land, Civil Engineering, Equipment, Freight, Insurance, Plant Construction	140.9	143.0
Total before Contingency	172.1	174.2
Contingency	34.4	34.8
Total Installed Cost	206.5	209.0
Spares	10.3	10.5
Pre-operational Expenses	6.2	6.3
TOTAL CAPITAL COST OF AMMONIA/ UREA PLANT - NATURAL GAS	223.0	226.0

Table 10.20 - Estimated Operating Costs for Ammonia/Urea Plant based on Natural Gas

Cost Item	Annual Cost - million $/year	
	Barranquilla Location	Antioquian Location
Direct Costs		
Wages and Salaries	2.8	2.8
Products and Materials		
- Natural Gas	10.6	24.7
- Chemicals, Catalysts, Boiler Feedwater	0.4	0.4
- Packaging	4.6	4.6
Utilities		
- Electric Power	0.3	0.8
- Steam	2.0	4.7
- Cooling Water	0.8	1.5
Maintenance Materials and Plant Insurance	7.8	8.0
Total Direct Costs	29.3	47.5
Additional Costs		
Overheads, Administration, Sales, General Expenses	1.4	1.4
TOTAL OPERATING COST OF AMMONIA/UREA PLANT - NATURAL GAS	30.7	48.9

Using the capital recovery factor of r = 19.2%, the cost of urea, including a return on equity of 12% after tax, can be calculated as follows:

- Barranquilla location t = $132/tonne
- Antioquian location t = $166/tonne

The cost in Antioquia of urea manufactured in Barranquilla would be in the order of $152/tonne (allowing transport cost at $20/tonne).

10.9 Comparison of Urea Production Costs

The cost of producing urea in Colombia from coal and natural gas are compared in Table 10.21, together with the existing selling price.

Table 10.21 - Comparison of Urea Production Costs and Selling Price (All costs relate to mid-1977 conditions)

Production Route	Process	Fuel Source	Fuel Cost	Urea Cost $/tonne	Notes
Gasification with Cogeneration of Tar	COED/Cogas Pyrolysis and Hot Char Gasification	Coal	$/tonne		
		New mines - Antioquia	20	136	(1)
		New mines - Antioquia	20	148	(2)
		Imported into Antioquia	30	155	(1)
		Opencast	10	117/137	(1)(3)
	Conventional Lurgi	New mines - Antioquia	20	160-165	(1)(4)
Total Gasification	Koppers-Totzek	New mines - Antioquia	20	182	
		Imported into Antioquia	30	198	
		Opencast	10	166/186	(3)
	Texaco	New mines - Antioquia	20	160	(4)
Production from Natural Gas		Natural Gas	$/10^{6}Btu		
		Guajira	0.9	132/152	(3)
		Pipeline to Antioquia	2.1	166	
Imports				185/205	(5)

(1) For tar products as Disposal Pattern 2.
(2) For tar products as Disposal Pattern 3.
(3) Urea cost indicated as Cost ex plant/Cost in Antioquia.
(4) Order of magnitude urea cost only.
(5) Urea cost indicated as Cost landed Colombian Port/Cost in Antioquia.

10.10 Discussion of Results

All prices and costs indicated below relate to mid-1977 conditions. Production costs for urea include a 12% return on equity after tax.

The selling price of imported urea is around $185/tonne landed Colombian port and $205/tonne delivered in Antioquia.

The production cost of urea from natural gas in a plant located near the Caribbean coast is estimated to be, at the scale and under the financial conditions assumed for this study, around $132/tonne ex plant and $152/tonne delivered to Antioquia. The construction of a pipeline to supply natural gas to a urea plant in Antioquia does not appear to be of immediate commercial interest.

The production cost of urea from coal with cogeneration of tar products would be around $136 to $148/tonne ex Antioquian plant, for a plant using the COED/Cogas pyrolysis route, the actual cost depending on the pattern of tar products manufactured. For the supply of inland urea markets in Colombia, this compares favourably with urea produced from natural gas on the coast. The proposed coal based project, therefore, appears potentially very profitable.

Because the COED/Cogas route is not yet mature and its implementation in Colombia would depend on the timing of its development programme in the USA, the options of producing urea by other more conventional routes merit further consideration.

The use of the Lurgi process could result in a production cost for urea of around $160-$170/tonne ex Antioquian plant, depending on the pattern of tar products manufactured. The production cost might be reduced by the use of newer developments of this process route, notably the slagging gasifier. However, the smaller tonnage of tar products manufactured (around 20 000 to 25 000 tonnes/year) would reduce the profitability of downstream processing of these products.

The production cost of urea alone , without production of tar, would be around $182/tonne for the Koppers-Totzek route and $160/tonne for the Texaco route, calculated ex Antioquian plant.

The use of these alternative routes in an Antioquian based plant, although not quite as favourable for the supply of inland urea markets as the manufacture of urea from natural gas in a coastal location, could still lead to a profitable commercial venture.

Urea manufactured from coal in a coastal location, using opencast mined coal at $10/tonne (assumed) could produce urea at $117/tonne ex plant, or $137/tonne delivered to Antioquia. For the supply of inland markets such a plant would produce urea at a cost lower than an Antioquian based plant.

11. LOCATIONS AND INFRASTRUCTURE

11.1 Requirements of the New Mines

The principal requirements in services of the new mines 1 and 2 are:

- Transport facilities for approximately 3400 tonnes/day of coal.
- Power supply capable of supplying approximately 7 million kWh per year with a maximum power load of 2.6 MVA.
- Workforce of around 1160 people, of which about 1000 are for work underground.

These requirements may be doubled at some future stage if mine 3 is put into operation whilst mines 1 and 2 are still in production.

The new mines are located in close proximity to an existing railway line. This line, which has been disused for some years would, after rehabilitation and purchase of suitable rolling stock (or reinstatement of existing unused rolling stock as appropriate), have ample capacity to handle the coal traffic required. Spur lines could be installed onto the mine site as necessary. This transport option has been retained in this study, although the comparative economics of other forms of transport require to be assessed at the mine feasibility study stage.

A 13.2 kV electric line fed by the local grid is already available on the site. It is not known whether the capacity of the existing system is capable of providing and handling the electric power required. It is known that, in periods of drought, the Medellin power supply system is incapable of meeting the region's needs.

The new mines are located close to Amaga and Angelopolis. These towns are the main sources of skilled mining labour in the area. Labour recruitment should not, therefore, present any major problems.

11.2 Requirements of Urea Plant

The principal requirement in services of the urea plant are:

- Coal supply of around 3400 tonnes/day.
- Water supply of around 1200 m^3/h.
- Disposal of 40 m^3/h of effluent containing approximately 65 ppm phenols and 2000 ppm ammonia.
- Land area of approximately 30-40 hectares.
- Transport facilities, principally by road, for approximately 50 000 tonnes/month of urea and approximately 8000 tonnes/month of chemicals and tar products.
- Workforce of about 850 people of which around 250 are staff.

The above requirements define the criteria which should be considered in the selection of a site for the urea plant. The plant should be located near the railway (assuming that this coal transportation system is retained in the last analysis), and as close as possible to the mine in order to reduce transport costs. The plant should be located near a river with a minimum flow of at least 12 000 m^3/h. The site should be reasonably flat over an area of around 40 hectares. The site should be located near a road system capable of absorbing the plant traffic estimated at some 300-400 lorries per day each way and the necessary personnel transportation vehicles. Finally the site should be located near centres capable of providing the necessary workforce.

The ultimate selection of site will take into consideration the cost of meeting these various criteria.

11.3 Possible Locations for Urea Plant

11.3.1 General

A detailed survey of the sites available for the urea plant and a detailed analysis of their relative economics would form a major task for the process plant feasibility study.

In the present study a brief qualitative review of possible sites was made. This did not produce any data from which positive recommendations could be made.

11.3.2 Envigado

The most obvious location for the urea plant would be on the Rio Medellin near Envigado, the industrial suburb of Medellin. Unoccupied land here is reasonably level, there are good road and potential rail connections with both the proposed mining area and Medellin and other parts of Colombia. Labour could be drawn from Medellin, Envigado and Caldas.

The Rio Medellin currently serves a variety of industrial enterprises in Medellin and Envigado for cooling and boiler feed water and for effluent disposal. Considerable doubts were expressed as to its capability of providing adequate supplies for an additional major plant and since it is already severely polluted, whether the authorities would permit any new developments which might add to this problem.

The cost of land at this location was stated to be of the order of 200 pesos/m^2 or $55 000 per hectare.

11.3.3 Caldas

The second possibility is a site, again on the Rio Medellin,near the small town of Caldas. This is 25 km from Medellin but nearer the new mines. It is on the Western Trunk highway and has potential rail communication with the mines in one direction and Medellin in the other. The land is fairly flat and according to those consulted, priced at around $3000/hectare. There is, however, considerable doubt about the adequacy of the Rio Medellin, which is smaller here than at Medellin or Envigado, to furnish the main water supply.

