

AN ENERGY SUPPLY AND DEMAND MODEL FOR SOUTH AFRICA

R B Silberberg

August 1981

University of Cape Town

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R B Silberberg

August 1981

Submitted to the University of Cape Town in fulfilment
for the degree of Doctor of Philosophy

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IN TERMS OF THE NATIONAL SUPPLIES PROCUREMENT ACT (1979) FIGURES RELATING TO THE ACQUISITION, DISPOSITION AND UTILIZATION OF PETROLEUM PRODUCTS IN THE REPUBLIC OF SOUTH AFRICA MAY NOT BE PUBLISHED OR PRINTED IN ANY FORM. SINCE A POLICY MODEL SUCH AS THAT DEVELOPED FOR THIS THESIS INCORPORATES FIGURES RELATING TO PETROLEUM, SUCH FIGURES MUST BE REMOVED IF THE THESIS IS TO BE MADE OPENLY AVAILABLE.

CONSEQUENTLY, ALL REFERENCES TO PETROLEUM PRODUCTS HAVE BEEN ERASED FROM THE TEXT. THE AUTHOR APOLOGISES FOR THE RESULTING GAPS IN THE TEXT THAT ARE UNAVOIDABLE IN TERMS OF PRESENT LEGISLATION.

segregate

A B S T R A C T

The topic of this thesis is the development of a model of energy supply and demand in South Africa to project energy flows up to the year 2005 and also to assess the implications of policy actions./

South Africa in the 1980's will be faced by a complex energy planning problem. Politically, socially and economically the country is in a process of significant change, resulting in rapidly increasing overall energy requirements and more selective demand for specific types and grades of energy carrier. Relatively large deposits of coal and uranium exist - providing opportunities for earning foreign exchange now, coupled, unfortunately, with the depletion of those resources in the future. Many questions relating to energy, and vital to South Africa, must be resolved in the next few years, particularly concerning the following:

- level of coal and uranium exports
- level of energy independence
- domestic synthetic fuels programme
- energy conservation policies
- alternative technology implementation.

Energy planning in the past has been inadequate because of its segregated approach in treating each energy carrier, its lack of economic and technological inputs and its inability to highlight sensitive and crucial aspects of the energy sector in the economy.

2. An assessment of probable output of the sector over the next 25 years.
3. An assessment of possible technological innovation within the sector over the next 25 years.

These three outputs were then combined to yield a set of functions describing demand for each energy carrier by each sector up to the year 2005. For each sector, three functions were defined for each carrier, to represent likely, high and low demand cases respectively.

ENERGY SUPPLY SECTORS

The energy supply and distribution system was represented by sixteen sectors. These sectors were studied as above to determine energy flows, conversion rates and own energy requirements. Possible technological innovation was also evaluated.

Using the above data, a set of 16 x 16 matrices was developed to represent the existing energy supply industry as well as possible variations based on improved or alternative technology.

SUPPLY/DEMAND EQUILIBRATION

In order to project total energy flows, final demand (represented by a set of functions) and the supply industries (represented by a set of 16 x 16 matrices changing in time) are solved using input/output techniques. Subsequent to integration of final demand, equilibration involves the solution of 16 simultaneous equations for each year of the model's horizon. Solution of the model does not involve the search for an optimal or other specific result.

In this thesis, a method of determining energy flows taking generally accepted economic and technological factors into account is developed. Also, various situations are tested, in order to determine the following:

- likely energy flows up to 2005, as well as possible upper and lower bounds
- significant final demand sectors, in terms of energy requirements
- the effects of changes in supply and demand sector technology
- the implications of policy options such as energy independence.

Owing to the different characteristics of the energy supply and demand sectors, the following techniques were used:

ENERGY DEMAND SECTORS

Seven major sectors, accounting for approximately 75 % of total final demand, were identified. Remaining energy demand is accounted for by a multitude of smaller industrial and commercial users. Using information derived from published data, personal interviews, site visits and references to the economic development programme of the office of the Prime Minister, these sectors were analysed to yield three outputs:

1. An energy flow diagram indicating major flows of energy within the sector as a whole.

OUTPUT

Through successive runs of the model, the policy-maker is able to indentify likely values of energy flows, as well as upper and lower boundaries given the described set of assumptions. He is also able to identify factors in the supply or demand sectors which have a big influence on those energy flows. Finally, the effect on resources of specific policy decisions, such as those concerning nuclear energy and synthetic fuels, may be assessed. To perform these functions, the model is run either singly or iteratively using probabilistic procedures.

As a result of various runs of the model, the following statements are made as conclusions:

- the growth rate of domestic coal demand is likely to be 5,5 % per annum up to 2005. However, there is a possibility of higher rates; up to 7 %.
(Further analysis, incorporating additional assumptions, shows that a rate of 5,8 % will permit coal exports in the vicinity of 70 - 80 Mt per annum. Higher rates seriously compromise this figure. This export figure is thus supported, qualified by the points that follow.)
- the Iron and Steel industry and the Mining industry have the greatest potential effect on coal demand. In view of the first point above, these sectors must be monitored closely.
- the coal growth rate stated above implies certain improvements in coal to liquid fuel and electricity conversion. These improvements are not automatic and major research and development funding must be allocated to energy research institutes to ensure their commercial viability.

- The coal demands of oil energy independence are listed, highlighting the fact that major coal exports and energy independence may be mutually exclusive.

Other conclusions regarding capital requirements, oil imports and coking coal utilization are described.

The model permits a consistent and integrated forecast of national energy flows to be made, providing the policymaker with projections that include the effects of uncertainty with regard to future technologies and economic output. This feature is crucial for policy formulation.

AN ENERGY SUPPLY AND DEMAND MODEL FOR SOUTH AFRICA

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Petroleum figures that have been deleted in terms of the National Supplies Procurement Act have been replaced by an asterisk '' in the text and in the reports.*

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1

INTRODUCTION

Energy is a vital input into any economic system. Surges in demand for energy caused by rising populations and improved lifestyles, coupled with supply fluctuations resulting from the finite nature of today's energy resources, have caused severe disturbances in many of the world's economies, emphasizing the significance of energy. A method of planning the overall energy-economy is essential if more serious disruptions in the future are to be avoided.

The model developed for this thesis attempts to fulfil the need for a system to test energy policy options in South Africa.

Because of the widespread effect on the rest of the economy that is caused by decisions in the energy sector, it is virtually impossible to evaluate correctly any proposed energy project without a framework that will permit quantitative comparison. Failing such a framework, decisions must inevitably be based on a limited and subjective knowledge of the economy.

At the same time, it should be noted that many questions relating to energy are not within the realm of energy policy formulation, such as optimization of oil refinery operations. Also, lack of data concerning energy utilization as a function of price and other expenditures, and the absence of information about the interrelationships between labour, capital and energy within the economy as a whole place serious constraints on the form that a useful model may take. Mathematical "solutions" are possible, but they by nature depend upon multiple assumptions that may be highly inappropriate for the "real" world.

Many strategic energy decisions with long-term influence must be made now, and any system that can assist in these

decisions must be based upon assumptions that are defined, relate to the real situation and that may be modified should new circumstances present themselves.

It was with these facts in mind that this model was developed.

This introduction outlines the energy situation in South Africa and highlights the features of a suitable model. Planning tools that are used by other countries are reviewed, and a model suitable for South Africa is described. Chapter 2 describes the energy supply industries, and Chapters 3 to 9 describe the final demand sectors for energy. Results of the combined supply/demand model are discussed in Chapter 10.

1.1 Energy in South Africa

South Africa's total primary energy consumption in 1978 was $2,4 \times 10^{12}$ MJ, and is expected to reach $5,55 \times 10^{12}$ MJ by the year 2000 (1).

Whereas in most countries the major energy carrier is oil, in South Africa indigenous coal satisfies approximately 75 per cent of the primary energy need and other energy some 25 per cent. A comparison of primary energy consumption in South Africa with consumption in France, Italy and Japan is illustrated in Fig. 1.1. Percentage contributions for different carriers in 1961 and 1976 are shown. It can be seen that in all cases oil accounts for a significant fraction of the primary energy requirement, and that this fraction has increased considerably since 1961. In the case of South Africa, however, coal continues to provide the biggest slice of the primary energy need. No significant oil deposits have been discovered in South Africa, despite the occurrence of promising off-shore gas deposits in the southern and western coastal regions. Large deposits of uranium exist, and production is such that South Africa

ranks as the second largest exporter of uranium in the West. If the energy content of South Africa's uranium exports is taken into account, the country is a net exporter of energy. As the markets and prices of all forms of energy are improving in the wake of petroleum price increases, the envisaged increasing exports of uranium and coal will to a large extent cushion the impact on balance of payments of expensive crude oil imports by South Africa. /

Economically extractable coal reserves were estimated by the Petrick Commission in 1975 to be 25 000M tons (2). This estimate assumed certain limits regarding the percentage of coal that may be extracted, the minimum thickness of a coal seam for it to be a viable mining proposition and the maximum ash content of coal supplied to the end user. Developments since that time show that the estimate should be revised. New reserves have been discovered, and the Chamber of Mines expects that developments in mining technology will allow the recovery of 60 per cent of the in-situ reserves. Recoverable coal reserves may thus increase to 60 000M tons. Improvements in utilisation would also increase reserves, for example, fluidised bed boilers may allow the use of coal with an ash content of more than 35 per cent, the limit for the Petrick reserve assessment. A detailed re-assessment of reserves and demand by the Department of Mineral and Energy Affairs suggests recoverable reserves of 51 000 M tons. /

In 1979, 126M tons of coal were mined, of which 22M tons were dumped as waste. Total sales were 98,2M tons including 23,3M tons for export; 94M tons were bituminous coal and 4,2M tons anthracite.

Nearly seven million tons of coking coal were used, primarily for Iscor. New sources of prime coking coal are needed to maintain supplies in future as Natal reserves become depleted, and large scale expansion of the

steel industry will depend on the use of new coking or reduction technology.

Uranium reserves in the 'reasonably assured' and 'estimated additional' categories recoverable at a cost of less than \$80/kgU (metal) total 331 000 tons, or 531 000 tons at less than \$130/kgU (3). As local consumption of nuclear fuel is likely to be small, South Africa is expected to maintain its position as one of the major suppliers of uranium to the Western World. South Africa's uranium reserves could support about 40 000 MW of light-water type nuclear plant assuming a 40 year life and a load factor of 65 per cent. The same uranium reserves could, however, support up to 100 times this amount if fast breeder reactors were used (4).

At present, 17 uranium producing facilities exist, and in 1979 production was 5 539 tons of uranium oxide, up 60 per cent over the previous three years. Foreign exchange earnings have increased significantly. Output is expected to increase over the next few years. Several gold mines are expected to join the ranks of uranium producers, and at least one mine is expected to open as a primary producer.

These developments are likely to double uranium production by 1985. The Nuclear Fuels Corporation (a part of the Chamber of Mines), which collects ammonium diuranate slurry from the mines and calcines it to produce uranium oxide, is at present improving and upgrading the process technology to increase considerably its present annual 6 000 ton uranium concentrates capacity.

Other forms of energy appear to be limited. The generation of hydro-electricity is small on account of average low rainfall patterns, so that a maximum contribution of less than two per cent is expected in the year 2000, excluding hydro-electricity imported from Cahora Bassa in Mozambique. Tidal differences of only 1,5 to 2m exist, as opposed to

11,4m in France, and as no suitable storage bay is available the harnessing of tidal energy is precluded. Forms of energy such as solar are also being investigated. Their net contribution by the year 2000 is expected to be not much more than five per cent of the total primary energy requirement and this will be mainly in the form of solar water heating and space heating.

Conversion of coal to liquid fuels by Sasol is a significant aspect of energy in South Africa. Over seven million tons of coal were mined in 1979 by Sasol for its liquefaction plants. This amount is expected to increase to 32M tons by the mid-eighties, when the three Sasol plants should be at full production. Sasol uses an indirect liquefaction route, by which the coal is first gasified with steam and oxygen, and the purified gas is catalytically converted to liquid hydrocarbons using the Fischer-Tropsch synthesis. Sasol also produces a considerable amount of fuel gas, chemicals and other hydrocarbons such as waxes. Only the indirect route to liquid fuels from coal has been commercialised so far.

Energy supply, clearly, is dominated by a small number of primary energy sources (coal, oil, gas, uranium, hydro) and also a small number of big converter/producer industries (electricity generation, coal mining, coal conversion).

Demand for energy is, however, far more diverse. Energy in every form is used by virtually every facet of the economy, and a high degree of substitution and alternative usage patterns are possible. A large number of enterprises use energy : clothing manufacture, food preparation, mining, building construction, transportation as well as a wide variety of domestic uses. It is impossible to treat each of these users separately ; some form of aggregation is essential. For this thesis, seven sectors have been identified :

Iron and Steel
Chemicals
Mining
Pulp and Paper
Cement
Domestic
Transport

As described in Chapter 10, these aggregated sectors account for the bulk of final energy demand (approximately 78%). The energy aspect of these sectors is discussed separately in the respective chapter. As this stage it suffices to note that the characteristics of these sectors, with regard to energy flows, are very different from those of the supply sectors. Alternative energy carriers, conservation, substitution, price sensitivity and in-house conversion characterise these final demand sectors, as opposed to the almost rigid characteristics of the supply side. This is an important factor to be considered when modelling the total energy system.

1.2 Energy Options

Traditionally the supply of energy has not presented serious problems, so that a minimum of overall planning existed. Several factors have changed this :

- — The search for oil has not yielded results so far. Dependence on imported oil continues.
- — Coal and uranium provide valuable sources of foreign exchange.
- — New technologies such as the production of methanol must be considered.
- — There are indications that special grades of coal are not as plentiful as previously believed and that shortages of these grades could develop.

Based on the above considerations, it is clear that a number of options are available when formulating energy policy in South Africa:

- — level of coal exports
- — level of oil imports
- — level of uranium exports
- — domestic nuclear programme - fission/enrichment/
breeder
- — domestic synthetic fuels programme - synthol/
methanol
- — conservation programmes
alternative technology programme - solar/ electric
vehicle
- — strategic aspects of energy trade.

Decisions made for any of these options will have far-reaching effects on labour requirements, capital, water and resource utilization and regional development.

An essential factor is that energy projects differ from other facets of the economy in two important ways :

1 : Large scale.

In general, energy projects are large in scope and investment, and are associated with lead times of up to 10 to 15 years for design, construction and ultimate commissioning.

2 : Limited flexibility.

Commitment to specific energy projects will set the direction of the rest of the economy for many subsequent years. Because of the heavy investments, alternatives are automatically excluded, even if they offer significant benefits.

-
- ✓ The above factors point to the need for an integrated planning system to highlight the overall and projected effect of policy decisions, so that detrimental decisions, based on a limited view of the economy, can be avoided.
-

1.3 Energy Modelling Techniques

The complexity of the interrelationships between energy and the rest of the economy, as well as the absolute necessity for energy planning has been recognized in most countries. This has lead to the development of various energy modelling systems. Several techniques have been adopted :

- statistical methods, specifically regression analysis
- input/output analysis
- mathematical programming techniques
- continuous simulation.

These techniques have been surveyed and described in detail (5). Below, the main methods are summarized in view of their potential for application in a South African energy model. /

1.3.1 Regression Analysis

The principle behind regression analysis is to find a formula for one of a number of measured quantities in terms of the others. This formula brings out relationships, summarizes data and predicts new or future situations. The technique computes the best estimates for a,b,c,..... in the equation:

$$y = a + b (x_1 - \bar{x}_1) + c (x_2 - \bar{x}_2) + \dots$$

A multiple regression model for fitting data can cover the simple y vs x straight line fit as a special case, as well as the frequently occurring curvilinear or polynomial model.

A typical application for regression analysis is for projecting demand for electrical energy (6).

1.3.2 Input/Output Analysis

The basis of the input/output technique is a set of identities known as the Input/Output (I/O) Transaction Table. This table shows the flow of goods and services among different industries as well as the flow from the industries to the final users. An example of an I/O table that shows the flows of goods along different branches of an economic system is illustrated in Fig 1.2.

- x_{ij} represents sales by industry i to industry j
- F_i is total final demand for industry i , and, for 4 demand sectors, is given by:

$$F_i = f_{i1} + f_{i2} + f_{i3} + f_{i4}$$

By adding intermediate and final demands for any industry, the basic input/output identity, called the row identity, results. It gives the total value of sales for that industry.

$$X_i = x_{i1} + x_{i2} + x_{i3} + F_i$$

For N industries and M final demand categories :

$$X_i = \sum_{j=1}^N x_{ij} + \sum_{k=1}^M f_{ik} \quad 1.3.1$$

The input/output coefficient, a_{ij} , gives the value of input needed from industry i to industry j per unit of industry j 's output :

$$a_{ij} = x_{ij} \div X_j$$

This may be combined with equation 1.3.1 :

$$X_i = \sum_{j=1}^N a_{ij} X_j + F_i$$

and written in matrix notation as :

$$\bar{X} = \bar{A} \bar{X} + \bar{F}$$

$$\text{or} \quad \bar{X} = (\bar{I} - \bar{A})^{-1} \bar{F} \quad 1.3.2$$

where $\bar{I}$ is the identity matrix.

Thus, given a final demand vector $\bar{F}$, the total output of the various industries can be readily determined by solving equation 1.3.2. In practice, $\bar{F}$ may also be derived from a set of final demand coefficients called bridge coefficients ($\bar{H}$).

An extension of input/output analysis is the determination of energy intensities. Using an $M \times M$ matrix of inter-industry transactions T , a vector of total outputs, X , and a vector of energy extraction data E :

$$X_j = \sum_{i=1}^N T_{ij} + E_j$$

Associated with the output of each sector, there is an energy intensity ϵ_j (per unit), so that as the energy in the output must equal the energy in the inputs :

$$\sum_{i=1}^N \epsilon_j T_{ij} + E_j = \epsilon_j X_j$$

so that

$\epsilon = \bar{E} (\bar{X} - \bar{T})^{-1}$ where $\bar{X}$ is a diagonal matrix with the elements of X along the diagonal.

These methods have been used in energy planning and are described by Proops (7), and Bullard and Herendeen (8).

1.3.3 Mathematical Programming Techniques

Mathematical programming techniques, especially linear programming, have found widespread use for energy modelling. The objective is the optimization of some function, usually cost related. In a typical linear programming application for an oil refinery, four products may be identified : crude, naphtha, middle distillate and heavy fuel oil. A particular crude yields 'a' barrels naphtha, 'b' middle distillate and '1-a-b' heavy fuel oil assuming no losses.

Then : $a P_n + b P_m + (1-a-b) P_h = P_c + C_d$

$P_n = P_m$ (surplus of naphtha sold as middle distillate)

$P_m = P_h + C_t$ (vacuum crack heavy fuel oil to produce middle distillate)

where : P_c, P_n, P_m, P_h = Price of crude, naphtha, middle distillate and heavy fuel oil, respectively.

C_d, C_t = cost of distilling/cracking.

The three equations relating to four prices complete the basic technical model, leaving one-dimensional indeterminacy. Imposing one condition (ie P_c) permits solution by the LP system.

This system has been used for world oil modelling by Queen Mary College, London (9).

1.3.4 Continuous Simulation

The underlying mathematical basis of continuous system simulation is a description of system behavior by its state-space relationships, namely a set of differential equations. The state of the system at any time is defined by a set of variables, and the structure of a model consists of : rate equations to define the time rate of change of variables ; level equations to transform rates into values for the variables ; and auxiliary equations to express intermediate variables.

A simple example is provided by a hydropower system with several reservoirs and electric generating plant. A dam receives its water at a random rate, and releases water proportional to the level of water held. Given values for the rate of receipt of water, initial levels and factor of proportion for water release, simulation permits the determination of output rate and dam level over time. At each successive period, the simulator cycles through four activities : advance time, generate input rate, compute output rate and compute next period's level.

The final level L is given by :

$$L = \int_{t=0}^n (\text{input rate} - \text{output rate}) dt + \text{init level}$$

A period by period history of rates and levels of all dams in the system is provided.

Computer languages such as CSMP (10) include integration algorithms and definition symbols for the description and automatic solution of the problem.

An example of continuous simulation is provided by Forrester's dynamic world model (11).

1.4 Energy Modelling in South Africa

In South Africa, the bulk of official long-term energy forecasting is based on regression techniques. Equations have been developed for the Department of Planning and the Environment in order to project energy flows to the year 2000 (12). Depending upon the sector, these equations are a function of GDP, output, energy prices and specific variables such as market share and vehicle population. As an example, the following equation was developed for electricity demand by the Industrial sector :

$$\ln E_t = -0,36 - 0,11 \ln Pe_t + 0,25 \ln Pc_t + 0,93 \ln E_{t-1}$$

where E = electricity demand
 Pe = price of electricity
 Pc = price of coal
 t = period
 ln = natural logarithm

The equation was based on data from 1934 to 1973 and yielded a multiple correlation coefficient (R^2) of 0,997. Since data up to 1978 is now available, the equation has been tested beyond 1973, as illustrated in Fig 1.3. Up to 1973, the fit is relatively close, but a major deviation is apparent after 1973, (from -21% to +10%). Equations were tested for other carriers and sectors, and a similar breakdown was discovered (13). In general it was found possible to formulate many different regression equations that appear to explain satisfactorily the variation in energy demand by different sectors. However, when these equations are exposed to new (post 1973) data, their forecasting ability appears to be severely limited. The equations appear to be representative given small, smooth

changes in the input variables, but they cannot handle the major shifts that have occurred after 1973. Since future changes in these variables can be expected to be similar to the post 1973 values, regression analysis is not recommended for energy demand forecasting.

On a higher level of representation, some success has been obtained using regression techniques (14), namely the relationship :

$$Z = aX + bY$$

where Z is the Gross Domestic Product, X is total demand for electricity and Y is total demand for all other carriers. This equation was used by the writer to develop an energy model using input/output techniques to represent the energy supply industries and the above equation to link energy to the rest of the economy (15). Although the energy supply sector was sufficiently segregated to permit adequate representation of the energy supply and conversion industries, it was found that the demand sectors could not be represented realistically. The need for a set of demand models to simulate the energy flows within the final demand sectors was highlighted.

A model to assist energy policy formulation in South Africa could therefore be defined :

- an input/output model to represent the energy supply and conversion system.
- a set of models to describe energy demand by the major energy consuming sectors of the economy.

Many other factors could be included in the model, for example price interfaces ; it was felt, however, that insufficient data and knowledge of the individual sectors was available at present, and that such a model would

therefore have to rely on a set of theoretical assumptions. This would reduce the usefulness of the model as a policy-making tool rather than enhance it.

1.5 Summary

The above sections describe the energy situation and the specific set of problems confronting the policy maker in South Africa. Modelling systems in use have been described, and the basic structure of a model for local use has been identified.

The model is presented as follows :

- Chapter 2 : energy supply industries
- Chapters 3-9: energy demand sectors
- Chapter 10 : output of complete input/output integrating model

The supply/demand model, comprising 16 simultaneous equations, is described in the following sections.

From the description given in the previous sections, it is clear that no single modelling technique is able to represent adequately the complex energy sector of the economy. The energy supply aspect is characterized by a relatively small number of large-scale energy converter/producers, while the energy demand aspect is characterized by a multitude of independent users, capable of adopting different processes to produce the same goods, capable of substituting and converting carriers, and sensitive to prices. Different procedures are needed to model each aspect. In addition, it is advantageous to relate the energy final demand sectors to the Economic Development Programme (16) so that a coherent projection can be made.

In this system, the following techniques are adopted :

- Energy Supply Model

An input/output representation of the energy supply industries, with flows measured in energy units to avoid price-induced distortion.

- Energy Demand Models

Independent energy flow models of the major demand sectors, modified by an assessment of future output and technology.

- Supply/Demand Integration

Supply and demand are reconciled (integrated) using input/output techniques to yield total output for each of the energy industries as well as total utilization of primary energy resources and capacity additions to the supply industries.

In a free enterprise system, supply and demand will be balanced by the cost of each respective energy carrier to the end user. This cost is, in turn, influenced by a complex combination of the following:

---- supplier decisions;

investments in major projects such as nuclear electricity or synthetic fuel systems will influence the price of the carrier

---- user decisions;

the adoption of certain processes for the manufacture of a product will determine the type and quantity of each energy carrier used

---- political considerations;

political factors such as the development of specific regions of the country will influence costs by changing certain government administered price elements such as levies, duties and incentives

---- trade benefits;

foreign exchange benefits for the import and export of energy carriers will influence prices by influencing the type of carrier exploited as well as the scale of exploitation

---- strategic factors;

the desired degree of exposure to the effects of uncontrollable events in the energy chain will affect the local energy supply industries, influencing the price

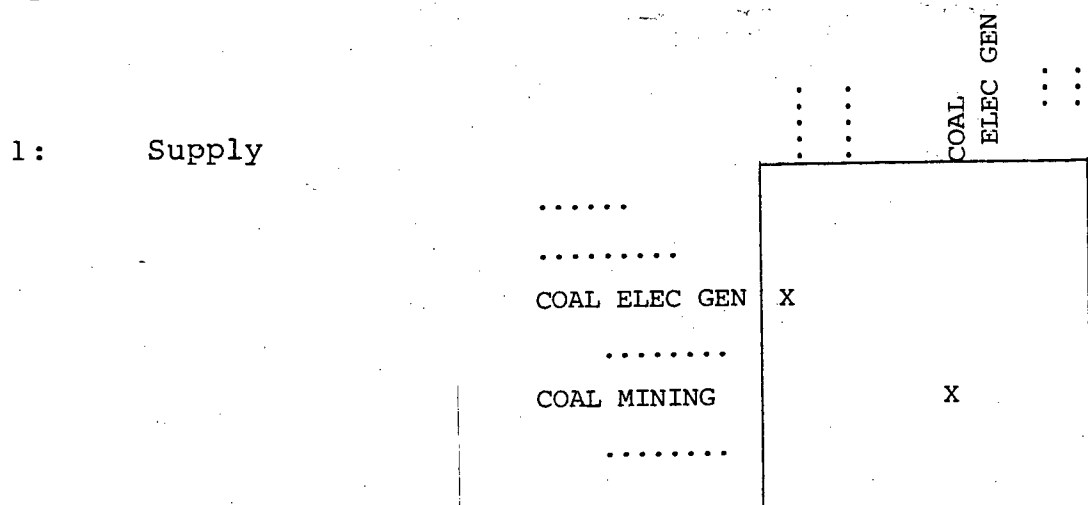
---- resource utilization;

remaining resources, and the perceived future value of resources is a major input in the determination of price.

To develop an accurate mathematical description of these factors would require a major study and evaluation of each supply and demand sector in terms of price ; future output ; technological change ; political and trade factors ; capital, water, labour and other resource utilization ; regional development factors as well as general trends in society.

It is not certain whether all of these factors may be expressed via mathematical equations. It is quite possible that some of them, or their interrelationships, will always require subjective assessment, so that a mathematically optimized solution is remote at this stage.

Operation of the model is illustrated, as follows:



The energy supply industries are represented by a matrix of inter-industry energy flows. In the example above, coal mining supplies coal to electricity generation, for the production and further distribution of electricity. Values are "per unit output" for each sector, and may change as new technology or processes are introduced, so that a separate matrix is required for each year.

2: Demand

The demand sectors are represented by set of functions to represent each energy carrier in each sector. For example, electricity demand by the Mining sector is given by the following function:

```
elec=f(ore milling projections, elec for milling,  
        other elec requirements, conservation)  
resulting in the following 26 element vector to describe  
electricity demand over the 26 year horizon 1980 to 2005:
```

```
elec←((674x0,88*0,125)x2692÷3,6x10*6)+((89,3x0,97*0,125)  
                                           x0,1794))
```

Several functions are formulated to represent likely, high and low cases. A final demand scenario is generated by combining a set of final demand functions.

3: Integration

Supply and demand are matched in the model through solution of the input/output equation(1.3.2) for each year, to generate total output of the energy sectors. This yields the volume of coal mining and other major energy flows over the horizon of the model. Cumulative values determine resource depletion, and annual changes in output indicate necessary investment in new plant.

The following sections describe the model in more detail:

- 1.6.1 Energy Supply Sectors
- 1.6.2 Energy Demand Sectors
- 1.6.3 Supply/Demand Integration

A flow diagram illustrating the process steps of the model is provided in Figure 1.5.

1.6.1 Sectors of the Energy Supply Model

The energy industry has been represented as a sixteen sector input/output matrix. A smaller number was found to be inadequate as subsequent aggregation distorted the coefficients of some sectors. It is possible that a larger number might provide some benefit: results have shown, however, that the 256 coefficients of the 16 x 16 matrix provide a very clear representation of the energy industry. The various sectors are described below; as illustrated in Fig 1.4.

Sector 1 : Electricity Distribution. ED

Electricity is supplied to the various end users via this sector. Electricity Distribution is supplied by the various generation techniques, and the relevant coefficient can be modified to simulate different "generation mixes". In addition, the input of ED to ED represents an important value - transmission losses.

Sector 2 : Coal Electric Generation. CG

Output of this sector is electricity into ED. Input is electricity (station requirements) and coal. The ratio of electricity output to coal input supplies the kWh/kg conversion factor that is well defined for various types of coal generating plant. For example, old plant runs at about 20% efficiency, while new plant runs at 40%. This fact can be incorporated by setting the factor according to the prevailing mix of new and old plant.

Sector 3 : Hydro Generation. HG

Output of this sector is electricity into ED. Input consists of water and is not shown in this model. It is, however, possible to calculate water requirements based on hydro output. Various other aspects are important, for

example the use of hydro stations for peak load requirements as well as the irrigation requirements of the dams that supply the hydro stations. These factors are not considered.

Sector 4 : Oil-based Generation. OG

This sector represents oil-fired electric generation, in particular gas turbines used for peak load requirements and also coal stations converted to run on oil. Input is from the fuel-oil sector.

Sector 5 : Nuclear Generation. NG

Nuclear Generation provides electricity for electricity distribution. Input comprises in-house electricity requirements and processed (enriched) uranium. The ratio of electricity output to uranium input supplies the kWh/kg conversion factor that is well defined for various types of nuclear reactor. The load factor at which the plant operates can also be incorporated by modifying these coefficients. The model thus provides a method for testing the effect of different reactor types and load factors - with an effect that is transmitted through the electric generation business as well as the uranium mining and processing sectors. Thus the overall effects on capital and resources may be analysed for different reactor types and also for different load factors.

Sector 6 : Uranium Mining. UM

Input to Uranium Mining is electricity and uranium ore. Ore represents a primary input to this industry, as for water in the Hydro Generation sector. Output is uranium in the form of 'yellowcake' to the processing industry and for export.

Sector 7 : Uranium Processing. UP

Uranium Processing receives uranium from the mining sector and electricity from ED, and produces reactor-grade fuel for Nuclear Generation and export. The efficiency of the conversion process is incorporated in the two coefficients - electricity input and processed uranium output; kWh/kg. This is derived from the kWh/Separative Work Unit of the refinement process. Thus various refinement processes can be simulated. It is possible to modify these coefficients to include waste processing, thus completing the nuclear cycle.

Sector 8 : Coal Mining. CM

The Coal Mining industry is complex and not readily adapted to input/output simulation techniques. Problems arise with different grades of coal produced as joint or secondary products. Consequently in this model, two independent grades are considered, general coal in this sector and coking coal in Sector 15. The general coal of this sector supplies power stations, coke production, gas production, coal conversion, the coal mines themselves and the various final demand sectors.

Sector 9 : Coke Production. CP

This sector represents the coke producing industries. The primary input is coal, both as a source of energy and for purposes of conversion. Alternative techniques, for example using electricity as the source of energy, can be tested by changing the a_{ij} coefficients.

Sector 10 : Gas Distribution. GD

As for Electricity Distribution, a number of industries or processes produce gas. To be able to handle these

processes independently, a gas distribution sector is created, supplying the gas needs of the oil refineries and end users. Input is gas from the SASOL process as well as direct gas production. The proportion of gas produced via these two processes is determined by the relevant a_{ij} coefficients.

Sector 11 : Fuel-Oil Distribution. FD

Various refined oil products are utilized by the final demand sectors. Heavy oils are required for lubrication, diesel oil for public transportation and lighter fractions for aviation and private transportation. These products are aggregated into one sector in this model, to supply the demand sectors. Input is from the various coal conversion processes and oil refineries, with suitable adjustment for heat value of the product.

Sector 12 : Oil Refineries. OR

Oil refineries have as input electricity, some gas, and imported oil (in this case also a primary input). Output is the refined product to Sector 11 for distribution to the end users.

Sector 13 : Coal-Fuel Conversion. SC

This sector represents the synthol coal conversion process. Inputs are coal and electricity, outputs are gas for distribution by GD to end users, and fuels for distribution by FD to end users.

Sector 14 : Gas Production. GP

Coal is the major input to this sector which produces gas for distribution by GD. In terms of energy units, flows are small; however it is possible to postulate a scenario

where gas is a major carrier. Typically this gas would be Hydrogen or some mixture. This sector allows such situations to be investigated.

Sector 15 : Coking Coal. CC

As coking coal is in limited supply in South Africa, a separate sector, apart from Sector 8, has been created so that it can be tracked separately. Coking Coal supplies the Iron and Steel Industry and some other, smaller, industries with a need for coal with special characteristics.

Sector 16 : Methanol Production. MP

Methanol represents an alternative fuel to refined oil and synthol-converted coal. A separate sector, supplying Fuel-Oil Distribution, is thus created.

This 16 by 16 matrix permits detailed representation of the major flows of energy within the energy supply industries of the South African economy. All major interrelationships between conversion industries are included. The supply industries are described in Chapter 2.

1.6.2 Energy Demand Models

Ideally, each energy demand subsector of the economy should be represented by a model that is able to simulate the demand for energy by that subsector as a function of output, energy prices, new technology and any other factors relevant to that subsector. Development of such models is a major task requiring data that is not available at present. Alternative systems such as regression models oversimplify the representation by assuming that economic and historical considerations are paramount in determining energy demand.

Consequently, the approach adopted in this study has been as follows :

1. an analysis of energy flows within each major energy demand subsector resulting in a set of energy flow diagrams. These diagrams are in effect models of the subsectors.
2. an analysis of potential technological progress within each subsector, to highlight possible future changes in the subsector models.
3. an assessment of potential future demand for the output of the subsector. This is an important aspect of the model since it links this energy model to the model of the economy used in the Economic Development Programme.
4. a synthesis of the above three assessments to generate likely future energy demand scenarios for the subsector as well as feasible or possible high and low scenarios. In each case, the set of three scenarios developed depend on economic, technological and social assumptions that are described. These may be modified to test the overall sensitivity of the system to such changes.

Although the energy flow diagrams provide a quantitative description of the subsectors in a form that may be used directly in many modelling systems, for example a simulation package, in this study they are qualified by the technological assessment and the link to the Economic Development Programme, and are used to generate likely, high and low projections of energy demand for each subsector. This replaces the assumptions necessary to obtain a solution

in a mathematical programming system by an engineering/economic assessment of each subsector.

Also, not all energy demand subsectors can be considered, since some account for very small portions of final demand. In this study the following subsectors were considered :

Iron and Steel	(Chapter 3)
Chemicals	(Chapter 4)
Mining	(Chapter 5)
Pulp and Paper	(Chapter 6)
Cement	(Chapter 7)
Transport	(Chapter 8)
Households	(Chapter 9)

These seven sectors were found to account for over 78% of net energy final demand. The remaining demand for energy is made up of a plethora of commercial and industrial enterprises, and is grouped together in one general (unspecified) sector, as described in Chapter 10.

1.6.3 Supply/Demand Integration

For a proposed scenario, the final demand vector $\bar{F}$ is given by :

$$\bar{F} = \sum_{i=1}^K f_{i1} \quad f_{i2} \quad f_{i3} \quad \cdots \quad f_{iL}$$

where : L represents the energy supply sectors;
K represents the energy demand sectors.

Total output of the energy industries for period N is then supplied by equation 1.3.2 :

$$\bar{X}_N = (I - \bar{A}_N)^{-1} \bar{F}_N$$

Matrix $\bar{A}$ may be modified for different N to represent the introduction of new or alternative technology. In addition, a vector $\bar{C}$ may be defined whose elements are the investments in 1980 Rand per unit output for the various energy producer/converters. The annual investment for the energy supply industries is then given by :

$$(\bar{X}_N - \bar{X}_{N-1}) \times \bar{C}$$

Inflation and depreciation are not taken into account.

Cumulative values and exports may be extracted from the resulting matrices. Structure of the model is shown in Fig 1.4.

Processing steps used to solve the model are illustrated in Figure 1.5. Data matrices are listed in Appendix 1&2.

1.6.4 Model Output

Output of the model is as follows ; referring to the listings in Reports 10.1 to 10.4 :

PAGE 1

**FINAL DEMAND

The total final demand values for the selected final demand scenario, and a description of the scenario.

PAGE 2

**ENERGY FLOW MEASURED AT 5 YEAR INTERVALS

Total output of the energy supply industries given at 5 year intervals where year 0 = 1980, and year 25 = 2005. Engineering units are used, as follows :

GKWH - 10^9 kWh

MTON - 10^6 ton

GM*3 - 10^9 m³

GLIT - 10^9 litre

KTON - 10^3 ton

TON - metric ton

****PER ANNUM CAPITAL REQUIREMENTS**

Annual investments required to develop the energy supply industries. Totals at 5 year intervals are also shown, as well as the overall total for the period 1980-2005.

****ANNUAL IMPORT AND EXPORT OF ENERGY CARRIERS**

Coal and Uranium exports, and oil imports are extracted and listed.

PAGE 3

****CUMULATIVE USE OF RESOURCES**

Cumulative use of coal, coking coal, uranium, exports and oil imports are listed.

****GRAPH OF ENERGY AND CAPITAL VALUES**

A graph of cumulative coal and uranium, capital investments and oil imports is presented.

The energy supply industry comprises a group of energy producers and converters set up to meet demand for energy by the final demand sectors. For the present industrialized structure of society, the forms of energy common for final demand are the following :

- coal
- liquid fuels (petroleum products)
- electricity
- gas/coke
- uranium (exports and nuclear industry).

Various processes are possible and may be implemented to generate the final demand carriers ; these are described below. Several processes are part of the demand sectors, such as coal mining, methanol production, coal conversion and uranium mining. These processes are consequently more fully described in the relevant demand chapter.

2.1 Coal

2.1.1 Coal Production

The extent and utilization of coal resources in South Africa is described in Chapters 1 and 5. As described in sections 5.1.4 and 5.2.3, this coal is extracted by a combination of longwall, opencast and pillar mining techniques. Historically, bord and pillar methods were prevalent in South African mines, but demands for increased output and better utilization have resulted in increased mechanization and new mining methods such as pillar extraction, longwall and opencast techniques. The rate of adoption of these new methods is moderated by their high capital costs and other factors such as the multiplicity and thickness of seams.

Whereas coal in South Africa occurs in many grades, ranging from sub-bituminous to semi-anthracite, in this model two grades are considered : coking coal (coal with special characteristics) and general coal. Further disaggregation requires an investigation of coal types, substitutability and scope for improvement by washing : this lies beyond the scope of this thesis.

2.1.2 Future Coal Mining Technology

Figure 2.1 is a forecast of future progress of these technological changes (1). The bord and pillar method is seen to be supplemented increasingly by opencast and longwall methods. Continuous miners, introduced in 1975, are likely to displace to an increasing extent the cutting, drilling and blasting operations. These major technological changes can be expected to influence productivity and coal recovery significantly in the future.

Figure 5.2 illustrates an energy flow diagram for the coal mining industry based on its 1979 structure.