11.3.4 Rio Cauca

A site on or within easy reach of the Rio Cauca would ensure adequate water supplies, but the terrain rises steeply in most parts from the river banks. Probably the most suitable location on the Rio Cauca would be at Bolombolo in the angle between the Rio Cauca and its tributory, the Rio Sinifana. This, in fact, is the site tentatively earmarked for a possible new thermal power station. Undeveloped land here is cheap, under $1000 per hectare. The railway would connect the plant with the new mines (about 50 km) and with Medellin (about 103 km). The disadvantages are the hilly nature of the land, the poor road access and the lack of an adjacent source of labour.

11.3.5 Palomos

A further possibility is a site north of Fredonia near Palomos where there are some reasonably level areas near the Rio Sinifana. This site is only 22 km from the mines and 65 km from Medellin. It is close to the railway line and within easy reach of the small towns of Fredonia and Minas. There is doubt, however, whether the supply of water from the Rio Sinifana would prove adequate.

The land is presently under cultivation for coffee and sugar cane and would probably be expensive to acquire.

11.3.6 Porce

Porce, to the north west of Medellin, has some advantages. The land here is not too hilly, could be purchased at about the same price as at Bolombolo and is served by the main railway from Medellin to Puerto Berrio. The Rio Medellin, at this point, has a flow of 8 m^3 per second. Studies for a new paper mill in Antioquia, which involved a detailed study of the whole area, came to the conclusion that the only two sites which combined adequate water supplies, cheap, flat land and proximity to a labour force were Bolombolo and Porce. The main disadvantage of this location is that it is 110 km from the new mines and 55 km from Medellin. Other matters being equal, the higher transport cost could lead to a production cost of urea in Porce some $4/tonne higher than in Medellin.

11.4 Rehabilitation of Railway Line

The disused railway line, which crosses the coalfield, would require rehabilitation before it could be used for the transport of coal between the new mines and the urea plant. According to Ferrocarriles Nacionales de Colombia, any proposal to use the railway for mineral traffic would be an important factor in inducing the authorities to sanction capital expenditure for repairs and new rolling stock. Such a rehabilitation would also benefit the mining towns in the Medellin coalfield and would assist, it is claimed by Colombian sources, in preventing a further decay of these communities and the drift of their population into Medellin.

An order of magnitude cost has been developed for the rehabilitation and equipping of the railway for the project under consideration. This is presented in Table 11.1.

It has, however, been assumed for the purpose of the project evaluation, that the capital costs of the rehabilitation and equipping of the railway would be borne by Ferrocarrile Nacionales de Colombia (estimated cost about $3.5 million), and that the mine will only purchase the coal wagons and install the spur lines and sidings (estimated cost about $3.25 million, see Section 10.5.4).

Table 11.1 - Estimated Capital Cost for Transportation System

Cost Item	Cost
	million $
Fourty-five 50 tonne Coal Wagons at $34 000 each	1.53
Two 170 tonne locomotives at $527 000 each	1.05
One 80 tonne locomotive at $336 000	0.34
Communications	0.05
Equipment Cost, FOB Port of origin	2.97
Freight, Taxes, Handling Charge at 30%	0.89
Equipment Cost, Mine Site	3.86
Repair of Track, 60 km at $10 000 per km	0.60
Spur Lines/Siding at Mine and Plant 2 km at $270 000/km	0.54
Engineering, Procurement and Construction Management, 8% of Equipment Cost (Origin)	0.24
Total before Contingency	5.24
Contingency	1.05
Total Installed Cost	6.29
Spares	0.30
Administrative Overheads	0.19
TOTAL COST OF TRANSPORTATION SYSTEM	6.78

12. IMPLEMENTATION OF PROPOSED DEVELOPMENT

12.1 Urea Demand and Phasing of Urea Production

The domestic demand for urea in Colombia was approximately 210 000 tonnes/year in 1976 and is estimated at around 310 000 - 320 000 tonnes/year in 1978, representing a growth rate of about 21.5% per annum.

In the 1976/77 IFI report analysing the 380 000 tpa urea plant proposed for Barranquilla or Guajira, a growth rate of 7.5% pa was predicted from 1977 onwards.

For the purpose of preliminary forward planning, it is reasonable to expect the demand for urea in Colombia to increase at a rate between 7.5% pa and 10% pa. These two demand curves are plotted in Figure 20.

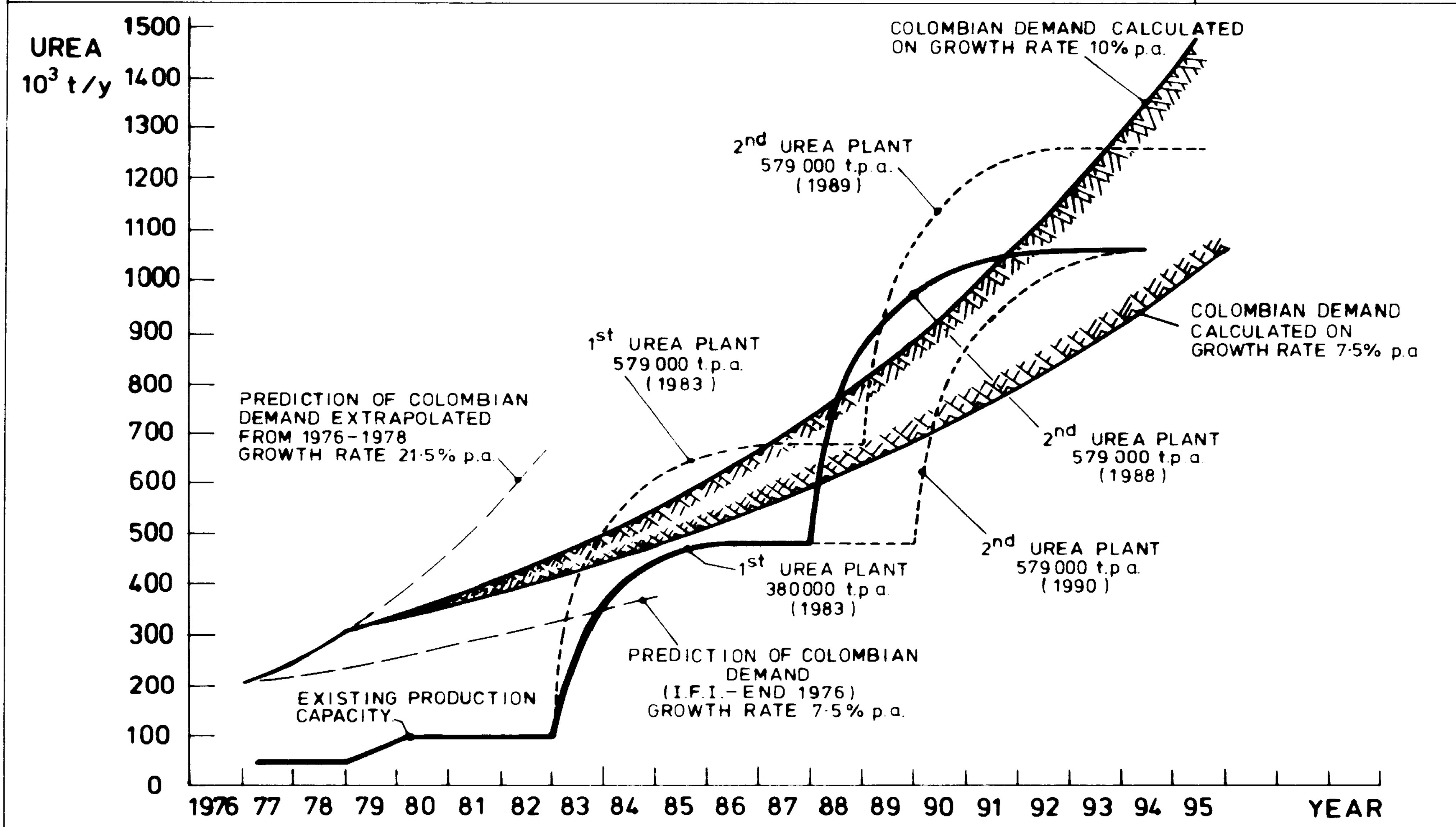
The existing installed capacity in Colombia for the production of urea is 100 000 tpa. Because of production difficulties the actual output has been less, but for the purpose of forward planning it has been assumed that the output could be restored to the rated capacity of the existing installations.

The difference between demand and present capacity represents a massive and ever increasing production deficit which must be made up by imports or by new production facilities. The use of imports to make up this shortfall in urea production will create a serious drain on the country's balance of payments. Thus,if Colombia wishes to reduce this outflow of funds, appropriate urea production facilities must be built in Colombia.

A first urea production plant, based on natural gas and with a capacity of 380 000 tpa is planned for the Barranquilla/Guajira area. This plant had not been ordered by end 1977 and the earliest

Figure 20.

POSSIBLE PHASING OF UREA PRODUCTION.



production start, assuming an order placed in 1978, will be 1983. The output of this plant, based on this timescale, is shown in Figure 20. On present predictions of demand, this will not satisfy the Colombian market and further production capacity will be required in the late 1980s.

The earliest production start of a 579 000 tpa urea from coal plant in Antioquia would be 1988 and this production step is shown on the diagram. If the Colombian demand for urea actually grows at the higher rate indicated, then this production phasing will be correct to ensure adequate coverage of the Colombian demand, with only a small surplus available for export in 1989 and 1990. If, on the other hand, the Colombian demand grows at the lower rate indicated, the correct phasing for the urea from coal plant is probably a production start around 1990.

An alternate production pattern is also shown on Figure 20, assuming that the first urea plant (based on natural gas) would have a capacity of 579 000 tpa. This capacity appears more appropriate to meet the immediate predicted demand. In this case the correct phasing for the second urea plant (from coal) would be 1989 for the high growth rate demand and possibly 1993 for the low growth rate demand.

The above considerations of phasing are all based on restricting the amount of surplus urea for export. Mexico, and to a lesser extent Venezuela, have plans for a massive build-up in their production facilities for ammonia and urea in the 1980s and substantial amounts of these products will be available for export to the Latin American countries. It is therefore felt that it would be unwise for Colombia to rely in its forward planning on any substantial export markets for urea.

12.2 Potential Coal Production Levels in Antioquia and Coal Demand

The present production level of the Antioquian coalfield is around 600 000 tonnes/year. In the short term, production from the existing mines could be raised to around 950 000 tonnes/year by some conversion to longwall mining in the larger mines and an increase in production from the small mines in response to the increase price of coal. In the longer term the production from the existing mines could be increased by around 400 000 tonnes/year to about 1 350 000 tonnes/year by maximum conversion to longwall mining of all the larger mines (see Section 5.2.4).

The new mining development in the Amaga area proposed in this study would have a total capacity of 2 million tonnes/year, produced by three mines (see Section 5.6.1). It is envisaged that the two smaller mines with a combined capacity of 1 million tonnes/year would be developed first.

A further area suitable for a potential mining development was identified in the Titiribi-Venecia area with geological reserves of 20 to 40 million tonnes of coal (see Section 5.4). This could possibly support a mining development with an output of some 500 000 tonnes/year.

The total potential capacity of the Antioquian coalfield, based on the above considerations and presently known reserves is thus of the order of 4 million tonnes/year.

The domestic demand for coal in Antioquia has remained fairly constant for several years at a level of 400 000 to 500 000 tonnes/year. The domestic demand in 1976 was around 500 000 tonnes/year and a further 120 000 tonnes/year were exported to Caldi and Caldas. Assuming a growth rate of 5% pa applied from 1985 onwards, it can be seen from Figure 21 that demand could overtake supply around the year 2014. If the coal demand of the proposed urea plant is added to the domestic demand, the total

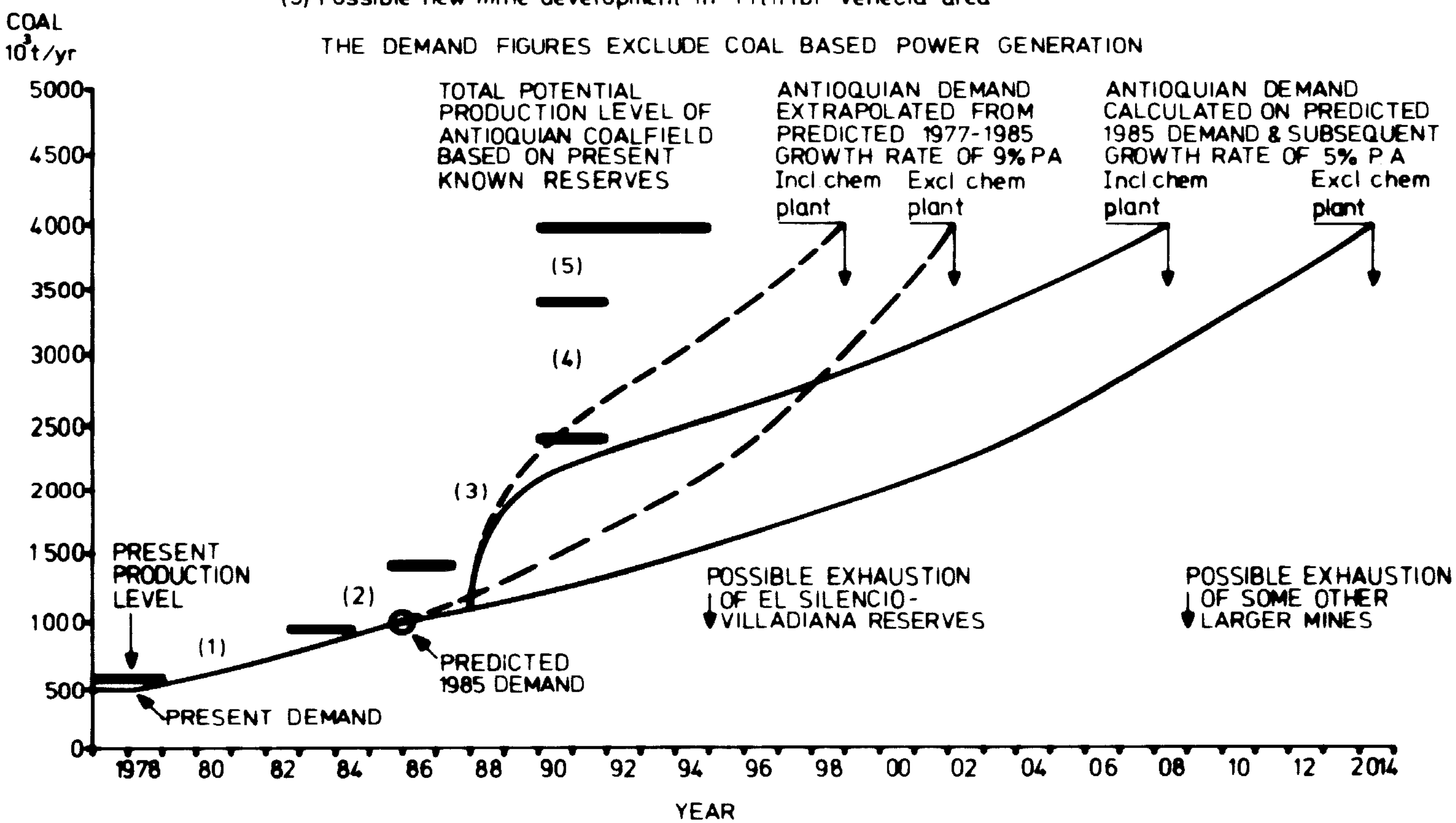
FIG.21 POTENTIAL COAL PRODUCTION LEVELS IN ANTIOQUIA

CPC Coal Processing Consultants

PRODUCTION LEVEL INCREASES

(1) Conversion to longwall operation of larger existing mines and increased capacity of small mines in response to higher prices.
(2) Increase to maximum production in existing mines.
(3) Amaga new mine development No 1
(4) Amaga new mine development No. 2
(5) Possible new mine development in Titiribi-Venecia area

THE DEMAND FIGURES EXCLUDE COAL BASED POWER GENERATION



demand could exceed supply by around the year 2008. Thus a urea plant, which started production in 1988 would have an assured coal supply from Antioquian sources for 20 years.

Other forecasts indicate a coal demand in Antioquia by 1985 of around 985 000 tonnes/year (see Table 6.2). This represents a growth rate of 9.5% which would result in assured Antioquian coal supplies for the urea plant of only 10 years. Unless further coal reserves were found and exploited, the plant would have subsequently to rely on coal imported from other provinces at much higher prices. More definitive information regarding the growth of coal demand in other industries and the extent of further Antioquian coal reserves is clearly essential before any decision is made to build a major coal based chemical plant.

It should be noted that the above considerations take no account of the possible use of Antioquian coal for the thermal generation of electric power. If a coal burning power station were to be built in Antioquia, it is considered that the coalfield could not support any coal based chemical manufacturing facility.