These values are used in the energy supply input/output model. The mining techniques described above can be expected to influence these figures; however, many additional factors must be considered. Moderate declines of 1% p.a. in energy requirement per ton coal produced have been suggested (2), but the energy (and capital) requirements for new fields such as in the Waterberg are unknown at this stage (3), and could be higher.

Energy for coal mining is not a major "demand" sector, so that pending a comprehensive study of the coal mining industry to establish energy costs, the values as illustrated in Fig. 5.2 will be used, namely 10,1 MJ coal, 59,3 MJ electricity and * MJ petroleum per ton coal produced.

2.2 Liquid fuels

Liquid fuels, in general, are produced by refining crude petroleum. In addition, a number of processes exist for converting gas, biomass and coal into liquid fuels, and these have become increasingly relevant given the rising price for crude petroleum.

There are four technical approaches to coal liquefaction, each designed to increase the hydrogen/carbon ratio of coal. There is generally less than one hydrogen atom for every carbon atom in coal ; liquefaction raises this ratio to about 2:1, similar to oil. The processes are outlined below.

1 : Gasification/Liquefaction

In this system coal is gasified into a mixture of hydrogen, carbon monoxide and methane. A catalyst converts the gas to liquids. Because the coal is gasified first, instead of being liquefied directly, the efficiency of conversion to liquid fuels (35% to 40%) is lower than the 60% obtainable from other liquefaction routes (4).

2 : Hydrogenation

In this process, powdered coal is mixed with coal-derived oil and hydrogen gas, and exposed to a catalyst at high temperatures. The substances react to form a solid-liquid mixture of oil, liquefied coal and residue solids consisting of ash and char. Solids and liquids are then separated either by using filters to trap the solids or by using centrifuges to spin out the solids and siphon off the liquids. The H-coal process of Hydrocarbon Research is an example of this technique.

3 : Solvent Refining

Coal is dissolved by oil or coal-derived solvents and hydrogen is then added to the slurry at elevated temperatures and pressures. Solids are removed as above, by filter or centrifuge. The original solvent is recovered and recycled through the system.

4 : Carbonization (Pyrolysis)

Coal is heated to high temperatures in the absence of air, driving out a combination of gaseous and liquid hydrocarbons and leaving a residue of char and inert ash. The vapourized liquid hydrocarbons are allowed to condense and are separated from the gas. No solid/liquid separation is required, but only 50% of the coal is broken down to yield gases and liquids. The technique is being incorporated into a broader process, called Cogas, that produces both oil and gas.

Both the Sasol process and the production of Methanol from coal are examples of the first process : Gasification/Liquefaction, with the additional requirement in the case of Sasol conversion of a refinery to extract the various liquid fuel, gases and chemical products from the wide range of products generated by the Fischer-Tropsch synthesis.

Other routes of converting coal to liquid fuels are also being researched in South Africa. A hydrogenation process is under investigation and the effects of catalyst, temperature and pressure on the liquefaction of different coal types is being studied. Using 1% stannous chloride as a catalyst at 500°C and 20 M Pa, oil yields of 40% on a dry ash-free basis have been achieved (5). The use of different catalysts for hydrogenation and upgrading the liquid products is currently being studied.

Also under investigation is the supercritical gas extraction route. In this process, toluene is used as a solvent at its supercritical state to provide extraction yields of 25%. Hydrogen donor solvents such as tetrahydronaphthalene have given conversion figures as high as 75% (6).

In general, the following major processes are important with regard to the generation of liquid fuels :

- Oil Refining
- Sasol Coal Conversion
- Methanol Production
- Hydrogenation
- Biomass

Several other processes exist, such as :

- Waste Conversion
- Natural Gas Liquefaction

As they are not expected to make major contributions up to 2005, these are not considered further, although some possibilities need to be watched, for example the gas deposits in the southern coastal regions could be converted to methanol, or even LNG or electricity.

2.2.1 Oil Refining

Distributed throughout the boiling range of a crude oil are various hydrocarbons that may be separated by distillation into a series of fractions. Almost all petroleum products have to be specially tailored, in terms of properties and level of impurities, and, at the same time, a wide range of light and heavy products must be manufactured in the proportions demanded by the market. Ideally, by blending crude oils with different characteristics from different fields, a suitable product pattern

can be achieved : since this is difficult to realise in practice, refineries incorporate processes such as cracking which permit heavier fractions to be broken down into lighter, allowing certain flexibility of operation.

Figure 2.2 illustrates the product flows in a typical refinery (7). Distillation is the start of the refining process, in which hydrocarbons are separated on the basis of boiling point. No fixed way of splitting the crude exists ; separation depends on the type of crude oil and the processing scheme used.

After distillation, the different fractions are either given a simple treatment to improve their quality or are processed further to change their chemical composition to produce more desirable materials. Subsequent processes include desulphurization, cracking and reforming.

Output of the refinery, as illustrated, is a wide range of products including heavy oils, motor and aviation fuels, gases and sulphur. Output products used as fuels are aggregated into one sector (oil refineries) in this model.

Inputs to the refining process are crude (primary input), some gas (8) and electricity (9). Based on an output of 10^9 l these are estimated at 29×10^6 kWh (electricity) and 58×10^6 m⁶ gas. As the refinery industry is not expected to change significantly over the programming period, because of the large contribution to fuel supplies made by coal conversion, these values will be used in the supply model without modification.

2.2.2 Sasol Coal Conversion

The Sasol process is described in Chapter 4 (4.1.9) and is illustrated in the energy flow diagram of Figure 4.2. A problem arises when determining the heat

rate or efficiency of the process because of the large volumes of chemicals and gases produced. If a market can be found for these products, then the coal required for their manufacture should be calculated and deducted from total coal requirements to yield the coal needed for fuel production, since these chemicals would otherwise be produced (also from coal) by other chemical industries within the economy. If on the other hand, there is no market for these products, they are effectively waste products that are inherent in the process and hence unavoidable.

It is perhaps too drastic to assume that all these products will be waste ; certain chemicals are already being passed into the fuel line (ethanol) and markets exist for ethylene and other chemicals. For purposes of this analysis, coal requirements of the non-fuel outputs have been removed, thus generating a very optimistic view of the efficiency of the process. The limitation will be set by chemicals production : if surplusses are produced, the conversion rates as used in the model must be significantly altered. This effect may be tested in the model, however, it is hoped that rather than produce vast quantities of possibly toxic wastes, which will need to be processed, stored and dumped, alternative technologies will be used with a higher yield of fuel. The implied assumption is that the Sasol process will be adopted only as long as the bulk of output products can be used by local or export markets.

Given these factors, 1000 litres of fuel may be produced from 2,42 t coal and $1,49 \times 10^3$ kWh. Converting to coal entirely, this results in 3,19 t coal 11000 litre, an efficiency of 58%. This may be compared with published values of approximately 60% (10).

Since the coal conversion industry is growing rapidly with the introduction of Sasol 2 and 3; faster than the

chemicals industry, a lower conversion efficiency must be used. 45% is proposed, increasing to 55% as better utilization is made of chemical output and as other, more efficient processes for coal conversion are introduced up to 2005, as described in Section 2.2.3.

This results in the following inputs for the supply model ; per 1000 litres fuel produced.

- * $\times 10^3$ kWh electricity
- * t coal (1986)
- * t coal (2005)

2.2.3 Hydrogenation

As described in Section 2.2.2, the Sasol coal conversion process yields a wide range of products in addition to fuels. Its coal to liquid fuel conversion rate is therefore low. Hydrogenation is one of several alternative systems of coal liquefaction that appear to offer higher conversion rates. No large-scale commercial hydrogenation plant exists at present, but a design based on data from a process development unit projects a yield of 2,8 to 3,2 barrels per ton of dry Wyoming sub-bituminous coal (11). At 25 MJ/kg (12) this suggests a conversion efficiency of around 70%.

Overproduction of chemicals by the existing Sasol process will ensure that longer term coal conversion projects to succeed Sasol plants in South Africa will be based on technology of this type and efficiency.

Parameters to represent the coal conversion sector in the supply model must consequently be adjusted in time to reflect this improvement. Demand for liquid fuels has a lower expected growth rate than electricity, so that new technology, adopted from 1985 will be assumed to represent half the installed capacity by 2005. If this

new technology operates at 60% efficiency on low-grade South African coals, the total coal conversion sector can be expected to operate at 55% efficiency by the year 2005. This change is built into the supply model.

2.2.4 Methanol Production

Methanol production is described in Chapter 4 (4.2.2). As described, methanol provides a viable alternative to petroleum and Fischer-Tropsch based fuels with the added advantages of improved efficiency of end use, reduced chemical production and reduced capital investments. Considerable interest is shown world-wide in direct methanol engines as well as blends with other fuels. As a blend, several problems occur, specifically with regard to its immiscibility with diesel fuels. A separate model is required to represent the existing and future engine stock, vehicle utilization and fuel grade requirements in order to simulate the introduction of various fuels and optimize the fuel mix. The model developed for this thesis permits the resource and capital requirements for various contributions to be assessed, but does not optimize the level of contribution.

In terms of conversion rate, values of 1,5 t to 2,5 t / 1000 litre have been suggested (13) (14). Taking a value of 1,5 tons, a conversion efficiency of 60% results, as used in the model.

Methanol may also be transformed to high quality gasoline by the Mobil - M process. Methanol is partially dehydrated to an equilibrium mixture of methanol, dimethyl ether and water. The methanol and dimethyl ether are then converted to hydrocarbons over a special Mobil catalyst. Almost no hydrocarbons are found higher than C₁₁ and no subsequent distillation step is needed to remove heavy ends (15).

As engines that use methanol directly are available, this conversion would appear to be unnecessary. The overall economics of methanol production and conversion vs gasoline production from other sources, as well as the existing engine stock and replacement rate may, however, make such a procedure useful in South Africa, and could shift the optimal production levels of oil refining and coal conversion.

2.2.5 Biomass

The production of energy from biomass, for example ethanol from sugar cane, methanol from wood and biogas from plants and dung is receiving increasing attention world wide in the wake of rising oil prices and energy shortages.

One of the major biomass programmes being implemented is for the production of alcohol from sugarcane, sorghum and cassava in Brazil. By 1985, total production of alcohol is expected to reach 5×10^9 litres with a total investment of $\$3,15 \times 10^9$ (16).

Costs for the production of ethanol from biomass and methanol from coal have been estimated for the USA (17) :

Ethanol from biomass : $\sim 35\text{c/litre}$

Methanol from gas : $\sim 11\text{c/litre}$.

This suggests a significantly higher cost for ethanol produced from biomass. These biomass systems have several advantages : they are renewable, use technology that is available, and are ecologically less offensive. Their disadvantages are : land area required, competition with food crops, dependence on weather and requirements for fertilizers, water and soil.

In South Africa, low coal costs will generate an economic advantage for coal-based fuels in the medium term. Biomass

systems have therefore not been explicitly represented in the model.

2.3 Electricity

Owing to its ease of use, lack of pollution and comparatively low cost, electricity has become a major energy carrier for the final demand sectors. Some sources (18) have estimated that demand for electricity will increase 5 times by 2000, and 25 times by 2030 (over 1977 levels). Over the period 1970 - 1977 annual sales of the Electricity Supply Commission (Escom) have increased by more than 9% per annum. 1976, a low growth year for the economy as a whole, saw a 9,5% increase, while in 1975 it was 10%. The major reason for this is that electricity is steadily taking over from other power sources, and this trend is likely to continue. The percentage contribution of electricity to South Africa's overall power demand is predicted to shift from 20,8% in 1977 to 41% in 2000 and over 69% in 2030 (19).

This demand for electricity may be met by a combination of the following :

- pithead coal-fired stations
- nuclear stations
- hydro-electric stations
- gas turbine stations

Each of these has different cost and conversion characteristics.

2.3.1 Coal - electricity generation

The basic cycle of the coal fired thermal power station as utilized by Escom is illustrated in Fig 2.3.

Coal is fed by conveyer belt from coal staiths to the

boiler bunkers, and from there it passes to the pulverising mills for grinding to powder. This pulverised coal is carried by a stream of air from the mills to the boiler burners where it is blown into the furnace and burns like a gas. The products of this combustion are dust and ash. The ash is sluiced away from the bottom of the boiler and the dust is carried in the flue gases to the precipitators, to be collected electrostatically. The remaining flue gases are expelled through the chimney.

Heat released by the burning coal is absorbed by boiler feed-water passing along the tubing that forms the boiler walls, and is converted to steam at high temperature and pressure. Further boiler tubes are used to superheat the steam. The superheated steam passes to the high - pressure turbine where it imparts its energy to the turbine blades. After reheating, the steam passes through an intermediate - pressure turbine, and from there to a low - pressure turbine. The motor of the generator (alternator) is coupled to the turbine shaft. Rotating at 3000 rpm, the alternator produces electricity at (usually) 20 kV ; this is raised by transformer to the national transmission voltage (usually 275 kV or 400 kV) and is distributed to consumers via the national transmission network.

After transferring its energy to the turbines, the steam is condensed and pumped back as water through the deaerator to the boiler economizer for reheating.

The various elements of the cycle, such as superheating, multi-stage turbines and economizers result in improved efficiency of extraction of heat energy from the coal and conversion into mechanical energy. Nevertheless, the inherent inefficiencies of the steam cycle impose an upper limit on overall conversion.

In practice, a modern station such as Kriel (3000 MW) is

capable of an overall conversion rate of 0,48 kg coal/kWh or an efficiency of 35% using coal with a calorific value of 21,5 MJ/kg (20). This is based on average capacity during the year. Under optimal conditions, a station such as Matla (3600 MW) consumes 1500 tons per hour, resulting in an overall conversion rate of 0,42 kg coal/kWh and an efficiency of 39% (21) using coal with a calorific value of 22 MJ/kg.

The overall system conversion rate is 0,574 kg coal/kWh sent out (for coal with a calorific value of 21,6MJ/kg) ; values of 1,13 are found for older stations such as Hendrina, and 0,48 for newer stations such as Kriel (22). Historically, the kg/kWh value has declined as follows :

1950	:	0,869
1960	:	0,723
1970	:	0,580
1974	:	0,560
1978	:	0,573

As is seen in Figure 2.4, the value has declined almost linearly from 1950 to 1970 but then levels off between 1970 and 1978. This is caused partly by the recent shift by Escom to the use of lower heat value coal, and also by the practical operating characteristics of modern stations approaching the theoretical limits of the steam cycle (the ideal Carnot cycle has a thermal efficiency of 60% at a peak cycle temperature of 560°C (23)).

Technical advances are thus felt to have brought fossil generation close to a "perfected" state (24), so that no major reduction in heat rate can be expected without new technological development (such as magnetohydro-dynamics). However, the overall heat rate of the South African electricity generating system can be expected to improve and tend towards the value of the newer stations as older, less efficient stations are replaced.

Countering this effect would be the use of lower heat value coal, increasing the conversion rate, and dry cooling towers, reducing efficiency by around 7% (25).

2.3.2 Future Coal Electricity Generation

Steam turbine systems cannot take full advantage of the high temperatures available from the combustion of fossil fuels because of materials limitations ; nor of the heat available at the low temperature end of the steam cycle because of economic considerations. Two or more heat engine cycles that cover different parts of the temperature range may be utilized ; this is referred to as a combined cycle plant. The second cycle may be added at the high temperature end of the steam cycle (topping cycle) or at the low temperature end (tailing cycle).

According to General Electric and United Technologies (26), future combined gas turbine/steam turbine combined cycle plants will have overall efficiencies between 40% and 44%. Other sources (27) suggest an efficiency of 45%. Various combinations of pressure fluidized bed coal combustion and subsequent combined cycle generation are under investigation (28).

Another cycle that may be combined to improve efficiency is the thermionic topping cycle. The operation of the thermionic device is based on the emission of electrons by metals at high temperatures. A thermionic converter contains an electron emitter and collector in a sealed envelope at reduced pressure. As the emitter is heated the electrons escape from its surface and migrate to the cooler electron collector, causing an electric current. Thermionic devices have been shown to be technically feasible but further development is required to solve problems associated with vaporization of surfaces, warping and shorting.

Based on the above considerations, an ultimate overall efficiency for coal-fired electric generating plant of 45% may be assumed. Taking a coal heat value of 20 MJ/kg, this results in a heat rate of 0,4 kg coal/kWh. If such plant were available by 1990, and were subsequently exclusively implemented by the electricity utility, approximately half the utilities capacity would comprise such plant by 2005 (with a growth rate for electricity of 5%). If the remaining plant operated at today's overall value of 0,574, the overall heat rate in the year 2005 would be 0,49 kg/kWh. This value is used to modify the a_{ij} coefficients in the energy supply model.

2.3.3 Nuclear electricity generation

In a nuclear power plant, heat energy is derived from the fission of uranium or plutonium atoms. Isotopes such as U-235, U-233 and Pu-239 fission readily when struck by a neutron, breaking into two lighter elements and releasing two or more new neutrons for further reaction. The kinetic energy of the lighter elements is subsequently converted to heat as these fragments collide with surrounding atoms. The maintenance of the nuclear chain reaction requires that at least one neutron from each fission cause fission in another atom. Factors such as the number of fissionable atoms per unit volume, neutron speed, leakage of neutron out of the core assembly and absorption of neutrons by other materials in the core alter the probability of neutron-induced fission. The various designs of nuclear reactors take advantage of the characteristics of different nuclear fuels, coolants and construction materials. Several reactor types are thus available :

- pressurized water reactor
- boiling water reactor
- Canadian deuterium - uranium reactor

Pressurized Water Reactor (PWR)

This reactor is the most common of all types in use through the world for commercial power stations, and is the type selected for the Koeberg power station near Cape Town. The reactor uses ordinary water (H_2O) as coolant and moderator, and, because of the neutron absorption properties of H_2O , it must be fuelled by uranium enriched to about 3% U-235. A steam generator transfers heat from the coolant to the water in the turbine steam cycle. The overall efficiency of the PWR, in common with other water-cooled reactors, is limited to about 32% since coolant temperatures cannot exceed $373^{\circ}C$ (critical point for water) (29).

A typical PWR of 1000 MWe operating at 75% capacity factor, requires an initial core of 120 tons and an annual reload of 33 tons of uranium fuel. This quantity of fuel is prepared from 180 tons and 48 tons respectively of enriched UF_6 (30). Fuel fabrication consists of the conversion of enriched UF_6 into uranium dioxide, uranium metal and uranium carbide. These fuel materials are then fabricated into pellets or rods and placed in tubes of stainless steel or zirconium, which are sealed and assembled in bundles to form fuel elements. Average annual requirements, assuming an operating lifetime of 25 years, are given as follows (31) :

fuel elements	:	35 tons
enriched UF_6	:	52 tons
U_3O_8	:	182 tons
ore	:	91 kilotons (at 0,2% conc: In SA average recovery grades are 0,008%) (32).

182 tons U_3O_8 are required per annum for a 1000 MW light water reactor operating at 75% load factor. This implies $(714 \div 842) \times 182 = 154$ tons U metal at 555×10^6 MJ/ton or $85,6 \times 10^9$ MJ to produce $6,57 \times 10^9$ kWh,

an efficiency of 28%. These values are used to set the a_{ij} coefficients in the energy supply model.

Boiling Water Reactor (BWR)

In the boiling water reactor the light water coolant is allowed to boil in the reactor core and the steam produced is used directly to drive a turbine. The design is consequently simpler than the PWR since no steam generator is required; however, the pressure vessel for the boiling water reactor is about three times larger (in volume) than the PWR's for the same power since space must be provided in the BWR for water circulation and steam separation.

The PWR and BWR are illustrated in Figure 2.5.

Canadian Deuterium Uranium Reactor (CANDU)

In the CANDU, natural uranium is used as a fuel in a reactor moderated and cooled by heavy water. (In a variation of this reactor, heavy water is used as a moderator and light water or organic liquids are used as the coolant. Slightly enriched uranium is required for these designs). In contrast to the heavy pressure vessels employed in the PWR and BWR, the CANDU comprises a large cylindrical tank (calandria) containing the moderator, penetrated by horizontal tubes that provide channels for the fuel elements and the pressurized, high-temperature heavy water coolant. The coolant removes the heat developed in the fuel and is used to generate steam in an external heat exchanger (33).

2.3.4 Future Nuclear Electricity Generation

Uncertainty associated with the nuclear programme in many countries caused by incidents such as the failure of certain safety procedures at Three Mile Island (USA) can be

expected to reduce the likelihood of new designs being implemented on a large scale. Future development of fission reactors over the horizon of this model can be expected to be concerned mainly with safety and automatic control systems on existing designs, in order to produce a socially acceptable product. Over the longer term, breeder reactors can be expected to replace today's reactors, owing to their improved utilization of uranium. This is however not expected to occur within the horizon of this model. The heat rate of nuclear reactors must therefore be assumed to be relatively constant over the next 25 years, so that the a_{ij} coefficients representing the nuclear electricity generation business will not be modified ; figures as for a typical PWR power station will be maintained over the planning horizon. PWR's have been selected for South Africa's first nuclear power station, and it must be assumed that use will be made of the experience gained by adopting this commercially widespread technology for the next few stations.

In addition to the reactor types described above, several specialized designs are available or under investigation. For example, the Steam Generating Heavy Water Reactor, the Magnox Gas - Cooled Reactor, the Advanced Gas - Cooled Reactor and the High Temperature Gas - Cooled Reactor. These reactors offer certain advantages where high temperature heat sources are required (coal gasification, iron and steel manufacture), however, they are not commercially available, and their inclusion in the electricity supply system during the horizon of this model is not anticipated at this stage.

Breeder reactors, using nuclear reactions that generate additional fuel during operation, and also fusion reactors, which use the nuclear reaction of light elements to release energy, are not expected to be available commercially during the programming period (2005) and are therefore not considered further.

2.3.5 Gas Turbine Electricity Generation

Apart from the steam cycles described above, electricity may also be generated by burning oil in a gas turbine (effectively a modified aviation jet engine) coupled to an electric generator through self-shifting clutches. Two gas turbine stations have been constructed in South Africa recently - in Cape Town (Acacia) and East London (Port Rex). These stations comprise three sets of twin gas turbines and can produce approximately 170 MW each at normal load. Gas turbines have the major advantage of fast start-up. The units described above can be synchronized onto the grid within 190 seconds of start-up and may then be brought up to full load in 20 seconds. The units are therefore ideal for peak load requirements and also as stand-by for unexpected loads or outages. As they use oil as a fuel and have operating costs that are higher than coal - fired stations, gas turbines will only find limited application in South Africa - for peak and emergency loads. As such, their contribution will not exceed a few percent of installed capacity and a lower percentage of generated electric energy.

The gas turbines described above consume approximately 60 000 litres per hour at full load of 170 MW output (34), implying an efficiency of about 29%. A heat rate 12 000 BTU (12,72 MJ)/kWh has also been published (35) suggesting an efficiency of 28%.

As their contribution to total electric energy production in South Africa is not expected to be more than a few percent changes to the efficiency of these peak loading installations will have a minor effect on overall energy flows. The conversion rate described above will consequently be used for the programming period of this model.

2.3.6 Hydroelectricity

While countries such as Norway and Sweden utilize hydro-power in a large scale, in South Africa low rainfall patterns and restricted water resources limit the quantity of electricity that may be derived from hydro sources to a few percent of total energy production.

Total hydropower installed in South Africa in 1978 was 540 MW; being Vanderkloof (220 MW) and Hendrik Verwoerd (320 MW) ; out of a total installed capacity of 14 434 MW (36). Some additional sites exist in South Africa, and may be exploited in the future (Tugela river). These projects are all associated with irrigation schemes, whose water requirements must also be taken into account.

Local hydropower is limited, but major sources exist outside South Africa's borders. Cahora Bassa in Mozambique provides power for South Africa, and the Zaire river has the potential for some major hydroelectric projects. Political and strategic considerations are the dominant factors associated with these sources, and it is unlikely that significant quantities will be derived from them over the period of this model.

Consequently the contribution of hydroelectricity is limited to a few percent over the horizon of this model.

2.3.7 Other Electricity Generation

In addition to the electricity generating systems described above, several other processes are currently under investigation :

- geothermal
- solar
- magnetohydrodynamics
- super conducting electric generators
- fuel cells
- wind / wave
- tidal
- cogeneration

Many authors have described the general nature of these energy sources and their application within the local context (37). In general, it is found that these systems cannot compete with electricity generated by the more conventional methods described earlier.

The price of coal will need to be several times higher (under today's conditions) before these systems become economically worthwhile. These sources are therefore not expected to make a significant contribution to electricity supply within the programming period (2005) and they have consequently not been included in the structure of this model.

2.4 Coke/Gas

Coal gasification is subject to major studies worldwide at present, in order to produce a substitute fuel for natural gas. In South Africa, gas and coke are produced in relatively small quantities by municipalities, and gas is produced as a by-product of the coal conversion process. These two energy carriers are not major contributors to the overall energy economy in South Africa.

As a result of potential applications to replace natural gas and in the steel and coal-liquefaction industries, several coal gasification techniques exist or are under investigation. These have been described in Chapter 3 (Iron and Steel Industry) section 3.2.2.

Operating characteristics of these gasifiers are as follows (38) :

Winkler

input	:	non-coking coal, steam, oxygen.
output	:	low/medium MJ gas, hydrogen.
conversion	:	1600 Nm ³ synthesis gas/ton coal.

Koppers-Totzek

input	:	any coal, oxygen, steam
output	:	synthesis gas, H ₂ for NH ₃ production
conversion	:	1600Nm ³ synthesis gas; 0,63 t NH ₃ /ton coal.

Hygas

input	:	non-coking bituminous coal, light oil, steam, oxygen
output	:	SNG
conversion	:	540 Nm ³ pipeline gas/ton coal.

Bigas

input	:	all types of bituminous coal, steam, oxygen
output	:	SNG
conversion	:	600 Nm ³ pipeline gas/ton coal.

Gas in South Africa is produced in Cape Town, Port Elizabeth and Johannesburg (town gas and Sasol gas); this plant operated as follows in 1977 (39):

	<u>Cape Town</u>	<u>Port Elizabeth</u>	<u>Johannesburg</u>
Calorific Value of Gas MJ/m ³ :	17	17	18
Gas output 10 ⁶ m ³ :	11	10,3	25,9 (77,2 ex Sasol)
Coke sold kt :	13,3	9,3	not available
Coal carbonized kt :	26,3	21,2	76,1

Assuming a calorific value of 28 MJ/kg for coal and 28 MJ/kg for coke, the following heat rates apply to the Cape Town and Port Elizabeth gasification plant, in 10⁶ MJ:

	<u>Cape Town</u>	<u>Port Elizabeth</u>
Gas output :	187	175
Coke output :	372	260
Coal input :	736	593
Coal to Gas/Coke Conversion efficiency :	76 %	74 %

The basic processes operated are coal carbonization to give gas, coke and by-products, and carburetted water gas manufacture using some of the coke and oil. All three works operate well below their rated capacity. Plant and distribution systems are old, resulting in gas losses and reduced efficiencies.

Conversion efficiencies are a function of the process used and gases produced, as well as the input coal quality. As these carriers are relatively minor, an overall conversion rate of 80% for coal to gas and coal to coke will be assumed for the model.

2.5 Uranium

2.5.1 Uranium production

The extent and utilization of uranium resources in South Africa is described in Chapters 1 and 5. As described in section 5.1.3, the bulk of uranium production in South Africa arises as a by-product of gold mining (40). Energy requirements must therefore be split into those required for gold and uranium respectively. Figure 5.1 illustrates the energy flows within the gold/uranium industry. In this model, the energy required for gold mining and production is considered to be part of the mining industry, while the energy requirements for uranium extraction are used in the energy supply model to represent the energy required for uranium mining. This representation would not be valid for a pure uranium producing facility operating in the Karoo region, for example, where the energy requirements for mining can be expected to be higher. Very little data is available regarding the extraction methods that would be used in the Karoo should these uranium deposits prove to be economically mineable. Consequently, in this model energy flows as illustrated in Figure 5.1 will be used: ie. 313×10^6 kWh per kiloton U_3O_8 . Alternative mining techniques will be assumed to form part of the "General" section which includes new mining operations (see Chapter 10).

Output of the uranium mining sector is U_3O_8 "yellowcake", which may be exported or used locally by the nuclear electricity generation industry.

2.5.2 Uranium Enrichment (Processing)

To be used as a reactor fuel, uranium must first be refined to remove impurities which would absorb neutrons in the reactor. Solvent extraction methods are used to produce UO_3 which is then converted by hydrogenation to UO_2 and then to UF_4 by reaction with HF . Further reaction with fluorine gas produces UF_6 . In order to be useful in light water reactors, the concentration of U-235 must be increased from the 0,7% (approx) in natural uranium to between 2 and 4% by enrichment.

Several methods exist for this enrichment, based usually on the slight difference in mass between the two isotopes. Photoexcitation and nuclear spin methods have also been proposed.

Energy requirements per kg separative work for various methods are listed below (41) :

	kWh/kg SW
Gaseous Diffusion	2330
UF_6 Distillation	5431
Redox Ion Exchange	6219
Mass Diffusion	10512
Becker Nozzle	5746

The South African process is described as an aerodynamic process using a cascade separation technique on UF_6 in hydrogen as a process fluid. Specific power consumption is estimated at 3000 kWh/kg (42). This value is built into the energy supply model, suitably adjusted for fuel that might be imported.

Subsequent to enrichment, fuel is fabricated by converting the UF_6 into uranium, uranium dioxide and uranium carbide. These materials are then fabricated into pellets or rods and sealed in stainless steel or zirconium tubes. Bundles

of these tubes constitute the fuel elements.

After use, the intensely radio-active fuel elements must be stored under water for several months and then reprocessed. The reprocessing part of the cycle, because it generates highly radio-active and toxic wastes which must be disposed, is one of the major problem areas of present day nuclear power technology. Strictly, the costs and energy requirements of reprocessing and waste disposal must be included in the nuclear sector. As the problems of waste disposal have not yet been effectively solved, these elements of cost and energy are omitted at this stage.

2.6 Summary

As described in Chapter 1, the Energy Supply model comprises a 16 x 16 matrix of energy flows within the energy industries, to supply demand as determined by the final demand sectors outlined in Chapters 3 to 9.

Coefficients for the matrix have been described above, and these are changed (in time) where it is felt that new technology is possible or desirable.

Matrix methods are used to solve the 16 simultaneous equations that represent the flows of energy within the energy industries and out to the end users. The energy supply model in its time-extended form represents the supply of energy in South Africa in 1980 as well as probable changes in the production and conversion of energy carriers up to the year 2005. Used in conjunction with the demand models, a range of scenarios may be developed, as described in Chapter 10.

3 THE IRON AND STEEL INDUSTRY

3.1 Description of the Iron and Steel Industry

3.1.1 Introduction

World iron and steel production is growing steadily, and amounted to 712 million tons in 1978 (1). It is expected to approach 1367 million tons by the year 2000. Total production of steel ingots and continuously cast billets in South Africa during 1975 amounted to 6,926 million tons and may increase at 6% pa (section 3.3) up to 1985. Future demand for iron and steel in South Africa (section 3.3) is difficult to predict with any degree of reliability because this will depend upon the development of export markets for iron in various forms, including iron ore, direct reduced iron in the form of sponge pellets, semi-finished iron and steel products such as pig iron including special grades, steel ingots, blooms and billets, steel mill products, alloy steels including finished and semi-finished stainless steel and also manufactured goods based on steel.

Steel may be produced by fully integrated plants such as ISCOR which have the capacity to beneficiate iron ore, produce coke, convert iron ore to iron in blast furnaces, convert iron to steel by any of several types of steel furnaces, semi-finish and finally finish steel. It may also be produced by mini-mills which convert scrap to steel in electric arc steel furnaces. Mini-mills produce a more limited range of products, confined to structural bars and light forms, and compete with the integrated mills for this particular demand. Several such mills exist in South Africa.

In order to assess future demand for energy by the iron and steel industry, several factors must be considered:

- probable production volume of each end product, as listed above.
- impact of new technology, for example new steelmaking processes.
- effect of conservation measures.

An assessment of probable production volumes for each product of the iron and steel industry lies beyond the scope of this thesis. In the following sections the energy flow in the iron and steel industry will be illustrated, and the effect of probable or proposed new technologies or conservation measures will be described. Matching this against estimates of future demand for iron and steel products will then yield energy flows by carrier. This is described in section 3.4.

Four major steelmaking processes may be identified, as described below:

Coke Ovens

Ore Preparation and Iron Making

Steel Production

Rolling and Finishing

3.1.2 Coke Ovens

The primary object of using coke in iron and steelmaking is to obtain a fuel or reducing agent of sufficient physical strength to withstand the heavy pressures found

in the blast furnace, and with as little volatile material and sulphur content as practicable. This coke is obtained by the destructive distillation of coking coals at high temperatures. Coal used to produce this coke should have the following characteristics:

- low sulphur content and very low phosphorous content
- low ash content
- suitable swelling index
- produce coke of considerable physical strength

At present, it appears that the high grade metallurgical coals with these characteristics, and even coal for blending and for producing formed coke, are in limited supply. Coke use is described in section 3.1.7.

The yield obtained from coke ovens (tons coal per ton coke produced) depends upon the grade of coking coal used. In the US, UK and Germany, a figure of 1,45 is generally quoted (2) while for South Africa, an overall figure of 1,43 is found. Since the carbon is used as a reducing agent, it may in theory be replaced by other reductants such as CO or H₂ which are found in oil and gas. This in fact is what is done in the "direct reduction" processes described later.

In addition to coke, the coke ovens produce coke oven gas and tar products which may be used elsewhere in the steelmaking process.

3.1.3 Ore Preparation and Iron Making

Correct sizing of the ore is critical for the operation of the blast furnace and ore preparation includes all aspects of ore sizing, sintering and pelletization necessary to obtain suitable physical dimensions.

The conventional pattern of steelmaking is based on coke-fired blast furnaces to produce iron from iron ores. This reduction of iron ore is effected by carbon monoxide which is generated by the action of oxygen in the air blast on the solid coke in the shaft of the furnace. Thus the blast furnace itself acts as a gas producer, and excess gases are used elsewhere in the process. A significant amount of this blast furnace gas is lost, flared or used outside the steelmaking process. Output from this process is approximately 0,8 ton hot metal per ton crude steel, while the approximate value for ISCOR alone is 0,86 ton. Approximately 0,6 ton coke is required per ton of hot metal produced, and it is important to note to what degree coke may be substituted by other reductants. A possible figure of 0,3 tons might be achievable, but it is doubtful whether this is possible in practice owing to the low physical strength of presently available coke.

Other technologies, using formed coke or no coke at all are also possible. These are discussed in section 3.2 - "Alternative Technology in the Iron and Steel Industry".

3.1.4 Steel Production

Crude steel is produced by four major processes: the basic oxygen furnace the open hearth, the electric arc and rotor furnace.

In the basic oxygen process, substantially pure oxygen is introduced above the surface of a bath of molten iron contained in a basic-lined cylindrical furnace. Basic oxygen steelmaking is relatively inflexible in its ability to use large proportions of cold pig iron or steel scrap in the charge because of the nature of the heat balance of the reactions.

The open hearth (OH) furnace generally comprises a long shallow charge bath heated by radiation from a flame generated by nozzles built into the ends of the furnace. Oxygen may be used for enrichment. The OH is flexible in terms of its ability to handle different charge proportions, from 100 % scrap to no scrap at all (3).

The electric arc furnace uses graphite electrodes set in a cylinder. Iron ore or pure oxygen may be used to provide oxygen for refining. Proper charge grade distribution is crucial, and determines the grade of steel produced.

In the rotor furnace molten pig iron is refined in a horizontally mounted, rotating, refractory lined vessel. Nozzles at one end of the cylinder are used to introduce oxygen at low pressure into the molten bath. Thermal efficiency of the process is very high, and the refining process can be so controlled that all reactions can be stopped at any desired carbon level (4).

Approximately 42 %, 8 %, 36 % and 14 % of South African steel is produced by these processes respectively (18). In addition to the hot metal produced by the iron-making process, a certain amount of scrap iron is used. The value for scrap iron is difficult to determine since it is highly variable and not clearly recorded. A value of 30 % (scrap to crude steel) has been assumed for 1979 based on approximate figures for each steelmaking industry.

3.1.5 Rolling and Finishing

Rolling and finishing includes all aspects of final steel processing - ingot casting, soaking and rolling, continuous casting, secondary rolling and treating as

well as grinding, polishing and buffing: Finished steel is the output from this stage. In the energy flow diagram developed below, a ratio of 1,25 for crude steel input to finished product output is used. This yields an overall figure of 6 100 MJ/ton crude steel, being the chemical and heat energy content of the finished steel. This may be compared to 6300 MJ/ton used in US flow diagrams (5) and 5 700 used in Belgium. A number of factors will influence this figure, namely the percentage scrap used by the process, the energy content assumed for the scrap, the amount and method of final finishing and secondary treatment as well as the mix of final products.

3.1.6 Auxiliary Operations

In addition to the four major steelmaking processes, several auxiliary facilities must be considered:

Oxygen production

Power plant

Producer gas

Oxygen is used by the iron and steel industry for iron making (blast furnace), and for injection into steel baths in the open hearth and electric arc by means of lances or jets to assist in the melting down of scrap and, during the refining period, to speed up carbon reduction. Other applications for oxygen are found in the final finishing (cutting) of steel.

In addition to the electricity purchased from the utility, the industry produces its own electricity. Gas, coal, petroleum products and the by-products of the coke ovens are used to generate electricity and steam, both used extensively in the process.

Producer gas is also generated by the industry and is used again in different steelmaking processes.

There are other aspects of the iron and steel industry, such as transportation and administration. These are, however, relatively minor in the sense of overall energy flows and are omitted here.

3.1.7 Energy Flow Diagram

The above major steelmaking processes may be represented as an energy flow diagram, illustrated in Figure 3.1. Data from the five major steel-producers has been aggregated (1979 values) and reduced to a per-ton crude steel basis for the figure. Output of these producers totalled 8,7666 MT in 1979, 97 per cent of South Africa's steel output, so that the figure is in fact representative of the entire steelmaking industry in South Africa.

Data to assess accurately all energy flows is unfortunately not available, so that in order to assign values to some flows overall values such as these found in the US (5) and Belgian (6) steel industries were used. In addition, certain assumptions were necessary where information was not available. The following general factors apply:

- 30 % scrap to crude steel ratio
- 1,25 crude steel to finished steel ratio
- oxygen is converted into equivalent electricity to produce that amount of oxygen. Efficiencies of conversion are thus included implicitly.

- oxygen produced in excess is sold or used elsewhere
- major output of the power plant is steam, and a 52% overall efficiency of conversion has been assumed
- producer gas is converted into its coal equivalent, so that efficiencies of conversion are implicit
- consolidated data, upon which the diagram is based, is listed in Table 3.1.

If electricity purchased by the industry is converted into tons of coal (equivalent) assuming a heat content for hard coal of 25 MJ/kg and an overall efficiency for the electrical generation and transmission system of 24,4%, final primary energy requirements of the industry are then 21 065 MJ coking coal, 13 722 MJ hard coal and 172 MJ gas and other energy per ton of steel produced. This translates into 0,719 tons coking coal and 0,549 tons hard coal per ton steel produced, a total of 1,268 tons coal/ton steel. However, if the oxygen and gas output is deducted (0,057) as well as losses (0,08) in the preparation of coke (screening), a figure of 1,268-0,057-0,08 or 1,13 tons coal (equivalent)/ton steel results. This is similar to US, European and Japanese figures.

Based on projected total steel output and the energy flow diagram (Fig. 3.1) it is possible to determine what quantities of coking coal and other energy carriers will be required in the future, the assumption being that the structure of the iron and steel industry will be approximately constant. Table 3.2 lists these values, based on 5% per annum growth in the GDP and steel demand values per capita as described by Bennett (7).