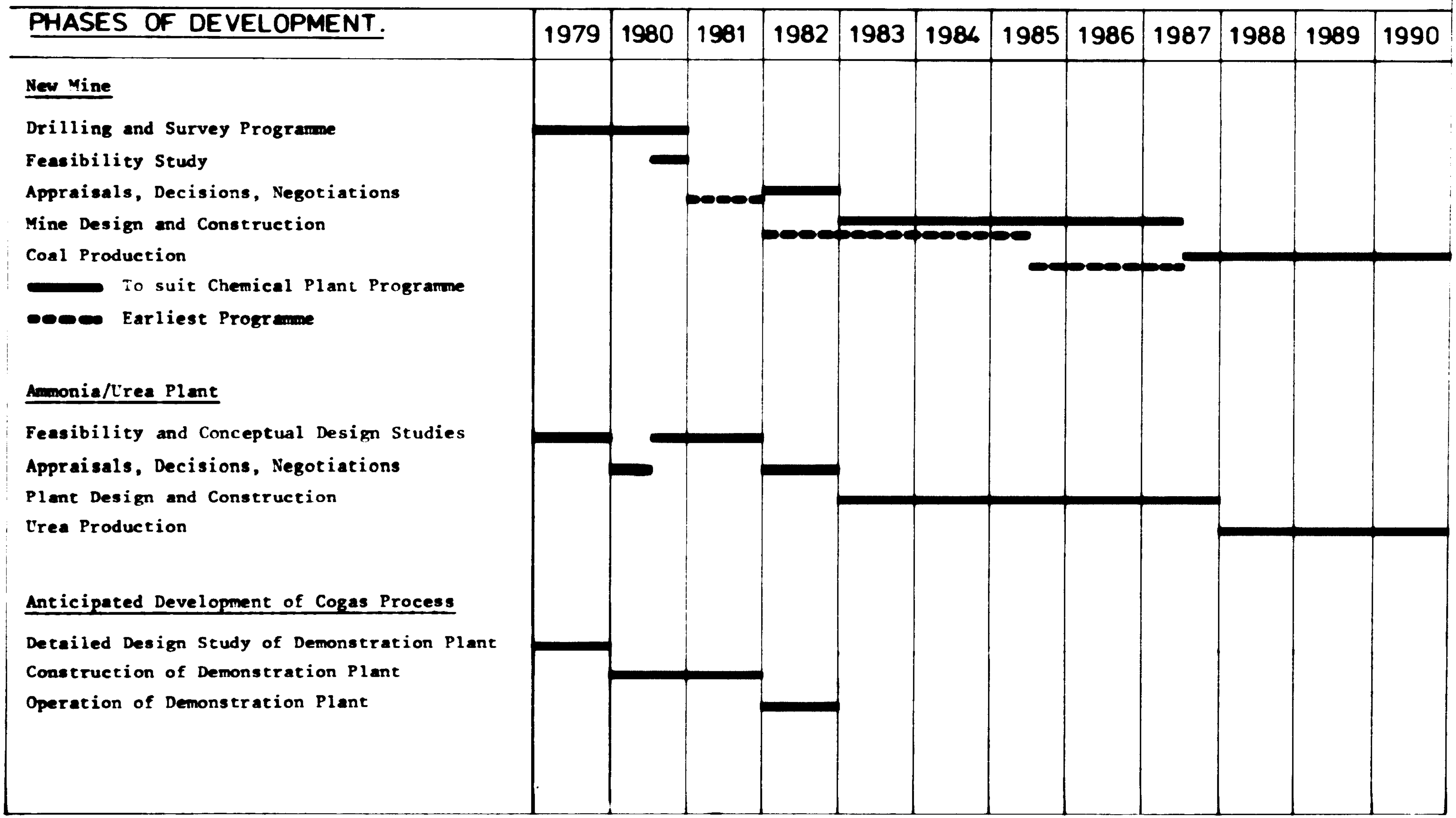
12.3 Possible Programme for Proposed Development

The various phases in the development of the project have been described in Section 9. The possible timescale for their implementation is shown in Figure 22.

As discussed in Section 12.2, the optimum phasing of the urea plant,assuming a growth rate for urea demand of 10% pa,would be a production start in 1988. This timing is used as the basis for the programme in Figure 22.

This programme indicates that if the project is to be implemented in the timescale shown, the mining investigation and the process plant feasibility study should be put in hand as rapidly as possible, and no later than early 1979.

Figure 22. POSSIBLE PROGRAMME FOR CHEMICAL PLANT DEVELOPMENT.



The development period for the mines can be shorter than that for the process plant, as shown on Figure 22. It would thus be possible to start-up one or more of the new mines prior to the urea plant, if the coal were required to supplement the existing coal production. However, in that case, it is recommended that the 3 new coal mines should be developed in such a sequence as to ensure segregation of coal production for local purposes and coal production for the urea plant. If this is not the case, then the mines feeding the urea plant would be subject to the fluctuations in the demand-supply situation for coal in the Medellin area, with all its consequent drawbacks for the smooth running of the urea plant.

The Cogas process has been identified as the most promising process route for the production of urea and tar. Figure 22 shows the anticipated programme for the development of the Cogas project, based on the latest known information. If this development proceeds to schedule, operating data on the demonstration plant could be available in 1982, in time for this information to be fed into the development of the Antioquian urea plant project. If this development programme is delayed, as may well be the case because the Cogas project is undertaken in stages, each requiring US Federal funding, then this would affect the Antioquian project which would either have to be delayed or would have to be based on a more readily available, if less commercially attractive route.

12.4 Possible Sources of Finance

Future financing of the project can be divided into two parts, firstly the financing of the feasbility studies and secondly the financing of the implementation of the project. In view of the significant cost of the mining investigation and planning as well as the plant feasibility and conceptual design studies, even these aspects of the work are likely to be beyond the capacity of private local investors.

Before any external finance is forthcoming the question of ownership of the coal mining rights in the Amaga-Fredonia area will have to be resolved together with the relationship which will exist between existing landowners and the state-owned coal company, Carbocol, should the feasibility studies indicate the economic viability of a new mine. Access to external investment funds will be considerably increased provided the project receives governmental support and financial guarantees. The funding of the feasibility study could then come from one or more of the following sources:

- Colombian Government
- National Aid Agencies
- International Development Banks
- United Nations System

It is doubtful if the Colombian government can find funds for the development of the Antioquia coalfield in the immediate future as it has already decided that the coal deposits in El Cerrejon and Sabana de Bogota will receive the first priority in the development of Colombia's coal resources.

National aid funds, although a possible source, will be difficult to secure as such finance tends to be allocated for social programmes of immediate political impact rather than for industrial projects with long gestation periods.

International Development Banks (e.g. World Bank Group and Inter-American Development Bank) are a source of funds for industrial projects but, apart from transportation studies, tend to favour the financing of projects after the feasiblity studies.

The United Nations System appears to be the most probable source of funds for the mining investigation and the mine feasibility study. The newly-created United Nations Revolving Fund for Natural Resources Exploration has been specifically established for financing exploration - the high-risk component of the mineral processing industry. An important difference between the Revolving Fund and the usual UNDP funding, which is very limited in its financial resources, is that there is a repayment obligation to the Fund. Successful ventures, which have used Revolving Fund finance, are required to repay the money in order to re-finance the Fund for further loans to other worthwhile projects in the developing countries.

Alternatively, funds for the immediate financing of the feasibility studies could be obtained from the International Finance Corporation (World Bank Group) which caters to private industry. However, this source of funding is by no means certain because of the high-risk nature of the project at this stage.

13. POTENTIAL BENEFITS OF THE PROPOSED DEVELOPMENT

The development in Antioquia of new coal mines and of an associated coal based urea manufacturing facility will have significant effects on the province and on the country as a whole.

The profits generated by such a development, probably in excess of $30 million per annum before tax, will contribute directly or indirectly to regional and national prosperity.

The substitution of local supply for products otherwise imported will have beneficial effects on the balance of payments. Investment in the project will, however, necessitate considerable foreign exchange expenditure on imported capital equipment and the amounts involved must be set against the import savings in later years.

The availability of a continuous local supply of urea at regular and cheaper prices will stimulate agricultural development both in Antioquia and in the inland areas served by the new facility. The availability of substantial quantities of locally produced tar products (wood preservatives, road pitch, etc.) will benefit the public transport sector, the construction industry and agriculture. The local availability of a range of coal derived chemicals could lead to the establishment of new downstream manufacturing facilities for the production of a number of products (see Sections 7.3.6 and 7.3.7) not presently prepared in Colombia but for which a ready market exists or could be developed.

A significant effect of the development would be the generation of new employment opportunities, initially during the construction of the works, and subsequently in operating and servicing the new facilities. This factor is important in an area with a high level of unemployment. Further employment will be generated outside the works resulting from the stimulation of the industries serving the works, the effects of the new development upon downstream industries, the stimulation of industrial, commercial and agricultural activities arising through the development of the physical infrastructure.

The extension of the infrastructure resulting from the development will benefit the community as a whole. The movement of products will necessitate the improvement of road links both within the region and its connection with other centres of population. It will also necessitate the rehabilitation of the existing disused railway. These improvements may in turn encourage further regional development.

The development of new mines, built and operated in accordance with modern mining technology and management techniques will,contribute substantially to raising the standard and particularly the safety of the Antioquian mining industry, at present in a very depressed state and relying on primitive technology.

The transfer of technology associated with the process plant and its downstream developments will contribute to technological progress in Antioquia and Colombia as a whole.

14. TERMS OF REFERENCE FOR FURTHER WORK

14.1 Supervision of Mining Investigation

The following terms of reference are submitted as a basis for the supervision of the mining investigation.

a) Examine available geological and topographical data, plans and maps and assess the quantity and quality of data with special reference to:

   topography,
   geology,
   data on coal seams,
   data on floor and roof conditions to the seams,
   indicated oal reserves,
   ground water and surface water,
   analytical data on coal quality.

b) Carry out preliminary geological field investigations in order to make recommendations on the choice of areas which have the greatest expectations of containing economically viable reserves of coal.

c) Advise on the necessity of additional topographic mapping using either photogrammetric techniques or survey field parties. Co-ordinate the topographic survey project if this work is found necessary.

d) Carry out a detailed field geological investigation of the selected areas in preparation for designing a suitable drilling programme.

e) Design and determine the cost of the drilling programmes with special reference to the density and depth of drilling, logging and sampling procedures.

f) Co-ordinate and advise on the execution of the drilling programme and the presentation of the geological, geotechnical, analytical and hydrological data.

g) Prepare suitable maps, cross-sections and tables of information detailing all the data gathered from the fieldwork.

h) Gather data required by transportation engineers in order to determine alternative transportation routes and methods from the mines to the coal chemical plant.

14.2 Mine Feasibility Study

The following terms of reference are submitted as a basis for the mine feasibility study.

a) Examine and assess the quantity and quality of data gathered in the preliminary stages of the project.

b) Prepare plans and sections suitable for reserve calculations and outline mine planning purposes for the main seams involved, indicating where necessary what further work should be done. From the data available the following would be prepared:

- floor of seam contours
- isophachytes
- iso-maps of properties of particular significance
- longitudinal- and cross-sections
- topography

c) Design in outline alternative layouts for the mine or mines required, together with the specifications of alternative methods of working, in sufficient detail for preparing schedules of equipment, materials and manpower.

d) Select the most favourable mine layout and prepare preliminary capital and production costs. Consideration will be given to the inclusion of estimates for the engineering services, workshops, stores, administrative offices, stockpiling and recovery facilities, and all other facilities required with the mine.

e) From the available analytical and coal-washing test data, establish coal preparation requirements and, should a coal preparation plant be considered necessary, prepare an outline flow sheet together with capital and production cost estimates.

f) Assess the coal handling and transportation requirements up to the wagon-loading stage and prepare outline designs, including schedules of equipment, materials and manpower, in order to derive capital and production cost estimates.

g) Assess the transportation requirements from the mine to the coal processing plant. Select the most favourable transportation system based on the data gathered in the preliminary studies. Prepare outline designs, including schedules of equipment, materials and manpower, in order to derive capital and transport cost estimates.

h) Indicate the overall manpower requirements and management structure for the mine including the mine engineering services, workshops and stores, coal preparation, handling and transportation and other infrastructural requirements.

i) Assess the requirements for power, water, housing and roads and prepare phased estimates of them for onward transmission to the relevant Municipal Department or Central Government Authority.

j) Specify, together with an estimate of costs involved, the data that would be required and additional work which would be necessary to:

- prepare the project implementation brief,
- commence mining operations.

This would include such aspects as further drilling, surface geological investigations, test mining, sampling and analytical work.

k) Prepare realistic time schedules for the overall implementation of the project indicating any particular constraints and deadlines.

l) Provide an overall assessment. over a range of the coal's sales price, of the pre-tax economics of the project, together with a cost and revenue analysis, cash flow statements, calculations of payback period and the return on investment (discounted cash flow and sensitivity analysis of the major economic and engineering parameters).

14.3 Process Plant Feasibility Study

The following terms of reference are submitted as a basis for the process plant feasibility study:

a) Review the findings from the mining investigation, as these become available.

b) Provide a detailed assessment of the future demand for Antioquian coal taking account of alternative energy sources.

c) Evaluate the possible sources of coal for the process plant in longer term (beyond 20 years), when the proposed new mines may have been exhausted. Make recommendations regarding the need for further mining surveys.

d) Evaluate the potential markets for urea in the various parts of Colombia and other Latin American countries, taking into account the availability of urea and other fertilisers which may be imported from these countries.

e) Provide approximate estimates for the potential markets in Colombia for the following by-products arising from coal pyrolysis, including:

- Concentrated liquid ammonia liquor.
- Ammonium sulphate.
- Glauber's salt
- Phenol
- o-Cresol and m/p Cresol
- Cresylic acids
- Light oil
- Cresylic creosote
- Wood preservation creosote
- Pitch
- Pipe coating enamel modulate
- Black varnish
- Road tar

f) F view the alternative locations for the process plant. Select the optimum site, taking into account the following factors:

- Land availability, elevation, water table, ground loadings, topography.
- Access roads, rail links etc.
- Any existing power or water supplies.
- Access to labour for plant construction and operation.
- Transportation costs for delivery of chosen coals.
- Transportation costs for delivery of products to chosen markets.

g) Select a single coal specification to be used as the design basis for the plant.

h) Meet with developers and suppliers of plant and evaluate the current state of development of the alternative process routes for the pyrolysis and gasification stages, and subsequent production of urea and coal pyrolysis by-products.

i) Arrange for bench or pilot plant testing of Antioquian coal in the chosen pyrolysis/gasification processes.

j) Select the optimum process route and plant capacity based on technical and economic data.

k) Prepare mass balances for the chosen process route and select the product mix which best suits Colombian conditions.

l) Prepare process flowsheets and preliminary specifications for equipment and bulk materials.

m) Prepare preliminary plot plans and layout drawings.

n) Prepare a budget cost estimate for the plant, including the costs of detailed design, plant supply, erection and commissioning.

o) Assess manpower requirements for operation of the plant and prepare an estimate of operating costs.

p) Prepare a programme with respect to cost and timing for the on-going work.

q) Prepare schedules of raw materials, utilities and saleable products.

r) Prepare a schedule of anticipated liquid, solid and gaseous emissions.

s) Prepare a report summarising the findings and making recommendations for future action.

APPENDIX 1 - BASIC DATA AND BIBLIOGRAPHY USED FOR MINING SURVEY

Data

The coalfield is covered by 1:100 000 and 1:25 000 topograhic maps drawn from a photogrammetric base flown in 1955 and 1961.

The general geology of the area has been described and mapped at a scale of 1:500 000 by Dr. E. Grosse in 1920-23[1].

Apart from some general information included in overall review of the coal deposits and mining industry of Colombia[2], the mining, production and reserve data for the Medellin coalfied are scant. No exploratory boreholes have been sunk in the coalfield. Historically most of the coal has come from small mines (50 to 500 tonnes per month) and few records have been kept of production of areas which have been mined. In more recent years the majority of the mines now producing more than 500 tonnes per month have been surveyed from time to time. However, none of the maps were officially made available to the UNIDO project staff for commercial reasons.

A survey of the coal mines of Colombia was carried out by Dr. William Balbin A. in 1974/75 on behalf of the Ministry of Mines and Energy[3]. This report described the working mines of the Medellin coalfield from which the annual production of the field can be estimated.

A summary written by Sr. A. Jaramillo in 1974 describing the commercial potential of establishing an ammonia plant in Antioquia using Medellin coal, and an analytical report by Montan Consulting GmbH on three coal samples from Industrial Hullera's mine was also made available to the UNIDO project by the carbo-chemical committee of ANDI.

BIBLIOGRAPHY

The titles of the above-mentioned reports are as follows:

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2. Garces, H., 1976, El Carbon en el Futuro Energetico de Colombia, XIII Congreso Nacional de Ingenieria, Colombia.

Olivar, E., 1973, Caracteristicas Tecnologicas de los Carbones Colombianos. Tecnologia, v.15, pt.86, Colombia.

Beltran, E., 1974, Carbones de Colombia, Ministerio de Minas y Petroleos, Instituto de Investigaciones Geologico-Mineras.

3. Balbin, W., 1975, Censo Minero del Carbon, Ministerio de Minas y Energia, Division de Minas, Formentio Minero, Colombia.