Total coking coal requirement up to the year 2000 can then be expected to be in the vicinity of 330 Mton (cumulative). This must be compared with published figures of coking coal reserves. The Petrick Commission (8) in 1975 reported total metallurgical coal extractable by underground mining to be 705 Mton and total anthracitic coal in the same category to be 375 Mton. According to the definition used in this report, only the metallurgical coal has the appropriate characteristic, swell index, to be used as coking coal, although the anthracite may be used for other metallurgical purposes, for example the ferro-alloy industry and the manufacture of calcium carbide.

Thus almost 50 per cent of the available coking coal will be required up to the year 2000 by the iron and steel industry alone, if no changes are made to the iron and steelmaking process in South Africa.

This highlights the critical nature of coking coal reserves and the need to develop and implement alternative technology that will reduce the requirement for this material.

In the following section, alternative technology that may be used in South Africa to reduce the need for coking coal is described, specifically with the aim of developing a more "likely" scenario of future steel production. Final demand is also considered, and in the final section of this chapter, three cases are defined to represent High, Likely and Low energy consumption. Many technologies and conservation possibilities exist, at this stage, no attempt is made to find the best set of options.

3.2 Alternative Technology - Iron and Steel Industry

3.2.1 General

In the absense of any proven reserves of petroleum or natural gas, South Africa must rely solely on reserves of coal for iron and steelmaking, until nuclear electric power becomes more extensively and economically available in the future. It is therefore necessary to conserve coal as far as possible and to devise ways of using low-grade midlings and even poor quality coal. Direct reduction processes have been considered although it is not felt that these processes will use less coal or other forms of energy than is used in the conventional blast furnace route. Total energy requirements may even be higher; however, these routes may be designed to make use of coal that is presently regarded as totally unsuitable for iron and steel making and possibly useless for any other purpose whatsoever.

In terms of standard coke production, improvement of the coke oven could lead to marginal savings in coking coal. The coke rate has been described by Bennett (9) and is similar for different steel producing countries. For example, a value of 1,45 is reported for USA and West Germany; 1,42 for Japan and 1,45 as well as 1,20 for UK. The figure used for South Africa is 1,43 so that little improvement can be expected.

Another method of reducing the coking coal requirement is the practice of oil injection. This has reduced the coke rate in countries such as the UK and USA, but is not used in South Africa since the country has no known oil reserves. The possibility of using output from Sasol II and III should be investigated.

The key problem remains one of using lower grades of coal.

3.2.2 Coal Utilization

In terms of the iron and steel industry, coal of different grades may be used in several ways:

- 1) Steam coal (low grade) may be used to produce electric energy. Less than 27 per cent of the energy in the coal is finally available in an electric-arc furnace, however.
- 2) High grade, low ash coal with low sulphur and zero phosphorous content may be used as a fuel or a reducing agent in a furnace.
- 3) Special grades of coal may be used to produce coke for use as a reducing agent in a blast furnace.
- 4) Formed coke may be made from non-coking coal as a substitute for coke.
- 5) Coal-char may be made from non-coking coal and may be used as a reducing agent.
- 6) Synthetic liquid or gaseous hydrocarbons may be prepared from coal by, for example, the Sasol process. Sulphur content of oil produced by Sasol is currently too high for use in iron and steelmaking processes, but future supplies of wax-base fuel oil (PW Furnace Oil) from Sasol II and III could find considerable application.

7) Gas may be obtained from various processes:

- Carbonization of coal to produce town gas
- Iron and Steelmaking by-products such as coke oven and blast furnace gas
- Producer Gas
- Water Gas
- Synthesis-gas manufacturing processes such as Lurgi, Koppers-Totzek and Winkler.

The most promising method of utilizing low-grade, high-ash coal appears to be gasification. This gas is then used in a gas-solid direct reduction process in which metallic iron is reduced from the ore by reaction with a gas that is a controlled and balanced mixture of carbon monoxide and hydrogen. This direct reduced iron is produced in a more or less spongy and porous form resulting from the removal of the oxygen from the oxide ore (sponge iron) or it may be obtained by the reduction of pelletized iron-ore concentrates (metallized pellets). In some processes, the iron ore may be reduced in a fluidized bed of fine iron ore. The product is a powder of virtually pure iron which may be made up into briquettes (metallized briquettes). Silica, alumina and sulphur content, as well as hardness of the ores are important factors and must be taken into account when evaluating these processes.

3.2.3 The Direct Reduced Iron (DRI) Method

Except for the fluidized-bed system, all the gas direct-reduction processes involve passing pelletized or suitably sized ore down a vertical shaft kiln through

which the reducing gas is passed upward. The system is brought up to reaction temperature either by heating the gas or by heating both ore and gas.

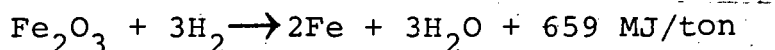
Existing plants using gas-solid reduction operate on a reducing gas produced from natural gas, crude oil or naphtha, because these plants have in general been installed in areas where these fuels are the cheapest and most abundant fuel.

No plants have so far been erected to operate on coal as a fuel. In terms of determining coal grade utilization in South Africa, it is necessary to estimate potential requirements based on existing knowledge of the gas reducing plant elsewhere and coal gasification technology in South Africa.

Operating plants make use of a reducing gas comprising a mixture of CO and H₂ with some gaseous hydrocarbons and some CO₂. Methane or gaseous hydrocarbons have little or no reducing effect on iron ore, but their presence influences the carbon content of the sponge iron. CO₂ is undesirable. In general, to balance suitably the exothermic CO reaction.



with the endothermic Hydrogen reaction:



taking losses into account a 1 to 1 mixture of H₂ and CO appears suitable. Sulphur content of the reducing gas should be low, gas input temperature should be in the range of 800°C to 1000°C (depending upon the ore to be reduced) at a pressure of 2,5 to 3 bar. The volume of gas required will then be about 2000 m³ per ton of iron (10) at normal temperatures.

Many coal gasification techniques exist (11), and a detailed description of these is beyond the scope of this thesis. Here, an assessment of potential coal-utilization patterns is of importance and a suitable gasification technique must therefore be selected. Low grade, high ash undersized coal that is presently being dumped may certainly be used for gasification, however use of this coal is likely to result in major additional problems as well as increased capital costs. The use of good quality coal of suitable size should therefore preferably be considered. There is no gasification system at presently specifically designed for the production of the appropriate H_2/CO mixture required for a direct reduction plant.

The following gasification processes are currently available:

Winkler
Producers
Koppers-Totzek
Lurgi
Otto Rummel (12)

Processes under development include:

High Temperature Winkler
Shell Koppers
Texaco
Saarberg-Otto
Ruhr 100
Lurgi Slagging

It is extremely difficult to compare costs and efficiencies of these various processes since this is usually strongly dependent on coal costs, coal type,

location and load factor. Also, secondary products such as char and oils must be considered, as well as additional requirements, such as oxygen plant. To determine possible coal requirements for this analysis an old but effective gasification technique will be assumed. Namely the reaction: $C + H_2O \rightarrow CO + H_2$ obtained when steam is passed through a fuel bed heated to 1200 to 1400°C. The reaction is endothermic, and temperature of the fuel bed drops sharply. Air must then be blown in.

This system has the advantages:

- The gas produced is the right blend for direct reduction.
- No oxygen plant is needed.
- Technology and costs are reasonably well known.
- The system can operate with the coal quality suggested.

The resulting gas has the following approximate composition when coke is used as the fuel:

CO	41 % by volume
H ₂	50
CO ₂	5
N ₂	3,5
C _n H _{2n+2}	0,5

This is considered to be an almost ideal composition for use as the reducing gas for a direct reduction plant. Certain disadvantages are associated with the process, namely its cyclic operation, its susceptibility to clinkering with low fusion point ash coals, and the tendency to build up columns of ash in the centre of the producer. These disadvantages could lead to the adoption of newer processes for the steel industry, but for purposes of calculating alternative coal requirements, this system will be assumed in this analysis. As no large scale plant is currently in operation, an estimate of the energy flow is needed. Also, for some of the newer processes, developers tend to be optimistic regarding cost and efficiency of the final project. Even a change in feedstock can radically influence the operation of a gasifier. The following figures will be used (13) :

$7 \times 10^6 \text{ m}^3/\text{day}$ plant needs 15 000 tons coal and 20 000 to 60 000 m^3 process water. New iron-making capacity, using gas-solid direct reduction techniques, will require:

$(2000 \text{ m}^3 \times 0,8 \times 15000) - 7 \times 10^6 \text{ m}^3 = 3,43 \text{ tons coal}$
per ton steel produced per annum, assuming 0,8 ton reduced iron per ton crude steel.

However, this assumes that the coke left after gasification is discarded. In practice it would be used for electricity generation or steam raising. To avoid double counting, only the coal converted to gas will be used, estimated at 1,7 tons. This figure is used in section 3.4 to develop a likely energy demand pattern for the iron and steel industry. Several questions must still be investigated, including capital costs and environmental problems associated with burning large quantities of coal. Newer gasification techniques are possibly an improvement in this respect: a large-scale installation is needed to test these factors.

3.2.4 Energy Conservation Possibilities

As can be seen from the energy flow diagram, over 50 % of energy consumption in the industry is "lost". Most heat consumption in the industry is needed for the endothermic iron ore reduction reactions and for heating steels to the high temperatures required for hot deformation to semi-finished and finished rolled products. There are a number of processes such as steel refining and heat treating of alloy steel that are carried out with a relatively low consumption of energy.

Scope for energy conservation exists in many sectors of the iron and steel industry:

- Increase the ratio of iron ore pellets to sinter in the charge entering the blast furnace.
- Waste heat recovery to decrease the energy requirements for sintering.
- Charge hot sinter, pellets, coke and coke oven gas directly to reduce sensible heat losses.
- Increase oxygen injection in electric arc furnaces for more complete combustion.
- Continuous cast installations increase the output of finished metal by 10 to 15 per cent and reduce energy requirements at that stage by an equivalent amount.
- Re-use of heat from continuous casting and "direct" hot rolling omitting the reheat furnace stage allow savings of 0,82 to 1,26 GJ/ton finished rolled product. By charging hot sinter into blast furnaces and molten pig iron into steel furnaces savings may also be obtained.

- Reuse waste gases from electric arc furnaces and carbon monoxide from conventional steel making is a fuel in process boilers.

- Replace open-hearth (OH) furnaces by basic oxygen. The OH method requires approximately 3 to 6 GJ/ton steel (14). The basic oxygen converter derives subsidiary thermal and chemical energy from converter waste gases and requires only 20 % of the energy needed by the open-hearth process.

- Scrap metal melting by high-frequency induction furnaces can save 25 % of the energy consumed at this stage.

A promising possibility is the use of nuclear energy to generate heat for various processes, for example ore heating, electric power generation and the generation of reducing gases. Research (15) has demonstrated the feasibility of using this heat to generate H_2 and CO from various kinds of fuel. Injection of hot reduction gases can reduce coke consumption by 24 to 30 per cent and can increase blast furnace productivity by 25 to 30 per cent.

Mention must also be made of the plasma direct reduction process. In this technique, a mixture of finely ground ore, coal and limestone is fed through a zone of ultra-high temperature plasma produced by an electric arc. The charge is exposed to short-term temperatures between 14 000 and 20 000°C. At this temperature the carbon in the coal is gasified and the iron oxides in the arc dissociated, the oxygen combining with the carbon of the reducing agent. Fully reduced iron and slag are produced while the coal is converted to CO and H_2 . The system is still at a prototype stage and it is therefore

difficult to determine what the coal requirements will be for electricity and for the reducing agent, however, the system appears to offer considerable promise as a possible method of direct reduction in the future.

Each of the above energy substitution or energy saving techniques would have to be studied in detail to assess its applicability and value in the local context. In addition, other factors must also be considered, such as the need to produce metal of higher quality, and measures for the protection of the environment and the use of poorer iron ores, or ores with certain unfavourable characteristics. These factors will tend to increase energy consumption in spite of the introduction of multiple energy saving measures.

Until the effects of the measures are better understood, from a sectoral as well as a national point of view, it is preferable to omit them from the scenarios developed in later sections.

To summarize, the amount of energy consumed by the South African steel industry is approximately 31 GJ/ton, chiefly of coking coal. More than half of this energy is at present emitted unused into the environment. Specific energy requirement may decline or increase in the future depending in the quality of metal produced, the introduction of new processes, the use of poorer iron ores and environmental problems. Coking coal is in limited supply in South Africa, however, it appears that the introduction of direct reduced iron techniques can make a significant difference in the demand for this grade of coal by substituting bituminous coal which is in plentiful supply. An energy flow diagram has been compiled from available statistics and is used to illustrate the effect of changes in the industry.

3.3 Final Demand

Products of the Iron and Steel Industry include billets, blooms, slabs and bars, as well as hot and cold rolled products such as sheets, tin plate, strips, tubes and pipes, rails, rods, wires, castings and forgings. Demand for these products may be split into domestic (for growth in the manufacturing industry as well as investment in the economic infrastructure) and export.

3.3.1 Domestic Demand

Most growth in domestic demand can be expected to be for flat products used in the production of durable consumer goods such as motor vehicles and appliances. Also, increased demand for these products will result in an increase in fixed investment, thereby also stimulating demand for steel. According to the Economic Planning Branch of the Office of the Prime Minister (16), investment in economic infrastructure is not expected to grow as rapidly up to 1990 as was the case in the early seventies, reducing the demand for profile products. At present, emphasis is placed on the provision of low-cost housing, for which few steel products are needed.

Table 3.3 illustrates the 1977 and projected 1987 domestic consumption of iron and steel, as well as the percentage annual change. It can be seen that no sector predominates, although some sectors, such as fabricated metal products are relatively large. Also, projected growth rates are not expected to differ substantially over the next ten years, except for motor vehicles with a growth rate of 11,8 %. Thus, major changes in any one of the domestic demand subsectors are unlikely to alter significantly the total production of steel products, which is of importance in this thesis. For the years following 1990, there does not appear to be any reason for expecting a major deviation from existing domestic demand patterns.

Projects such as new coal conversion and nuclear electric plants are major users of steel products. Present projects such as SASOL II and III and KOEBERG are included in the demand figures, and there does not appear to be any reason to expect an above-normal growth in the implementation of these projects over the next 20 to 30 years.

3.3.2 Export Demand

Exports of steel products are dependent on a number of factors:

- local demand as a fraction of installed steelmaking capacity. Producers are forced to export to achieve better utilization of production capacity when local demand is low.
- the relative value of the Rand with regard to European and Japanese currency. A depreciated Rand can boost exports significantly.
- subsidization of steel products by governments, effectively changing the relative price structure.
- high transport and energy cost of steel products.
- excess capacity, leading to the implementation of protective measures by various countries.

1977 exports of basic iron and steel products are illustrated in Table 3.4. Volumes compared to domestic demand are not high so that changes in export market, unless very large, will not affect total steel production significantly. However, as mentioned above, high transport and energy costs are an important factor in steelmaking and it is possible that present steelmaking countries that do not possess adequate energy resources may decide to import energy by

importing steel rather than manufacturing it themselves. In effect, steelmaking would be shifted to countries such as South Africa that possess adequate energy and mineral resources. In addition, environmental problems caused by the emission of pollutants from the steelmaking process will also induce several countries to import rather than manufacture. Thus the potential for big increases in exports exists, but is difficult to quantify. Exports must therefore be used as a parameter in evaluating total final demand, constrained by the rate at which new steelmaking capacity can be commissioned in South Africa.

3.4 Description of Likely/High/Low Cases

Based on the above description of the Iron and Steel Industry, and the characteristics of the market for the end product, the following scenarios may be defined:

- the steel industry develops "as is" i.e. new steelmaking equipment is effectively the same as existing equipment. This must be considered a "worst case" since present technology uses coking coal extensively, which is in short supply.
- DRI plant is used for all new steelmaking projects. This is probably a "best case" since the demand for coking coal is reduced. However, it is unlikely that any manufacturer would opt totally for a new, untested technology. Possibly the most likely case could be partial implementation of DRI; this can be simulated at a later stage by an optimizing model. At this stage general constraints are being sought.
- demand for steel products increases at 6,5 % per annum. This is the figure developed by the Office of the Prime Minister, and can be taken as a base case. No sub-sector appears to dominate the market for steel products.

- exports are highly uncertain, but could increase significantly. One is tempted to suggest that this could push the steel production growth rate up to 10 % per annum, however, as described by Bennett (17) this could require vast amounts of capital. 7 % is suggested as a maximum, and is used here to test the "maximum export" case.

The above factors may be used to define the limits of energy demand by the Iron and Steel Industry, as follows:

1. Likely case: 6,5 % per annum growth rate, DRI used for new plant.
2. High case: 7 % per annum growth rate, steel industry develops "as is".
3. Low case: 3 % per annum growth rate, DRI used for new plant.

Many other possibilities exist, assuming different conservation measures in the steelmaking industry and the introduction of new steelmaking techniques. A detailed study of these options is beyond the scope of this thesis, for which the general integrated energy demand pattern is sought.

The total demand for energy for these three cases is listed in Tables 3.5, 3.6 and 3.7. The above assumptions are used to determine steel output, DRI contribution (iron manufactured by the DRI process), and coal requirements (hard and coking). Electricity has also been converted into coal requirements for these Tables, in order to compare primary resource requirements for the iron and steel industry as a whole.

Tables 3.8, 3.9 and 3.10 list the demand for energy carriers, based on the above assumptions.

These three cases constitute the final demand scenarios for the iron and steel industry, to be used in the integrating model.

4 THE CHEMICALS INDUSTRY

4.1 Description of the Chemicals Industry

4.1.1 Introduction

The chemicals industry in South Africa is one of the more complex industries with regard to the flow of energy carriers, and is at the same time one of the more important regarding the utilization of indigenous and imported energy carriers. Ideally, an energy flow diagram such as that for the Iron and Steel Industry must be developed, to facilitate analysis of energy carrier utilization within the industry. Several factors suggest, however, that such an integrated diagram would not be suitable, and that some disaggregation of the industry is necessary.

Firstly, a large sector of the industry is concerned with the conversion of coal and oil into fuels used by other sectors for heating, transportation and power generation. On a world basis (1) 69% of crude oil consumption is used for space heating and power generation, 25% for gasoline and only about 6% for the manufacture of petrochemicals. Since the oil price increases, there has been a shift towards the use of coal as a feedstock for the chemicals industry. However, in South Africa, coal is also used extensively to produce liquid fuels. These fuel conversion aspects are in fact part of the energy supply system and will be built into the supply aspect of the model.

Secondly, considering the rest of the industry for which energy carriers such as oil, coal and gas are used to produce chemical products such as plastics, fertilizers and pharmaceuticals, a highly dynamic situation exists. A wide variety of products is produced, the mix of

products can change dramatically with the development of new markets, and the advent of new technology can significantly change the intermediate steps and products in the manufacture of a specific item.

Thirdly, a major sector of the chemicals industry is involved in the reprocessing of the chemical outputs of another process. The polymerization of ethylene produced by Sasol to generate polyethylene is a case in point. These sectors of the chemicals industry use relatively little energy. The example above, namely polymerization of ethylene, is in fact an exothermic reaction.

These factors, combined with the overall aim of providing an energy demand projecting system, suggest that the chemicals industry needs to be treated as a number of sub-industries, with main emphasis being placed on those sub-industries that use significant quantities of the various energy carriers.

The chemicals industry may be split into the following subsectors:

- fertilizers and pesticides
- plastic raw materials and man-made fibres
- basic chemical products including refineries
- pharmaceuticals
- paints, varnishes, lacquers
- soaps, cleaners and beauty preparations (2).

4.1.2 Fertilizers and Pesticides

This subsector comprises the manufacture of straight, mixed, compound and complex nitrogeous, phosphate and potash fertilizers, the formulation and preparation of ready-to-use pesticides, insecticides, fungicides and herbicides and of concentrates of these products. Included are sulphuric, phosphoric and nitric acid plants operated in conjunction with fertilizer plants.

During 1977/1978, pesticides constituted 28% and fertilizers 72% of the production of the pesticides and fertilizers subsector. The agricultural demand for fertilizers and pesticides constituted 83% of the total domestic demand for the products of this subsector. The growth in the total domestic demand for fertilizers and pesticides is therefore dependent mainly on the demand of the agricultural sector, especially the field crop and horticulture subsectors. Growth rates were relatively low in the 1960's, but considerably higher growth rates were achieved during 1970's. This growth during the 1970's may be attributed first to the establishment of an export market for fertilizers and pesticides and, secondly, to the more intensive use of fertilizers and pesticides in the agriculture sector. In the future, however, the expected more rapid rise in the price of fertilisers in relation to those of other production inputs (excluding fuel) and also in relation to the price of the end product may lead to an eventual decline(2) in the demand for fertilizers. The demand for pesticides, and specifically herbicides, is expected to be improved by the fuel situation. The chemical control of weeds will probably be more advantageous in the future than mechanical control because of the fuel crisis and high fuel prices.

Total production of the fertilizers and pesticides subsector is expected to increase at about the same rate as the rate of production growth in the agriculture sector.

4.1.3 Plastic Raw Materials and Man-made Fibres

This subsector comprises the manufacture of synthetic resins, plastic materials and non-vulcanisable elastomers in the form of moulded and extruded products, solid and liquid resins, sheets, rods, tubes, granules and powders, the production of cellulosic and other man-made fibres, except glass, in the form of monofilament, multifilament, staple or tow suitable for further processing by textile machines, and the production of vulcanisable elastomers (synthetic rubber).

The most important products of this subsector are polyvinyl chloride (PVC), low-density polyethelene (LDPE), high-density polyethylene (HDPE), polypropylene (PP) and polystyrene (PS). The artificial fibres subsector also makes an important contribution to production, namely, one fifth of the total value of production of this subsector. Vulcanisable elastomers, however, make only a small contribution to the subsector's total production. Polypropylene is the newest of the group and has most potential for growth at this stage. Considerable investment in HDPE and LDPE plants is taking place at present. Sasol I, II and III will be able to supply South Africa's total ethylene requirements for a number of years which will considerably improve the raw material supply position for the manufacture of HDPE and LDPE. Coalplex is expected to be able to satisfy South Africa's total PVC requirements

for the foreseeable future. Polystyrene production is being expanded in the near future to provide for the growing demand on the local market. Capacity in the man-made fibre subsector is also expected to be expanded greatly. It is considered that production will increase at a relatively high rate because of various import replacement projects and the increase in exports envisaged in this subsector, however, the replacement of plastic products by cheaper substitutes (e.g. steel pipes) should be considered a possibility, especially in view of the fact that plastic materials may become considerably more expensive in future.

4.1.4 Basic Chemical Products

This subsector comprises the manufacture of organic and inorganic industrial chemicals such as cyclic intermediates and crudes, dyes, organic pigments, non-cyclic organic chemicals, solvents, polyhydric alcohols, rubber processing chemicals, synthetic and natural tanning materials, gum and wood chemicals, esters of polyhydric alcohols, urea and fatty and other acids, inorganic acids, alkalis, inorganic pigments, hydrogen peroxide, carbon bisulphide, phosphorous, magnesium carbonate, bromine, iodine, and industrial gas in compressed, liquefied and solid form, sodium nitrate, potassium nitrate and dry ice (solid carbon dioxide). The manufacture of chemical materials for atomic fission and fusion and the products of these processes are also included.

The petroleum refinery subsector and the miscellaneous products of petroleum and coal subsector are also included in the basic industrial chemicals subsector. Petroleum refineries include the production of petrol (motor fuel),

fuel oils, illuminating oils, lubricating oils and greases as well as other products of crude petroleum or coal or their fractionation products. Miscellaneous products of petroleum and coal are used in the manufacture of asphalt paving and roofing materials, fuel briquettes and packaged fuel (from purchased coal or lignite) and compounded and blended lubricating oils and greases (from purchased materials other than crude petroleum).

Figure 4.1 illustrates some of the major products that may be fabricated from oil or coal. Via distillation, cracking and reforming in the case of oil, and gasification or hydrogenation in the case of coal, a wide range of fuel and chemical products may be produced. Various fuels are produced, namely, the many grades of gasoline and diesel, and in the case of coal, methanol. This methanol may in turn be converted to gasoline and chemical products via the MOBIL process, or it may be used directly as a fuel extender or as a pure fuel for a methanol engine.

As described in Section 4.1.8, fuel production (oil refining and coal conversion) is handled as part of the energy supply system in this model: co-production of chemical products such as ethylene and ammonia must, however, be considered. In this thesis, basic chemical products produced by the fuels industry supply part of the final demand for basic chemical products. In addition, the basic chemical products subsector produces the same and also other chemicals to satisfy total final demand for the subsector. An example is provided by ammonia, produced separately by the chemicals industry as well as

by the coal to fuel conversion process. In the fuel conversion process ammonia may be manufactured directly or recovered from the flue gases. In developing future demand scenarios, care must be taken to determine how final demand for these commonly produced products is met. This is discussed in Section 4.3.

The large variety of products from this subsector, and the degree of interaction between products generates a level of complexity that is unsuitable for establishing major energy flows. Some major products such as ammonia and ethylene are identified and described below, in addition, a host of other important chemicals such as carbide, chlorine and caustic soda is manufactured. As these products cannot be defined separately, for this study they are grouped into one sector - Basic Chemical Production.

4.1.4.1 Ammonia

Ammonia may be manufactured from methane in a number of separate reaction stages (3): methane is converted to carbon monoxide and hydrogen in a reformer stage, the carbon monoxide is used to generate additional hydrogen from water in a conversion stage, carbon dioxide is removed, and the final synthesis stage produces ammonia from nitrogen and hydrogen at 450°C and 250 bar. In South Africa, the bulk of ammonia production is from coal. In this case an air separator produces oxygen and nitrogen. The oxygen is used by coal gasifiers to produce a suitable gas consisting mainly of carbon monoxide (54%), hydrogen (28%), carbon dioxide (11%) and water (6%). Traces of hydrogen sulphide, methane and argon are also present (4). Sulphur and carbon dioxide are removed, and ammonia is synthesised at high pressure from the hydrogen and nitrogen streams.

Unit energy consumption depends largely on the feedstock used. In the case of natural gas, this is 35 to 45 MJ/Kg, while for coal it is in the region of 80MJ/kg (5).

4.1.4.2 Ethylene

The major manufacturer of ethylene in South Africa is Sasol. In the Sasol II installation, methane formed in the coal gasification process is concentrated in the tailgas of the synthol reactors. After recovery of condensible hydrocarbons, this gas is routed to a low temperature separation plant for separation into methane, C₂, C₃ and C₄ streams. The mixed ethylene/ethane (C₂) stream is directed to an ethane cracker for conversion to ethylene:

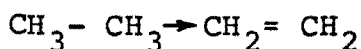


Table 4.2 illustrates the product selectivities obtained for the commercial Sasol synthol operation where the objective is to increase the volume of light olefins (6). In the Sasol process it is possible to reform the methane and full C₂ fraction into synthesis gas for recycling back to the synthol reactors. Additional motor fuels are produced; however, an unavoidable thermal loss results in a total product value of about 85% of the original value. Certain trade-offs between chemicals and fuels are therefore possible, further complicating the energy flows within the chemicals industry.

Owing to the wide range of chemicals manufactured, it is virtually impossible to assign specific energy values to each product. Synthesis of the ethylene monomer requires from 53 to 76 MJ/kg when based on naphtha. Polyethylene, ultimately produced from ethylene, requires from 7,3 to

19MJ/kg depending on the feedstock and density of the product (feedstock energy excluded) (7).

4.1.5 Pharmaceuticals

This subsector comprises the manufacture, fabrication and processing of drugs and medicines, including biological products such as bacterial and virus vaccines, serums and plasmas, medicinal chemicals and botanical products such as antibiotics, quinine, strychnine, sulpha drugs, opium derivatives, adrenalin, caffeine, codeine derivatives, vitamins and pharmaceutical preparations for human or veterinary use.

At present South Africa is heavily dependent on other countries with respect to the raw materials needed for modern medicines. Only about 13% of the active ingredients are produced locally and the largest proportion of the raw materials needed to produce them also has to be imported. It will, however, be very difficult for South Africa to achieve import replacement in respect of a wide variety of medicinal and pharmaceutical preparations since the South African market is too small for large-scale production and because of the problems resulting from the fact that patent rights are held by the large, multi-national companies.

Physical volume of production is expected to grow slowly during the next 10 to 15 years. This is a result of the difficulty in forecasting new developments in the field of medical research, and also because of the extended time required to place a product on the market because of strict control exercised over new products by the authorities. Research and development is

expensive, and this limits the marketing of new products and restricts it mainly to the large, financially powerful, multi-national companies. Moreover, expansion in this subsector takes place stepwise. Expected increased in real Black buying power together with a greater acceptance among Blacks of Western medications, however, will generate sufficient demand to result in steady growth in production.

4.1.6 Soaps, Cleaners and Beauty Preparations

This subsector comprises the manufacture of soap in any form, synthetic detergents, shampoos and shaving products, cleansers, washing and scouring powders and similar cleaning preparations, candles, crude and refined glycerine from vegetable and animal oils and fats, natural and synthetic perfumes, cosmetics, lotions, hairdressings, toothpaste and other toilet preparations.

The total domestic demand for the products of this subsector derives mainly from private consumption. With the expected increase in the real per capita income of the non-White sector, a higher standard of living and the acceptance of Western-type toilet preparations, an increasing demand can be anticipated.

Exports constitute an unimportant part of the total supply of the subsector and are not expected to increase significantly. Most exports go to neighbouring states and an increase in exports will be closely related to political and economic conditions there.

4.1.7 Paints, Varnishes, Lacquers and Others

This subsector comprises the manufacture of paints, varnishes, stains and shellac, lacquers, enamels and japans. It includes the manufacture of allied products such as composite thinners, paint removers, paint brush cleaners, putty and other caulking and filling materials. Also included is the manufacture of furniture, metal and other polishes, waxes and dressings, disinfectants and deodorants, wetting agents, emulsifiers and penetrants, explosives and ammunition, adhesives, glues, sizers and cements from vegetable, animal or synthetic plastic materials, ink and carbon black, incense and camphor products, essential oils, blueing and laundry sours, boiler and heat insulating compounds, water-proofing compounds, metal, oil and water treating compounds, prepared photo-chemical materials and sensitized film, paper and cloth.

Biggest demand for the products of this subsector derives from final demand and the rest from intermediate consumers. The government is the dominant final consumer of the production of the subsector and this component is expected to expand at a relatively high rate in the near future. The most important intermediate consumers are the mining (explosives), other fabricated metal products and construction (paint, varnish, etc.) sectors. The consumption of other chemical products by the gold and uranium sectors is expected to increase only marginally as a result of stagnation and later decline in gold production.

The value of explosives as an energy input to the gold mining industry is illustrated in Chapter 5, Figure 5.1.

The actual value is relatively small and can be expected to decline with increasing use of thermal and mechanical rock breaking techniques.

4.1.8 Summary

Table 4.1 illustrates the coal and electricity input to the six subsectors described above, as well as output from the sector for 1977 (actual) and 1987 (forecast) (8). 1977 Producer prices have been used, so that transport and intermediate profit margins are excluded. The figures thus represent volumes. Sectors such as Plastics and Synthetic Resins, Fertilizers, Pharmaceuticals, and Soap and Cleaning Components are minor in terms of direct energy requirements. They do, however, use the output of Basic Chemical Products as a feedstock. This feedstock represents the original energy carrier in such a highly modified form that it in fact may no longer be considered an energy carrier.

There is little value then in determining the detailed energy flows for these subsectors in the form of an energy flow diagram. They may preferably be used as final demand industries to determine the future output and characteristics of the Basic Chemical Products subsector. The significant subsector, from an overall energy flow point of view, is Basic Chemical Products, which includes petroleum refineries and coal conversion.

Coal conversion and oil refining processes constitute the largest segment of the Basic Chemical Products subsector.

In this model these energy conversion industries are part of the energy supply system and are not part of final demand. They are thus included in the input/output system described in Chapter 2. A major output of this coal conversion process is however basic chemical products such as ethylene and ammonia. It is therefore essential to establish energy flows within this subsector so that the proportional production of liquid fuels and of chemical products can be measured. An energy flow diagram for the coal conversion process has been developed and is illustrated in Figure 4.2. Similarly, Figure 4.3 illustrates the general energy flows within the Basic Chemicals Production subsector (described in Section 4.1.9). The remaining subsectors are relatively minor in terms of energy flows and will not be treated separately. For this thesis, they will be considered as part of general energy demand.

A further complicating factor in the chemicals industry is the confidentiality of data. Fierce competition exists for products as well as new processes, and consequently much of the needed data is effectively unobtainable. For general energy planning purposes, however, details of individual product manufacture and outputs are not required. The greatest level of detail required is on the national production level, and it was found that such overall figures were more readily available.

In order to develop energy flows, the fuel-from-coal aspect was evaluated in order to determine the energy flows for fuels and chemicals respectively, and then an aggregate energy flow for the remaining Basic Chemicals subsector was compiled, including the chemicals

generated by the fuels process. This procedure must be handled carefully, since it is only possible within certain limits to modify the output of one part of Basic Chemicals without affecting the other part. Thus fuels output cannot be changed significantly without having an effect on chemicals production.

Nevertheless, this split is essential since the larger part of Basic Chemicals is the production of liquid fuels, i.e. energy conversion, used as a final demand carrier by almost every sector of the economy.

4.1.9 Energy Flow Diagrams

As described above, two energy flow diagrams have been compiled, one for the coal conversion process and the other for the remaining Basic Chemicals Products as a whole.

4.1.9.1 Coal Conversion

Figure 4.2 illustrates the generalized energy flows within the coal conversion process (9) (10). Per ton of fuel oil product, 106 000 MJ of coal and 6 850 MJ of electricity is required. Using an overall coal to electricity conversion efficiency of 0,244 and coal heat content of 20 MJ/kg for the relatively low grade coal used by Sasol, this translates into * tons coal per ton of fuel oil products. Chemical products are, however, included. Total output per ton of final product is

* MJ fuel oil products and * MJ chemical products
(based on heat values).

This flow diagram is used to tailor the coefficients of the energy supply input/output matrix, as described in Chapter 2.

4.1.9.2 Chemicals Production

Because of the need to protect details of processes and the manufacture of products, the entire basic chemicals production, including output of the coal conversion process is illustrated in Figure 4.3. Full output of the coal conversion process is assumed, resulting in a production of 3 M ton basic chemicals. Inputs per ton of final product are as follows :

Coal	44 400 MJ	
Petroleum	* MJ	
Electricity	2 800 MJ	
Gas	2 967 MJ	
Coke	200 MJ	(11)

(Details of individual energy inputs cannot be listed since this is confidential information.)

This diagram may be used to determine future energy demand given output of the chemicals industry. Caution must be exercised since the future product mix of this subsector may not be the same as today, and also, the processes used to manufacture the products shown may be different. These factors will influence the relationship between output volume and energy input. Assumptions must be made either for each product (and potential future product) or for the subsector as a whole.

For purposes of this study, a linear relationship is assumed, except for the effects of conservation, described in Section 4.2.3.

Compared to other estimates, oil demand appears somewhat low. Harrison (12) has estimated that the liquid fuels demand of the chemicals industry accounts for 55% of total industrial usage for liquid fuel products. However, the effect of a new ammonia plant increasing coal consumption by a factor of 2,5; and Coalplex increasing it by 15% again is noted. In addition, the effects of Sasol II and III must be considered. Also, only the Basic Chemical subsector is considered in this flow diagram. Other subsectors of the chemicals industry will account for additional petroleum product consumption. Further, the coal sector is boosted and the electricity sector diminished because of the large amount of "own" power generation by Sasol II and III.

4.2 Alternative Technology in the Chemicals Industry

4.2.1 General

The chemicals industry is one of the more dynamic industries with regard to new products, new processes and other innovation. A wide variety of materials is used as input to produce an even wider variety of output products. As economic conditions and new processes make these products competitive, they rapidly find markets.

As opposed to the bulk of chemicals production in the world, South Africa's chemical industry is effectively based on coal, particularly the major coal to fuel

conversion processes Sasol II and Sasol III. It can be expected that future chemicals production in South Africa will be dominated by the chemicals output of these conversion plants. Nevertheless, the output of these plants provides considerable scope for a multitude of final products. It is beyond the scope of this study to examine all possibilities. In the following sections, products of major relevance to South Africa and overall conservation effects are described.

4.2.2 New Chemical Products - Methanol

Of the available chemical products, the most significant is methanol, because of its use as a fuel for transportation. Modifications are required to a combustion engine if it is to be used with a methanol/petroleum blend or with pure methanol. Nevertheless, methanol represents a viable alternative to the Sasol process for producing transportation fuels.

Methanol can be made from coal, gas, municipal waste and wood. The yield of methanol from coal is approximately 2,5 - 3,5 tons coal per ton of methanol (2,5 - 3,0 barrels of methanol/ton coal @ 20MJ/kg) (13).

Several methods may be used to produce methanol. The ICI low pressure methanol plant produces approximately 1 100 tons of methanol per day over a copper based catalyst using $3,39 \times 10^4$ MJ low pressure exhaust steam per ton methanol (14).

The Sasol process may also be used; a different catalyst leads to the production of methanol rather than a range

of hydrocarbons. In the case of methanol production, the refinery and associated equipment is not required, reducing capital costs.

Because of lower capital costs, higher efficiency of conversion and higher efficiency of end use, methanol has been suggested as an alternative to petroleum-based fuels. The University of Cape Town has calculated that taking the entire conversion and end use processes into account, the methanol route uses 70% of the coal of the Sasol route for the same vehicle kilometres (15). Coupled with the fact that it can be produced from offshore gas, methanol must be seen as an alternative fuel capable of conserving the coal resources of South Africa. Since transport fuels are part of the energy supply system in this model, a sector for methanol has been defined so that the overall effect of various contributions can be tested, as described in Chapter 2.

Other chemical products are also of interest, for example, hydrogen. Given an adequate distribution network, many applications now using electricity may be converted to hydrogen (16). This is, however, a longer term prospect; beyond the range of this study.

4.2.3 Energy Conservation Possibilities

Within the chemical production plant, energy savings may be attained by technological improvement of the production process. A study of the US chemical industry (17) identified the production of organic chemicals and synthetic organic fibres as areas of major potential savings. A total possible saving for the whole industry of 15,6% was calculated. Unit energy consumption depends upon the

feedstock used, the production method and scale, and the purity and concentration of the final product.

In general, techniques such as heat recovery and heat generation from wastes may be adopted to reduce energy consumption. Heat recovery may be effected by waste heat boilers, heat exchangers and gas-to-gas exchangers for preheating feed gases or combustion air. Heat generation from waste is attractive because the volume of some liquid and solid wastes can be reduced at the same time as conserving valuable mineral and organic resources. It was estimated in the US that 800 million tons of organic wastes per year may yield $250 \times 10^9 \text{ m}^3$ methane (18).

In general, a wide variety of techniques may be used to reduce energy carrier demand:

- improved control using computer systems
- improved furnace efficiencies
- increased distillation plant efficiency with additional stages
- upgrading heat using heat pumps
- use of low grade waste heat for space heating
- optimization of hydraulics to reduce pump horsepower
- insulation
- recovery of mechanical energy from process steam

- minimizing venting of exhaust steam
- better organization of processes and coordination of management.

These techniques are applicable to a greater or lesser degree to any specific process, and their overall effect can only be evaluated if each product is studied separately. Based on the overseas experience described above, a potential energy conservation saving of 10% is assumed for South Africa. This must be balanced against changes in processes and products that are likely to have a far greater effect on overall energy consumption.