APPENDIX 2 - DATA ON EXISTING MINES

Table A2.1 - Mines in the Medellin Coalfield with a Production Capacity in Excess of 500 tonnes/month - 1977

Mine	Owner	Municipality	Production Capacity tonnes/ month
Eastern Limb			
*Nechi	Geominas	Amaga	1500
El Silencio	Alfonso Angel	Amaga	300-1500
*Industrial Hullera	Industrial Hullera	Amaga	20 000
El Chorro	Industrial Hullera	Amaga	1500
*San Fernando	Carbones San Fernando	Amaga	6500
San Jose	Jose Correa	Amaga	200-500
El Mango (Onix)	Jesus Montoya y B.Arango	Amaga	500-900
El Mango No.1	Jesus Montoya y B.Arango	Amaga	1400
La Cueva	Sociedad Correa	Amaga	600-1200
*La Guali	Empresa de Departimento de Antioquia	Amaga	1500
*La Eda	Empresa de Departimento de Antioquia	Angelopolis	400-500
La Corona	Suc. Velasquez Correa	Angelopolis	1800
La 3	Juan y Jaime Velasquez	Angelopolis	0-500
Horizontes	Gustavo Gomez	Angelopolis	600
*El Palomo	Industrial Hullera	Fredonia	500
Western Limb			
Sabaletas	Hernan Posada	Titiribi	800
*Excarbon	Abelardo Moreno	Titiribi	1600
*Corcovado	Velez y Diozar	Titiribi	1000
*Rincon Santo	Oscar Paez	Venecia	560

* Mines visited by Dr. S. R. Rexworthy, 1977, as part of current study.

APPENDIX 3 - COAL DATA

Table A3.1 - Identification of Coal Samples

Sample	Mine/Area	Sample Location
1	Industrial Hullera-Amaga	Manto 1, L/W face, 10 yds from Inbye gate
2	"	Manto 1, L/W face, 5 yds from Outbye gate
3	"	Manto 1, Inchne 2, west part of mine
4	"	Manto 2, Main level, 200 m from Silencio portal
5	"	Manto 2, L/W face, 5 m in from Inbye gate
6	"	Manto 2, L/W face, 5 m in from Outbye gate
7	"	Manto 2, Development heading, centre part of mine, 2nd level
8	Industrial Hullera-Fredonia	Manto 3, 350 m from adit mouth
9	"	Manto 3, 350 m from adit mouth
10	"	Manto 2, 450 m from adit mouth
11	"	Manto 2, 450 m from adit mouth
12	"	Manto 1, 200 m from adit mouth
13	"	Manto 2, 50 m from adit mouth
14	"	Manto 2, 50 m from adity mouth
15	Geominas - Nechi	Manto 1, 12° level, x-cut 10 m north
16	" "	Manto 2, 12° level, x-cut 10 m north
17	" "	Manto 2, 14° level, x-cut 60 m north
18	Rincon Santo C De Dianunte	Manto 1, 200 m from adit mouth
19	" " "	Manto 2, open cut
20	Excarbon - Titiribi	Solapucla, 100 m from adit mouth

Table A3.1 continued

Sample	Mine/Area	Sample Location
21	Ex carbon - Titiribi	La Giando, 130 m from adit mouth
22	" "	Cenisosa, 220 m from adit mouth
23	" "	La Mejida, 250 m from adit mouth
24	" "	La Regular, 310 m, x-cut 100 m S
25	" "	Alemana, 310 m, x-cut 100 m S
26	Titiribi	La Luz
27	Corcovado Mine	Solapucla, Lwr adit
28	" "	La Grande, Lwr adit
29	" "	Cenisosa, Upr adit
30	" "	Mejida, Upr adit
31	EDA, Guali	Manto 1, 60 m from mouth, x-cut 20 m S
32	" "	Manto 1, 250 m from mouth, x-cut 120 m N
33	EDA, Est. Angelopolis	Manto 1, 50 m from adit mouth
34	" " "	Manto 2, 80 m from adit mouth
35	" " "	Manto 3, 120 m from adit mouth
36	EDA, La Mani	Manto 3, 180 m from adit mouth
37	" "	Manto 3, 350 m from adit mouth, y-cut 120 m S
38	San Fernando	Manto 2, 1° level, 200 m from adit mouth
39	" "	Manto 1, 8° level, 120 m NW of Inchne 2
40	" "	Capotera, road out of property

Table A3.2- Proximate Analyses, BS Swelling Numbers and Total Sulphur Contents of Samples

Sample No.	Proximate Analysis (wt %)					BS Swelling Number	Total (wt %) Sulphur (as analysed)
	Moisture (as analysed)	Ash (as analysed)	Volatile Matter (as analysed)	Fixed Carbon (as analysed)	Volatile Matter (daf)		
1	11.6	3.3	41.0	44.1	48.2	½	0.36
2	12.1	4.2	41.3	42.4	49.3	½	0.33
3	13.1	5.1	39.9	41.9	48.8	0	0.25
4	14.3	5.2	37.7	42.8	46.8	0	0.60
5	11.1	4.7	41.2	42.8	49.0	½	0.50
6	12.8	3.0	39.6	44.6	47.0	½	0.55
7	13.0	4.5	38.7	42.8	48.1	½	0.55
8	12.6	6.6	40.4	40.4	50.0	0	0.65
9	11.7	5.8	41.5	41.0	50.3	½	0.70
10	9.5	41.7	25.9	22.9	53.1	0	1.00
11	14.6	4.3	38.7	52.4	47.7	0	0.90
12	13.5	3.4	40.7	42.4	49.0	0	0.40
13	9.7	44.2	25.3	20.8	54.9	0	0.95
14	12.0	8.4	40.6	39.0	51.0	0	0.90
15	10.5	8.7	40.3	40.5	49.9	0	0.40
16	10.0	7.6	40.9	41.5	49.6	0	0.60
17	11.6	5.7	40.3	42.4	48.7	0	0.40
18	4.8	10.4	37.3	47.5	44.0	½	1.40
19	6.9	16.9	34.6	41.6	45.4	0	1.05
20	6.6	7.1	40.1	46.2	46.5	½	0.90
21	6.1	3.9	42.4	47.6	47.1	½	0.65
22	6.7	2.8	40.5	50.0	44.8	½-1	0.40
23	5.0	12.3	37.0	45.7	44.7	½-1	0.80
24	5.2	2.2	35.6	57.0	38.4	½-1	0.50
25	3.7	3.9	22.9	69.5	24.8	½-1	0.55
26	2.3	38.7	11.4	47.6	19.3	0	1.40
27	7.5	8.0	40.2	44.3	47.6	½	1.05
28	7.8	2.5	41.9	47.8	46.7	½	0.70
29	9.1	8.2	37.6	45.1	45.5	½	0.55
30	7.0	27.5	31.2	34.3	47.6	0	0.65
31	12.1	3.1	41.3	43.5	48.7	0-½	0.30
32	14.4	2.8	39.0	43.8	47.1	0	0.40
33	14.9	2.7	39.9	42.5	48.4	0	0.35
34	15.4	2.9	38.1	43.6	46.6	0	0.60
35	14.3	3.2	39.0	43.5	47.3	0	0.55
36	12.9	4.1	39.4	43.6	47.5	0	0.40
37	12.5	6.0	39.5	42.0	48.5	0	0.46
38	12.5	4.7	39.5	43.3	47.7	0	0.65
39	11.6	8.2	40.6	39.6	50.6	0	0.40
40	13.7	8.6	34.7	43.0	44.7	0	1.05

Table A3.3 - Composition of Bulk Samples

Bulk Sample	Component Samples	Representative of Seam	Location
B1	1, 2, 3, 31, 32, 33, 39	Manto 1	North
B2	12, 15	Manto 1	South
B3	20, 21, 22, 23, 24, 27, 28, 29	Titiribi	
B4	4, 5, 5, 7, 38	Manto 2	North
B5	11, 16, 17	Manto 2	South
B6	35, 36, 37	Manto 3	North
B7	8, 9	Manto 3	South

Table A3.4 - Full Analysis of Composite Samples

Sample Number	B1	B2	B3	B4	B5	B6	B7
Proximate Analysis %							
Moisture	13.3	12.7	7.0	13.2	12.5	13.6	12.5
Ash	4.1	6.1	5.8	4.3	6.2	4.3	7.4
Volatile matter	39.5	39.1	38.9	38.7	39.0	38.7	39.6
Fixed carbon	43.0	42.1	48.3	43.8	42.3	43.4	40.5
Volatile matter (daf)	47.9	48.2	44.6	46.9	48.0	47.1	49.4
Coking Properties							
BS Swelling number	0	0	½	0	0	0	0
Gray-King coke type	A	A	B	A	A	A	A
Calorific Value							
Btu/lb	13 100	13 020	13 840	13 120	13 100	13 120	13 100
kJ/kg	30 470	30 280	32 200	30 520	30 480	30 520	30 480
Ash Fusion Range °C							
Deformation temp.	1100	1140	1230	1100	1110	1090	1190
Hemisphere temp.	1120	1150	1350	1110	1150	1140	1280
Flow temp.	1150	1190	1400	1180	1170	1210	1340
Atmosphere	Reducing - 50% H_2/50% CO_2						
Ultimate Analysis %							
Mineral matter (calc)	4.8	7.2	6.8	4.9	7.4	4.7	8.4
Carbon (dmmf)	75.1	76.0	78.6	74.9	75.2	74.6	74.7
Hydrogen (dmmf)	5.4	5.5	5.8	5.3	5.3	5.5	5.7
Oxygen (dmmf)	17.4	16.7	13.5	17.3	17.3	17.5	17.2
Nitrogen (dmmf)	1.75	1.80	1.85	1.95	1.90	1.90	1.90
Sulphur (total) (ad)	0.35	0.40	0.70	0.55	0.65	0.45	0.70
Chlorine (ad)	0.04	0.05	0.02	0.02	0.03	0.02	0.04
Carbon dioxide (ad)	0.45	0.94	0.50	0.32	0.76	0.17	0.28

daf = dry, ash-free

dmmf = dry, mineral matter-free

ad = as delivered

Table A3.5 - **Ash Fusion Characteristics and Ash Compositions**

	Sample No. 1	Sample No. 2
Ash Fusion Characteristics (°C)		
Hemisphere temperature	1130	1040
Deformation temperature	1160	1070
Flow temperature	1190	1150
(Atmosphere - reducing: 50% H_2/50% CO_2)		
Ash Analyses (% on ash)		
Na_2O	11.1	9.2
K_2O	0.6	0.9
CaO	20.8	15.7
MgO	6.6	5.4
Fe_2O_3	12.2	9.9
Al_2O_3	12.4	18.0
SiO_2	13.5	26.5
TiO_2	0.63	0.88
Mn_3O_4	0.04	0.04
SO_3	20.9	14.8
Phosphorus (% P on coal)	0.001	0.001