4.3 Final Demand for Chemical Products

4.3.1 Domestic Demand

Because of the innovative nature of the chemicals industry and the rapidly changing economic situation, it is virtually impossible to forecast future chemical products. New markets are being found for existing products, and new products are constantly being developed to replace glass, steel and paper components. In certain areas, the converse is also true; rising chemical feedstock prices have resulted in the chemical product becoming uncompetitive. For purposes of this study, an initial approach is to project the existing chemicals industry according to anticipated future demand for end products. It is then assumed that the chemicals industry remains more or less constant in its overall pattern of energy demand, i.e. that new products in total have the same overall energy requirements as the present mix.

Final demand for Basic Chemical Products is relatively evenly distributed over a wide range of end users, including construction, motor manufacture, general industry and the Basic Chemicals subsector itself (as illustrated in Table 4.3. Over the next ten years (19) the highest growth rate anticipated is for plastic materials and synthetic resins, at 7,9% per annum. The lowest is for fertilizers and pesticides at 3,8% per annum. Overall, Basic Chemical Products is expected to grow at 6,7% per annum. Exports of Basic Chemical Products is relatively low, at 3,7% per annum, however, exports of the other subsectors are higher, suggesting that higher value products are being favoured for export. Total demand for the chemicals sector is expected to grow at 4,7% per annum.

Factors influencing these values will be the development of new products that find rapid acceptance (increase values) and rising feedstock prices that will make products uncompetitive (decrease values). Overall, an increase greater than the GDP can be expected, since plastic components can be expected to be used extensively in the replacement market - in consumer products for ease of manufacture, and in the automotive industry for mass saving, leading to fuel conservation.

Since substitution and replacement cannot continue indefinitely, a rate of growth equal to the GDP must be taken for the period 1990 - 2005. This must be considered a "best estimate" given available information. The advent of hitherto unknown products could affect this significantly. On the other hand, the need for foodstuffs, cleaning and building materials will effectively set a

lower limit equal to the growth in GDP of consuming countries.

Of the other chemical products, methanol is important to South Africa as a fuel for transportation. In this model it is considered to be part of the energy supply sector and methanol options are therefore treated as part of energy supply, as described in Chapter 2.

4.3.2 Export Demand

With regard to exports, the same considerations apply as for domestic demand, namely the uncertainty surrounding new products and processes. As illustrated in Table 4.3, exports in 1977 amounted to R493M out of a total supply of R4 677M (including imports of R832M). This is relatively small; also, the growth rates of exports are roughly similar (overall) to domestic growth rates. This suggests that the export market be considered equivalent to the local market for planning purposes. Increasing petroleum prices for overseas countries could change this by making the South African coal-based product competitive on overseas markets with their oil-based product. This would boost exports significantly. Extensive adoption of nuclear energy would, in contrast, release coal in overseas countries for chemical production, eliminating this advantage.

4.4 Description of Likely/High/Low Cases

Based on the above considerations, the following factors will influence future demand for energy by the chemicals industry:

- economic growth
- replacement of non-chemical products with chemical derived products
- advent of new products and processes
- price of chemical products vs competitors
- product mix of the chemical industry
- conservation
- export market.

Conservation, as described in Section 4.2, should yield a possible 10% savings in energy input, and the general assumption has been that the product mix of the basic chemicals industry changes in such a way as to leave the overall per unit energy carrier requirement unaltered. This leaves exports, economic factors and potential new products as the prime determinant of future energy demand.

As a likely case the 6,7% growth rate of the output of chemical products as described in Section 4.3 will be assumed up to 1990 followed by a growth rate equal to the longterm GDP growth rate of 4,5%. This figure includes the possibility of moderately increasing exports of chemical products. In addition, energy conservation measures resulting in an overall saving of 10% by 1990 will be included.

The high case will assume no additional conservation measures and a growth rate of 7,9% (highest anticipated) up to 1990. Thereafter a growth rate of 6,5% is used.

The low case will assume conservation measures as for the likely case; growth of chemical output of 3,8% (lowest anticipated) up to 1990, followed by a growth rate of 3% (up to 2005).

The effect of new products is assumed to be included in these figures. The adoption of totally revolutionary products that would dramatically affect chemicals production is by implication not anticipated.

The resulting energy demand patterns for the cases defined above are listed in Tables 4.4, 4.5 and 4.6. Since the energy flow diagram includes chemicals production from Sasol II, it is thus representative of the basic chemicals industry in 1981/2. An overall reduction of 10 per cent is therefore assumed for 1980. Remaining aspects of the chemicals industry are taken as part of general demand.

These three cases constitute the final demand scenarios for the chemicals industry, to be used in the integrating model.

5 THE MINING SECTOR

5.1 Description of the Mining Industry

5.1.1 Introduction

The mining industry in South Africa is one of the major sectors of the economy and also one of the bigger users of energy. In 1978, the mining industry utilized 28,6% of the electric energy and 10% of the fossil fuels consumed in South Africa (1). In 1978, gold production amounted to R3,9 billion, and coal production R874 million (2). In addition, the sector includes the recovery and beneficiation of a variety of other metal ores and minerals, the most important being copper, diamonds, platinum, iron, asbestos, manganese, limestone, vanadium, chromium, phosphates and building stones.

Based on size of the subsector, importance to the supply of energy in South Africa, and the strategic value of the product, the gold/uranium and coal mining industries are of paramount importance. Several of the other mining subsectors such as aluminium are relatively energy intensive. However, their overall energy demand is small compared with the major subsectors. These other mining activities will be considered part of the general energy demand pattern in this model. The gold/uranium and coal sectors are evaluated in more detail below.

5.1.2 Gold

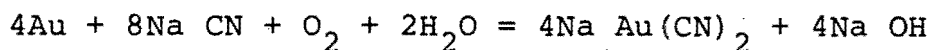
Gold in South Africa is generally obtained from quartz veins and in deposits derived from these veins by natural processes of weathering. These quartz deposits

occur at depths of hundreds to thousands of metres, as found in the Witwatersrand and Orange Free State occurrences of the Dominion Reef.

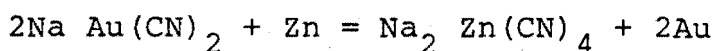
The first step in gold mining therefore involves the recovery of gold-containing ore from these deposits. Compressed air drilling equipment and explosives are used to break up the rock face, and the resulting fragments are hoisted to the surface for processing. Several alternative rock-breaking systems have been proposed, owing to the general inefficiency of the intermittent drilling/explosives cycle. These include heat systems using microwaves, lasers or high temperature gases. Rock cutting machines are also under investigation. These systems, if they prove effective, can be expected to change the energy utilization profile of the gold mining industry.

The broken rock is then hoisted to the surface by electrically driven hoists. In order to reduce the volume of rock lifted to the surface, some primary crushing and selection may occur at lower levels.

Gold is recovered from the ores by a cyanide process developed by Mac Arthur and Forrest in 1890. The two main reactions are:



and:



Zinc dust being used to precipitate the gold. Oxygen is important in this reaction, since gold will not dissolve in cyanide solution devoid of oxygen. Certain minerals, notably the sulphides of copper, iron,

antimony and arsenic are frequently present in the ore and enter the solution, depriving the gold of both oxygen and cyanide thereby leading to poor extraction. For these ores, flotation methods are used to concentrate the goldbearing ore. Because of electric charge differences, some of the mineral particles adhere to the air bubbles blown into the solution, while others adhere to the water. The froth is collected, heated and then passed on to the cyanide process.

Since gold occurs so sparsely in the ore and in such a fine state of subdivision, a high degree of milling and grinding must be achieved in order to expose it to the solvent action of the cyanide. This is achieved by rod and ball mills for primary milling and pebble mills for secondary milling. Alternative milling methods are always under consideration to improve overall efficiency. Vibratory and centrifugal mills have been considered because of their low capital cost and small size, which would permit underground installation. A certain amount of free gold is available after milling, and this may be extracted, prior to the cyanide process, by gravity concentration.

The remaining process comprises classification of the mill output by separating the fine material from the coarser particles, thickening of the pulp from the classifiers by dewatering, agitation and aeration of the solution made up to appropriate strength with cyanide, and final precipitation of the gold from the filtered output of the agitators. Lead nitrate is added to precipitate any soluble base-metal sulphides and also to form a zinc-lead couple for assisting precipitation. This precipitate is calcined to oxidize the zinc and then mixed with borax and sand, and melted

in a crucible. Zinc and other impurities form a slag and separate from the gold. Silver and base metals remaining in the gold are removed by subsequent processing at the Rand Refinery.

5.1.3 Uranium

Uranium resources in South Africa comprise ore deposits of the following basic types:

- Quartz-pebble conglomerate (Witwatersrand Supergroup and Dominion Reef)
- Sandstone (Beaufort Group)
- Carbonatites

As described by von Backström (3) important concentrations of uranium minerals occur in the gold-bearing conglomerates of four contiguous precambrian formations covering tens of thousands of square kilometres in the Transvaal and the Orange Free State. The Dominion Reef and Witwatersrand Supergroup are of most significance because of their relatively large uranium deposits. In the Witwatersrand Supergroup, conglomerate reefs selected for development have generally been those with the highest gold values.

Thus, in South Africa the bulk of uranium production arises as a by-product of the treatment of tailing residues left after gold is extracted by the cyanide plants. The uranium occurs as uranitite, at a concentration of 0,03 % U_3O_8 . Treatment of current production and the accumulation of past gold mining operations enables the ore to be economically processed. During the last few years certain mines have been producing uranium as a primary product and some projects have been developed to recover it from

old gold plant residues in slimes dams on the surface. The latest plant erected to reclaim uranium from slimes dams was recently constructed in the Klerksdorp area, and has a present reclamation rate of 135 000 tons per month. At present, 17 uranium producing facilities exist, and in 1979 production was 5637 tons of uranium oxide (4). The Nuclear Fuels Corporation collects ammonium diuranate slurry from the mines and calcines it to produce uranium oxide. Present capacity of 6 000 tons per annum is being significantly upgraded.

Uranium reserves in the 'reasonably assured' and 'estimated additional' categories recoverable at a cost of less than \$80/kgU (metal) total 331 000 tons, or 531 000 tons at less than \$130/kgU (5). As local consumption of nuclear fuel is likely to be small, South Africa is expected to maintain its position as one of the major suppliers of uranium to the Western World.

Uranium, in the form of a feedstock for nuclear electric power generators, is considered to be a part of the energy supply industry in this thesis. Energy flows associated with uranium production are therefore built into the input/output supply model and are not treated as part of final demand. Exports are, however, a significant portion of final demand for uranium, and are discussed separately in section 5.3.2 "Uranium Exports".

5.1.4 Coal

Coal deposits in South Africa occur primarily in the north-eastern region of the country. The most important coal region stretches over 300 kilometres from Witbank to Ladysmith, which contains 80 % of South

Africa's extractable reserves. Coal quality varies from low rank bituminous to anthracite or semi-anthracite, and has a relatively high ash content - only 30 % of mineable in-situ resources contain less than 25 % of ash. Coal sold on the open market, including that for power generation and liquefaction, averaged 24MJ/kg and that for export 27MJ/kg (6). Table 5.1 illustrates the characteristics of coal produced in South Africa (7). In 1979 126M tons of coal were mined, of which 22M tons were dumped as waste. Total sales were 98,2M tons including 23,3M tons for export; 94M tons were bituminous coal and 4,2M tons anthracite. There were 74 collieries in operation, of which 10 produced more than 3M tons each, and 22 less than 250 000 tons each(8). The largest was Kriel Colliery, which produced 8,3M tons for power generation, but a number of larger collieries are under development, including Bosjespruit Colliery, which is designed to produce 27M tons a year for liquefaction.

Bord-and-pillar mining has for a long time been the basic production method in this country. Because much of the reserves are relatively shallow, this method still accounts for 72 per cent of production, including three per cent using pillar extraction. Large scale opencast coal mining started in South Africa only in 1970, but last year 23M tons were produced in this way. The necessary heavy capital investment was made possible by the higher demand and increased prices over that period. The pressure in recent years to maximise recovery of reserves has also been a factor in the use of high recovery methods.

The degree of mechanisation in underground mining has also increased considerably. Less than eight per cent of coal mined is now hand-loaded, as compared to 63 per cent in 1970. Continuous miners, however, still produce less than 10 per cent of the amount mined, partly because of the abrasive nature of some of the South African coal. Longwall operations produced three per cent of the coal, from eight longwall faces, in 1979.

A number of new longwall operations have been announced, but the applicability of the method is limited in some fields by the shallowness or discontinuous nature of the seams. Recovery of coal from dumps, especially of anthracite, accounted for two per cent of production. Almost half the coal sold is used without washing, primarily because it is often used near the mine-head and the contained ash does not need to be transported more than a few kilometres, and also because the sulphur content of South African coal is generally low. The requirements of the commercial, metallurgical and export markets now, however, demand sophisticated washing procedures. The preparation plant at the Grooteegeluk mine in development for the Iron and Steel Corporation (IsCOR) will treat 3 000 tons of run-of-mine coal and shale per hour, which will place it among the largest in the world.

The capital cost of the 11 most recent large mines announced averages \$37 per annual ton in 1980 terms, for a total capacity of 94M tons a year. This average incorporates a range from \$20 per annual ton for a strip mine without washing to nearly \$60 for a deep longwall mine. The coal mining industry employs 120 000 people, and output per manshift averages 7,2 tons, compared to 2,2 tons in the UK and 17,9 tons in the United States (both in 1977) (9).

Two-thirds of the coal used in South Africa is burnt to generate electricity. The state Electricity Supply Commission (ESCOM) generates nearly 90 per cent of the country's electricity, with a number of municipal power stations, also mainly coal-based, generating the balance. Ninety-five per cent of the electricity generated is coal-based, the rest being mainly from hydroelectricity and gas turbines.

Reserves of coal are not expected to be a constraint up to about 2020, except for specific types of coal. The last official estimates published in 1975 (10) estimated economically extractable reserves to be 25 000 million tons. This estimate assumed certain limits regarding the percentage of coal that may be extracted, the minimum thickness of a coal seam for it to be a viable mining proposition and the maximum ash content of coal supplied to the end user. Developments since that time show that the estimate should be revised. New reserves have been discovered, and the Chamber of Mines expects that developments in mining technology will allow the recovery of 60 per cent of the in-situ reserves. Recoverable coal reserves may thus increase to 60 000M tons. Improvements in utilisation would also increase reserves, for example, fluidised bed boilers may allow the use of coal with an ash content of more than 35 per cent, the limit for the Petrick reserve assessment. A detailed re-assessment of reserves by the Department of Mineral and Energy Affairs (1981) suggests a value of 51 000M ton (1).

Of particular concern is the availability of coking coal. In 1979, nearly seven million tons of coking coal were used, primarily for Iscor. New sources of prime coking coal are needed to maintain supplies in future as Natal reserves become depleted, and large scale expansion of the steel industry will depend on the use of new coking or reduction technology.

It is one of the prime objects of this thesis to highlight coal utilization patterns given various possible supply and demand scenarios.

Coal mining, to produce feedstock for the chemicals industry, liquefaction, or fuel for electricity generation, is considered to be a part of the energy supply industry in this thesis. Energy flows associated with coal production are therefore built into the input/output supply model and are not reckoned as part of final demand. Exports are, however, a significant portion of final demand for coal and are discussed separately in section 5.3.3, "Coal Exports".

5.1.5 Energy Flow Diagrams

5.1.5.1 Gold/Uranium Diagram

The energy flow diagram for the Gold/Uranium industry is illustrated in Figure 5.1. Major processes have been aggregated into Hoisting, Ventilation/Refrigeration, Compressed Air, Pumping, Crushing, Milling, Extraction and Refining (11). It is felt that further detail would not provide any significant improvement with regard to the analysis of major energy flows.

Total output in 1979 was 703,5 tons fine gold and 5637 tons U_3O_8 .

Hoisting, Ventilation/Refrigeration, Compressors, Pumping and Reduction consume 13 %, 18 %, 20 %, 14 % and 23 % of the total kWh used, respectively (12). Milling alone is estimated to consume approximately 27 MJ/ton and the remaining energy for reduction is assumed to be split evenly between crushing and extraction. Uranium extraction accounts for approximately 13 % of the energy supplied to reduction (13). A

comparatively small amount of energy is used in the final refining process - 133 MJ per kg gold refined in 1979 (14).

Steam is generated for gold and uranium extraction, accounting for approximately one third of the direct coal requirement (15). Other uses of energy carriers include transportation, heating, lighting and cooking as well as non-energy uses such as lubrication. Almost all of the petroleum requirement is consumed by these activities as well as 12 % of the electricity used, and two thirds of the coal. Energy in the form of explosives is relatively small - 887 MJ (coal equivalent) per kg gold (16).

Direct energy requirements per kg gold are 15493 MJ (0,65 ton) coal, 84425 MJ (23 451 kWh) electricity and 2985 MJ (81 litre) petroleum products, for a specific net energy requirement of 102903 MJ/kg.

Total coal requirements, including that required for electricity generation, are then 362425 MJ (15,1 ton coal equivalent) per kg.

Energy used for uranium extraction is included.

5.1.5.2 Coal Diagram

Since washing and other methods of grade separation are not considered in this model, a simplified energy flow diagram is possible for the coal mining industry. For 1979 production of $89,1 \times 10^6$ tons (Chamber of Mines members), $1,32 \times 10^9$ kWh of electricity, $0,037 \times 10^6$ tons of coal and $43,5 \times 10^6$ litre petroleum products were used. Total coal production was $103,8 \times 10^6$ t, excluding dumping of unsuitable products. This yields the Energy Flow Diagram illustrated in Figure 5.2 and the following energy requirements:

Specific Net Energy - 89 MJ/ton

Specific Gross Energy - 256,1 MJ/ton

The specific net energy requirement falls into the range of 61 - 89 MJ/ton suggested by Bennett (17), however, the gross energy requirement is higher. This is accounted for by the factor of 0,244 for overall electricity system efficiency used, as opposed to 0,29 by Bennett. Also, the energy value of lubricating oils and greases is included, since these are derived from energy carriers.

These figures are used in the supply system model to define energy flows within the coal industry.

5.2 Alternative Technology in Mining

5.2.1 General

Mining activities, as large users of energy, offer many opportunities for energy-saving new technology.

Refrigeration, hoisting and ventilation systems may all be optimized, and newer methods may be applied to other processes to improve overall efficiency. Perhaps more than in any other industry, safety and environmental considerations are critical and will influence any decisions to implement new technology. The following sections describe some of the more important factors associated with gold and coal mining.

5.2.2 Changes in Gold Mining

The continuing programme to improve the underground mining environment through better ventilation practices and the use of refrigeration can be expected to

increase the consumption of electrical energy. Also, the long-term mechanization of underground mining will increase the consumption of electrical energy which will be further boosted by the need to cool the machinery. In 1980, of a total industry power demand of 1 800 MW, 605 MW was accounted for by environmental control (18), suggesting a rapid increase in power for Ventilation/ Refrigeration. Pumping power is not expected to increase as mining depth increases, since the water to be pumped originates from the higher levels, but hoisting power will increase at a rate faster than the increase in the depth of mining (19). A big change in overall power requirements may result from improved strata control to decrease the tonnage of rock to be hoisted and treated in the reduction works, since reduction and hoisting account for almost 36 % of the total energy consumed. More selective mining could possibly reduce the tonnage of rock to be hoisted and treated by up to 25 %. The industry expects little change in expected energy consumption per ton treated in the reduction works, even taking into account newer gold recovery processes such as adsorption onto activated charcoal. One of the more important innovations being considered is the replacement of explosive ore extraction techniques by rock cutting equipment. This would substitute chemical energy in the explosives by electrical energy to drive the impact breaker cutting equipment (20). For the mines, a chief concern underlying any decision to change mining methods is safety.

Because of the conflicting effects of improved mining methods and improved mining environment, it is felt that the specific energy requirement of the gold mining industry (per ton production) will not change significantly. In any event, the effect of uncertainty of future

production overwhelms the likely results of a change in specific energy requirement, in contrast to the Iron and Steel Industry where possible new technology has a significant impact on energy demand. These technological factors will therefore not be considered when developing the scenarios in section 5.4.

5.2.3 Coal Extraction

The most important technological change in the coal mining industry involves the mining method used to extract coal. The most commonly used method is bord and pillar mining, where coal is extracted by driving a grid of roads into the seam leaving the roof supported by the coal which is left in the form of pillars between the roads. This primary recovery may be followed by subsequent operations in which all or some of the coal left in the pillars is mined. Recovery of coal depends on economic and geological circumstance and may lie between 30 % and 80 % of the coal in an undivided seam and between 10 % and 50 % of the coal in a property in which multiple seams occur.

Longwall coal mining methods are used to mine coal from continuous faces. The method is not well suited to shallow depths where systematic cave-in of the roof is difficult to control, and also not for situations where the mining height exceeds three metres since safe support at the face then becomes too costly. Where conditions for this type of mining are suitable, recovery of 70 % or more of the coal in a seam or series of seams can be achieved. This is significantly higher than for bord and pillar methods, but it is clear that safety and economic considerations prevent universal application of this method. It is also important to note that longwall mining requires more

capital investment than bord and pillar mining. If improved extraction rates are postulated assuming increased use of the longwall method, they must be accompanied by increased capital investment.

Opencast or strip mining involves trenching down from the surface through the overburden of rock and soil to expose the coal which is then mined separately. The economic attractiveness of this method decreases as the depth of the seam and the ratio of overburden to coal thickness increases. The higher this ratio the more highly specialized machines that are required and the higher the working cost per ton of coal recovered. Price control in South Africa has restricted opencast mining to depths of about 50 metres and to locations where the overburden ratio does not exceed 4 to 1 (21).

These technological changes will alter the energy consumed by coal mines; more importantly, they will alter the capital required and the value of extractable reserves. Their main effect therefore will be reflected in the capital costs for coal mining built into the energy supply input/output model.

Other advanced possibilities for coal mining include the underground gasification of coal (22). This would make exploitation of otherwise inaccessible coal possible. More research would be required before the possibilities could be evaluated in this model.

5.3 Final Demand

5.3.1 Gold Exports

Almost the whole production of gold is exported. Domestic demand is negligible and derives mainly from demand for jewellery and dental applications.

Several factors must be taken into account when estimating the long term production trends for gold:

- Quantities and grades of ores available
- Production costs
- Labour availability
- Price

Over the next ten years, the expected production trend for gold shows a decline of approximately 0,54 % per annum since restricting factors such as the limited deposits and production costs appear to cancel factors such as new mines and technological improvements.

Also, the sharp rises in the gold price during 1978/79 are not expected to have a fundamental effect on the pattern of production, but might postpone the expected decline in production trend (23). Figure 5.3

illustrates the expected physical volume of production of gold up to 1987.

The price of gold, coupled with production costs, determines the size of reserves, the grade of ore mined and consequently the quantity of ore required to recover a specific quantity of gold. To estimate future ore requirements would require assumptions for all the factors described above. In addition, a certain amount of future gold production can be expected to come from old mine dumps; also, certain gold mines will attempt to reduce production costs by increasing ore production to achieve economies of scale. These numerous opposing factors will influence the ore requirements per ton of gold in both an increasing and a decreasing direction. As a base case it is proposed to assume an ore grade decline equivalent to the decline in gold production, resulting in an almost constant quantity of ore being mined. To test overall sensitivity in terms of energy demand, a range of

values can be assumed, however, this must be coupled with the effects of technological advance on extraction processes. For the period beyond 1987, little evidence is available to suggest any change in the above general trends. Major political problems are probably the biggest factor in determining future production, and these cannot be postulated here. It is proposed, therefore, to continue the trends as above up to the year 2000. When running the model, increases or decreases in production may be attempted in order to determine the overall sensitivity of energy demand to these changes.

5.3.2 Uranium Exports

Uranium is used by the energy industry for electric power generation, and is handled as such by the energy supply input/output model. Here, only the remaining element of demand is discussed, namely exports. Since South Africa's nuclear energy requirements are likely to be relatively low, the uranium export market will in fact represent the major demand for the metal. Historical demand has been somewhat erratic, largely a function of overseas nuclear energy programmes (Fig. 5.4).

On an international scale, the demand for uranium will be closely related to the demand for electricity as well as the rate of commissioning of nuclear electric generating plant. Environmental and safety problems have led to cancellations and postponements in the nuclear programmes of most of the large Western economies, especially since the Three Mile Island incident. Since this is the only market for uranium, these delays can be expected to reduce demand for the metal in the short to medium term. Demand for coal can

be expected to increase proportionately. In the longer term, large-scale coal consumption can also be expected to lead to social and environmental problems, so that uranium demand can be expected to increase. An opposing factor is the advent of the breeder reactor which uses uranium more efficiently, again reducing pressure on demand for uranium.

The US outlook for nuclear energy has changed significantly over the last few years. Nuclear energy as a percentage of total generating capacity is expected to increase from the present 10 % to reach 18 % by 1988 (based on existing orders), and then remain constant at about 18 % up to the year 2000. (Down on earlier forecasts which saw the nuclear energy contribution growing to 25 % by the year 2000 (24)). This implies a growth rate up to 1988 of around 12 % per annum, and a long-term growth rate up to 2000 of 5 % per annum. The situation in other Western countries is similar, so that a growth rate for uranium exports of 10 % up to 1990 and then a lower growth rate of 5 % up to 2000 will be assumed as a possible case for uranium exports. Since it can be shown that this export rate will nearly exhaust existing reserves in South Africa, this will be taken as a high case.

The following factors would increase this figure:

- improved acceptance of nuclear power
- improved economic conditions, world-wide
- recognition of the fact that solar and biomass are not effective substitutes
- increasing prices of fossil fuels

- environmental problems associated with fossil fuels

The following factors would decrease this figure:

- competition from other suppliers, i.e. Australia
- declining economic conditions
- social and political problems associated with radwaste disposal
- improved technology, i.e. the breeder reactor.

The above figures may be compared with the projection of world nuclear power installations made by the World Energy Conference (25). Growth of 12 % from 1975 to 2000 and 6 % from 2000 to 2020 is anticipated.

These factors may be combined to develop high and low scenarios, as described in Section 5.4.

5.3.3 Coal Exports

As a commodity of final demand, coal is used by the various sectors of industry, transport and households. These are discussed separately in their respective sections and are treated by the model as part of final demand. Here, only the last remaining element of demand is discussed, namely exports.

Owing to the foreign exchange and profits that may be obtained, the export of coal has become one of the fastest growing sectors of the industry. Revenue from coal export sales rose from R103 million in 1976 to R509 million in 1979 placing it in the top five earners in foreign exchange. Coal export figures for the years 1976 to 1979 are illustrated in Table 5.2 (26).

At present, a system of export allocations is applied to limit the volume of coal exported. This allocation of 44 million tons per annum can be expected to be taken up on completion of the coal handling and railage facilities at Richards Bay during 1986. The immediate scenario, therefore, is one of coal exports rising from their 1979 value of 23 million tons to reach 44 million tons in 1986, and from then on constant at 44 million tons per annum. Delays in the nuclear programmes of western countries as well as the uncertainties associated with oil have increased international demand for coal significantly, and it is certain that South Africa could export larger quantities. The general feeling obtained from discussions with the coal mining industry is that an additional 200 million tons per annum could be exported. Limiting factors such as the actual international demand for coal, the availability of suitable transport and handling facilities, local demand and the size of local reserves will influence this figure.

The World Coal Study (27) has defined two scenarios for future coal demand. One scenario considers a moderate increase in coal demand up to the year 2000, while the other assumes a high increase in coal demand to a level that would now appear to be the feasible upper limit. Based on these scenarios, exports from South Africa are assumed to lie between 55 million tons and 105 million tons per annum in the year 2000. The figure of 105 million tons is in fact the "Importer Preference" (28) while 100 million tons is suggested as the "Exporter Potential" or capability. Based on this study, then, the local industry total figure of 250 million appears overly optimistic.

Coal exports from South Africa will therefore be assumed to lie between 55 million tons (low) and 105 million tons (high) in the year 2000. Factors such as the actual value of local reserves and possible improvements in extraction will of course play a big role in determining the final figure. Total coal requirements as determined by this model for each scenario will assist this decision.

5.4 Description of Likely/High/Low Cases

From the above description of technology and future demand for the output of the mining sector, scenarios may be developed to represent the likely, high and low possibilities for the future.

- Gold

The general trend for gold appears to be declining production, at approximately - 0,54 % per annum using the data supplied by the Office of the Prime Minister (29) and at approximately - 12 % per annum using the Gaussian distribution determined by Bennett (30). Depending upon the relationship between the gold price and gold mining costs, the quantity of ore milled per ton of gold produced can vary significantly. As described, increasing prices tend to increase the quantity of ore milled, but new technology, such as underground separation to reduce hoisting volume, and also more selective mining, reduce the quantity of ore milled. To include the effect of all factors, the following cases are proposed:

A likely case with gold production declining at - 0,54 % per annum and ore milled constant at 1980 levels.

A high case with gold production declining at - 0,54 % per annum and ore milling increasing at 5 % per annum.

A low case of gold production decreasing at - 12 % per annum and ore milling decreasing at 3 % per annum (31).

Resulting gold production, ore milling and energy requirements are listed in Tables 5.3, 5.4 and 5.5.

- Uranium

Nuclear electric generation growth as outlined in section 5.3.2 would result in a demand for uranium increase of 10 % per annum up to 1990 and 5 % per annum thereafter. If South Africa is to follow this pattern in its exports of uranium, it would imply cumulative usage of about 350 000 tons by the year 2000, practically exhausting reserves (unless the price increases significantly, which is unlikely owing to other sources of uranium). This case is consequently taken as the high case. A low case of 2 % growth per annum is assumed, and this implies a relatively small increase in worldwide nuclear electricity generation, or South Africa's participation in such growth. As a likely case, and intermediate value of 5 % growth per annum is assumed. The resulting uranium export figures for 1980, 1985, 1990, 1995 and 2000 are listed in Table 5.6.

Energy requirement for the uranium industry are automatically included by the energy supply input/output model.

- Coal

In the case of coal, exports are being considered here and these are 23,3 M ton at the time of writing and are

scheduled to reach 44 M ton by 1986. The high case assumed is 105 M ton by the year 2000, a growth of 6,4 % per annum from 1986. The low case assumes exports of 55 M ton per annum by 2000, providing a growth rate of 1,6 %. An intermediate value of 85 M ton for 2000 may be assumed as a likely case, this requiring a growth rate of 4,8 % per annum. Coal exports for the three cases are listed in Table 5.7. Depending on the outcome of these cases, it might be valuable to test export cases as high as 200 M ton, since this figure has been mentioned as a possibility for coal exports in the year 2000.

Energy requirements for the coal industry are automatically included by the energy supply input/output model.

These cases constitute the final demand scenarios, to be used in the integrating model.

6.1 Description of the Pulp and Paper Industry

6.1.1 Introduction.

The production of pulp and paper is an energy intensive process which accounts for approximately 2,5% (1) of total final demand for energy in South Africa.

The basic raw material for paper is wood, prepared by removing the bark from logs, cutting the logs into small pieces and then cooking these pieces with sodium or ammonia based liquors. This chemical pulping process dissolves the lignin in the wood, allowing the fibres to separate. Paper is subsequently prepared from the pulp by a paper-machine.

Several pulp manufacturing processes are used in South Africa, the most common being the "sulphate" or "kraft" process described below.

6.1.2 The Sulphate Process.

In the sulphate digestion process, the wood chips are cooked in a strongly alkaline liquid. Spent cooking liquor is evaporated and burned, fresh cooking liquor being recovered from the chemicals recovered during combustion. Chemical losses are made up by adding

sodium sulphate.

The energy system in a sulphate pulp mill is illustrated in Figure 6.1. Heating requirements of the plant are supplied by generating high pressure steam in boilers. Wood waste and bark may be burned, as well as oil and coal. Spent liquor burned in the recovery boiler results in the simultaneous recovery of chemicals. The high pressure steam produced is also used to generate electricity.

Controlling the production of sulphate pulp is relatively complex. The process is frequently subject to disturbances and other abnormal operating conditions which have a strong influence on the efficiency of energy utilization.

6.1.3 Other Processes.

Other than chemical processes, mechanical methods may also be used to prepare pulp. The groundwood pulp method is extensively used to produce papers for short service. It is manufactured by pressing a log against a high speed grindstone. After the pulping process, the fibres, mixed with water, are passed to the paper machine.

6.1.4 Paper Manufacture.

Paper manufacture is a continuous process starting with mechanical beating of the pulp in order to separate and cut short the fibres. Various chemicals may be added to

reduce transparency of the paper (clay), or reduce porosity (size). Subsequent processes include mechanical water removal, steam drying and final calendering to impart a gloss to the paper. Finishing processes such as waxing and cutting are performed depending upon the final use of the paper product.

Several grades of paper are produced :

- Newsprint and Mechanical Printings; used for newspapers and magazines.
- Woodfree Printings; used for stationery and books.
- Kraft and Packaging; used for corrugated board and other packaging material.
- Tissue; used for tissue, wrapping and cigarette papers.
- Special; comprising carbon, gummed and other special papers.

Paper may be manufactured by integrated mills which manufacture pulp and paper, and paper mills which purchase pulp to produce paper. Large quantities of steam are needed, generated primarily by coal-fired boilers (inland) and oil-fired boilers on the coast.

6.1.5 Energy Flow Diagram.

The specific energy consumption of the Pulp and Paper

Industry has been assessed at 14,6 MJ/kg for paper production and 14,7 MJ/kg for the manufacture of pulp alone (2), yielding a specific energy consumption of 29,3 MJ/kg for pulp and paper production. Based on a survey of the pulp and paper industry (3), a breakdown of energy carrier utilization was established, as listed in Table 6.1. These figures were based on 90% of paper production and 50% of pulp production in 1974. Changes since that date in the relative quantities of pulp and paper manufactured would alter this figure; for purposes of this study, however, these percentages will be used, specifically since the Pulp and Paper industry is seen to account for only 2 to 3% of total energy final demand. Refinements in the breakdown of energy carrier utilization within the industry cannot therefore be expected to significantly improve the overall forecast. Based on the described electricity generation (4) within the industry, it is possible to estimate direct steam and electricity requirements.

Paper production in 1974 is given as 915 615 tons (5), and output of the sector has grown by approximately 5,8% p.a. during the period 1973-1980 (6) suggesting an output of 1 284 200 tons in 1980.

These figures are used to determine the energy carrier input values in Table 6.1, and the energy flow diagram illustrated in Figure 6.2.

6.2 Alternative Technology

6.2.1 General.

The method used to make paper has remained basically the same for a long time, and it does not appear that major changes will occur in the foreseeable future. This is largely because of the fact that the pulp and paper industry is highly geared to mass production; and it is therefore difficult to develop new procedures because of the reluctance to run a production line at less than optimum capacity during experimental trials. As a result, it was found in an overseas survey (7) that although multiple procedures could be identified that would offer substantial savings in energy, because these would involve considerable capital expenditure more attention is usually given to short-term good-housekeeping conservation measures such as steam and water recovery and recycling. Energy savings resulting from various measures undertaken ranged between 0,1% and 20%. Drying and general conservation appear to offer the best scope for energy savings.

6.2.2 Paper Drying Techniques.

The most energy intensive process in the manufacture of paper is drying, to reduce the water content to about 7%. This is usually done by evaporating the water from the paper as it passes over drums which are internally heated by steam. Several other drying techniques have

been proposed :

- Infra-red heating.

Gas-fired infra-red heating elements are installed to cover the width of the paper machine, to create rapid evaporation of water from the web. A disadvantage of this system is a result of the wide range of wavelengths produced by the infra-red elements, and the comparatively narrow part of the spectrum which is absorbed by water. The radiation produced is consequently not used very efficiently.

- Radio frequency and microwave heating.

This method of heating can take the heat directly to where it is required, without transfer losses. Also, no excess heating is used once the required dryness has been achieved (8).

In addition, alternative non-wet manufacturing methods are possible; for example the use of heat pumps for pulp drying, and electrostatic laying of dry fibres. These are long-term developments, requiring considerable funding for development.

6.2.3 Energy Conservation Possibilities.

Many techniques have been implemented by the paper industry in overseas countries, resulting in the 0,1% to 20% saving described above.

- Computer control for maximizing boiler operating efficiency.
- Insulation and leak prevention.
- Replacement of inefficient motors.
- Installation of mechanical water extractors.
- Waste heat recovery from boiler flue gases.
- Condensate recycling.
- Use of waste paper as a raw material to replace pulpwood.

Pulp and paper mills are complex so that efficient energy utilization requires detailed co-ordination and supervision of both energy production and consumption aspects. Using existing techniques, it is both difficult and laborious to ascertain whether a plant, process, steam system or other entity is actually functioning satisfactorily. Monitoring systems are needed for the continuous supervision of energy utilization, preferably aided by a computer. The monitoring system provides information on deviations from the desired condition, thus enabling appropriate corrective action to be taken quickly. A project conducted by the Swedish Forest Products Research Laboratory (9) uses a computer system to measure the energy flows in the steam network, turbine generated electricity, boiler fuel consumption and condensate return system conditions. The system detects typical faults such as :

- poor co-ordination of turbine operation, resulting in electric power losses.

- loss of steam in pipelines and valves.
- heat exchange leakage.
- increased steam consumption caused by faults in the process or method of operation.

In this project, a conservative estimate of the potential savings has been made on the basis of historical reports and interviews with personnel responsible for energy matters in this plant. Reduced losses and higher energy utilization efficiency are expected to yield a saving of 20 GWh/year consisting mainly of oil (2000 m³/year). This should be typical of the order of savings resulting from this type of programme. On a national scale, the saving would be of the order of 400 GWh/year. Separate monitoring of energy-intensive process unit is also considered essential. For example an essential complement to whole-system monitoring is supervision of the recovery boiler. This has suggested that carbon monoxide sensors can provide the basis for controlling both energy usage and pollution. This sensor has resulted in a savings of 300m³ (oil) in this particular plant, per annum.

6.3 Final Demand

Final demand for pulp and paper products is generated by establishments using paper and paperboard as main raw materials in the manufacture of paper bags, cardboard boxes and other paper containers, and also by the ultimate production of stationery, paper towels and cards and other

finished paper products.

The expected annual growth rates during the 1980's of raw pulp and paper, paper containers, and finished paper products is given as 5,8%, 4,8% and 5,1% respectively (10). These relatively high growth rates are caused by a world-wide rapid increase in demand for paper products owing to rising standards of living, increases in literacy and the substitution of paper for other materials.

Printing and publishing and the wholesale and retail trade are in fact the chief factors in final demand for paper products. Despite the availability of television and radio, the demand for printed material continues to show a high growth rate; also, the need for packaging materials is directly related to the output of the wholesale and retail trade, with the possibility of substitution by plastic products. Rising prices of plastic products, influenced by the exhaustible nature of their fossil feedstocks, can, however, be expected to boost demand for the paper product.

Based on the nature of final demand it would appear feasible to assume final demand growth rates for the pulp and paper industry of 5,8% and 4,8% as a maximum and minimum respectively. Exports are not expected to influence these figures (11).

6.4 Description of Likely/High/Low Cases.

From the above description, it is apparent that the following factors can be expected to influence the trend in energy consumption by the Pulp and Paper industry :

- type of product produced; specifically the increasing emphasis on production of high quality goods.
- future demand for paper products in the face of competition from plastic products.
- environmental considerations leading to increased use of energy for water and gaseous effluent treatment (12).
- general conservation measures leading to increased recycling and utilization of wastes.
- improved process control systems leading to improved overall efficiency.
- substitution of energy carriers, specifically conversion of oil-fired to coal-fired boilers.

Since very little is known about the overall effectiveness of the newer processes described in section 6.2.2, only general conservation procedures will be considered for the proposed scenarios. These, as has been described, can result in an overall saving of up to 20%. Some energy conservation measures have already been implemented in South Africa so that a further 10% reduction up to 1990 is proposed for the likely case. This is coupled with the

growth of output described in section 6.3 of 5,8%.

For the high case, a maximum growth of demand for paper products of 5,8% is assumed. No further conservation measures are included.

The low case assumes low growth in demand for paper products (4,8%), and conservation measures as for the likely case.

Resulting energy carrier demand values are listed in Tables 6.2, 6.3 and 6.4, and will be used as the final demand scenarios by the integrating model.

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7. THE CEMENT INDUSTRY

7.1 Description of the Cement Industry

7.1.1 Introduction

Portland cement is produced by burning, usually in a rotary kiln, an accurately proportioned, finely ground mixture of limestone, silica, alumina and iron oxide. Kiln discharge, in the shape of rough spheres, is a fused mixture of calcium silicates and aluminates termed clinker, which is mixed with gypsum (calcium sulphate), 4 to 5% by weight, and ground to a fine powder to form portland cement. By close control of the raw mix, of burning conditions and of the use of additives in the clinker grinding procedure, finished cements displaying various properties can be produced.

The name 'Portland' was coined because of the similarity of the hardened portland cement to a popular building stone quarried near Portland, England (1).

After mixing and proportioning of raw materials, a wet or dry method may be used for cement production.

- Wet Process

In the wet process, raw materials are ground with water

and the slurry is further mixed and blended before being fed to a rotary kiln system. This method is used where the clay component is very wet.

- Dry Process

In the dry process, the raw materials are dried to about 1% moisture content and are ground before being introduced to the kiln in dry powder form. This process offers lower fuel costs, because of the saving in heat energy required to evaporate the water, but the wet process claims a more uniform clinker because of the superior blending made possible in the slurry state. Better blending techniques applied to dry mixes and pneumatic handling of fine powder have, however, reduced this advantage of the wet process.

The kilns are fired with petroleum, natural gas or pulverized coal, depending on costs, availability and convenience. The control of the amount of fuel and the amount of air entering to support combustion, regardless of the fuel used, together with the amount of proportioned raw material fed to the kiln and the rate at which it passes through the kiln regulate the temperature of the fused material (clinker). The production of high-quality clinker requires accurate adjustment of these variables.

Energy requirements (total) for the wet and dry processes are listed in Table 7.1 (2). As shown, a figure of 4,53 MJ/kg for the wet process, and 3,04 MJ/kg for the dry

process is obtainable. This must be compared to the figures of 7,6 MJ/kg and 3,6 MJ/kg obtained by Bennett, respectively (3).

In total, the cement industry is a major user of energy in South Africa, accounting for 18% and 3% of the industrial demand for coal and electricity, respectively (4) in 1973.

7.1.2 Cement Production in South Africa

In 1979, the Cement Industry operated 32 kilns capable of manufacturing 8,9 million tons of cement per annum. Fifteen of the available kilns are of the older "wet" type (capacity 1,9 Mt p.a.) the rest being the more efficient dry kilns (capacity 7,0 Mt p.a.) (5). Also in 1979, 6 Mt cement was sold, a 4,5% increase over 1978, and highlighting the economic upswing that followed the decline from 1974 when just under 7 Mt was sold. Slack capacity is therefore somewhat greater than the 15% considered necessary to keep the market fully supplied and cater for an average growth rate of 5% p.a. Considering that several wet kilns have been shut down because of the overcapacity, and may not be used again, actual operating capacity may lie in the vicinity of 8,5 Mt, so that dry kilns accounted for 82% of cement production in 1979.

Types of cement produced in South Africa are listed in Table 7.2. As illustrated, ordinary portland cement predominates, at 87% of the market for cement in 1979. The various types of cement have the following characteristics:

- ordinary portland
this is "average" with respect to heat of hydration and sulphate resistance.
- rapid hardening
this cement provides high strength properties at early stages ; up to half its ultimate strength in one day.
- blast furnace
blast furnace slag is used in the manufacture of slow-setting, low-strength cement.
- sulphate resistant
developed for concrete structures where severe reaction from alkaline sulphate soils exists.
- PC 15
a 15% slag content cement, with properties similar to ordinary cement. The slag component results in less energy for manufacture since it saves the energy used in burning the limestone.

7.1.3 Energy Flow Diagram

In 1980, the industry used 1,293 Mt coal and $0,801 \times 10^9$ kWh to manufacture 7,42 Mt cement (6).

Converted to MJ/kg, this results in the following specific energy values :

coal energy : 4,18 MJ/kg
electric energy : 0,39 MJ/kg

These figures have been used in the energy flow diagram illustrated in Fig. 7.1.

The specific energy requirement has been described above (Section 7.1.1). Based on the proportion of dry and wet kilns, from 7,6 MJ/kg down to 3,6 MJ/kg is required, wet kilns needing additional energy to evaporate the water. Since over 80% of cement is being produced by dry kilns, a lower specific energy is applicable.

7.2 Alternative Technology in the Cement Industry

New technology in the cement industry may apply to the manufacture of the cement, the development of new types of cement as well as new applications for cement and cement products. These new cement-making processes can be expected to lead to less expensive products as well as products with improved characteristics. Both of these factors can be expected to increase the market for cement. In the following sections, cement production processes,

modernization techniques and new cement products are described.

7.2.1 Cement Production Processes

In South Africa, the switch to dry kilns is expected to continue up to the year 2000 (7). By the year 2000, it is possible that new techniques will be available for even more efficient cement production, leading to obsolescence of the dry kiln system. Little information could, however, be obtained on totally new systems, so that dominance of the dry kiln will be assumed for the horizon of this model. Other countries are characterized by predominant use of the wet process ; 70% of the kilns are of the wet type in the U.K., for example (8).

Most development is consequently expected to be replacement of the wet process by the dry process.

7.2.2 Modernization

Technological changes as well as wear and tear may cause a plant to become uneconomic ; modernization then becomes necessary to improve productivity and efficiency. In the cement industry, this modernization is usually confined to machinery units and plant layout, to make room for larger and more efficient units. In the US and Western Europe, some old wet-process long kilns have been converted

to short dry-process kilns. Significant increases in production (50% to 70%) as well as greatly improved fuel efficiency have been reported (9). Since the South African cement industry utilizes the dry kiln extensively, these modifications are not relevant.

7.2.3 New Cement Products

Cement has traditionally been used as a convenient glueing agent and as a cheap bulk filler material : in general, for outside structural uses. There is now increasing interest in inorganic materials that can be produced cheaply to compete with and even replace other common materials which are more costly in economic or ecological terms. Table 7.3 lists the energy cost of production of some materials, per unit volume, relative to cement (10). As shown, cement is the cheapest, some 5 times cheaper than polystyrene and 35 times cheaper than aluminium. Clearly, cement does not possess specific characteristics of the other materials, but with improvements in tensile strength and fracture energy, a wide variety of new applications will become possible.

Some new cement products are already available :

- Glass Reinforced Cement

This material is a composite of between 5% and 6% by mass

of glass fibre mixed into a cement/sand mortar, to form a section 3 to 12mm thick. This fibre reinforced mortar is used to surface bond dry stacked blocks providing a strong wall, and giving substantial labour saving over the standard method of wall construction. Extensive application in low-cost housing schemes and in mines can be expected (11).

- High Alumina Cement

High alumina cement (HAC) has some special properties which result from the fact that it is a calcium aluminate based material with different hydration mechanisms than those of portland cements based on calcium silicates. Aluminous cements when mixed with appropriate aggregate produce concrete which is resistant to high temperature, chemical attack, abrasion, corrosion and thermal shock. When mixed with portland cement, HAC sets very quickly. Because of its properties, HAC has found several applications :

- overnight repair of airport runways
- rapid mould turn-around precast sections
- roof rock bolting in mines
- pipelines for corrosive products

The long-term strength of this cement is, however, only modest, and it is not recommended for load bearing structures (12).

Depending upon their long-term characteristics, these new compounds may generate totally new markets for cement products, significantly boosting the industry. Within the programming period of this model, however, it will be assumed that cement fulfils its traditional role ; the effects of expanded application of cement, in terms of national energy utilization, will require a major study of the new materials compared with the old materials that are replaced.

7.2.4 Energy Conservation Possibilities

Given the present dry-kiln technology, several techniques may be employed to reduce energy requirements :

- increase inside surface area of kiln
- increase feed-end diameter of kiln
- recover heat from exhaust gases of kiln
- increase size of the kiln
- utilize blast furnace slag and power station fly-ash, to replace limestone

Based on these possibilities, the Department of Planning (13) has suggested a possible efficiency increase of 10% over the period 1980 to 2000: coupled with total replacement of wet-type kilns, this results in a final specific energy consumption of 3,3 MJ/kg (72% of the 1980 value). This figure (28% saving) will be used in the development of the

Likely/High/Low scenarios.

7.3 Final Demand

Final demand for energy by the cement industry can be expected to be closely related to demand for cement by the various subsectors of the building construction industry :

- domestic housing
- shops and offices
- civil engineering

7.3.1 Domestic Housing

With regard to domestic housing, the recent (1979) low phase in the business cycle has revealed the extent to which this subsector is tied to the activity level of the rest of the economy. For instance, there has been a sustained decline in demand, continuing for almost three years, for both residential and non-residential buildings, followed by an increase during 1980 (14). A moderate increase in the demand for domestic buildings is expected over the medium to longer terms. The introduction of the 99 year leasehold system for Blacks, enabling them to acquire property rights outside the Black homelands can also be expected to stimulate the house building industry.

7.3.2 Shops and Offices

Shop and office space is considered to be in reasonable supply and renewed demand for this type of building will depend largely on the pace of general economic development.

7.3.3 Civil Engineering

Civil Engineering and construction involves the establishment of an economic infrastructure of roads, dams, rail links, pipelines, airports and harbours. During the 1960's and 1970's many large-scale projects were initiated, but with the exception of a few large projects that still offer opportunities for expansion, most projects can be considered complete (15). Examples here are Iscor (Newcastle), Richards Bay and Sishen-Saldanha. Certain projects are in process, such as Sasol II and III and Koeberg power station. New projects would include the doubling of the Richards Bay railway line to accommodate additional coal exports, new rail shunting yards, coal conversion projects and extensions to Iscor. These expansions are not considered to be as extensive as the original project. No dramatic increase in demand for civil construction work is expected over the next 10 years : demand is expected to remain fairly stable because of continuous expansion work and maintenance. Over the longer period, the possibility of South Africa becoming a major exporter of coal, exporting up to 100 Mt p.a. as well as other minerals, must be considered. Also, the construction of local facilities to beneficiate ores

prior to export will increasingly boost the civil engineering subsector.

7.3.4 Total Final Demand

Overall, the building construction sector is expected to grow at a rate of 3,7% p.a. up to 1987, down from 8,0% p.a. for the period 1963 - 1977 (figure 7.2). Building construction is expected to show the highest rate at 4,5% p.a. and civil engineering and other construction the lowest, at 2,6% p.a. (16).

The Cement Industry itself expects a sales growth rate of 4,2% p.a. for the period 1979 - 1985, and a long-term growth rate of 3,5% (17).

7.4 Description of Likely/High/Low Cases

Based on the above description of growth rates and alternative technology the following factors apply to the cement industry :

- likely long term growth rate : 3,5%
- high/low rates probably 4,5% and 2,6%
- no new processes anticipated that will radically alter cement production
- overall conservation and the elimination of wet-type kilns could reduce energy consumption to 3,3 MJ/kg by 2000, a 28%

reduction from 1980

- no radically new markets for cement products anticipated in the programming period

The following scenarios are thus proposed :

- Likely case

Growth rate of cement production at 3,5% p.a., coupled with a conservation programme to generate a specific energy value of 72% of its 1980 value by 2005.

- High case

Growth rate of cement production of 4,5% p.a. No conservation measures.

- Low case

Growth rate of cement production of 2,6% coupled with a conservation programme as for the likely case.

Final energy demand figures for the cement industry for these three scenarios are listed in Tables 7.4, 7.5 and 7.6.

These three cases constitute the final demand scenarios as supplied to the energy supply integrating model.

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8. THE TRANSPORT SECTOR

8.1 Description of the Transport Sector

8.1.1 Introduction

The transport sector is a major consumer of energy in South Africa, accounting for 29,5% of final demand for energy in 1974 (1).

In addition, the transport sector is heavily dependent on oil as an energy carrier. Table 8.1 illustrates the percentage oil used for transportation in some countries, highlighting the fact that from 20% to 55% of oil demand may be attributed to the needs of transportation (2).

Over the last two decades in the UK, for example, two-thirds of all energy-use increases have been caused by transportation activities; one half of the total increase has been a result of private travel alone (3).

Transport in South Africa may be split into the following subsectors :

- road
- rail
- air
- harbours
- pipelines

Pipelines in South Africa are used for fluid transportation over long distances, specifically between Durban and the Transvaal. In common with harbour activities, relatively small quantities of energy are used by pipelines, and these two subsectors will consequently be omitted from this study.

In this chapter, the road, rail and air transport systems are discussed in terms of their present and projected energy demand characteristics. Finally, likely, high and low cases for energy demand are proposed, for use with the energy supply input/output (integrating) model.

Transportation in South Africa is affected by various laws. The inception of road transport in the 1920's lead to a position where the railways could not successfully compete with the more flexible road transportation, resulting in the Motor Carrier Transportation Act of 1930 to co-ordinate road and rail transport systems. In 1977 the Road Transport Act (No. 74 of 1977) was promulgated to generate a situation of freer competition. By providing for certain goods which may be transported within the Republic without any prior authority, this act is intended to serve as a blueprint for the gradual deregulation of transportation in South Africa. The railways can be expected to meet this challenge by improving its own road and rail services (4).

Owing to the clauses of the Petroleum Act (No 120 of 1977) which prohibit publication of information concerning the acquisition and disposition of petroleum products acquired or manufactured in South Africa, it is impossible to use real data in this chapter. As a result, previously published data is used together with published and expected trends to arrive at an estimate of present and future needs. This is considered adequate for planning purposes. Actual figures may be used in the model as required.

8.1.2 Road Transport

Road transport is the largest consumer of energy within the sector, comprising the following :

- Cars; light motor vehicles for private and business use.
- Commercial vehicles; light goods and heavy goods vehicles for transport of materials, products and equipment.
- Buses and minibuses; primarily public transport vehicles.
- Motor cycles; for private and business use.
- Tractors; for agricultural use.

In 1975, the biggest energy users in the transportation sector were petrol driven vehicles consisting mainly of passenger cars, which were responsible for approximately 48% of the total transportation energy requirement, or approximately 51% of useful transportation energy. Diesel vehicles (mostly trucks) were the second largest users, consuming approximately 18% of the total transportation energy (5).

As fuel utilization figures are confidential, it is necessary to estimate the demand figures to develop a basis for projecting future demand. This may be done by combining vehicle population figures with average

distance and fuel consumption values.

Table 8.2 illustrates the vehicle population for 1980 (estimated) (6); average consumption (7); average distance travelled per annum, and resulting demand for fuel.

A total demand of $\ast \times 10^6$ litres is thus estimated for 1980. Other fuels in road transportation, such as electricity, are negligible and are not considered in this study (electric vehicles are discussed in Section 8.2.2).

8.1.3 Rail Transport

In South Africa, the greatest proportion of long distance freight transport is handled by the railways. Typical examples are the Saldanha and Richard's Bay rail links for the bulk export of mineral ores and coal. Three modes of traction are used :

- steam
- electric
- diesel

Route distance in 1977 was 22 509 km, of which 5 079 km was electrified (8). Owing to its low efficiency and difficulty in use with long, multi-locomotive trains, there has been a significant swing away from steam traction,

in favour of diesel and electric. The recent increases in the price of petroleum fuels have, however, reduced this trend. The present policy is to electrify railway lines as rapidly as possible where it is economically justified. Steam locomotives are not expected to take the place of diesel locomotives on unelectrified sections, but the programme of phasing steam locomotives out of operation is expected to proceed more slowly in the future than was envisaged a few years ago (9).

The efficiencies of operation of the various types of traction have been calculated by the Department of Planning and the Environment, as follows :

steam	:	3%	
electric	:	60%	
diesel	:	30%	(10)

These figures include conversion efficiencies, the energy demand of auxiliaries, idling losses and operating duty cycle.

Since there are such significant differences in the efficiencies of the different tractive units, the mix of units in use at any time will have a major effect on the net energy used by the railways; with the actual demand for tractive energy playing a secondary role. Primary energy (gross energy) will be affected to a lesser degree, since the electric/steam traction substitution in effect

transfers the coal to electricity conversion losses to the electricity supply sector. As the electricity supply and consumption functions operate at a higher efficiency than the typical steam locomotive, some reduction in primary energy demand will occur.

Based on trends and published information, the demand for energy by the rail transport sector in 1983 may be estimated (11) (44) :

Coal	1,8 Mt
Electricity	$4,2 \times 10^9$ kWh
Petroleum	* Ml

8.1.4 Air Transport

Air transportation in South Africa is handled primarily by South African Airways, with a fleet of 36 aircraft; total cargo traffic was 60 604 tons and total passenger journeys were 3 225 124 in 1979 (12). Aircraft used comprise the Airbus A300, Boeing 727, 737, 707, 747B and 747SP and Hawker Siddeley 748, operating out of ten airports in South Africa.

Several smaller carriers operate lesser routes under licence to South African Airways. They will not be considered separately for purposes of this study of final demand.

Advances in aircraft technology, particularly airframe and engine design, have resulted in increased carrying capacity and reduced fuel consumption, so that in the decade preceding 1973, passenger kilometres increased by 325%, while aircraft kilometres and hours flown increased by only 130% and 53% respectively (13). These trends can be expected to continue, with new generations of aircraft being even more efficient and fuel consumption improvements of up to 50% possible up to the year 2000. In terms of fuel usage, this implies an increase in services of 50%, for zero additional fuel consumption.

Based on an extrapolation of published trends (14), it is estimated that 1980 consumption of energy by the air transportation sector amounted to $* \times 10^6$ litres of petroleum products.

Since energy demand for the three subsectors depends on different factors, namely vehicle population, ton-kilometres transported and passenger-kilometres flown, it was not considered viable to develop an energy flow diagram, as has been done for other final demand sectors.

8.2 Alternative Technology in Transportation

Much scope for alternative technology exists within the transport sector. This may be divided into the following:

- alternative fuels; being alternatives to the traditional petroleum-based fuels. The most important here are methanol, ethanol and Sasol products.
- alternative transport systems, such as underground rail systems and electric cars.
- conservation possibilities, such as mass reduction and computerized control.

8.2.1 Alternative Fuels

A range of alcohols and vegetable oils are currently under investigation as possible alternative transport fuels. In order to be viable as an alternative fuel, a number of criteria must be met with regard to cost against standard fuels, level and type of pollutants, safety factors, security of supply, available technology, ease of use and utilization of available resources.

Of prime importance to South Africa are the Sasol coal conversion process and the alcohols - ethanol and methanol. Vegetable oils may also be used as replacements for diesel fuel, but because of high production costs and the tendency of these fuels to gum, they will not be discussed

further.

Other fuels, such as hydrogen, may be used to propel vehicles and, in particular, aircraft. However, availability of technology to permit widespread application of this fuel in transport applications is considered to lie beyond the horizon of this model.

- Sasol

Fuels produced by the Fischer-Tropsch process used at Sasol have the major advantage of conforming to the specifications of conventional petroleum based fuels so that no modifications are needed to existing engines. The Sasol process is also well understood and is technically viable. As a result, Sasol fuel is widely available in South Africa, and considerable interest in the process has been shown by overseas countries.

Fuel produced by the Sasol process is consequently distributed together with other petroleum fuels. Production of the fuel is described in Chapter 4 (Chemicals Industry), and various contributions of the Sasol process to the overall demand for petroleum products are tested by the model as described in Chapter 10.

In terms of overall efficiency, the Fischer-Tropsch conversion of coal to liquid fuel is approximately 40% efficient (15). To this must be added a distribution loss of 2%, motor

vehicle transmission efficiency of 90% and engine efficiency of 15% (petrol; diesel is 30%). An overall energy efficiency of 8% results. The process may, however, be applied to low-grade, high-ash coals which are abundant in South Africa (16).

- Methanol

Methanol may be produced from coal, natural gas, wood or municipal wastes. Owing to the large reserves of coal in South Africa, the production of methanol from coal is of great interest. Methanol in this case is produced from synthesis gas in a route closely related to the Fischer-Tropsch process. As opposed to the spectrum of products yielded by the Fischer-Tropsch process, one product results from the methanol reaction :



As described by Dutkiewicz (17), the methanol route uses 70% of the coal of the Sasol route for the same vehicle kilometres.

In general, 2,5 - 3,5 tons of coal are required per ton of methanol, and capital costs of a methanol plant are estimated to lie between 65% and 85% of a Sasol plant. A methanol engine uses only 75% of the energy of a petrol engine, while the output of a given engine is 25% greater using methanol than when it uses petrol.

Methanol may be used directly in high compression, spark-ignition internal combustion engines, and it may also be blended with petrol. Since a diesel engine cannot accept large amounts of alcohol during starting, idling and low-load operation, a dual-fuel system is preferable for blending with diesel fuels.

Because of these factors, methanol is an attractive alternative fuel for motor vehicles. In this model, an independent energy supply sector has been generated for methanol, so that these fuel options can be tested separately. These are described in Chapter 10.

- Ethanol

Ethanol is made either by the synthesis of ethylene or by fermentation of vegetable matter such as sugar, maize, sorghum and cassava. Ethanol is therefore attractive because it is derived from a renewable resource. However, being a farming operation, it is labour intensive and also uses agricultural resources that could be adapted to food crops.

In Brazil a 20% ethanol-petrol blend is available in addition to 100% ethanol. Volkswagen(Brazil) estimate that 80% of its 1981 cars will have alcohol engines, while Ford is aiming for 60% (18).

It has been estimated (19) that one ton of maize will yield 465 litres of ethanol against 67 litres produced by one ton of sugar cane. Disadvantages of ethanol production are, however, its dependence on weather, and current high price.

8.2.2 Alternative Transport Systems

In 1976, the passenger bus population in South Africa was approximately 20 000 busses (20). Also, a study of the use of motor cars in urban areas of South Africa has revealed that the average distance travelled per day is 57,6 km for the first (only) car and 34,2 km for a second car (21). These figures suggest that alternative transport systems such as underground railways and electric vehicles must be considered when reviewing South Africa's long-term transportation needs.

- Underground Railways

Underground railways are attractive as mass transportation systems within urban areas because of their low level of noise and air pollution and because of their dependence on local energy resources; electricity from coal. Unfortunately, because of their high cost and the dispersed nature of urban development in South Africa, they have not been implemented locally.

Because of the long lead-times needed for construction of a major underground rail system, and the preliminary status of present proposals and investigations, the effect of such systems will not be tested by the model at this stage.

- Electric Vehicles

Electric vehicles are an attractive transport possibility because of their use of local energy resources (coal) and also their value in reducing pollution in urban areas. However, their high purchase price and inferior performance place them at a distinct disadvantage when compared to internal combustion engines. The very limited performance of storage batteries currently available is the greatest factor inhibiting the competitiveness of battery vehicles compared with internal combustion vehicles in terms of price, speed and range.

Battery energy density is thus a crucial factor for electric vehicles. With low densities, the battery accounts for over 50% of the gross vehicle mass; improving the energy density reduces the mass of the batteries as well as that of the unladen vehicle. At present, the best lead-acid traction batteries have an energy density of 140 MJ/ton, and this is expected to be improved to 180-200 MJ/ton over the next 10 years (22). Other battery systems offer substantially higher theoretical energy densities. The sodium/sulphur battery has achieved 250 MJ/ton and could possibly reach 550 MJ/ton with the life cycle and duty cycle requirements of a commercial traction battery.

A study of South African conditions has revealed that

although electric vehicles are suited to some present day applications (mainly in municipal transport and certain industrial requirements), only by the year 2000 will the development of electric vehicles have progressed far enough to enable it to fulfil the conditions set for motor vehicles currently in use (23;24).

Widespread introduction of electric vehicles, in terms of increased demand for electricity by the transport sector, will consequently not be tested by the model at this stage.

8.2.3 Additional Conservation Possibilities

Many possibilities exist for direct energy conservation within the transport sector. Better driving techniques and improved management of rail systems and transport fleets can result in significant savings; as described in many publications (25) (26). Basic techniques involve car pooling, route planning, suitable maintenance and the fitting of devices such as air deflectors to reduce drag (27).

Delays to traffic in urban areas (and consequent fuel wastage) caused by goods vehicles, have been investigated in Pretoria, with the recommendation that double-parking be eliminated by effective law enforcement (28).

Computerized vehicle scheduling can also lead to major savings. The object of scheduling is to generate the

"best" route pattern to satisfy the following :

- lowest marginal cost
- least distance
- least time
- smallest fleet
- fullest capacity of fleet

The latest computer software is capable of determining travel times between locations based on route characteristics supplied to the system, further improving the proposed schedule (29).

Fuels may also be used more efficiently in transportation through use of storage systems. In these systems, a small internal combustion engine is used to charge batteries or speed up a flywheel, which is then used to drive the vehicle. Through appropriate control systems, the internal combustion engine is made to run at its optimum operating point, thereby reducing pollution and improving efficiency.

Railway transportation systems may benefit considerably from advances in truck technology, for example lighter trucks and the cross-anchor radial bogie system that permits each axle to "steer" around curves, substantially reducing wear and friction. Reduced fuel consumption automatically follows from reduced mass and improved curving ability (30). The major inefficiency of most

rail systems is the 100% empty return haul for mineral carrying unit trains. Opportunities for a return load of any commodity are, unfortunately, slight.

Finally, the use of plastics to reduce the mass of a vehicle and thereby increase mileage must be mentioned. The change in materials usage from 1978 to 1987 for the average General Motors car has been estimated as follows :

Material	Mass 1978 kg	Mass 1987 kg	% Change	
Plastics	86	116	+35	
Aluminium	55	82	+49	
Steel	938	766	-18	
Iron	284	128	-55	
Rubber	45	37	-18	
Glass	43	36	-17	
Lead	10	10	0	
Zinc	8	4	-50	
Other	<u>120</u>	<u>95</u>	<u>-20</u>	
TOTAL	1589	1274	-20	(31)

Increased use of plastics will depend on the extent to which they can replace steel stampings for hoods, boot lids, doors, mudguards and other panels. Depending upon vehicle size and on the efficiency of motor and transmission, a 100kg saving may result in an improvement of up to 1 litre per 100km in fuel consumption.

Major substitution of steel by plastics is of importance to South Africa, since it will shift the emphasis of steel manufacture, chemicals (plastics) production and fuel consumption . While this model is capable of testing these substitutions in terms of overall energy resource utilization, it is felt that further study regarding local conditions is a prerequisite.

8.2.4 Conclusions

Based on the above description, it is apparent that many opportunities exist for energy substitution and energy saving within the transport sector. Unfortunately, in most cases, the technology is not fully developed and potential savings have not been adequately assessed.

Certain guidelines have, however, been established for the motor industry. Based on a combination of mass reduction, engine supercharging, electronic control systems, gearbox ratio optimization and improved engine design it is estimated that the potential for automobile fuel economy improvement in the U.S.A. lies between 25% and 60% for some 1980 models over the 1974 version (32).

(Such improvements are however not expected from the European and Japanese motor industries in view of their already smaller vehicles and engines). A 25% improvement in fuel economy is set down in the guideline for the U.S. automobile industry between 1980 and 1985.

These improvements will clearly also affect the

consumption figures for cars in South Africa; a quantitative assessment is, however, difficult given available information. For purposes of this study, a 20% improvement in consumption will be assumed over the model's horizon, i.e. up to the year 2005. This is possibly conservative and new figures may be tested as they become available.

With regard to rail transportation, no specific conservation figure is assumed since it is a relatively smaller user and also because the uncertainty underlying the replacement of steam and diesel traction is considered to play the major part in determining future demand.

The effect of new technology in demand for fuel by air transportation is included in section 8.3 - "Final Demand".

8.3 Final Demand

Final demand for transportation services (road, rail or air) are closely related to economic activities in general, as well as structural factors and restrictions placed on transport such as speed limits and increased fuel prices. In addition, interrelationships between the various modes of transport exist, so that reduced road traffic may be compensated by increased air and rail traffic, for example.

8.3.1 Road Subsector

During the 1970's, speed limits, restricted fuel selling hours and elevated fuel prices not only resulted in a decline in the use of motor vehicles, but also had a negative effect on the demand for new cars (33). An increase in the economic life of cars from 7 to 10 years was noted, as well as a swing to smaller and lighter cars. Another factor also expected to influence the demand for motor vehicles is market saturation. This applies specifically to the White section of the market, where a fair degree of saturation exists. Growth of the Black section of the market will depend largely on the relationship between increases in the price of new cars against increases in the income of Blacks.

The Economic Advisor (34) has determined a growth rate of 4% p.a. for passenger and commercial vehicles up to 1987, with commercial vehicles increasing at 4,4% p.a., and passenger vehicles at 3,8% p.a. Other studies (35) have suggested a growth rate for motor cars and light commercial vehicles of 5,1%, and 5,4% for heavy commercial vehicles, with an overall growth in vehicle population of 5,2% per annum.

Based on these studies, a value of 5,2% p.a. will be assumed for the high case, and 3,8% p.a. for the low case, with 4,5% p.a. used for the likely case. Projection of

each class of vehicle will not be attempted at this stage. These growth figures must be coupled with the conservation possibilities described in section 8.2.3 to yield the overall growth scenarios.

8.3.2 Rail Subsector

Final demand for rail transportation may be measured in terms of tons-kilometre moved. In 1980, the estimated value was 79×10^9 ton kilometre (36). Historically, a mean annual growth rate of 3% has been recorded; however, given the essentially smooth and uniform development of the economic growth points (with few new, major development areas) as well as the use of pipelines for fuel transportation, and the swing to air travel for passenger transportation, a growth rate of 2½% has been proposed (37). This figure is in effect the demand growth rate for tractive energy, to be met by a mix of steam, electric and diesel units. Various estimates have been made for the relative contribution of these three possibilities, influenced largely by current fuel price expectations. Thus a figure of 15,3% p.a. for the decline in steam traction has been suggested (39) as well as total elimination of the steam component by 1990 (39).

As described in section 8.1.3, the decline in steam traction is expected to be less rapid than in the past (4). For this study, a value of 7% p.a. will be assumed. The remaining tractive effort will then be provided by electric and diesel units. Since diesel implies a dependence on imported fuel,

large increases in diesel units cannot be expected. However, since the possibility exists of using locally produced methanol in a methanol locomotive, elimination of the diesel sector would also be unlikely. (In this model, diesel and methanol both supply the "Fuel products" supply sector). A growth rate of 1% is assumed, resulting in a growth rate of 3,88% for electric traction as illustrated in Table 8.3.

8.3.3 Air Subsector

The projected final demand for energy by the air transportation subsector cannot be simply derived by extrapolating the demand for passenger or ton kilometres. The rate of technological progress within the air industry is such that during the 15 years up to 1976, SAA handled a 10 fold increase in total traffic with essentially the same number of aircraft in the total fleet (41). Based on an analysis of future demand for air services, advances in aircraft design and improvements in aircraft operating procedure, a mean rate of increase of 2% p.a. in fuel demand has been calculated (42), up to the year 2000. In addition, the fact that SAA uses a growth rate (for fuel demand) of 5% p.a. up to the year 2000 is noted.

These two figures (2%, 5%) may be used to develop final demand scenarios for transportation fuels, as described in section 8.4.

8.4 Description of Likely/High/Low Cases

- Road

Final demand scenarios for energy in road transportation have been described in section 8.3.1. In addition, the effect of alternative technology has been described in section 8.2.3. The likely case is taken as a 4,5% p.a. growth rate (vehicles) combined with a 20% overall conservation value (fuel consumption) up to the year 2005. A similar conservation figure is used for the low case coupled with a 3,8% p.a. growth rate. The high case assumes a 5,2% p.a. growth rate and 10% overall energy conservation (fuel consumption) by the year 2005.

- Rail

The likely case for energy demand for rail transportation is described in section 8.3.2. Several assumptions are necessary for high and low cases. It is not considered significant to modify the steam decline rate since this will be influenced by many factors and also because steam does not provide a large component of tractive effort. High case will be taken to mean the high primary energy case which implies rapid electrification. A constant contribution at 1980 values is assumed for diesel traction, coupled with a 3% increase in annual ton-kilometres (43). For the low case, growth in ton-kilometres is taken as 2% p.a. while the diesel contribution is as for the likely case namely

a 1% p.a increase.

Growth of final energy demand is thus determined:

	electricity	diesel	coal
likely case:	3,88%	1%	-7%
high case :	4,90%	0%	-7%
low case :	3,14%	1%	-7%

(As illustrated in Tables 8.4 and 8.5).

Net energy requirements may then be recalculated for the year 2000 using the efficiencies for steam, diesel and electric traction :

likely case:	$69,82 \times 10^9 \text{ MJ}$
high case :	$72,15 \times 10^9 \text{ MJ}$
low case :	$65,53 \times 10^9 \text{ MJ}$

These trends are assumed to continue up to the year 2005.

- Air

The effects of new technology in air transportation have been included in the final demand assessment as described in section 8.3.3. For the likely, high and low cases, a fuel demand increase of 2%, 5% and 2% respectively will be assumed. The total final demand for energy by the transport sector based on the above assumptions is listed in Tables 8.6, 8.7 and 8.8; being the likely, high and low (combined) cases, respectively.

These three cases constitute the final demand scenarios for coal, electricity and petroleum, to be used in the integrating model.

9 THE DOMESTIC SECTOR

9.1 Description of the Domestic Sector

9.1.1 Introduction

The Domestic Sector in South Africa is a major consumer of energy, accounting for 11,3% of the total net final energy consumption in 1978 (1). All final energy carriers are used by the Domestic sector - electricity, coal, petroleum products, gas and coke, with coal the major carrier, at 58,4% of total net domestic energy consumption (2).

Largely because of the heterogenous structure of society in South Africa, there are large differences in energy usage patterns between urban and rural dwellers. According to the Department of Planning (3) 99,5% of the respondents in a 1978 survey utilized electricity, while only 72,9% of the rural population utilized this energy source, also while electricity accounted for about 67% of the total energy requirements of the urban population (excluding transport), it only accounted for about 7% of the input requirements of the rural sector, with diesel accounting for 44%. Oil accounted for only 1% of the urban energy requirements.

In contrast to the other sectors of the economy, there are no single large users in the domestic sector, but rather a multitude of small users. In addition, many factors

influence the demand pattern for energy in the domestic sector : population levels and growth rates, relative affluence levels and energy conservation techniques. In 1980, average White monthly earnings stood at R682, compared to average Black earnings of R167 (4). This difference in income, coupled with geographical factors (rural nature of the Black population) results in significantly different patterns of energy consumption.

9.1.2 White Households

White domestic energy demand is primarily for electricity. The biggest consumers of electricity within the White household are hot water heating (33%), refrigeration (28%), general heating (12%), lighting (8%) and stoves (5%) (5). Other, smaller, consumers are appliances such as floor polishers, washing machines, TV sets and kettles.

Significant variations in the above figures exist for the different income groups, probably as a result of the higher income groups' owning more appliances and using them more frequently. It has been found that the group with an income exceeding R20 000 p.a. (1978) used between 1,5 and 2 times as much electricity as the group with an income between R2 000 and R11 000 (6).

Although coal is not nearly as important as electricity as an energy source in the urban household, it is widely used in rural areas, primarily because rural areas are in general less electrified, and alternative fuels are thus

required. In the urban household, coal is used for space heating in winter; in rural areas it is used for cooking and water heating as well.

Small quantities of oil are used in urban households primarily for heating, however 44% of the input to rural households is oil (7), to drive farm implements and electricity generating plant.

Although gas is relatively widely used (15% urban users, 51% rural users), it only accounts for about 3% of the total input requirements. It is used chiefly for heating, with about 2% used for lighting (8).

Other carriers such as paraffin contribute relatively small amounts. In this thesis they will be considered part of the liquid fuel sector in the energy supply input/output model.

9.1.3 Black Households

Of a total Black population of 18,6 million in 1977, 5 451 000 lived in and around the major cities and were the major users of energy (9). In the rural areas, energy consumption is relatively low, comprising mainly non-commercial fuels such as wood. The prime source of energy for the "urban" population is coal, since most (77,7%) Black houses in the country do not have electricity.

1,7 M ton coal was used by Blacks in urban areas in 1977 (10), primarily for cooking, water heating and room heating. Depending upon the area, as much as 4 000kg coal may be used per household (Highveld), or as little as 100kg (coastal areas) (11). Total coal usage figures, as determined by the Department of Health, are listed in Table 9.1.

Electricity used by the 22,3% of Black households with access to electricity amounted to 400×10^6 kWh in 1977 (12), about 12 528 MJ per house. This energy is used for customary household appliances, however insufficient information is available to present a detailed breakdown of electricity consumption by appliance. In addition, other carriers such as gas and paraffin are used by Black households. No information is, however, available on the quantity or application of these energy carriers.

Owing to the pollution caused by large-scale burning of coal in domestic appliances, a program to provide electricity to urban Black households has been initiated. This can be expected to alter the energy demand characteristics of the domestic sector significantly.

9.1.4 Total Energy Input

Total energy used by the household sector has been estimated (13) as follows ; for 1978 :

Electricity	:	44 x 10 ⁹ MJ
Coal	:	93 x 10 ⁹ MJ
Petroleum Products	:	* x 10 ⁹ MJ
Gas	:	0,5 x 10 ⁹ MJ
Coke	:	0,03 x 10 ⁹ MJ

Owing to the strong dependence of demand for energy carrier type on ethnic, geographic and economic considerations, it is not appropriate to develop an energy flow diagram for the Domestic sector as has been done for other sectors, for example the Iron and Steel Industry.

9.2 Alternative Technology in the Domestic Sector

9.2.1 General

As described in Section 9.1, energy is used primarily for heating, cooling, lighting and cooking within the domestic sector. Alternative technologies, such as solar energy, heat pumps and hydrogen gas systems, to provide improved versions of the above functions, are under continuous review. Depending upon the economics of the situation, these systems may have relevance to South Africa. They are described below under "Alternative Systems and Energy Conservation", Section 9.2.3.

Because of the large quantities of energy involved, the electrification of the Black sector (representing an alternative technology for that sector) will have a major

influence on domestic energy demand patterns in South Africa.

9.2.2 Electrification of the Black Sector

Electrification of the Black household sector can be expected to lead to major shifts in energy utilization patterns. Based on a study (14), it has been estimated that from 1980 to 1985 the domestic usage of electricity may increase by over 50% whilst coal usage may drop by 33%, largely as a result of the decision to electrify Black areas.

Growing affluence of the Black sector must also be taken into account. This can be expected to result in increased usage of a growing number of electrical appliances in the average Black household, further boosting the demand for electricity.

9.2.3 Alternative Systems and Energy Conservation

Many alternative systems are possible in the household, depending upon accessibility and price of each energy carrier. Of prime importance to South Africa are solar energy, heat pumps and general energy conservation, as described below.

9.2.3.1 Solar Energy

Since hot water heating accounts for 33% of the demand

for electric energy in the domestic sector (section 9.1.2), solar hot water heaters are attractive, given a favourable climate. Although the energy itself is free, the cost of converting it to a useful form is usually expensive : typical solar domestic hot water systems for an average family of four may range in cost from \$800 to \$1500 uninstalled, depending on geographic location, collector efficiency and other factors (15).