Table A3.6 - Ultimate Analyses/Forms of Sulphur Analyses

	Sample No. 1	Sample No. 2
Ultimate Analysis (wt%)		
Mineral matter (ad)	3.3	4.3
Carbon (dmmf)	75.7	75.8
Hydrogen (dmmf)	5.4	5.5
Oxygen (dmmf)	17.3	17.1
Nitrogen (dmmf)	1.65	1.70
Sulphur (org) (dmmf)	0.35	0.35
Forms of Sulphur Analysis (ad)		
Total sulphur	0.36	0.33
Organic sulphur	0.28	0.25
Pyritic	0.03	0.03
Sulphate	nd	nd

ad = as detemined dmmf = dry, mineral matter-free

Table A3.7 - Gray-King Coke Types, Calorific Values and Capacity Moistures

	Sample No. 1	Sample No. 2
Coking Properties		
Gray-King coke type	B	B
Capacity Moisture (wt%)		
(equilibrated at 30°C and 97% RH)	19.3	25.7
Calorific Value (Btu/lb)		
Dry, ash-free basis	13 240	13 240
Moist, mineral matter-free	10 685	10 000

Table A3.8 - Simulated Fischer-Schrader Assay of Sample 2

In practice the carbonising time was found to be 2½ hours. The mean yields of duplicate determinations were:

Assay (wt %, dry)

% Coke	64.7
% Liquor	7.7
% Tar	15.9
% Gas	11.2
Volume of gas mls per 100g of dry coal	9160
Yield of gas cu.ft per ton	3290

Gas Analysis

% by volume (air-free)

H_2	8.9
O_2	0.0
N_2	8.2
CO	14.8
CO_2	27.3
CH_4	30.1
C_2H_6	4.76
C_3H_8	2.86
n-C_4H_{10}	0.82
i-C_4H_{10}	0.28
C_2H_4	1.77
C_3H_6	0.39

APPENDIX 4 - DATA ON NEW MINING AREA

Table A4.1 - Estimated Geological Reserves - Amaga-Fredonia Area

Section	Length of Coal	Coal Thickness x Length				Coal Volume	Tonnage
		Seam 1 (1.6m)	Seam 2 (1.3m)	Seam 3 (1.5m)	Total (4.4m)		
m	m	m^2	m^2	m^2	m^2	$10^3 m^3$	10^3
1 160 000	2440	3904	3172	3660	10 736		
						10 648	14 907
1 159 000	2400	3840	3120	3600	10 560		
						10 758	15 061
1 158 000	2490	3984	3237	3735	10 956		
						10 978	15 369
1 157 000	2500	4000	3250	3750	11 000		
						10 846	15 184
1 156 000	2430	3888	3159	3645	10 692		
						10 362	14 507
1 155 000	2280	3648	2964	3420	10 032		
						10 560	14 784
1 154 000	2520	4032	3276	3780	11 088		
						9 020	12 628
1 153 000	1580	2528	2054	2370	6 952		
						5 896	8 254
1 152 000	1100	1760	1430	1650	4 840		
TOTAL							110 694

Specific Gravity = 1.4

APPENDIX 5 - CALCULATION OF CAPITAL RECOVERY FACTORS

Table A5.1 - Calculation of Capital Recovery Factor r for Mine and Associated Transport

Column 1	2	3	4	5	6	7	8	9	10	11	12	
Year	Equity Expenditure on		Tax Value (40%) of		Total Net Expenditure	Operating Surplus	Tax (40%) on Surplus	Surplus Net of Tax	Discount Factors at 12%	Present Expenditure	Values of Surplus	
	Fixed Assets	Interest ($7\frac{1}{2}$%)	Depreciation	Interest								
1	0.852	0.032		-	0.884				0.8929	0.789		
2	1.323	0.114		0.013	1.424				0.7972	1.135		
3	-	0.163		0.046	0.117				0.7118	0.083		
4	0.035	0.164		0.065	0.134				0.6355	0.085		
5	4.171	0.322		0.066	4.427				0.5674	2.512		
6	15.815	1.071		0.129	16.757				0.5066	8.489		
7	18.247	2.349		0.428	20.168				0.4523	9.122		
8	8.516	3.353		0.940	10.929				0.4039	4.414		
9	1.041	3.711		1.341	3.411				0.3606	1.230		Operating Year
10	4.167	3.594	-	1.484	6.277	0.70x	-	0.70x	0.3220	2.021	0.2254x	1
11	4.167	3.281	5.308	1.438	0.702	0.85x	0.28x	0.57x	0.2875	0.202	0.1639x	2
12	4.167	2.969	4.512	1.312	1.312	0.95x	0.34x	0.61x	0.2567	0.337	0.1566x	3
13	4.167	2.656	3.835	1.188	1.800	1.00x	0.38x	0.62x	0.2292	0.413	0.1421x	4
14	4.167	2.344	3.260	1.062	2.189	1.00x	0.40x	0.60x	0.2046	0.448	0.1228x	5
15	4.167	2.031	2.771	0.938	2.489	1.00x	0.40x	0.60x	0.1827	0.455	0.1096x	6
16	4.167	1.719	2.355	0.812	2.719	1.00x	0.40x	0.60x	0.1631	0.443	0.0979x	7

Table A5.2 continued

17	4.167	1.406	2.002	0.688	2.883	1.00x	0.40x	0.60x	0.1456	0.420	0.0874x	8
18	4.166	1.094	1.702	0.562	2.996	1.00x	0.40x	0.60x	0.1300	0.389	0.0780x	9
19	4.166	0.781	1.446	0.438	3.063	1.00x	0.40x	0.60x	0.1161	0.356	0.0697x	10
20	4.166	0.469	1.230	0.312	3.093	1.00x	0.40x	0.60x	0.1037	0.321	0.0622x	11
21	4.166	0.156	1.045	0.188	3.089	1.00x	0.40x	0.60x	0.0926	0.286	0.0556x	12
22	-	-	0.888	0.062	(0.950)	1.00x	0.40x	0.60x	0.0826	(0.078)	0.0496x	13
23			0.755	-	(0.755)	1.00x	0.40x	0.60x	0.0738	(0.056)	0.0443x	14
24			0.642		(0.642)	1.00x	0.40x	0.60x	0.0659	(0.042)	0.0395x	15
25			0.546		(0.546)	1.00x	0.40x	0.60x	0.0588	(0.032)	0.035[illegible]x	16
26			0.464		(0.464)	1.00x	0.40x	0.60x	0.0525	(0.024)	0.0315x	17
27			0.394		(0.394)	1.00x	0.40x	0.60x	0.0469	(0.018)	0.0281x	18
28			0.335		(0.335)	1.00x	0.40x	0.60x	0.0419	(0.014)	0.0251x	19
29			0.285		(0.285)	1.00x	0.40x	0.60x	0.0374	(0.011)	0.0224x	20
30			1.614		(1.614)	-	0.40x	(0.40x)	0.0334	(0.054)	(0.0134x)	21
TOTALS	100.000									33.621	1.6336x	