In terms of overall energy saving, if solar collectors were to become universal in South Africa, the sun's energy could replace about 5% of our electricity needs or 1% of our net energy needs (16).

In addition to the local application of solar energy, large scale installations for the generation of electricity or hydrogen are also possible. For example, in the solar thermal electric converter, heat at temperatures as high as 4000°C are produced by concentrating direct solar radiation onto an absorber using mirror arrays. This heat is used to operate a turbine to generate electricity. Direct production of electricity by photovoltaics is also a possibility. The monocrystalline silicon cell is the most advanced in this respect, but the US development program is still a factor of 20 from the 1986 cost goal of 50 US cents/peak watt for a module (17). Other possibilities include gallium arsenide, amorphous silicon, multijunction silicon, cadmium sulphide-copper sulphide

and polycrystalline silicon systems. These are in the early development stage. In order to match cyclic supply characteristics with demand patterns, some storage system is essential. Production of hydrogen by electrolysis or thermolysis has been proposed (18) ; the hydrogen would then be distributed by pipeline and used directly as a fuel.

Widescale implementation of solar energy, both for local and central applications is considered to lie beyond the scope of this model, and is not considered further. In fact, large-scale use of sunlight in the future may well use technologies not yet available, and even technologies still unknown.

9.2.3.2 Heat Pumps

A cardinal principle of energy conservation is to provide heat from sources at the lowest practicable temperature. Thus instead of diluting the very high grade heat developed in a furnace to produce low grade heat at 20°C to 80°C, a more efficient approach is to upgrade ambient heat through the small temperature difference needed to produce a comfortable living environment. This may be done using a heat pump, illustrated in Figure 9.1.

The most usual form of heat pump employs a vapour compression cycle and is driven by an electric motor. Refrigerant fluid circulating through the heat pump is compressed,

and the resulting hot vapour flows through the heat exchanger where it condenses to a liquid, releasing its latent heat to warm the inside environment. Expansion through a valve causes a drop in pressure so that the fluid partly vapourises before it enters the second heat exchanger, outside. The fluid will then pick up heat energy as long as it is colder than the outside environment. The efficiency of a heat pump is the ratio of heat output to the energy input to the compressor, and is called the coefficient of performance (COP). The COP increases as the temperature difference between the external heat source and the pump's output declines. If a heat source can be replenished by some form of waste heat or solar energy, the overall system efficiency will greatly improve. Table 9.2 lists practical and theoretical COP's for a "typical" heat pump using air as the source and delivering heat at 20°C (19).

With present technology and UK climatic conditions, electric heat pumps can warm buildings with a seasonal COP of 2,5 or more : that is, more than two and a half times as much energy is delivered in the form of space heating as is consumed in the form of electricity by the heat pump. Increasing attention is also being given to heat pumps that run on fossil fuels rather than electricity. For example, a small internal combustion engine may be used to drive the compressor with the advantage that significant amounts of the engine waste heat can be captured to boost the heating efficiency of the pump, and

heat losses at the power station are avoided (20). If rejected warm air from the bathroom and kitchen is used, the COP may be still further increased.

45% of electric consumption in South African households is for heating - water and space (section 9.1.2). Since Black households can be expected to follow a similar pattern, the use of heat pumps must be seriously considered. 45% of a projected electricity demand of 178×10^9 MJ (year 2000) represents $80,1 \times 10^9$ MJ which could be reduced to $26,7 \times 10^9$ MJ using heat pumps with a COP of 3, thus changing the year 2000 forecast to $151,3 \times 10^9$ MJ; a 15% saving.

Because of the costs of heat pump systems compared with energy savings, it has generally been found that the heat pump is not price effective (21). As a result, in some countries (Canada, Germany, Sweden, US) incentives in the form of subsidies and grants are provided to promote the use of heat pumps (22). Loans with a payback period of 4 years, interest free, for the purchase of appliances ; and 15 to 20 years payback at 4,5% for longer term projects are available. Similar measures must be considered for South Africa if the energy saving caused by heat pumps is to be encouraged.

9.2.3.3 Conservation

Many opportunities for energy conservation exist within the household :

- more energy efficient bulbs for lighting
- insulation of hot water tank and pipes
- draught proofing and overall insulation
- improved building design in terms of orientation, fenestration, interior layout and siting
- use of more efficient appliances
- correct maintenance of appliances
- correct heater selection
- light colours for permanent external finishes
- thermostat adjustment.

These techniques are described in several publications (23) (24).

Although public awareness of energy conservation measures is recognized as being vital to the success of an effective energy programme, information alone is often not enough to motivate the consumer to conserve energy. Financial or fiscal incentives, including tax credits or refunds, subsidies, grants or loans are provided in most European countries. Building codes, applying to the insulation of outer ceilings, outer walls, ground floors and windows, are mandatory in Denmark, Germany, Italy, Holland, Norway, Sweden and the UK (25) (26). Energy efficiency labelling for consumer appliances encourages consumers to buy energy efficient products, and producers to make them. Mandatory labelling exists in Canada, Spain and the USA (27).

Other systems, such as combined generation of heat and power, can conserve significant quantities of energy because of the improved efficiency of the generating plant. Since electric generation is geographically distant from residential areas in South Africa, this option will not be considered further.

Taking all energy conservation measures into account, a UK study has forecast a 43% reduction in domestic sector delivered energy by the year 2025 as a low case, and a reduction of 36% as a high case, based on 1975 values (28).

During the period from 1960 to 1973 energy demand in the residential sector in IEA countries increased by an average of 5% p.a. Since 1973, IEA countries growth rate for energy demand was 0,4%, with some countries showing negative growth rates (29).

Clearly, a major study would be required to determine the probable effects of conservation within the domestic sector of South Africa.

9.3 Final Demand

9.3.1 Factors Influencing Demand

From the above description of the domestic sector, and possible alternative technology, it appears that several major factors can influence future energy demand by this

sector ; increasing or decreasing energy demand :

- Conservation

increasing energy prices lead to the reduction of energy use and energy waste, and also lead to the introduction of more efficient appliances such as washing machines and heating systems (Decrease energy demand).

- Labour Shortage

more attractive employment opportunities elsewhere in industry can be expected to lead to a declining servant population, with a consequent increase in demand for appliances such as dishwashers, washing machines and vacuum cleaners (Increase energy demand).

- Increasing Disposable Income

this permits additional expenditure on goods, resulting in the acquisition and use of additional electrical appliances such as TV sets, radios, hi-fi sets and other equipment such as electric tin-openers. (Increase energy demand).

- Electrification of Black Areas

a significant number of new customers will be added to the

electricity distribution network by the transfer from coal to electricity of the urban Black consumer (Increase electricity demand).

- Increasing Population

South Africa's growing population effectively sets a lower limit to the growth in demand for energy (Increase energy demand).

The first step in any projection of domestic energy use is to define how many households there will be, what kind of buildings will be used and what the basic activity levels or energy-related material standards will be. These activity levels can be reduced to the internal temperature for space heating, the amount of hot water used, the amount of cooking and the average ownership and use of appliances per household. Energy use in any one building is complex, with many interactions between space heating, water heating, cooking and use of appliances. There is also almost an infinite variety of buildings and of people who live in them, each with different opportunities and constraints for saving energy. A major study of population growth, demographic structure and economic growth is needed to define the number of households. Assumptions must then be made about dwelling construction and demolition rates as well as the utilization of energy for space and water heating, cooking, appliances and lighting, within each household.

9.3.2 Demand Studies

Based on studies of the domestic sector (30). Final demand values of 178×10^9 MJ for electricity and $32,5 \times 10^9$ MJ for coal have been suggested for the year 2000. This suggests the following growth rates, using 1978 as a basis, up to the year 2000 :

electricity : 6,6%

coal : -4,9%

(no forecast made for gas/coke/petroleum)

A prior study of the domestic sector (31) yielded a demand value for electricity in 2000 of 74×10^9 kWh, or $266,4 \times 10^9$ MJ ; providing the following growth rate :

electricity : 8,7%

(no forecasts made for gas/coke/petroleum)

The difference between this figure and the one above (6,6%) is accounted for by different assumptions and treatment for the Black sector.

The Department of Planning (32) has forecast growth rates up to 2000 for the domestic sector (including agriculture) as follows :

electricity	:	5,8%
coal	:	-4,8%
petroleum	:	3,9%

Coke and gas have not been forecast, but their demand values have been relatively constant from 1970-1974.

Average growth rates for dwelling houses completed during the period 1962-1975 were 8,3% for White, 7,3% for Coloured and Asian and -23% for Black (33). This cannot, however, be translated directly into energy growth rates.

9.4 Description of Likely/High/Low Cases

Fairly divergent information is supplied by the above studies, except for coal where there is some agreement that the rate of decline in use is around 4,9%. The effects of conservation are not explicitly included in these projections, however, from an evaluation of conservation possibilities, in particular the heat pump and solar energy (section 9.2), it is felt that an overall 15% reduction in demand for fuel oil is feasible over the programming period. The following rates have been assumed to represent the Likely, High and Low Cases :

	Likely %	High %	Low %
electricity	6,6	8,7	5,8
oil conservation			
by 2005	15,0	0	15,0
coal	-4,9	-4,9	-4,9
petroleum	3,9	3,9	3,9
gas	0	0	0
coke	0	0	0

The immediate demand for energy for these three cases is listed in Tables 9.3, 9.4 and 9.5. These three cases constitute the final demand scenarios for the domestic sector, to be used in the integrating model.

BLANK

10.1 Introduction

Chapters 1 - 9 describe the set of energy supply and demand models. In this chapter, the output of the model is described as follows :

.. Total Final Demand

A description of total, projected final demand, consolidating all demand sectors.

.. Total Output

Possible energy system scenarios, including a base case, sensitivities to final demand, an energy independence case and other possibilities.

.. Conclusions

A description of key results of the above runs and a discussion of the characteristics of the model.

10.2 Total Final Demand

10.2.1 Unspecified Sectors

The seven industries described in Chapters 3 to 9 are major "bulk" users of energy. In addition to these users, there are a large number of smaller, less well defined industries and commercial activities that account for the remainder of final demand for energy in South Africa.

These remaining users include the following :

- other mining activities (copper, chrome)
- food preparation
- clothing production (shoe and apparel)
- furniture manufacture (household, office)
- household appliances (stoves, lawnmowers)
- building construction (residential, commercial)
- equipment manufacture (pumps, motors).

Some final demand elements are included in the energy supply input/output model, for example :

- uranium extraction (: 7×10^9 MJ elec.)
- coal mining (: 7×10^9 MJ elec.)
- coal conversion (: 9×10^9 MJ elec.).

Also, other industries, though not defined in this analysis, may be identified, such as :

- ferro-alloys : 12×10^9 MJ coal
($3,5 \times 10^9$ MJ gas
 $8,5 \times 10^9$ MJ coke).

Eliminating those final demand sectors that are accounted for in the supply model, energy demand by the unspecified sectors may be estimated at :

electricity	:	35×10^9 kWh
coal	:	2,93 Mt
petroleum	:	$* \times 10^9$ l
gas	:	$1,88 \times 10^9$ m ³
coke	:	0,25 Mt
coking coal	:	0,5 Mt

This is based on an estimate (1) of 1980 total final demand, and accounts for 22% of total final demand. The

remaining 78% being accounted for by the defined industries and final demand by the supply/converter industries.

Final demand by the unspecified sectors and total final demand are listed in line 1 (1980) of Tables 10.1 and 10.4. As may be seen from these two Tables, the biggest element of this unspecified demand, relative to total final demand, is electricity. This is because these unspecified sectors are primarily the light manufacturing industries such as plastics and appliance manufacture, which are largely dependent on electricity.

As this remaining "sector" accounts for 22% of total final demand, assumptions made about its future growth will significantly affect total energy demand. At the same time, the diverse nature of this "sector" will also ensure relatively stable demand patterns; that is, the demand profile is not likely to be seriously affected by shifts in energy demand by any one sub-industry.

With regard to the GDP as a whole, the Economic Development Programme has identified an annual economic growth rate of 3,6% as possible (2), and 4,5% as attainable, given certain policy adjustments (3). Given various export efforts, a rate of 5% is also considered possible (4).

With regard to electricity, the Economic Development Programme anticipates an annual growth rate of 6,6% for the years 1978 - 1987, down from 8,4% for the preceding decade (5). Escom's expectations for electricity is, however, given as 10% p.a. in the medium term (6). The Department of Planning (7) has used the values 4,71% and 5,5% to define lower and upper growth rates for energy as a whole, up to the year 2000.

Given the above estimates, and recognizing that these unspecified sectors will tend to follow the general economy, the following annual rates are assumed for electricity :

likely case	:	6%
high case	:	7%
low case	:	5%

As there is a general shift toward the use of electricity in South African industry, the remaining energy carriers may be expected to display somewhat lower growth rates, more in line with the Department of Planning figure. The following values are assumed for the remaining carriers :

likely case	:	4,5%
high case	:	5,0%
low case	:	3,6%

In addition, since the writing of the Economic Development Programme, steep increases in the price for petroleum products have resulted in widespread interest in alternatives to oil as an energy carrier. It must be assumed that conservation measures and substitution will influence the growth rate of petroleum demand. Consequently, for the likely and low cases, conservation measures are assumed to be introduced that will result in an oil saving of 15% by the year 2005. Based on experience with the other industries, this is a feasible figure. The high case assumes no conservation measures, in order to detect the upper boundary for demand.

These values may be used to determine the final demand for the unspecified sectors, as listed in Tables 10.1, 10.2 and 10.3. These three cases constitute the final demand scenarios for the unspecified sector, to be used in the supply/demand integrating model.

10.2.2 Total Final Demand Projection

The previous chapters and sections define $9 \times 3 = 27$ possible final demand elements that need to be combined to generate a final demand scenario. Many combinations are possible, since it is not necessary that all sectors follow a high, likely or low path simultaneously. For example, a high coal export pattern would probably suggest low growth rates for the world nuclear electricity industry, and consequently low international demand for uranium. This has been described in Chapter 5. Uranium exports would then probably approach the low case. Many such possibilities exist and may be tested by the model; the ability of the model to test sensitivity of total output to variations in individual sectors is an advantage.

In order to illustrate the boundaries of final energy demand represented by this model, all likely, high and low cases have been combined and are listed in Tables 10.4, 10.5 and 10.6.

Final demand in the year 2005 is seen to range from a low of 215×10^9 kWh to a high of 424×10^9 kWh for electricity, with a likely value of 290×10^9 kWh. Petroleum ranges from * Gℓ to * Gℓ, and coal (including coking coal) from 110 Mt to 240 Mt.

This range in final demand is a direct consequence of present-day uncertainty with regard to rates of change and overall effects of the following variables :

- energy conservation techniques
- new technology
- future growth of the economy
- obsolescence and replacement of products

Combining the final demand models with the energy supply model permits the overall variability in resource utilization to be measured and highlights the final demand sectors that have the greatest influence on total output. This is described in the following sections.

10.3 Total Output - Energy Flow to 2005

10.3.1 Base Case

As described in the preceeding chapters, variability exists with regard to projection of final demand and of the conversion efficiencies of some of the major supply industries.

Combining likely demand projections with likely supply options in the energy supply/demand model yields the base case scenario as illustrated in Report 10.1 (Case 275811). Headings of the reports are described in Chapter 1.

Key results of this "likely" projection are as follows :

cumulative coal utilization	:	6431 Mt
cumulative coking coal utilization	:	188 Mt
cumulative uranium utilization	:	326 kt
electricity growth rate	:	5,6%
coal mining growth rate	:	5,9%
oil imports (2005)	:	* G\$
cumulative capital for energy projects	:	79034 MR.

The above figures include coal and uranium exports, which are listed separately.

These results may be compared to other forecasts :

Coal demand has been estimated by the Department of Planning (8) to lie between 162 Mt and 193 Mt in the year

2000 (excluding exports). Later figures suggest 248,6 Mt. The model forecasts 258,7 Mt.

Petroleum products have been listed as * , * and * Gl (9) in 2000. The model forecasts * Gl.

Electricity generation is listed as 281, 326,5 and 312,6 x 10⁹ kWh (9) in 2000. The model forecasts 303,8 x 10⁹ kWh (sent out).

Many other comparisons are possible, but not worthwhile since the basis of the other forecasts is not generally known. In broad outline, the model, when provided with generally expected assumption arguments, projects values similar to other forecasts.

In common with these other forecasts, this run suggests a "hard" or unique solution. It is important for the policymaker to understand the ranges and sensitivity of the projection ; this capability is provided by the model, as described below.

10.3.2 Final Demand Sensitivity

Sensitivity of the solution to final demand may be determined as follows :

- High/Low Final Demand Cases
- Sectoral Final Demand Sensitivity
- Monte Carlo Simulation

10.3.2.1 High/Low Final Demand Cases

These two cases, in which all final demand sectors have been assumed "high" and "low" respectively, are shown in Report 10.2 (Case 295811) and Report 10.3 (Case 295812).

All flows alter, however, the most important variable is internal coal demand. This is seen to have the following

growth rates, up to 2000 and 2005 respectively :

<u>Year</u>	<u>2000</u>	<u>2005</u>
High Case	6,6%	6,5%
Likely Case	5,6%	5,5%
Low Case	4,0%	3,8%

Since it has a strong influence on the rate of depletion of coal resources, this growth rate is important in determining how much coal may safely be exported : the range described above is consequently vital to the policy-maker.

10.3.2.2 Sectoral Final Demand Sensitivity

Sensitivity of total energy output to variations in final demand may also be tested by altering each final demand sector between its high value and its low value independently, while running the total model. In this manner, 19 cases may be defined, where all sectors are "likely" except for the following changes :

<u>CASE</u>			<u>CASE</u>		
1	Steel	"Low"	11	Steel	"High"
2	Exports	"	12	Export	"
3	Chemicals	"	13	Chemicals	"
4	Paper	"	14	Paper	"
5	Transport	"	15	Transport	"
6	Domestic	"	16	Domestic	"
7	Cement	"	17	Cement	"
8	Unspecified	"	18	Unspecified	"
9	Mining	"	19	Mining	"
10	All	"Likely"			

Table 10.7 illustrates the values for cumulative coal, uranium and oil utilization resulting from each case, up to 2005. In Table 10.8 the results are illustrated

graphically.

Predictably, exports have the greatest effect on coal, followed by the Iron and Steel Industry and Mining. Transportation has the greatest effect on cumulative oil utilization, followed by the Unspecified sectors ; and Uranium is sensitive only to exports with the given scenarios.

In terms of cumulative resource utilization, the Iron and Steel industry, Mining and Transportation as well as the Unspecified sectors have the greatest potential effect. The large effect of the Unspecified Sectors on coal is a result of the sector's heavy demand for electricity.

Since efforts to reduce consumption in the above sectors will have the greatest effect on overall energy conservation, this suggest to the policy-maker that these sectors require further analysis and investigation to determine their operating characteristics in more detail, and also that research and development funds be directed accordingly.

10.3.2.3 Monte Carlo Simulation

The above scenarios serve to determine likely energy demand as well as high and low possibilities. In addition the model may be used to determine the probability distribution or range of occurrence of specific variables. This provides information concerning the likelihood of any specific value occurring for a variable, under the given set of assumptions. Simulated sampling (Monte Carlo simulation) makes it possible to introduce data that have the statistical properties of some distribution. Ideally, additional information, namely probability distributions, are used to select each input parameter. In this thesis,

a random number, R, is generated between 1 and 100 for each final demand sector. Values N and M are chosen so that if $R \leq N$ a low case is selected while for $N < R \leq M$ and $M < R$ likely and high cases are selected, respectively. (M and N in fact determine the distribution of input data.)

The model is run repeatedly (200 times) and in each case the specific variable is observed over the period 1980 to 2005. A frequency distribution curve, illustrating the number of occurrences of the variable in each slot, is produced.

Any of a number of variables may be selected - oil imports, capital requirements, electricity demand or the growth rate of domestic coal demand.

The growth rate of domestic coal demand is of major importance. Based on separate studies, the Department of Mineral and Energy Affairs has established a rate of 5,8 % up to 2000, and further analysis has suggested that exports of 70 to 80 Mt per annum would be possible given this rate. Higher internal growth rates would result in coal shortages in the early years of 2000 if this export figure were maintained (1).

The result of two simulation runs is illustrated in Figures 10.1 and 10.2. In Figure 10.1, likely cases have a 60 % probability of occurring, while high and low cases have a 20 % probability each. In Figure 10.2, each case has an equal probability of occurring. Little difference exists between the two curves, except that Figure 10.1 tends to be more peaked owing to the greater likelihood of likely cases being selected. Both cases highlight the fact that a significant probability of 20 % exists for a coal growth rate higher than 6 % per annum.

Since this value is critical in setting coal exports, the sensitive sectors identified in section 10.3.2.2 need additional attention.

10.3.3 Energy Independence

The capital and resource requirements for a scenario of independence from oil imports may also be tested by the model. A possible path to energy independence is tested in Report 10.4 (Case 26811). In this case, coal liquefaction is assumed to provide 50% of the liquid fuel requirement by 2005, the other half being provided by methanol. Since the end use efficiency of methanol is higher than conventional petroleum (10), demand for liquid fuels can also be expected to be reduced by 2005. This effect has not been included in this run.

Key results of this run are as follows :

- Cumulative coal utilization : 6863 Mt
- Growth in coal mining output : 6,3%
- Cumulative capital requirement
to 2005 : 94256 MR

The impact of such a programme of energy independence on the coal resource base of South Africa is apparent.

In the year 2005, coal is being mined at a rate of nearly 500 Mt p.a., 5 times the value of 1980, placing a tremendous strain on resources and infrastructure. In addition, over half the available resources of coal can be expected to be depleted by the year 2025.

Clearly, a programme of energy independence will entail more than the building of coal liquefaction plants. Conservation, substitution and other methods of reducing demand for liquid fuel will have to be examined and implemented. The model provides the vehicle for testing these factors.

10.3.4 Other Possibilities

Many other possibilities may be tested by the model, for example, combinations of existing supply technology and "high" demand, in order to understand the ranges of energy flows in South Africa. A combination of existing technology and "high" demand results in a coal demand growth rate of 7,1% assuming 50% domestic liquid fuel production. This is a high growth rate, depleting 50% of the coal reserve base soon after 2020. A programme of energy independence coupled with this scenario would severely impact coal resources.

An interesting alternative study is provided by the non-nuclear, non-coal-conversion study. In this case all liquid fuels are imported and electricity generation is exclusively "conventional" with no nuclear component. Given "likely" demand, cumulative coal requirement by 2005 is 5802 Mt, and capital requirements only MR 54142, however oil imports in the year 2005 amount to * G£.

10.4.1 Energy in South Africa up to 2005.

The key result of this model is a description of the development of the energy system in South Africa up to the year 2005, set against a background of alternatives generated by present-day uncertainty regarding future technology and economic performance.

The "likely" case which incorporates a number of final demand assumptions such as new technology for Iron and Steel manufacture and conservation measures, as well as improved energy supply technology, presents a scenario that may be considered feasible in the light of strategic, resource and capital considerations. Deviation from these measures results in scenarios which deplete resources and require excessive capital funding. This in turn will affect the economy as a whole and also the post - 2005 energy pattern. As an example, the "high" case, implying present-day technology for Iron and Steel, utilizes 489 Mt coking coal by the year 2005, 70% of South Africa's extractable reserve of 705 Mt (11). Alternative technology, for example the direct reduced iron method, is vital to South Africa, and adequate research and development funds must be made available on a priority basis to ensure that the new technologies are available in the next 5 to 10 years.

Improved technology in energy conversion by the supply industries is also essential. Present-day technology applied to coal conversion and electricity generation is seen to result in accelerated depletion of domestic coal. These processes are inefficient, resulting in excessive conversion losses. New coal conversion techniques, including methanol production, must be considered, since the existing coal conversion route is not optimal. Again, the necessity for large-scale

research regarding the liquid fuels programme is emphasized. Similar considerations apply to electricity generation.

Owing to local conditions, including coal grades, quality and resources, South Africa should no longer wait to adopt technologies developed overseas, but should actively develop and implement its own solutions. Major research funding is a priority.

These are policy decisions, and the model points to areas where they will be effective. Other policy decisions, such as conservation, also affect energy flows, and the model highlights the sectors of maximum impact. The next step for the policy-maker is to determine how these measures may be implemented - by incentive, taxation, education or any combination.

Finally, the model provides a significant input into the energy export decision. Demand growth rates for coal and uranium determine when new technologies such as fusion, fast breeder and solar will become imperative ; the model provides expected and high values for these variables so that export decisions can be made that will not expose the country to a real energy deficiency in the future.

10.4.2 Characteristics of the Model

The model is effective in its representation of supply and demand sectors, however certain inherent characteristics of the techniques used must be considered when reviewing results :

- no explicit price factors :

- the effect of price changes is implied in the final demand scenarios, explicit evaluation of price changes is not incorporated

- aggregation of coal/oil sectors :

different grades of coal and different oil products are aggregated into their respective sectors (except for coking coal, which is treated separately)

- dependence on Economic Development Programme :

final demand scenarios have been linked to the forecasts of the EDP. Changes to these forecasts should be referred back to the model

- no optimization :

no optimal solution is found for any variable or parameter. Successive runs of the model are required to identify suitable policies.

The model is useful for energy policy formulation in that it permits supply options and demand sensitivities to be tested. It is transparent to the user in that all assumptions are specified and may be changed, solution of the model does not depend on mathematical constraints. Also, a model cannot represent the entire real world, and certain other factors must be taken into account :

- pollution :

specifically atmospheric, caused by large-scale coal burning, but also thermal and nuclear waste

- labour :

jobs, skills and training

- infrastructure :

road, rail and distribution system

- other resource utilization :

water, land and materials.

Vital policy decisions regarding energy must be made, as described in Chapter 1. Traditionally, econometric forecasts or sectoral projections of demand are used as a basis for these decisions. Generally, these differ and cannot easily be reconciled. The set of models developed for this thesis are a new and original tool for policy formulation because of the following characteristics :

- The representation of supply as an input/output matrix and demand as a set of energy flow diagrams provides a quantitative description of the major elements of energy flow.

- Reconciliation of supply and demand using matrix techniques provides an integrated and consistent picture of the energy system.

- Links to other activities in the economy via growth rates projected by the Economic Development Programme ensure consistency with the rest of the economy.

- The ability to test sensitivities to supply and demand options avoids the weakness of traditional 'unique' forecasts that do not emphasize key variables.

Previously, one-off energy balances and projections were made; a slow, time-consuming task with little internal checking and consistency. The model permits energy balances to be readily assembled as a function of known or expected economic and technological parameters, thus providing a valuable policy-making tool.

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YEAR	ELEC.	COAL	COKE	PETRO. PROD.	GAS	URAN.	COKE COAL
	10*9KWH	MT	MT	10*9L	10*9M*3	KT	MT
1980	80.4	42.3	.3	*	2.3	6.1	6.8
1985	101.7	65.8	.3	*	2.9	7.8	6.9
1990	130.4	89.9	.4	*	3.7	9.9	7.1
1995	168.9	118.3	.5	*	4.6	12.7	7.3
2000	220.6	155.7	.7	*	5.7	16.2	7.5
2005	290.3	204.7	.8	*	7.1	20.7	7.8

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***FDS99***|TOTAL FINAL DEMAND  ---  ALL ASSUMPTIONS 'LIKELY'
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SCENARIO OF LIKELY DEVELOPMENT OF THE ENERGY SYSTEM IN SOUTH AFRICA.

1986 COEFFICIENTS: ECDEFN4S:
ASSUMES 10%/ NUCLEAR ELECTRICITY CONTRIBUTION
AND 40%/ COAL CONVERSION CONTRIBUTION
(SYNTHOL)
CONVERSION PROCESS EFFICIENCIES EQUAL TO
1980 VALUES.

[illegible]

235

DFDS990 ECOEFFICIENTS/ECOEFFN4S/ECOEFFN4SM(1980/1986/2005)LIKELY

**ENERGY FLOW, MEASURED AT 5 YEAR INTERVALS

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
ELEC DISTRIB	GKWH	96.35	135.00	171.92	221.00	286.42	373.78
COAL ELEC GEN	GKWH	99.35	125.62	159.99	205.65	266.54	347.83
HYDRO GEN	GKWH	2.19	3.06	3.90	5.01	6.50	8.48
OIL GEN	GKWH	.69	.96	1.22	1.57	2.03	2.65
NUCLEAR GEN	GKWH	.01	13.58	17.29	22.23	28.81	37.59
URAN MINING	KTON	6.11	8.17	10.42	13.30	16.99	21.70
URAN PROCESS	TON	.01	72.66	92.54	118.95	154.16	201.18
COAL MINING	MTON	103.22	163.77	209.31	264.66	336.02	427.88
COKE PRODUCT	MTON	.28	.34	.43	.53	.66	.82
GAS DISTRIB	GM*3	3.14	3.52	4.34	5.33	6.54	8.04
FUEL DISTRIB	GLIT	*	*	*	*	*	*
OIL REFINING	GLIT	*	*	*	*	*	*
COAL CONVERS	GLIT	*	*	*	*	*	*
GAS PRODUCT	GM*3	3.14	3.10	3.83	4.70	5.77	7.09
COKING COAL	MTON	6.81	6.93	7.08	7.28	7.51	7.81
METHANOL	GLIT	.01	.01	*	*	*	*

**PER ANNUM CAPITAL REQUIREMENTS -- RAND MILLIONS

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
ELEC DISTRIB	MR	.00	471.67	444.99	592.52	790.42	1055.80
COAL ELEC GEN	MR	.00	604.38	800.58	1066.00	1422.04	1899.49
HYDRO GEN	MR	.00	14.25	13.45	17.90	23.88	31.90
OIL GEN	MR	.00	4.45	4.20	5.59	7.46	9.97
NUCLEAR GEN	MR	.00	602.33	155.13	206.57	275.56	368.07
URAN MINING	MR	.00	108.33	116.84	149.42	191.12	244.50
URAN PROCESS	MR	.00	60.75	15.65	20.84	27.79	37.13
COAL MINING	MR	.00	385.36	262.47	336.26	433.15	557.41
COKE PRODUCT	MR	.00	.41	.52	.63	.79	.98
GAS DISTRIB	MR	.00	1.56	3.41	4.06	5.01	6.19
FUEL DISTRIB	MR	.00	21.02	24.55	29.36	34.92	41.48
OIL REFINING	MR	.00	37.68	11.69	13.20	14.73	16.35
COAL CONVERS	MR	.00	1541.14	275.86	329.79	392.79	467.36
GAS PRODUCT	MR	.00	.29	3.01	3.58	4.42	5.45
COKING COAL	MR	.00	.94	1.17	1.46	1.82	2.26
METHANOL	MR	.00	.00	84.92	116.29	156.44	207.53

TOTAL

.00 3778.63 2218.44 2893.48 3782.34 4951.88

CUMULATIVE CAPITAL, OVER TOTAL PERIOD

79034.53

**ANNUAL IMPORT AND EXPORT OF ENERGY CARRIERS

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
COAL EXPORTS	MTON	23.3	39.6	53.1	67.1	84.8	107.2
URAN EXPORTS	KTON	6.1	7.8	9.9	12.7	16.2	20.7
OIL IMPORTS	GLIT	*	*	*	*	*	*

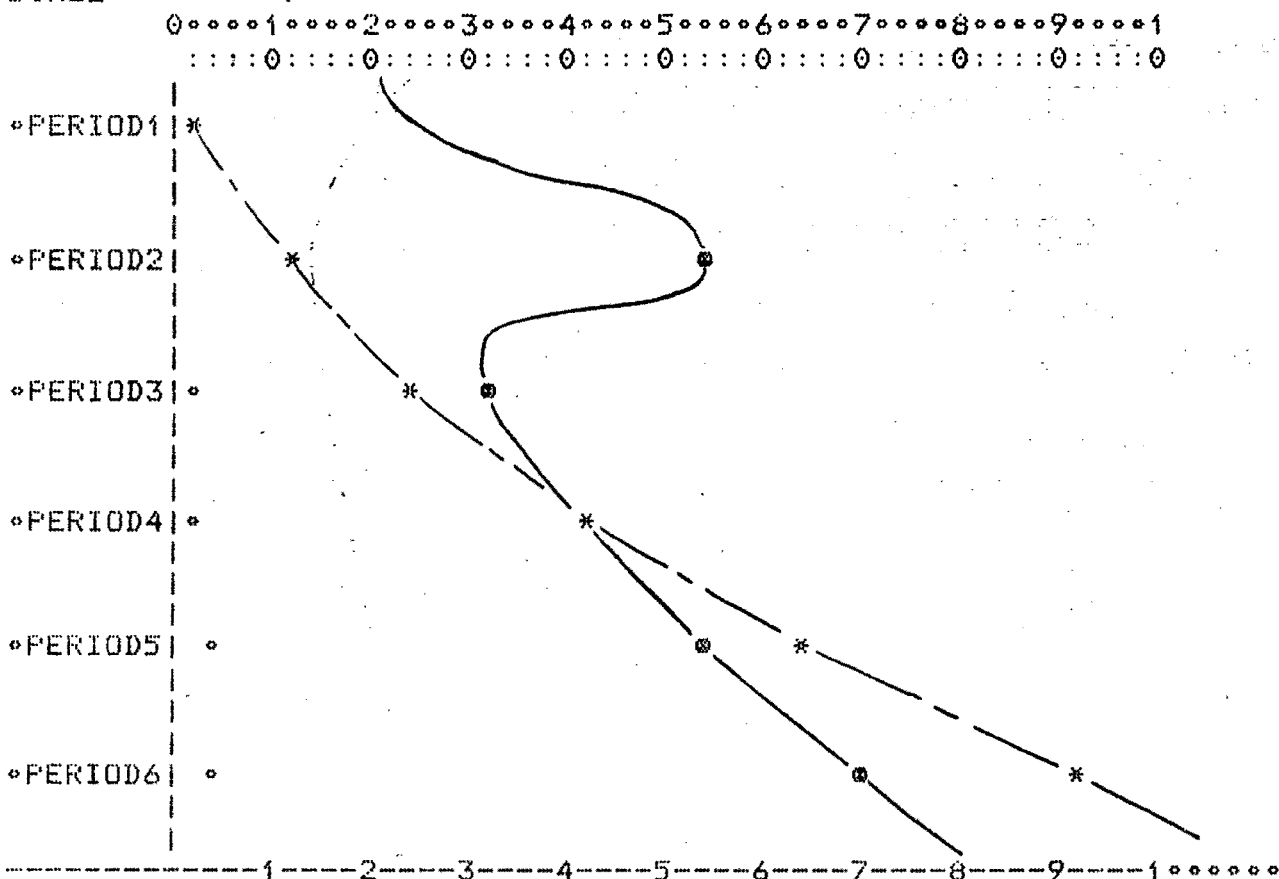
累积资源使用 CUMULATIVE USE OF RESOURCES

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
COAL TOTAL	MTON	103.2	791.8	1747.5	2954.5	4484.6	6431.0
COKE COAL T	MTON	6.8	41.2	76.3	112.2	149.3	187.7
URAN TOTAL	KTON	6.1	42.6	89.9	150.3	227.5	326.1
COAL EXPORTS	MTON	23.3	185.3	427.5	733.6	1120.6	1609.8
URAN EXPORTS	KTON	6.1	41.5	86.7	144.3	217.9	311.8
OIL IMPORTS	GLIT	*	*	*	*	*	*

**GRAPH OF ENERGY AND CAPITAL VALUES

10 PRINTSFACES = 200 UNITS

SCALE::: x 7



LEGEND

* CUMULATIVE COAL	MTON	103:	792	1748	2954	4485	6431
o CUMULATIVE URANIUM	KTON	6	43	90	150	228	326
+ OIL IMPORTS (PA)	10MLIT	*	*	*	*	*	*
@ CAPITAL INVESTMENTS	MR	0	3779	2218	2893	3782	4952

BLANK

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*9L	10*9M*3	KT	COAL MT
1980	80.4	41.4	.3	*	2.3	6.1	7.2
1985	111.3	60.8	.3	*	3.0	9.8	10.1
1990	154.9	83.0	.4	*	4.0	15.8	14.1
1995	215.9	110.8	.6	*	5.1	20.2	19.6
2000	302.1	148.9	.7	*	6.7	25.7	27.4
2005	424.2	201.1	.9	*	8.7	32.8	38.3

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|**FDS98***|TOTAL FINAL DEMAND ---- ALL ASSUMPTIONS 'HIGH'
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SCENARIO OF THE DEVELOPMENT OF THE ENERGY SYSTEM IN SOUTH AFRICA,
WITH 'HIGH' ASSUMPTIONS FOR ALL FINAL DEMAND SECTORS.

1986 COEFFICIENTS: ECDEFFN4S:
100% NUCLEAR ELEC CONTRIBUTION
400% COAL CONVERSION CONTRIBUTION
CONVERSION PROCESS EFFICIENCIES EQUAL TO
1980 VALUES.

2005 COEFFICIENTS: EC0EFFN4SM:

100% NUCLEAR ELEC CONTRIBUTION
400% COAL CONVERSION CONTRIBUTION.
CONVERSION PROCESS EFFICIENCIES IMPROVE WITH
THE INTRODUCTION OF COMBINED CYCLES
IN COAL ELECTRICITY GENERATION AND
HIGHER EFFICIENCY PROCESSES FOR CONVERTING
COAL TO LIQUID FUEL.

DFDS980 ECOEFFICIENTS/ECOEFFN4S/ECOEFFN4SM(1980/1986/2005) HIGH
 **ENERGY FLOW, MEASURED AT 5 YEAR INTERVALS

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
ELEC DISTRIB	GKWH	96.38	147.59	204.37	281.84	390.34	542.84
COAL ELECEN	GKWH	99.38	137.35	190.18	262.27	363.24	505.15
HYDRO GEN	GKWH	2.19	3.35	4.64	6.39	8.85	12.31
OIL GEN	GKWH	.69	1.05	1.45	2.00	2.77	3.85
NUCLEAR GEN	GKWH	.01	14.85	20.56	28.35	39.26	54.59
URAN MINING	KTON	6.11	10.24	16.38	20.96	26.83	34.37
URAN PROCESS	TON	.01	79.44	110.00	151.70	210.10	292.18
COAL MINING	MTON	102.36	166.89	222.75	293.90	389.59	518.20
COKE PRODUCT	MTON	.28	.35	.45	.58	.74	.95
GAS DISTRIB	GM*3	3.14	3.66	4.72	6.04	7.74	9.93
FUEL DISTRIB	GLIT	*	*	*	*	*	*
OIL REFINING	GLIT	*	*	*	*	*	*
COAL CONVERS	GLIT	*	*	*	*	*	*
GAS PRODUCT	GM*3	3.14	3.23	4.16	5.32	6.82	8.75
COKING COAL	MTON	7.25	10.10	14.09	19.65	27.43	38.30
METHANOL	GLIT	.01	.01				

**PER ANNUM CAPITAL REQUIREMENTS -- RAND MILLIONS

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
ELEC DISTRIB	MR	.00	640.24	698.90	952.53	1335.81	1879.94
COAL ELECEN	MR	.00	888.76	1257.40	1713.70	2403.26	3382.20
HYDRO GEN	MR	.00	19.35	21.12	28.78	40.36	56.80
OIL GEN	MR	.00	6.05	6.60	8.99	12.61	17.75
NUCLEAR GEN	MR	.00	694.99	243.65	332.07	465.69	655.39
URAN MINING	MR	.00	234.58	342.10	237.73	304.87	391.23
URAN PROCESS	MR	.00	70.10	24.58	33.50	46.97	66.11
COAL MINING	MR	.00	418.23	335.34	439.13	590.34	793.34
COKE PRODUCT	MR	.00	.48	.62	.79	1.01	1.30
GAS DISTRIB	MR	.00	2.19	4.49	5.52	7.12	9.20
FUEL DISTRIB	MR	.00	29.15	36.54	46.33	58.85	74.77
OIL REFINING	MR	.00	34.64	18.87	22.68	27.23	32.58
COAL CONVERS	MR	.00	1689.41	408.66	517.69	657.83	836.30
GAS PRODUCT	MR	.00	.21	3.96	4.87	6.28	8.11
COKING COAL	MR	.00	22.72	31.74	44.34	61.97	86.64
METHANOL	MR	.00	.01	98.80	148.68	218.54	315.62

TOTAL .00 4681.82 3533.35 4537.33 6238.76 8607.27

CUMULATIVE CAPITAL, OVER TOTAL PERIOD 121112.93

**ANNUAL IMPORT AND EXPORT OF ENERGY CARRIERS

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
COAL EXPORTS	MTON	23.3	39.6	56.4	76.9	104.9	143.0
URAN EXPORTS	KTON	6.1	9.8	15.8	20.2	25.7	32.8
OIL IMPORTS	GLIT	*	*	*	*	*	*

BLANK

YEAR	ELEC.	COAL	COKE	PETRO. PROD.	GAS	URAN.	COKE COAL
	10*9KWH	MT	MT	10*9L	10*9M*3	KT	MT
1980	80.2	41.7	.3	*	2.3	6.1	6.8
1985	94.3	60.9	.3	*	2.6	6.7	6.9
1990	113.3	71.9	.4	*	3.3	7.4	7.0
1995	138.7	80.8	.5	*	3.9	8.2	7.2
2000	171.9	91.1	.5	*	4.6	9.1	7.3
2005	215.0	103.0	.6	*	5.5	10.0	7.5

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***FDS97***|TOTAL FINAL DEMAND  ----- ALL ASSUMPTIONS  'LOW'
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SCENARIO OF THE DEVELOPMENT OF THE ENERGY SYSTEM IN SOUTH AFRICA,
WITH 'LOW' ASSUMPTIONS FOR ALL FINAL DEMAND SECTORS.

1986 COEFFICIENTS: ECOEFFN4S:___
10%/ NUCLEAR ELEC CONTRIBUTION
40%/ COAL CONVERSION CONTRIBUTION .
CONVERSION PROCESS EFFICIENCIES EQUAL TO
1980 VALUES.

'LOW' ASSUMPTIONS USED FOR ALL FINAL DEMAND SECTORS.

[FDS97] ECOEFFICIENTS/ECOEFFN4S/ECOEFFN4SM(1980/1986/2005) LOW
 **ENERGY FLOW, MEASURED AT 5 YEAR INTERVALS

	YEAR	0	YEAR	5	YEAR	10	YEAR	15	YEAR	20	YEAR	25
ELEC DISTRIB	GKWH	96.11	125.48	149.80	181.75	223.12	276.40					
COAL ELEC GEN	GKWH	99.10	116.77	139.40	169.13	207.63	257.21					
HYDRO GEN	GKWH	2.18	2.85	3.40	4.12	5.06	6.27					
OIL GEN	GKWH	.69	.89	1.07	1.29	1.59	1.96					
NUCLEAR GEN	GKWH	.01	12.62	15.07	18.28	22.44	27.80					
URAN MINING	KTON	6.11	7.09	7.86	8.72	9.69	10.78					
URAN PROCESS	TON	.01	67.54	80.63	97.82	120.09	148.77					
COAL MINING	MTON	102.55	152.90	177.72	203.78	235.18	272.72					
COKE PRODUCT	MTON	.28	.33	.39	.46	.55	.65					
GAS DISTRIB	GM*3	3.14	3.36	3.92	4.59	5.37	6.30					
FUEL DISTRIB	GLIT	*	*	*	*	*	*					
OIL REFINING	GLIT	*	*	*	*	*	*					
COAL CONVERS	GLIT	*	*	*	*	*	*					
GAS PRODUCT	GM*3	3.14	2.96	3.45	4.04	4.74	5.55					
COKING COAL	MTON	6.81	6.90	7.02	7.16	7.32	7.52					
METHANOL	GLIT	.01	.01									

**PER ANNUM CAPITAL REQUIREMENTS -- RAND MILLIONS

	YEAR	0	YEAR	5	YEAR	10	YEAR	15	YEAR	20	YEAR	25
ELEC DISTRIB	MR	.00	355.14	291.10	382.08	493.43	634.58					
COAL ELEC GEN	MR	.00	409.57	523.72	687.40	887.74	1141.66					
HYDRO GEN	MR	.00	10.73	8.80	11.55	14.91	19.17					
OIL GEN	MR	.00	3.35	2.75	3.61	4.66	5.99					
NUCLEAR GEN	MR	.00	535.11	101.48	133.20	172.02	221.23					
URAN MINING	MR	.00	49.78	37.88	42.56	47.86	53.93					
URAN PROCESS	MR	.00	53.98	10.24	13.44	17.35	22.31					
COAL MINING	MR	.00	317.19	125.44	154.45	185.42	221.22					
COKE PRODUCT	MR	.00	.31	.37	.44	.52	.62					
GAS DISTRIB	MR	.00	.78	2.26	2.71	3.19	3.75					
FUEL DISTRIB	MR	.00	16.56	18.53	21.38	24.47	27.94					
OIL REFINING	MR	.00	39.28	8.10	8.78	9.35	9.88					
COAL CONVERS	MR	.00	1455.88	207.17	239.36	274.21	313.45					
GAS PRODUCT	MR	.00	.92	1.99	2.39	2.81	3.31					
COKING COAL	MR	.00	.73	.87	1.03	1.23	1.47					
METHANOL	MR	.00	.00	77.60	100.33	127.89	161.13					

TOTAL .00 3168.91 1418.29 1804.69 2267.06 2841.65

CUMULATIVE CAPITAL, OVER TOTAL PERIOD 52375.05

**ANNUAL IMPORT AND EXPORT OF ENERGY CARRIERS

	YEAR	0	YEAR	5	YEAR	10	YEAR	15	YEAR	20	YEAR	25
COAL EXPORTS	MTON	23.3	39.6	46.9	50.8	54.9	59.5					
URAN EXPORTS	KTON	6.1	6.7	7.4	8.2	9.1	10.0					
OIL IMPORTS	GLIT	*	*	*	*	*	*					

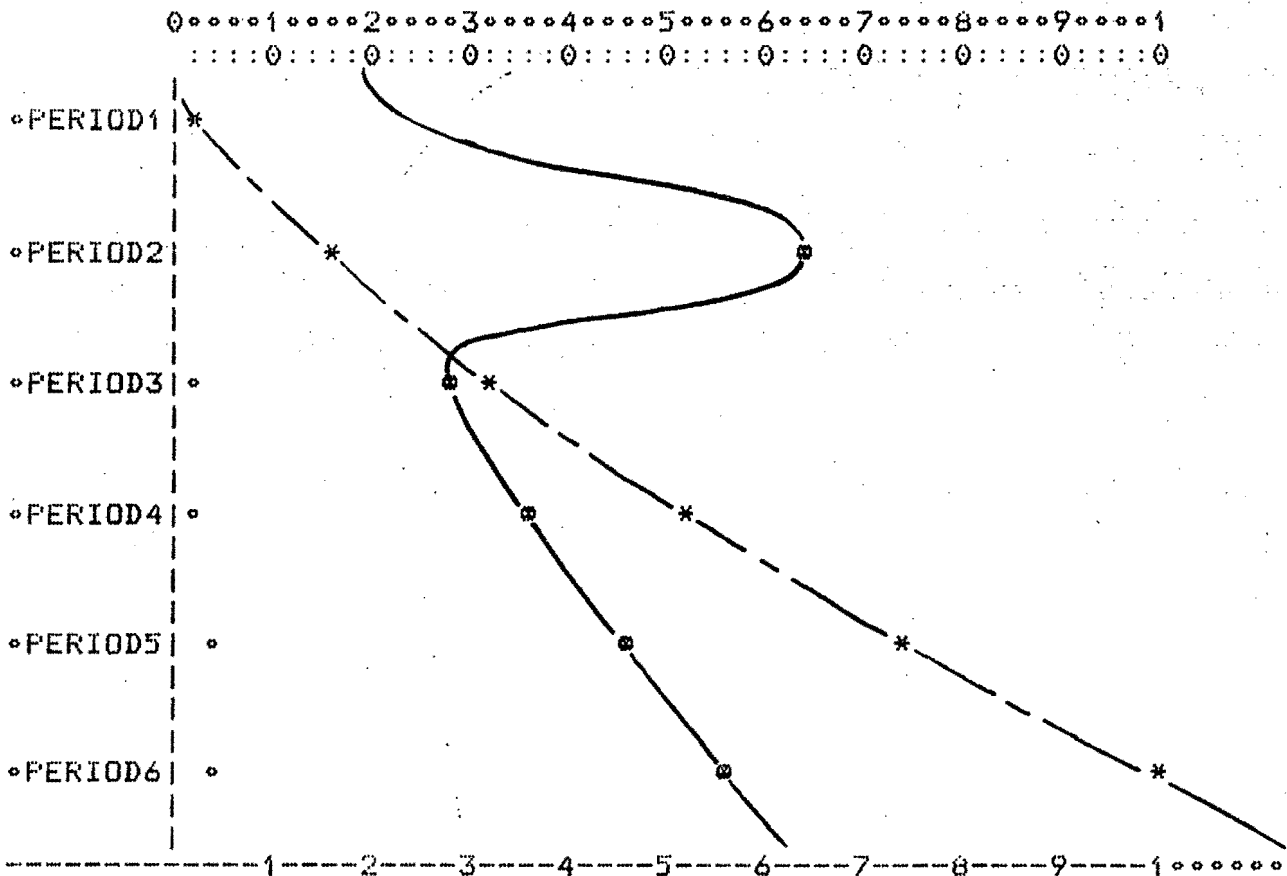
CUMULATIVE USE OF RESOURCES

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
COAL TOTAL	MTON	102.5	759.5	1604.2	2569.0	3679.8	4965.6
COKE COAL T	MTON	6.8	41.1	75.9	111.4	147.7	184.8
URAN TOTAL	KTON	6.1	39.5	77.2	119.0	165.4	217.1
COAL EXPORTS	MTON	23.3	185.3	412.5	658.4	924.6	1212.8
URAN EXPORTS	KTON	6.1	38.5	74.2	113.7	157.3	205.4
OIL IMPORTS	GLIT	*	*	*	*	*	*

GRAPH OF ENERGY AND CAPITAL VALUES

10 PRINTSPACES = 200 UNITS

SCALE::: x 5



LEGEND

* CUMULATIVE COAL	MTON	103	759	1604	2569	3680	4966
o CUMULATIVE URANIUM	KTON	6	39	77	119	165	217
+ OIL IMPORTS (PA)	10MLIT	*	*	*	*	*	*
@ CAPITAL INVESTMENTS	MR	0	3169	1418	1805	2267	2842

BLANK

YEAR	ELEC.	COAL	COKE	PETRO. PROD.	GAS	URAN.	COKE COAL
	10*9KWH	MT	MT	10*9L	10*9M*3	KT	MT
1980	80.4	42.3	.3	*	2.3	6.1	6.8
1985	101.7	65.8	.3	*	2.9	7.8	6.9
1990	130.4	89.9	.4	*	3.7	9.9	7.1
1995	168.9	118.3	.5	*	4.6	12.7	7.3
2000	220.6	155.7	.7	*	5.7	16.2	7.5
2005	290.3	204.7	.8	*	7.1	20.7	7.8

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***FDS99***|TOTAL FINAL DEMAND    ---      ALL ASSUMPTIONS   'LIKELY'  
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SCENARIO OF DEVELOPMENT OF ENERGY SYSTEM IN SOUTH AFRICA
ASSUMING 40% COAL CONVERSION CONTRIBUTION AND 10% NUCLEAR
ELECTRICITY CONTRIBUTION BY 1986; FOLLOWED BY A PROGRAMME TO
ACHIEVE OIL ENERGY INDEPENDENCE BY 2005 BY BUILDING UP TO
50% COAL CONVERSION BY SYNTHOL AND HYDROGENATION AND REPLACING
REMAINING OIL IMPORTS BY METHANOL (50%).
NUCLEAR ELECTRICITY TO SUPPLY 10% ELECTRICITY SUPPLY FROM 1986

1980 COEFFICIENTS: ECOEFFICIENTS:
ASSUMES SMALL NUCLEAR, COAL CONVERSION
CONTRIBUTION.

2005 COEFFICIENTS: ECOEFFIND:
 ASSUMES 50% COAL CONVERSION(SYNTHOL/HYDROG)
 50% METHANOL CONTRIBUTION
 (0% OIL IMPORTS)
 10% NUCLEAR CONTRIBUTION.

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[FDS99] ECOEFFICIENTS/ECOEFFN4S/ECOEFFIND(1980/1986/2005) LIKELY
 **ENERGY FLOW, MEASURED AT 5 YEAR INTERVALS

	YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
ELEC DISTRIB GKWH	96.35	135.00	173.20	223.91	291.42	381.43
COAL ELEGGEN GKWH	99.35	125.62	160.85	207.53	269.58	352.16
HYDRO GEN GKWH	2.19	3.06	3.92	5.06	6.57	8.58
OIL GEN GKWH	.69	.96	1.23	1.58	2.06	2.69
NUCLEAR GEN GKWH	.01	13.58	17.39	22.43	29.14	38.06
URAN MINING KTON	6.11	8.17	10.42	13.31	17.00	21.72
URAN PROCESS TON	.01	72.66	93.04	120.04	155.93	203.69
COAL MINING MTON	103.22	163.77	216.88	282.60	367.89	478.20
COKE PRODUCT MTON	.28	.34	.43	.53	.66	.82
GAS DISTRIB GM*3	3.14	3.52	4.20	4.99	5.95	7.10
FUEL DISTRIB GLIT	*	*	*	*	*	*
OIL REFINING GLIT	*	*	*	*	*	*
COAL CONVERS GLIT	*	*	*	*	*	*
GAS PRODUCT GM*3	3.14	3.10	3.68	4.34	5.12	6.05
COKING COAL MTON	6.81	6.93	7.08	7.28	7.51	7.81
METHANOL GLIT	.01	.01	5.09	12.11	21.60	34.26

**PER ANNUM CAPITAL REQUIREMENTS -- RAND MILLIONS

	YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
ELEC DISTRIB MR	.00	471.67	460.16	611.93	815.19	1087.32
COAL ELEGGEN MR	.00	604.38	819.87	1088.47	1447.54	1927.34
HYDRO GEN MR	.00	14.25	13.77	18.28	24.31	32.37
OIL GEN MR	.00	4.45	4.30	5.71	7.60	10.12
NUCLEAR GEN MR	.00	602.33	158.87	210.92	280.50	373.47
URAN MINING MR	.00	108.33	116.97	149.58	191.30	244.69
URAN PROCESS MR	.00	60.75	16.02	21.27	28.29	37.67
COAL MINING MR	.00	385.36	309.63	400.35	518.80	670.31
COKE PRODUCT MR	.00	.41	.52	.63	.79	.98
GAS DISTRIB MR	.00	1.56	2.81	3.23	3.89	4.70
FUEL DISTRIB MR	.00	21.02	23.76	28.27	33.45	39.54
OIL REFINING MR	.00	37.68	10.88	17.71	26.85	38.81
COAL CONVERS MR	.00	1541.14	376.58	468.03	579.23	715.33
GAS PRODUCT MR	.00	.29	2.35	2.67	3.18	3.78
COKING COAL MR	.00	.94	1.17	1.46	1.82	2.26
METHANOL MR	.00	.00	442.25	605.67	814.79	1080.93

TOTAL .00 3778.63 2738.15 3598.77 4723.83 6191.99
 CUMULATIVE CAPITAL, OVER TOTAL PERIOD 94256.98

**ANNUAL IMPORT AND EXPORT OF ENERGY CARRIERS

	YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
COAL EXPORTS MTON	23.3	39.6	53.1	67.1	84.8	107.2
URAN EXPORTS KTON	6.1	7.8	9.9	12.7	16.2	20.7
OIL IMPORTS GLIT	*	*	*	*	*	*

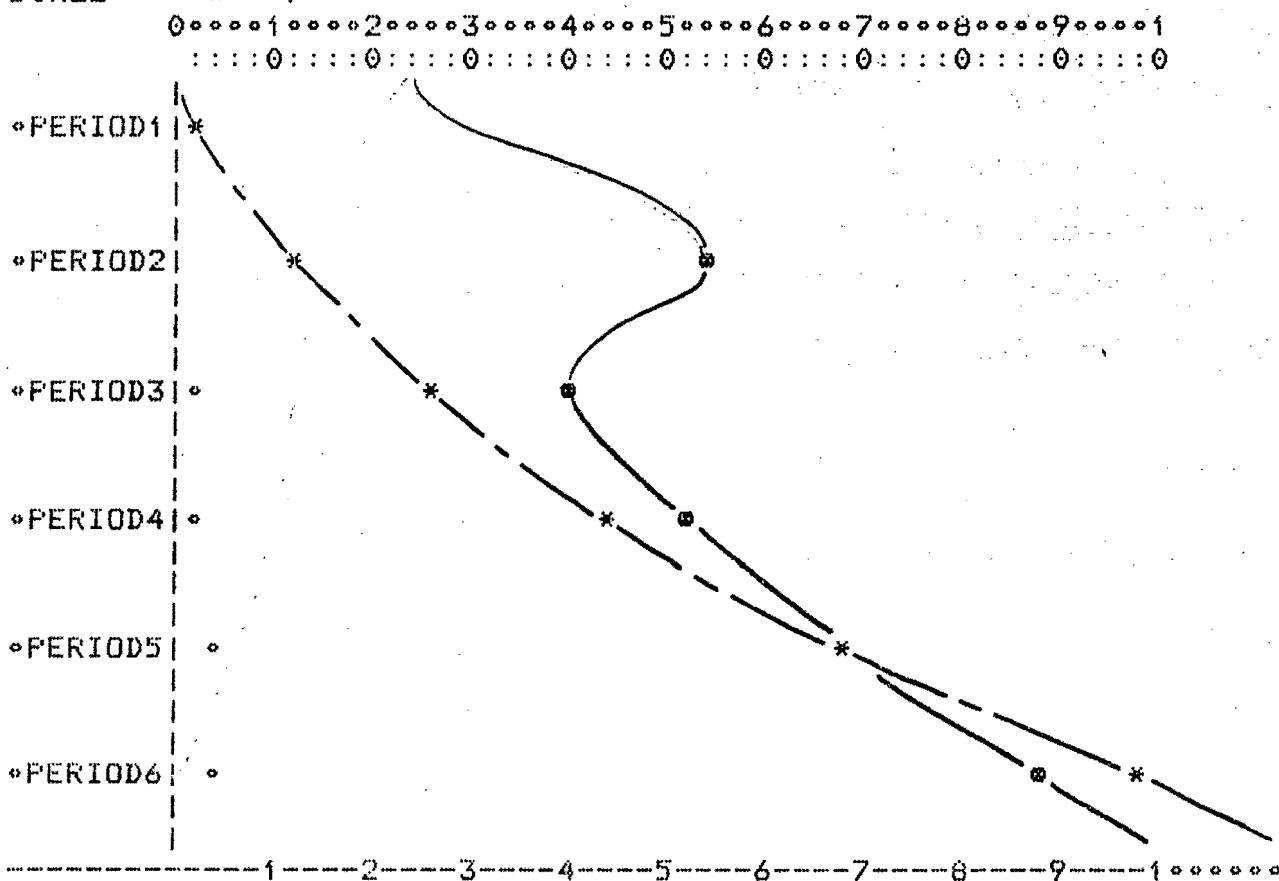
**CUMULATIVE USE OF RESOURCES

		YEAR 0	YEAR 5	YEAR 10	YEAR 15	YEAR 20	YEAR 25
COAL TOTAL	MTON	103.2	791.8	1769.3	3043.9	4703.9	6863.0
COKE COAL T	MTON	6.8	41.2	76.3	112.2	149.3	187.7
URAN TOTAL	KTON	6.1	42.6	89.9	150.4	227.6	326.3
COAL EXPORTS	MTON	23.3	185.3	427.5	733.6	1120.6	1609.8
URAN EXPORTS	KTON	6.1	41.5	86.7	144.3	217.9	311.8
OIL IMPORTS	GLIT	*	*	*	*	*	*

**GRAPH OF ENERGY AND CAPITAL VALUES

10 PRINTSPACES = 200 UNITS

SCALE::: x 7



LEGEND

* CUMULATIVE COAL	MTON	103	792	1769	3044	4704	6863
* CUMULATIVE URANIUM	KTON	6	43	90	150	228	326
+ OIL IMPORTS (PA)	10MLIT	*	*	*	*	*	0
@ CAPITAL INVESTMENTS	MR	0	3779	2738	3599	4724	6192

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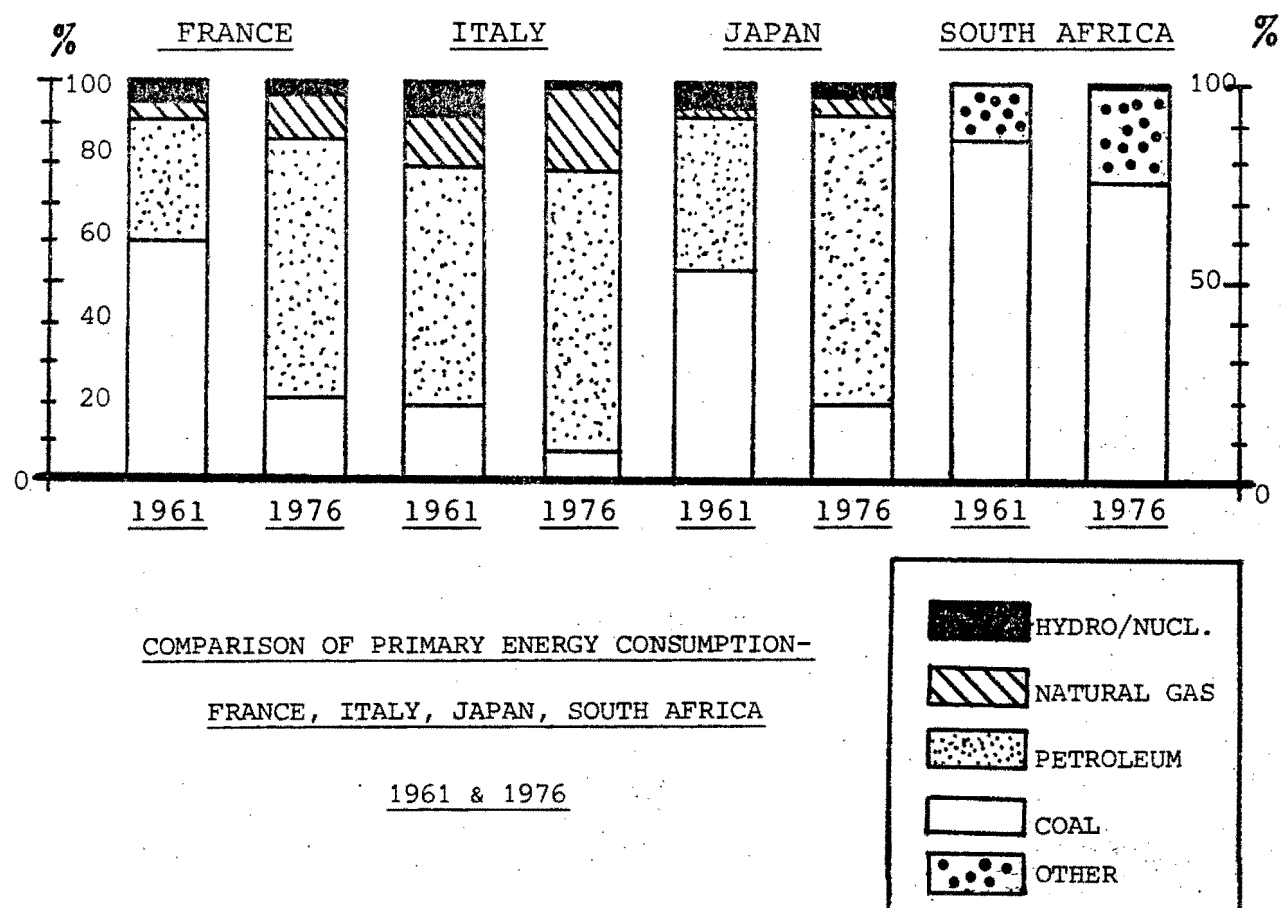


Fig 1.1

SELLING INDUSTRIES	INTERMEDIATE DEMAND						FINAL DEMAND				TOTAL OUTPUT
	1	2	...	j		N	1	2	3	4	
1	x_{11}	x_{12}	...	x_{1j}	...	x_{1N}	f_{11}	f_{12}	f_{13}	f_{14}	x_1
2	x_{21}	x_{22}	...	x_{2j}	...	x_{2N}	f_{21}	f_{22}	f_{23}	f_{24}	x_2
...	...	...	...	...	...	...	...	...	...	...	...
i	x_{i1}	x_{i2}	...	x_{ij}	...	x_{iN}	f_{i1}	f_{i2}	f_{i3}	f_{i4}	x_i
...	...	...	...	...	...	...	...	...	...	...	...
N	x_{N1}	x_{N2}	...	x_{Nj}	...	x_{NN}	f_{N1}	f_{N2}	f_{N3}	f_{N4}	x_N
VALUE ADDED	V_1	V_2	...	V_j	...	V_N					

EXAMPLE OF AN INPUT/OUTPUT TABLE

Fig 1.2

FOOP

36 49

YR	ACTUAL	FORECAST	o/o	▽		▽	▽
46	1939.0	1939.0	.0		•		
47	1994.0	2033.8	2.0		•		
48	2207.0	2185.6	-1.0		•		
49	2471.0	2379.4	-3.7		•		
50	2818.0	2858.5	1.4		•		
51	2995.0	3193.7	6.6		•		
52	3323.0	3535.7	6.4		•		
53	3444.0	3847.6	11.7		•		
54	3890.0	4183.2	7.5		•		
55	4503.0	4558.8	1.2		•		
56	4852.0	5048.4	4.0		•		
57	6204.0	5546.8	-10.6		•		
58	6478.0	6117.7	-5.6		•		
59	6758.0	6774.0	.2		•		
60	7202.0	7434.6	3.2		•		
61	7751.0	8093.2	4.4		•		
62	8801.0	8780.2	-.2		•		
63	10337.0	9484.3	-8.2		•		
64	10536.0	10307.3	-2.2		•		
65	11069.0	11188.9	1.1		•		
66	12397.0	12241.6	-1.3		•		
67	13676.0	13299.1	-2.8		•		
68	15446.0	14322.6	-7.3		•		
69	16951.0	15491.2	-8.6		•		
70	19192.0	16771.0	-12.6		•		
71	20739.0	18046.5	-13.0		•		
72	23287.0	19512.0	-16.2		•		
73	26013.0	20568.0	-20.9		•		

74	28933.0	22789.9	-21.2		•		
75	32010.0	26179.7	-18.2		•		
76	35114.0	30840.5	-12.2		•		
77	36506.0	36024.3	-1.3		•		
78	38424.0	42362.8	10.3		•		

Δ o/o NEG E POS o/o Δ

UNITS : GIGAWATT HOURS

DEMAND FOR ELECTRICITY BY INDUSTRY

AS A FUNCTION OF ENERGY PRICES AND LAGGED VALUES
OF DEMAND

Fig 1.3

ENERGY SUPPLY INDUSTRIESINTERMEDIATE
DEMANDFINAL DEMAND
SECTORSTOTAL
OUTPUTOUTPUT
INCREASECAPITAL
INVESTMENT

ED	CG	HG	OG	NG	UM	UP	CM	CP	GD	FD	OR	SC	GP	CC	MP
ELECTRICITY DISTRIBUTION	ED														
COAL ELEC. GENERATION	CG														
HYDRO ELEC. GENERATION	HG														
OIL ELEC. GENERATION	OG														
NUCLEAR ELEC. GENERATION	NG														
URANIUM MINING	UM														
URANIUM PROCESSING	UP														
COAL MINING	CM														
COKE PRODUCTION	CP														
GAS DISTRIBUTION	GD														
FUEL DISTRIBUTION	FD														
OIL REFINERIES	OR														
COAL CONVERSION	SC														
GAS PRODUCTION	GP														
COKING COAL	CC														
METHANOL PRODUCTION	MP														