$$x = \frac{33.621}{1.6336} = 20.58 \qquad r = \frac{20.58}{100} = 20.6\%$$

Table A5.2 - Calculation of Capital Recovery Factor r for Process Plant

Column 1	2	3	4	5	6	7	8	9	10	11	12	
Year	Equity Expenditure on Fixed Assets	Equity Expenditure on Interest (7½%)	Tax Value (40%) of Depreciation	Tax Value (40%) of Interest	Total Net Expenditure	Operating Surplus	Tax (40%) on Surplus	Surplus Net of Tax	Discount Factors at 12%	Present Expenditure	Values of Surplus	Operating Year
1	-	-		-	-				0.8929	-		
2	0.156	0.006		-	0.162				0.7972	0.1291		
3	0.156	0.018		0.002	0.172				0.7118	0.1224		
4	0.116	0.025		0.007	0.034				0.6355	0.0216		
5	2.483	0.119		0.010	2.592				0.5674	1.4707		
6	12.418	0.677		0.048	13.047				0.5066	6.6096		
7	19.869	1.889		0.271	21.487				0.4523	9.7186		
8	10.928	3.043		0.756	13.215				0.4039	5.3375		
9	3.974	3.602		1.217	6.359				0.3606	2.2931		
10	4.167	3.594	-	1.441	6.320	0.70x	-	0.70x	0.3220	2.0350	0.2254x	1
11	4.167	3.281	5.519	1.438	0.491	0.85x	0.28x	0.57x	0.2875	0.1412	0.1639x	2
12	4.167	2.969	4.691	1.312	1.133	0.95x	0.34x	0.61x	0.2567	0.2908	0.1566x	3
13	4.167	2.656	3.987	1.188	1.648	1.00x	0.38x	0.62x	0.2292	0.3777	0.1421x	4
14	4.167	2.344	3.389	1.062	2.060	1.00x	0.40x	0.60x	0.2046	0.4215	0.1228x	5
15	4.167	2.031	2.881	0.938	2.379	1.00x	0.40x	0.60x	0.1827	0.4346	0.1096x	6
16	4.167	1.719	2.449	0.812	2.625	1.00x	0.40x	0.60x	0.1631	0.4281	0.0979x	7

Table A5.2 continued

17	4.167	1.406	2.080	0.688	2.805	1.00x	0.40x	0.60x	0.1456	0.4084	0.0874x	8
18	4.166	1.094	1.769	0.562	2.929	1.00x	0.40x	0.60x	0.1300	0.3808	0.0780x	9
19	4.166	0.781	1.504	0.438	3.005	1.00x	0.40x	0.60x	0.1161	0.3489	0.0697x	10
20	4.166	0.469	1.279	0.312	3.044	1.00x	0.40x	0.60x	0.1037	0.3157	0.0622x	11
21	4.166	0.156	1.087	0.188	3.048	1.00x	0.40x	0.60x	0.0926	0.2822	0.0556x	12
22	-	-	0.923	0.062	(0.985)	1.00x	0.40x	0.60x	0.0826	(0.0814)	0.0496x	13
23			0.785	-	(0.785)	1.00x	0.40x	0.60x	0.0738	(0.0579)	0.0443x	14
24			0.667		(0.667)	1.00x	0.40x	0.60x	0.0659	(0.0440)	0.0395x	15
25			0.567		(0.567)	1.00x	0.40x	0.60x	0.0588	(0.0333)	0.0353x	16
26			0.482		(0.482)	1.00x	0.40x	0.60x	0.0525	(0.0253)	0.0315x	17
27			0.410		(0.410)	1.00x	0.40x	0.60x	0.0469	(0.0192)	0.0281x	18
28			0.349		(0.349)	1.00x	0.40x	0.60x	0.0419	(0.0146)	0.0251x	19
29			0.296		(0.296)	1.00x	0.40x	0.60x	0.0374	(0.0111)	0.0224x	20
30			1.680		(1.680)	-	0.40x	(0.40x)	0.0334	(0.0561)	(0.0134x)	21
TOTALS	100.000									31.2246	1.6336x	

$$x = \frac{31.2246}{1.6336} = 19.11 \qquad r = \frac{19.11}{100} = 19.2\%$$

APPENDIX 6 - SUMMARY OF TERMS OF REFERENCE FOR PREFEASIBILITY STUDY

The Consultant is to carry out the following tasks:

1. General Survey of the project area which covers the coal deposits in the Amaga, Titiribi, Angelopolis and Fredonia basin, with the assessment of both the quantity and quality of those deposits through sampling and technical analysis and classification of coals in this area.

2. Prefeasibility Study on the production of gas and chemicals by the utilisation of coal deposits in the above area as an integrated industry, taking into account both the technical and economic aspects of exploitation of coal reserves, production of gas from coal, production of chemicals (e.g. ammonia, urea, aromatics, etc.) from coal and production of coke, as well as the marketability of those products in domestic and export markets.

   Due consideration should be given to the following items:

   a) Supply of coal - mining methods and supply systems, handling and transportation etc.
   b) Markets of products, both their local demand and export potentials:

      Coal
      Coke
      Gas
      Chemicals (ammonia, urea, aromatics etc.)

   c) Capacities and locations of the plants for the production of those products, to be built as an integrated complex.
   d) Processes and technologies to be adopted for those products.
   e) Infrastructure and utilities.
   f) Investment requirement, estimates of production, cost and profit.
   g) General outlook of the benefits derived from this development to the national economy of Colombia.
   h) Other relevant items.

3. Formulation of terms of reference for a detailed feasibility study on the establishment of a chemical complex for the production of gas and chemicals from coal of Antioquia.

4. Drawing up a work plan for the establishment of a complex utilising coals of Antioquia as the basic raw material.

APPENDIX 7 - PERSONS INTERVIEWED IN COLOMBIA

Organisation	Personnel Interviewed
AGA-FANO SA	Sr. Eduardo Para Torres
Annidridos y Derividos de Colombia SA	Dr. Jario Gomez Hoyas
Asociacion Nacional de Industriales	Sr. Carlos Escobar Pizza
	Sr. Augusto Muñoz Baez
	Sr. Luis Ortiz M.
	Sr. Jesus Valteja
	Sr. J. Pierahitta
Carbocol	Dr. Herman Garces
	Dr. Jose Cordoba Maria
Carboquimica SA	Sr. Francisco Javier Gonzalez Leon
	Sr. Jaime Londoño Jaramillo
	Sr. Eduardo Velosa Marulanda
	Dr. Jorge Recamen Garcia
Colombiana de Carburo de Derividos SA	Dr. Carlos Pizano A.
Coltejer Ltda	Dr. Noel Gutierrez
Carbones de San Fernando	Dr. Jose Bentancur G.
	Sr. Adriano Betancur
	Sr. Rafael Alvarez
Concovado Mine	Dr. Emillio Diozar
Departimento Nacional de Planeacion	Sr. Luis Londoño
	Sr. Jaime Torro
Ecopetrol	Sr. Jose M. Herrera S.
	Dr. Pedro Alonso A.
Empresas Publicas de Medellin	Sr. Alonso Palacios B.
	Sr. Luis Guillermo Gomez Atehortna
Empresas de Departimento de Antioquia	Dr. John Villega Meija
Explotaciones Carboniferas SA (Excarbon)	Sr. Abelardo Moreno Maya
Fabricato SA	Dr. Santiago Toro Villa
Ferrocarriles Nacionales de Colombia	Sr. James Ypes Londoño
	Sr. Herman Zapata Bustamente

Organisation	Personnel Interviewed
Geominas	Sr. Elkin Vargas Pimiento
	Dr. Tiberio Escobar
	Dr. Elkin Oguendo
Hullera Colombiana	Dr. Luis Ortiz Edmundo
Industrial Hullera	Dr. A. Jaramillo Angel
	Sr. Jaime Arrismendimirra
	Sr. Raul Chardrriga
	Sr. Humberto Zapata
Instituto Fomento Industrial (IFI)	Dr. Jose Barake A.
Instituto Investigiones Technologicas (IIT)	Dr. Jaime Ayala Ramirez
	Dr. Emiliano Olivar G.
Ingeominas	Sr. Michel Henelian
	Sr. Francisco J. Zambrano Ortiz
	Sr. Eduardo Alvarez
Integral SA Ltda	Sr. Jose Tejeda Saenz
Mineros Colombiana SA	Dr. Emilio Alvarez Santamaria
Ministerio de Minas y Energia	Dr. Ignacio Zulaga Escobar
Mingetec Ltda	Sr. Jaime Gomez Gomez
	Sr. Cesar Dugue
Serrano Gomez y Cia (Immunizadora de Maderas)	Dr. Maruicio Bernal
	Dr. Jaime Concha Martinez
	Sr. Alfonso Gomez Borda
Simesa SA	Sr. Jorge Alvarez E.
	Ing. Manuel Alvarez
University of Medellin, School of Mines.	Prof. Nestor Castro
	Sr. Eduardo Lopez P.
	Sr. Luis Meza A.
	Sr. Pedro F. Keucvez C.

Member of the project team wish to tender their sincere thanks to all the above who without exception received them most cordially and patiently answered all their questions. Special thanks are due to Sr. Munoz, the Carbochemical Committee Coordinator of ANDI at Medellin for the splendid office accommodation and secretarial services which he provided and to his counterpart at Bogota, Sr. Luis Ortiz, for introducing the project team members to, and arranging interviews with, so many of the persons listed above.

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