DIMENSION: 16x16x26

16x26

16x9x26

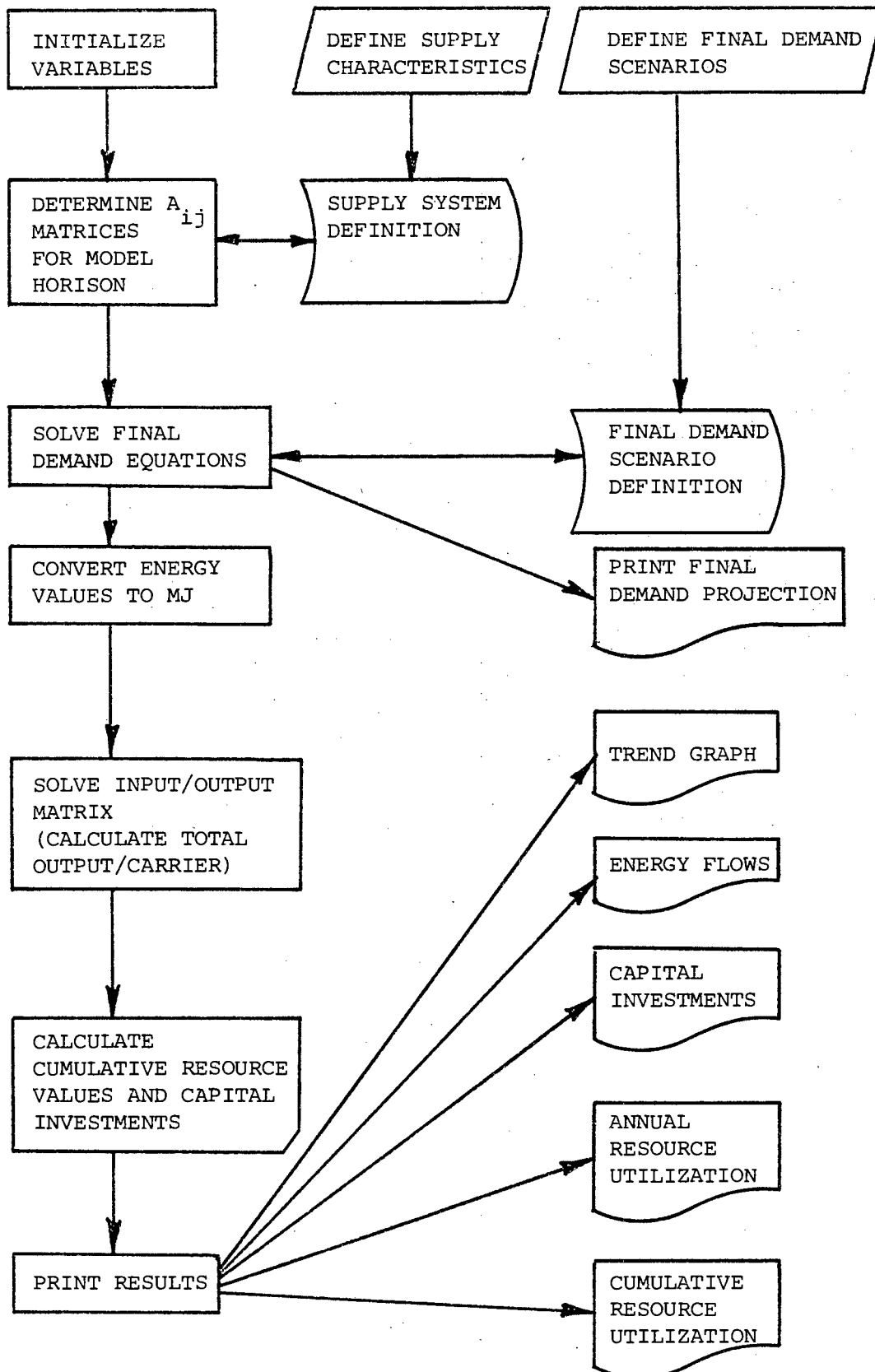
16x26

16x26

16x26

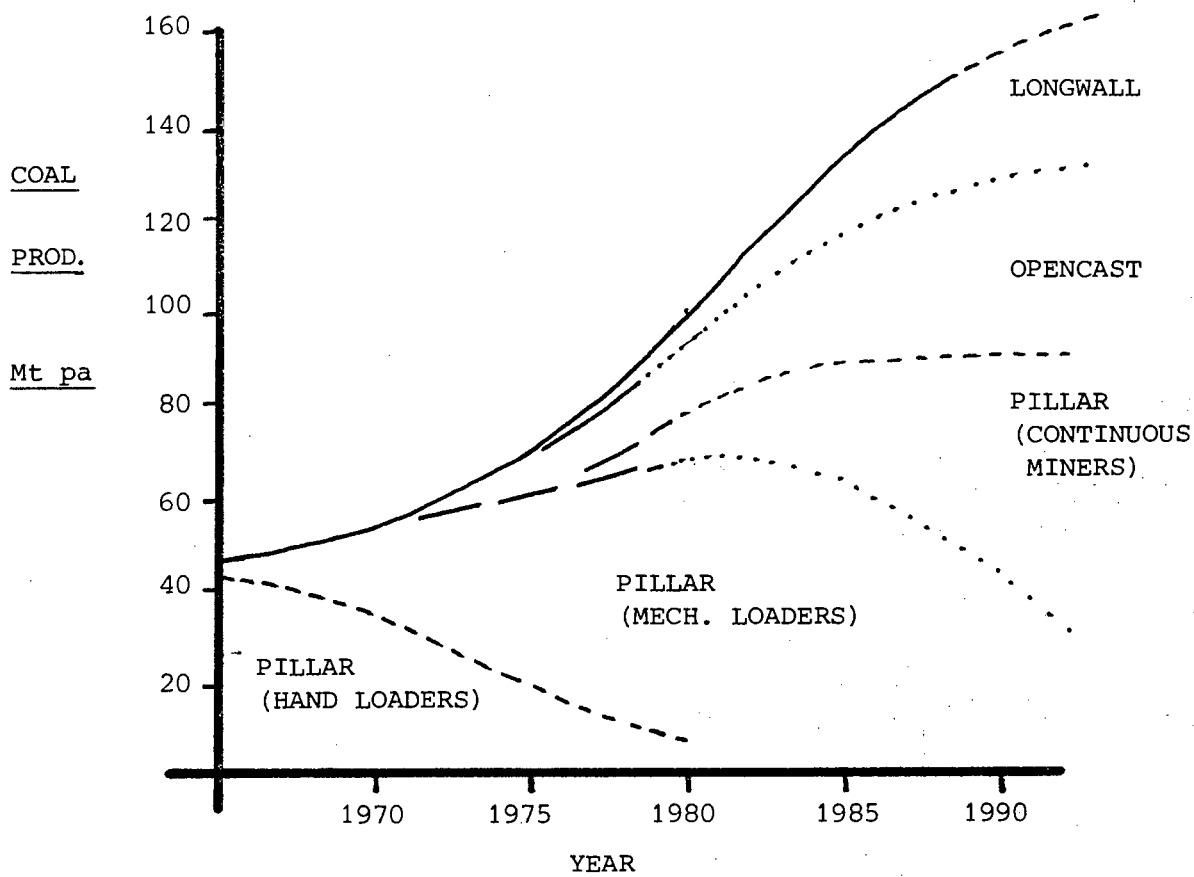
SUPPLY MODELDEMAND MODELSOUTPUTSTRUCTURE OF THE SUPPLY/DEMAND MODEL

Fig 1.4



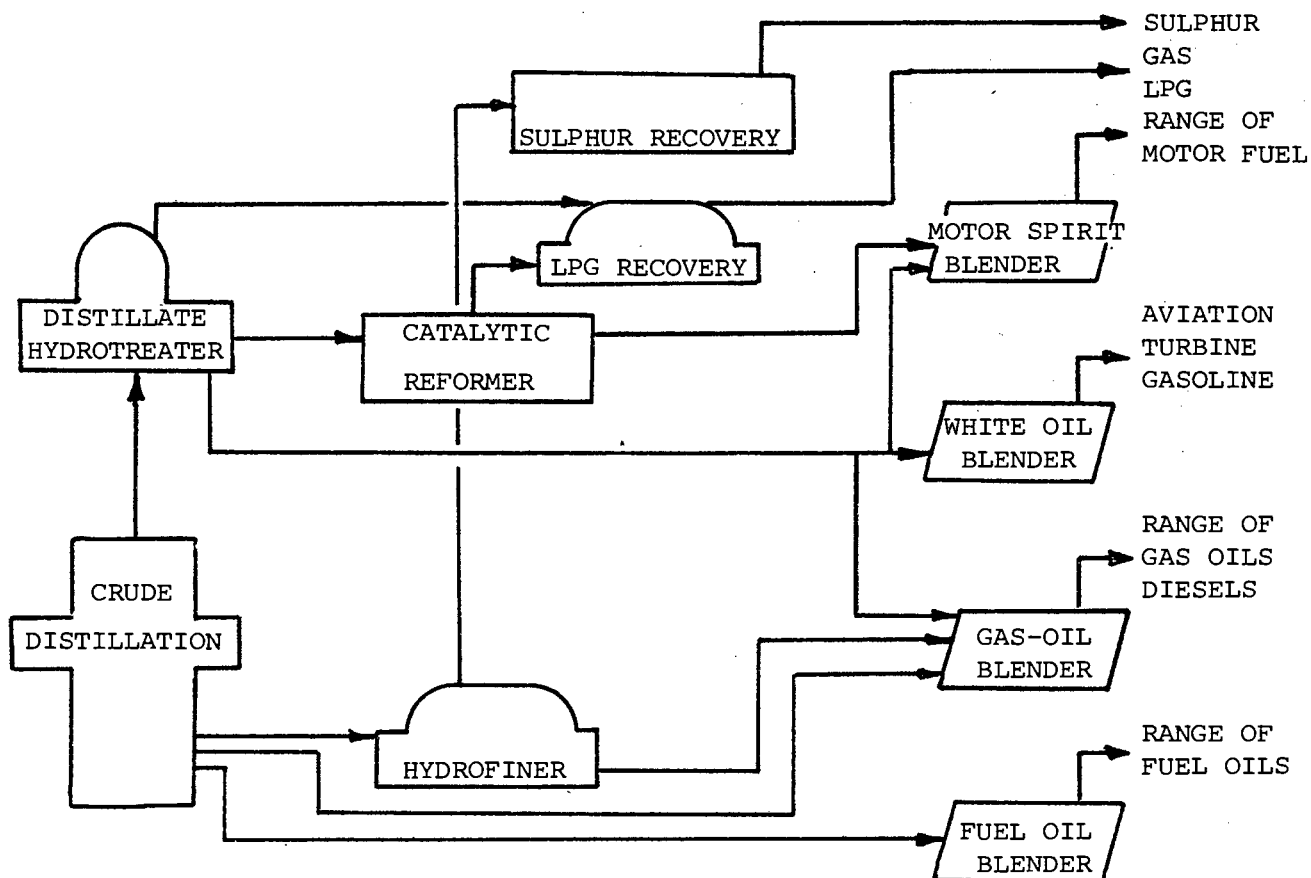
FLOW DIAGRAM ILLUSTRATING THE PROCESSING STEPS
OF THE ENERGY MODEL

FIGURE 1.5



FORECAST OF ANNUAL COAL PRODUCTION IN SOUTH AFRICA:
SHOWING TRENDS FOR DIFFERENT MINING METHODS

FIG 2.1



REFINERY OIL FLOW DIAGRAM

FIG 2.2

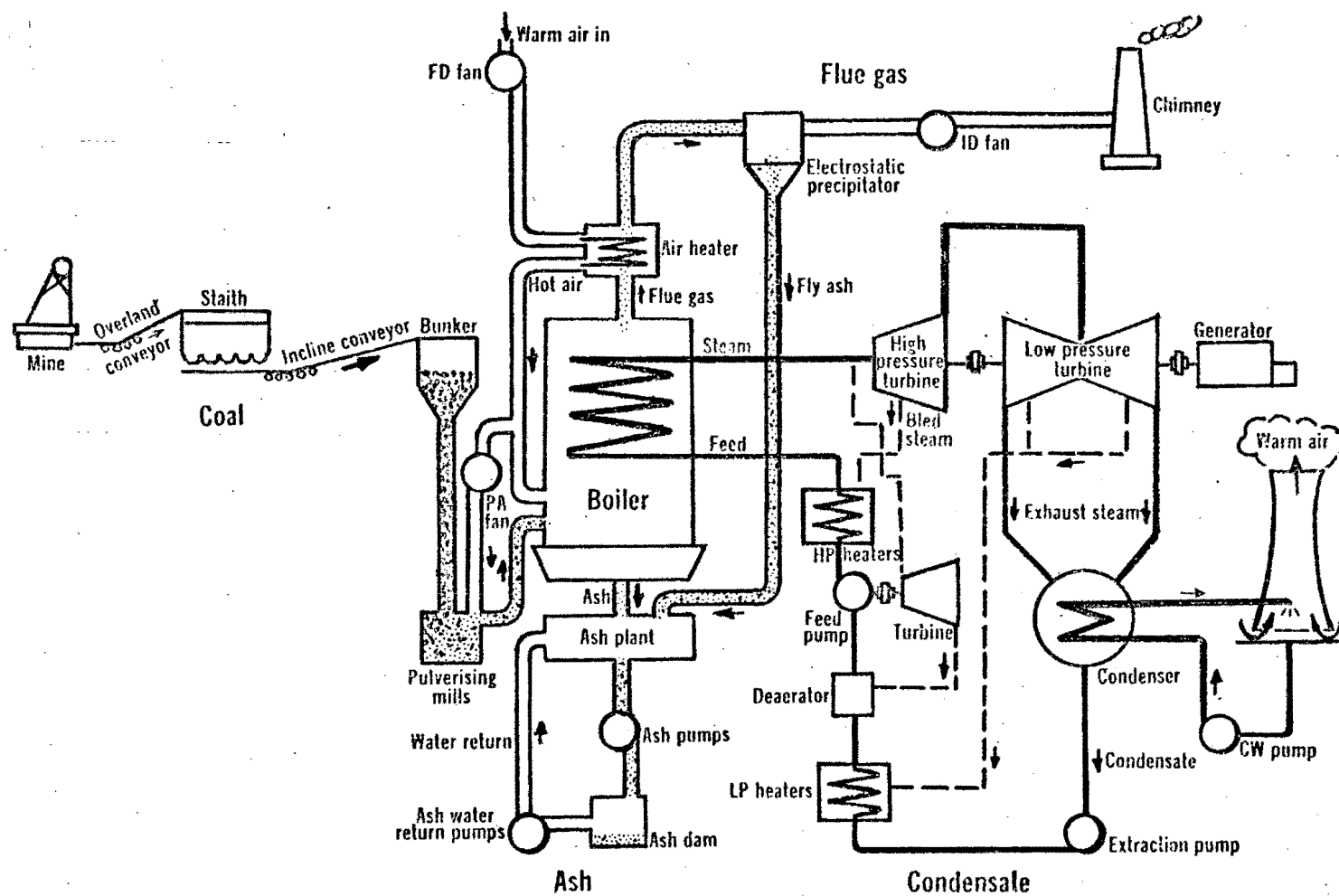
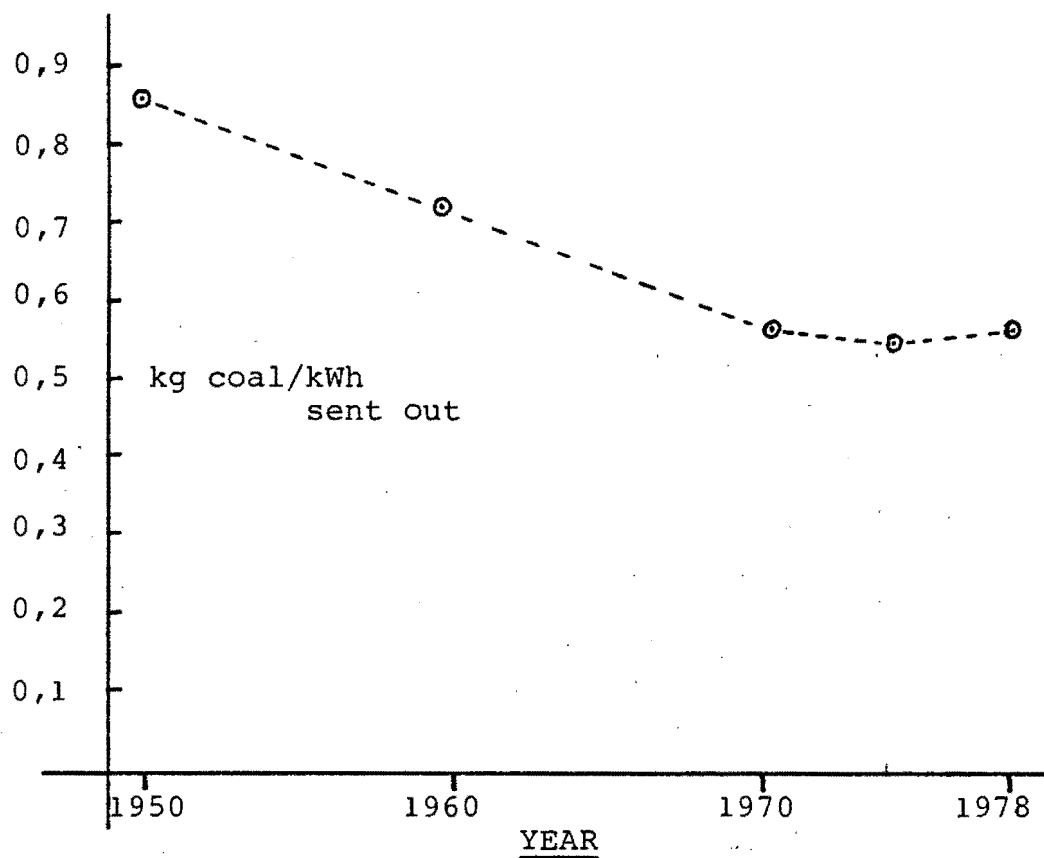


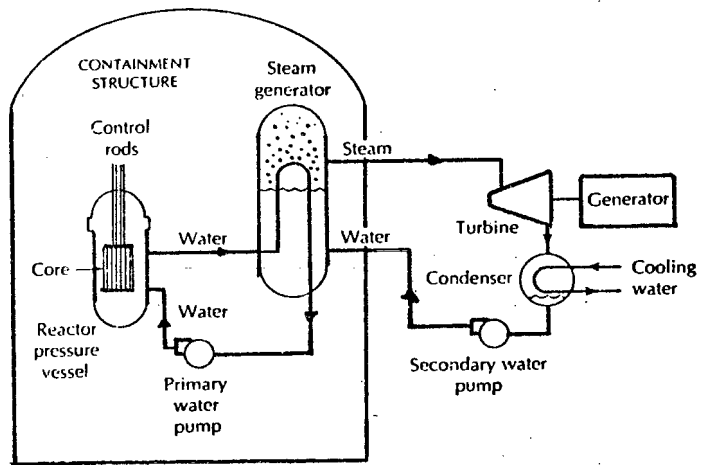
Fig 2.3

FLOW DIAGRAM - COAL FIRED POWER STATION

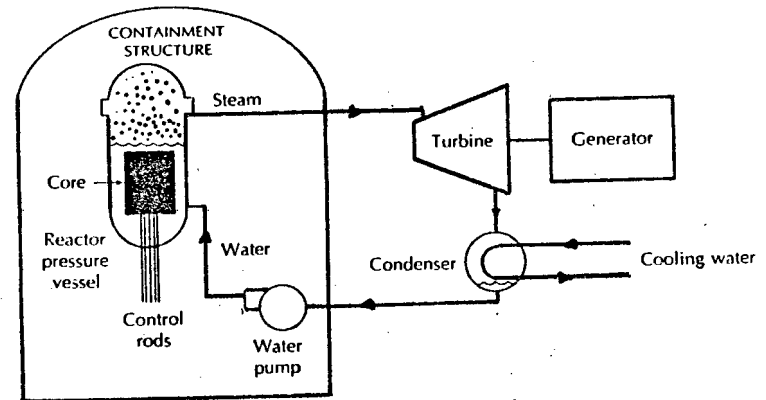


kg coal/kWh elec sent out TREND FOR
ELECTRICITY GENERATION IN SOUTH AFRICA

FIG 2.4



PRESSURIZED WATER REACTOR (PWR)



BOILING WATER REACTOR (BWR)

EXAMPLES OF LIGHT WATER NUCLEAR FISSION REACTORS

FIG 2.5

Fig 2.5

FIG 3.1

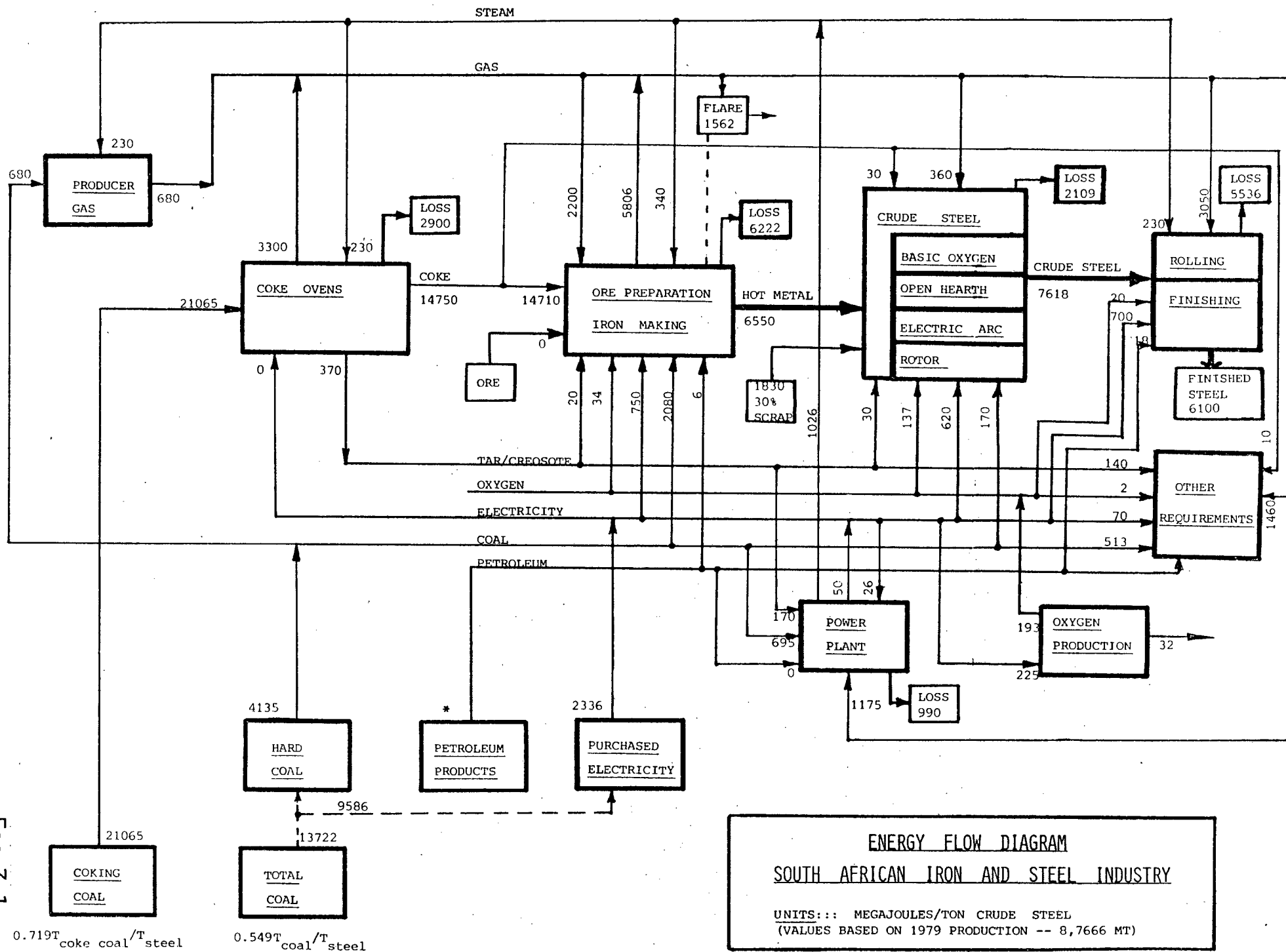
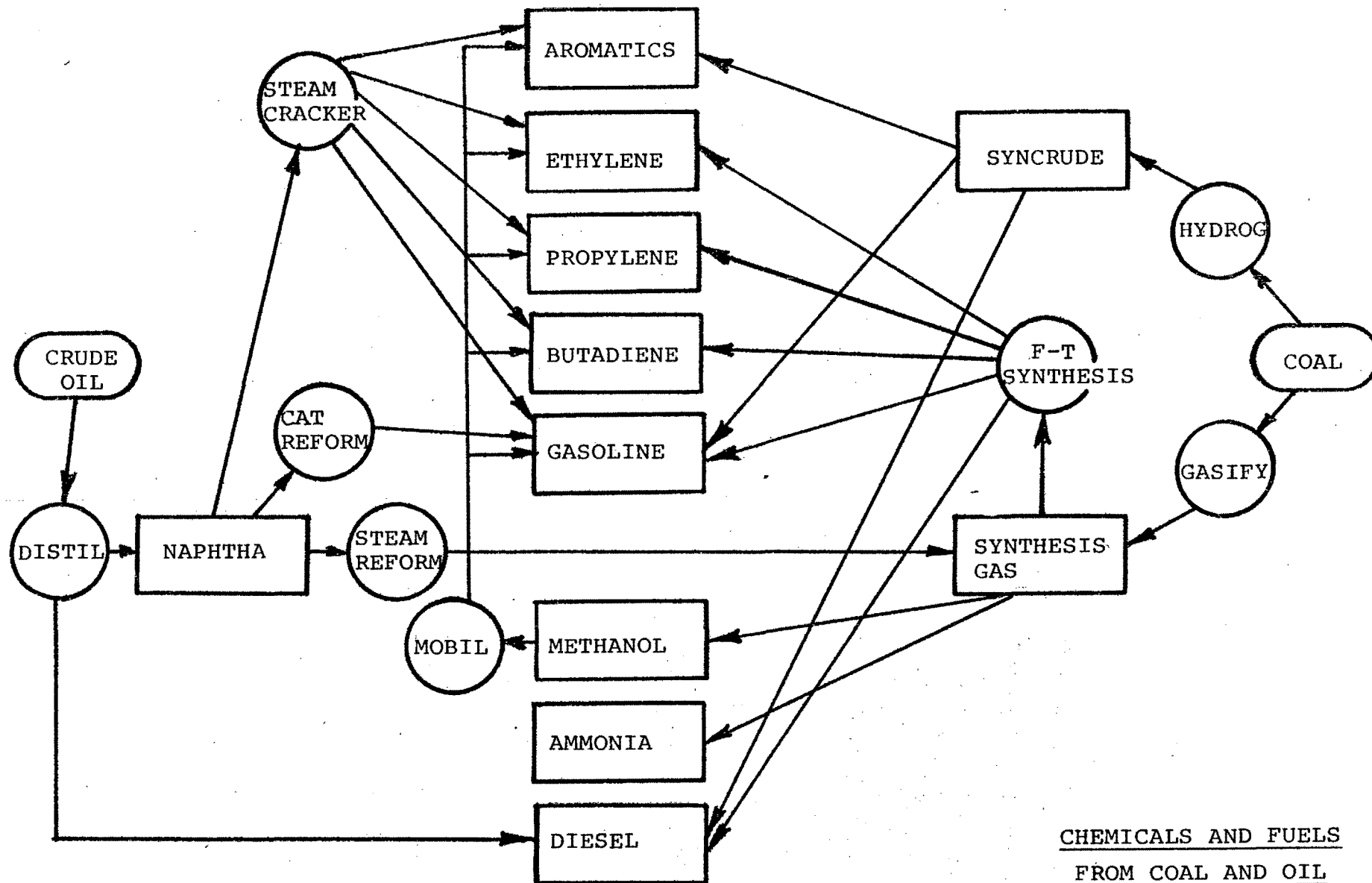


FIGURE 3.1



CHEMICALS AND FUELS
FROM COAL AND OIL

FIGURE 4.1

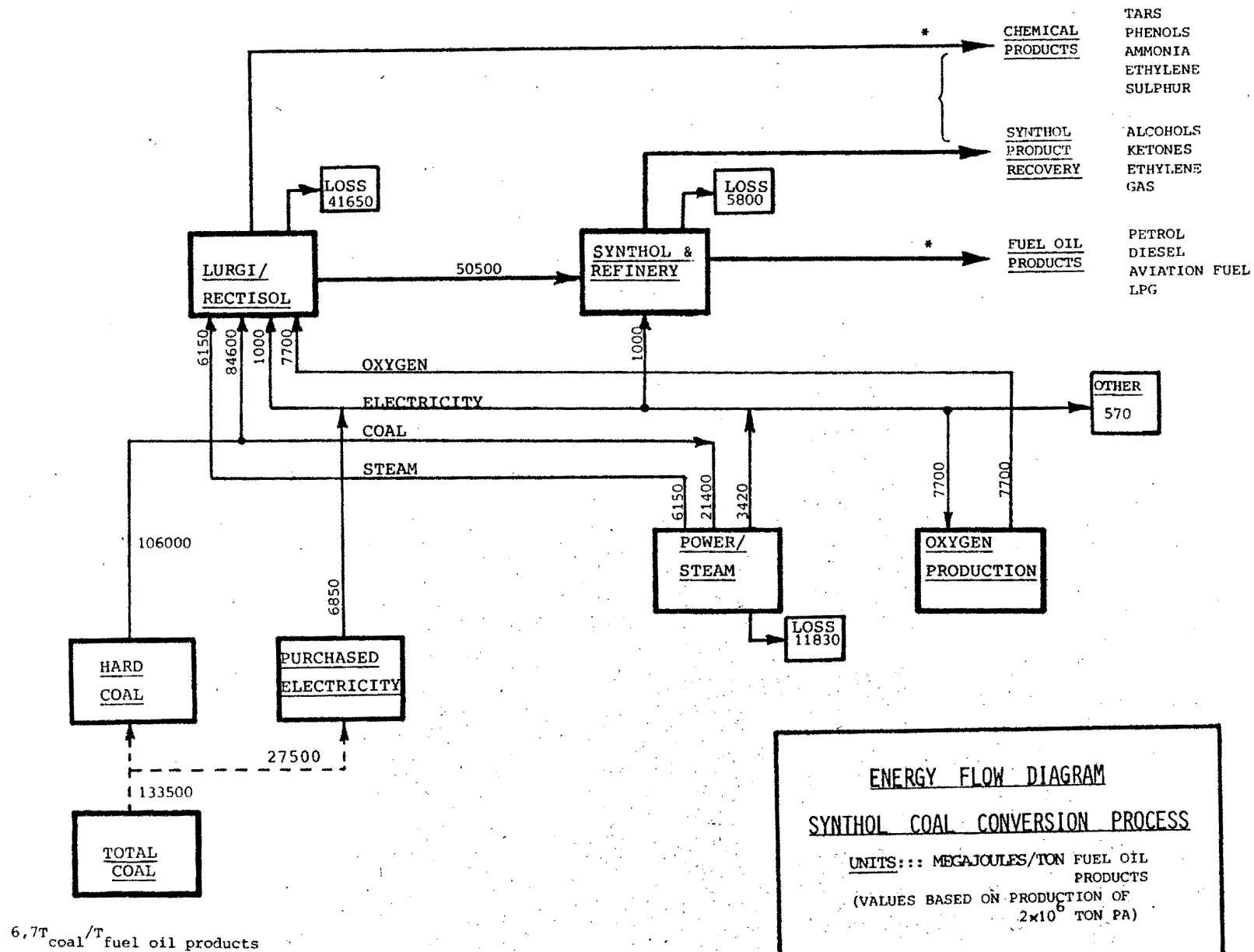
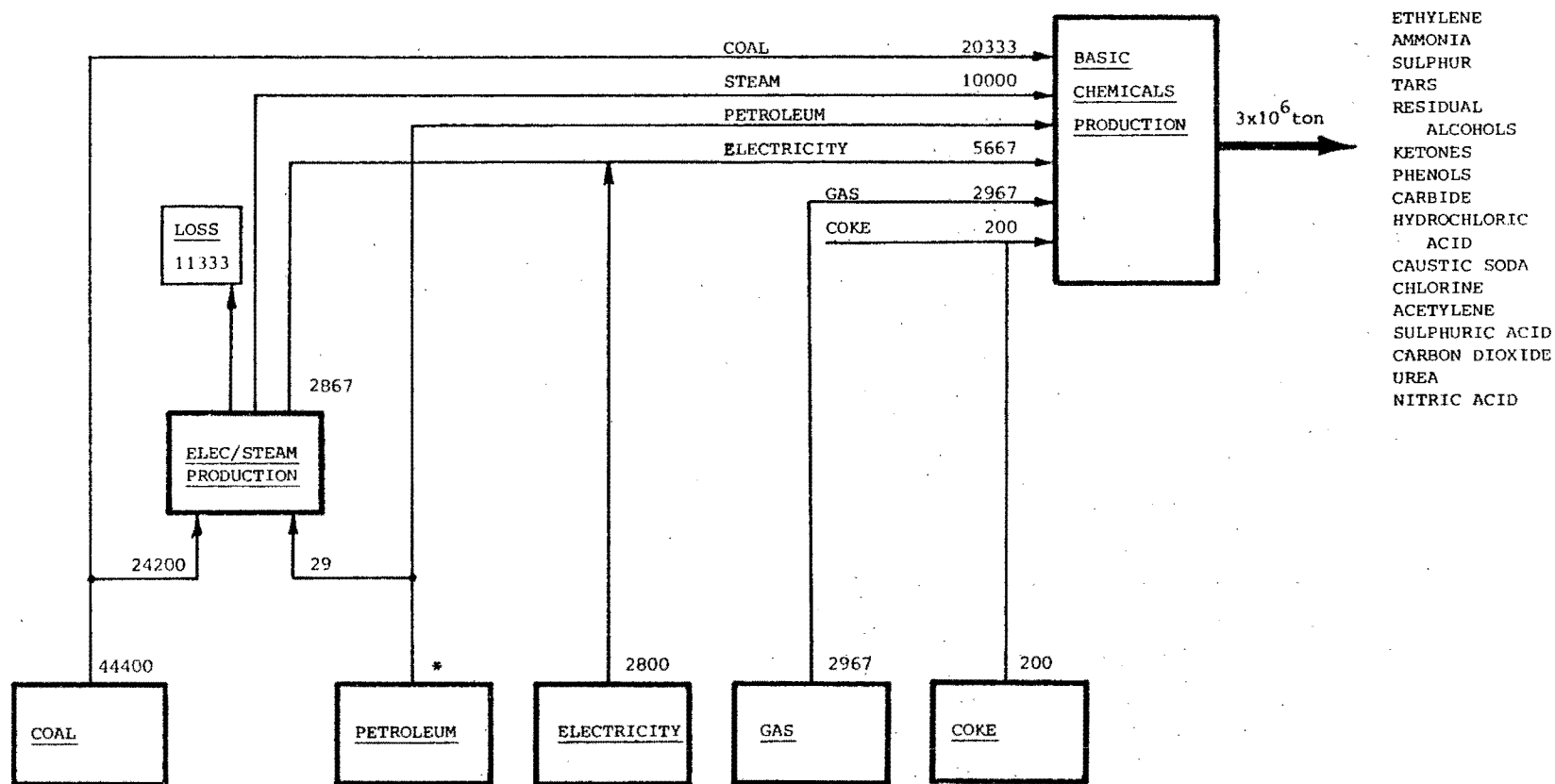


FIGURE 4.2

6.7T_{coal}/T_{fuel oil products}



ENERGY FLOW DIAGRAM SOUTH AFRICAN BASIC CHEMICALS INDUSTRY

UNITS::: MEGAJOULES/TON FINAL PRODUCTS (TOTAL)
(VALUES BASED ON TOTAL PRODUCTION OF 3×10^6 TONS--
--ALL PRODUCTS)

FIGURE 4.3

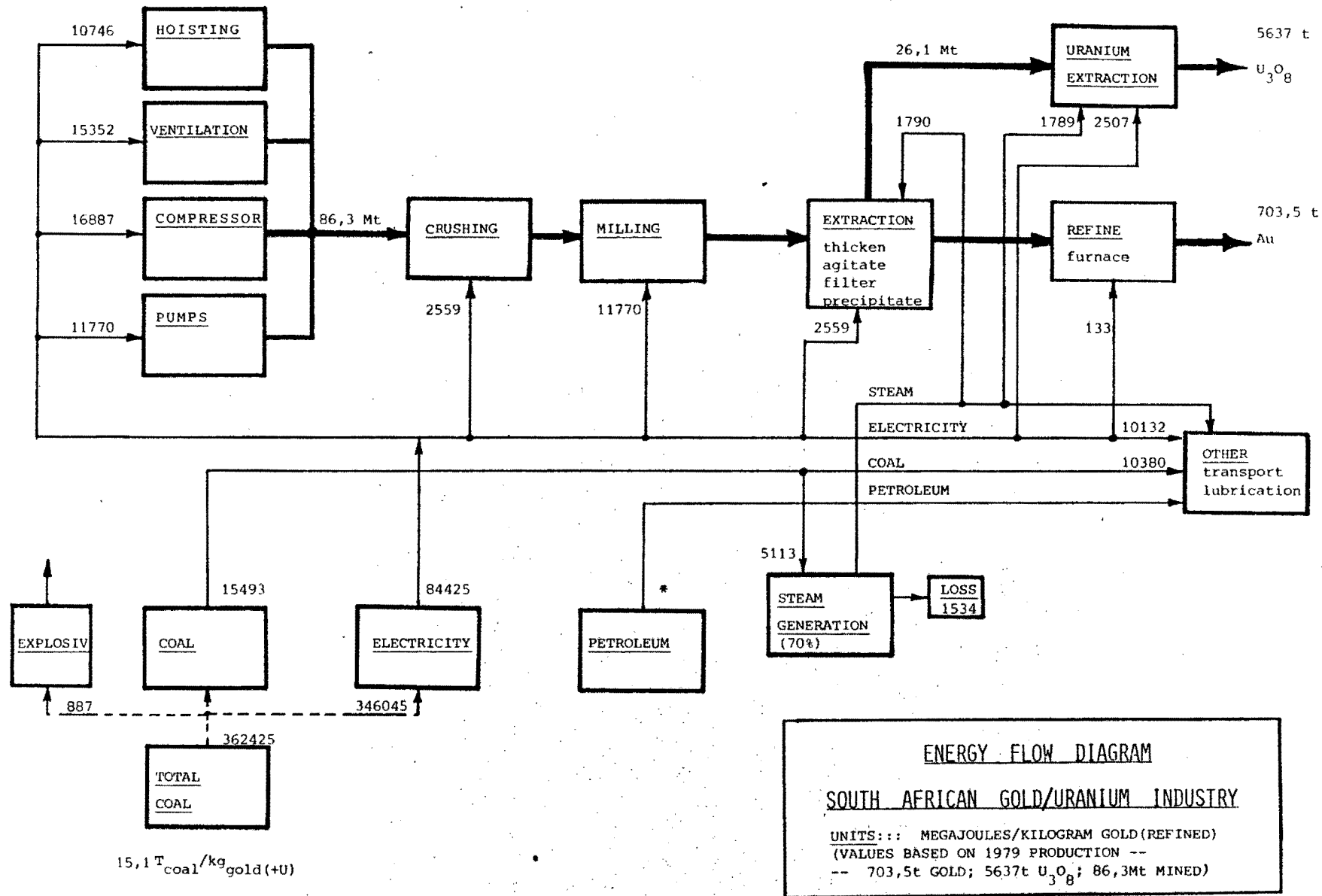


FIGURE 5.1

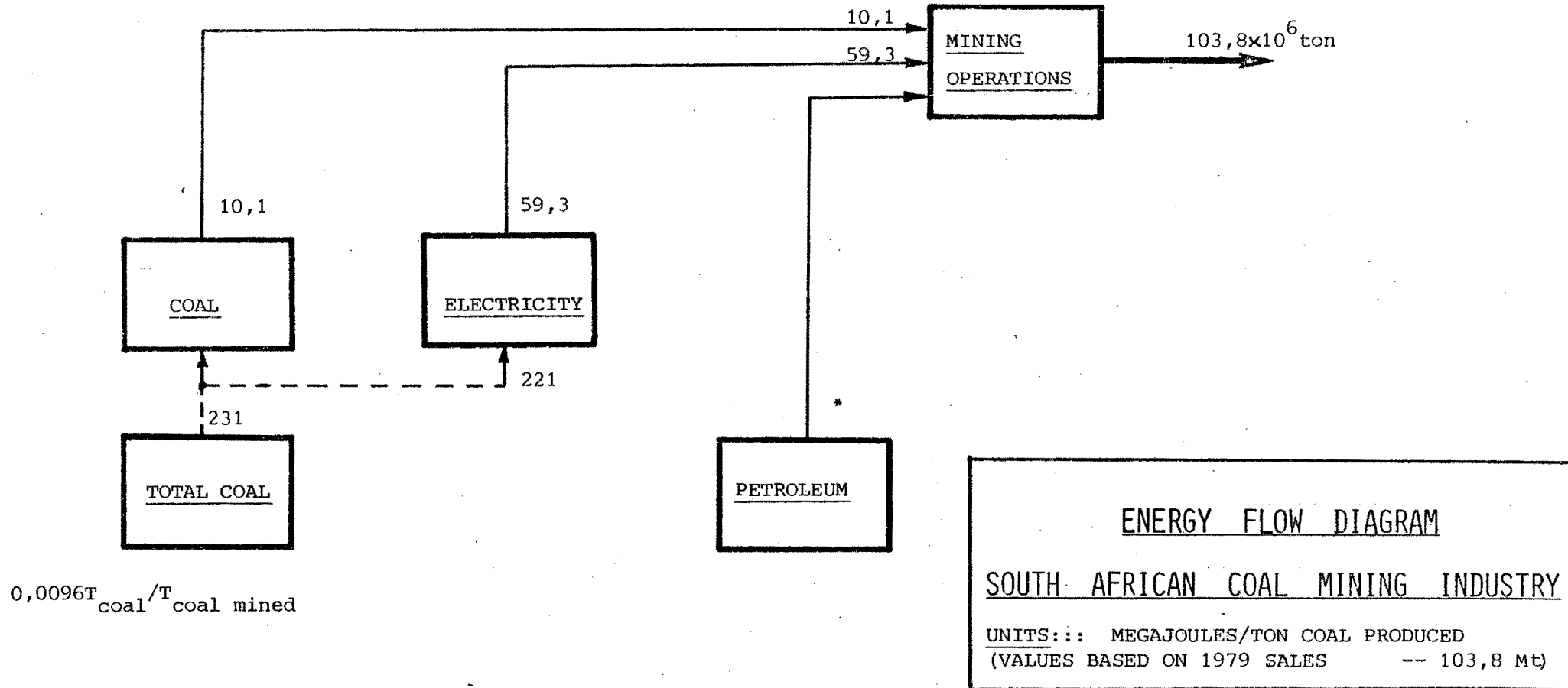
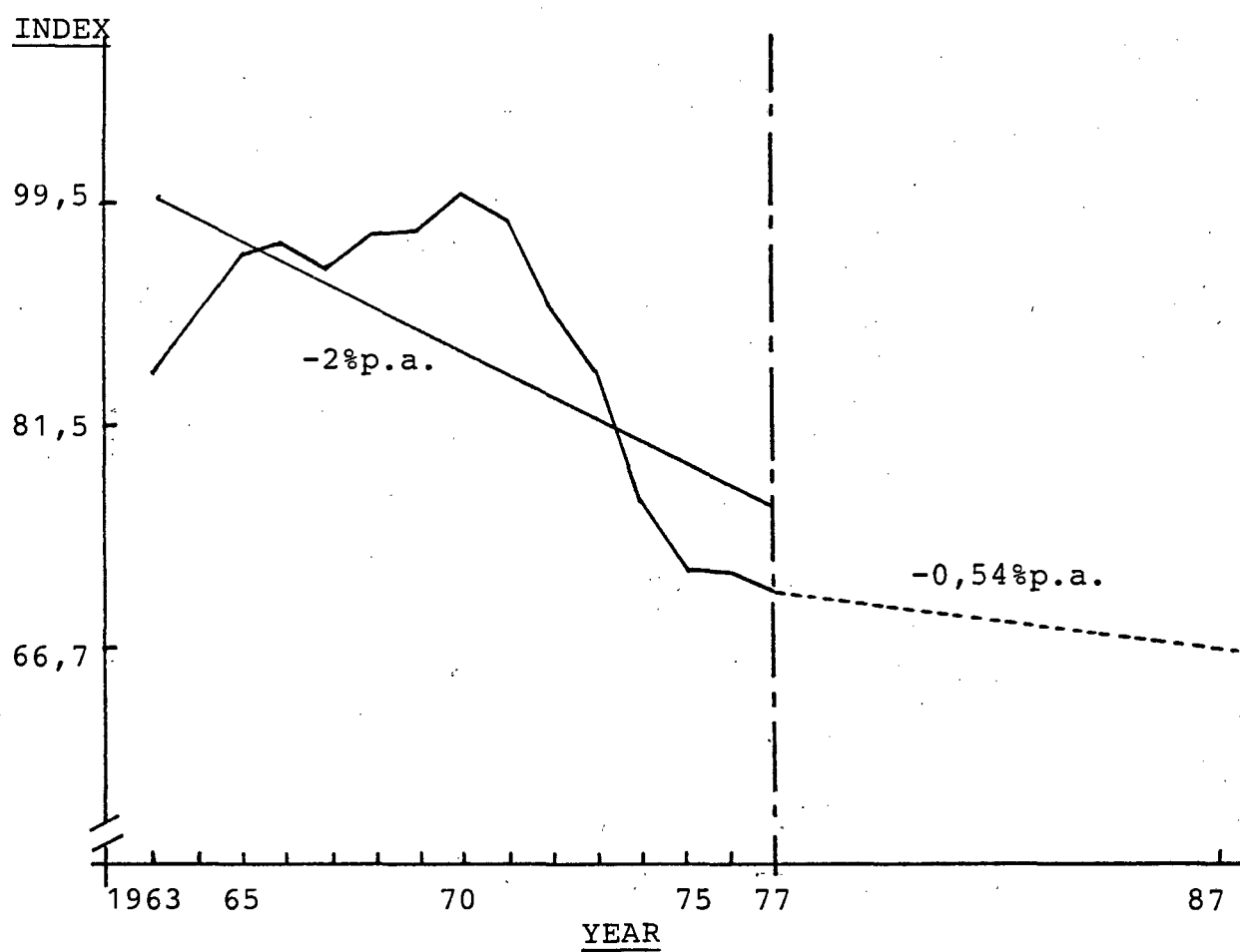


Fig 5.2



CHANGES IN THE PRODUCTION OF GOLD
ANNUAL OUTPUT 1963-1987
(1970 = 100)

Fig 5.3

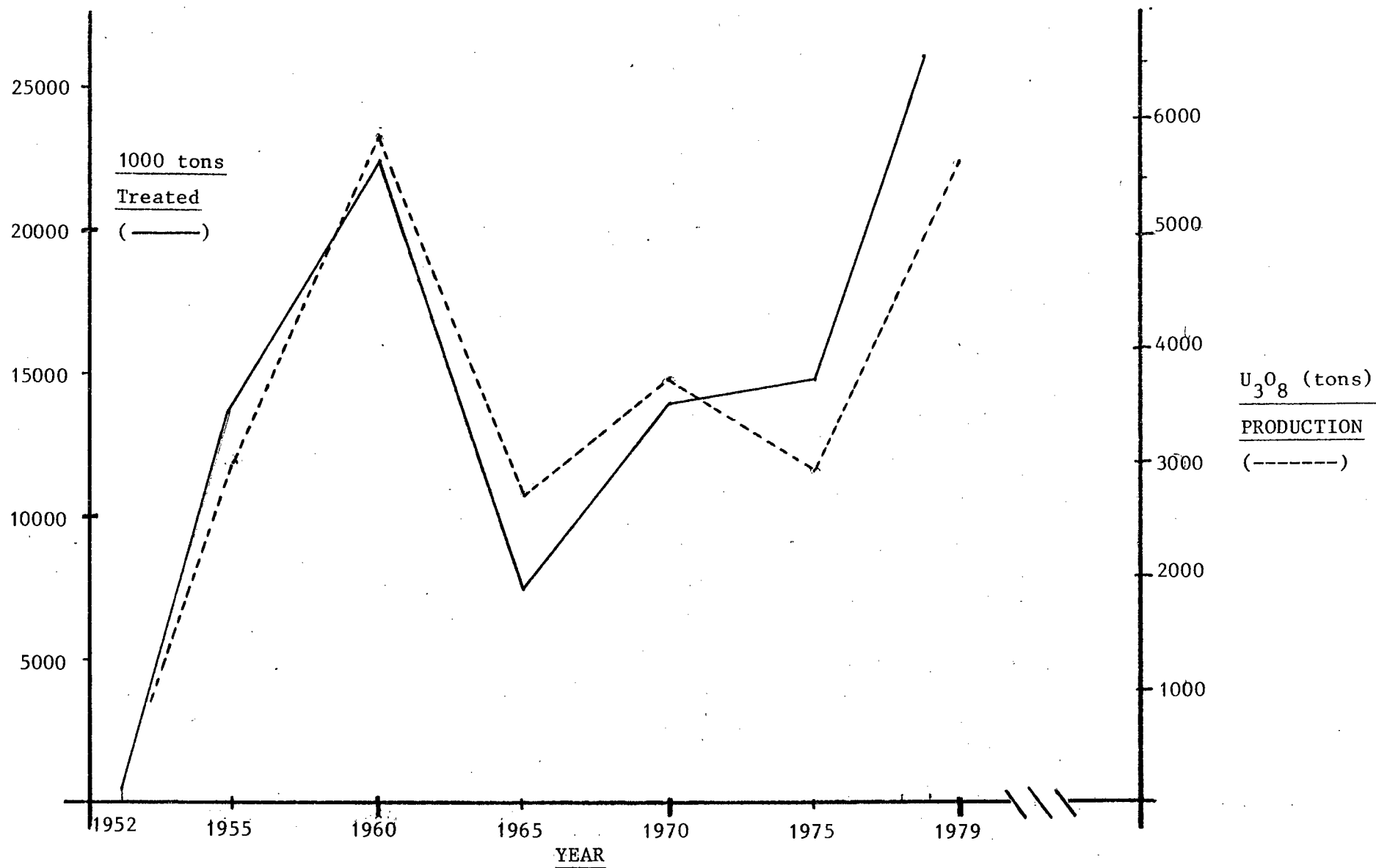
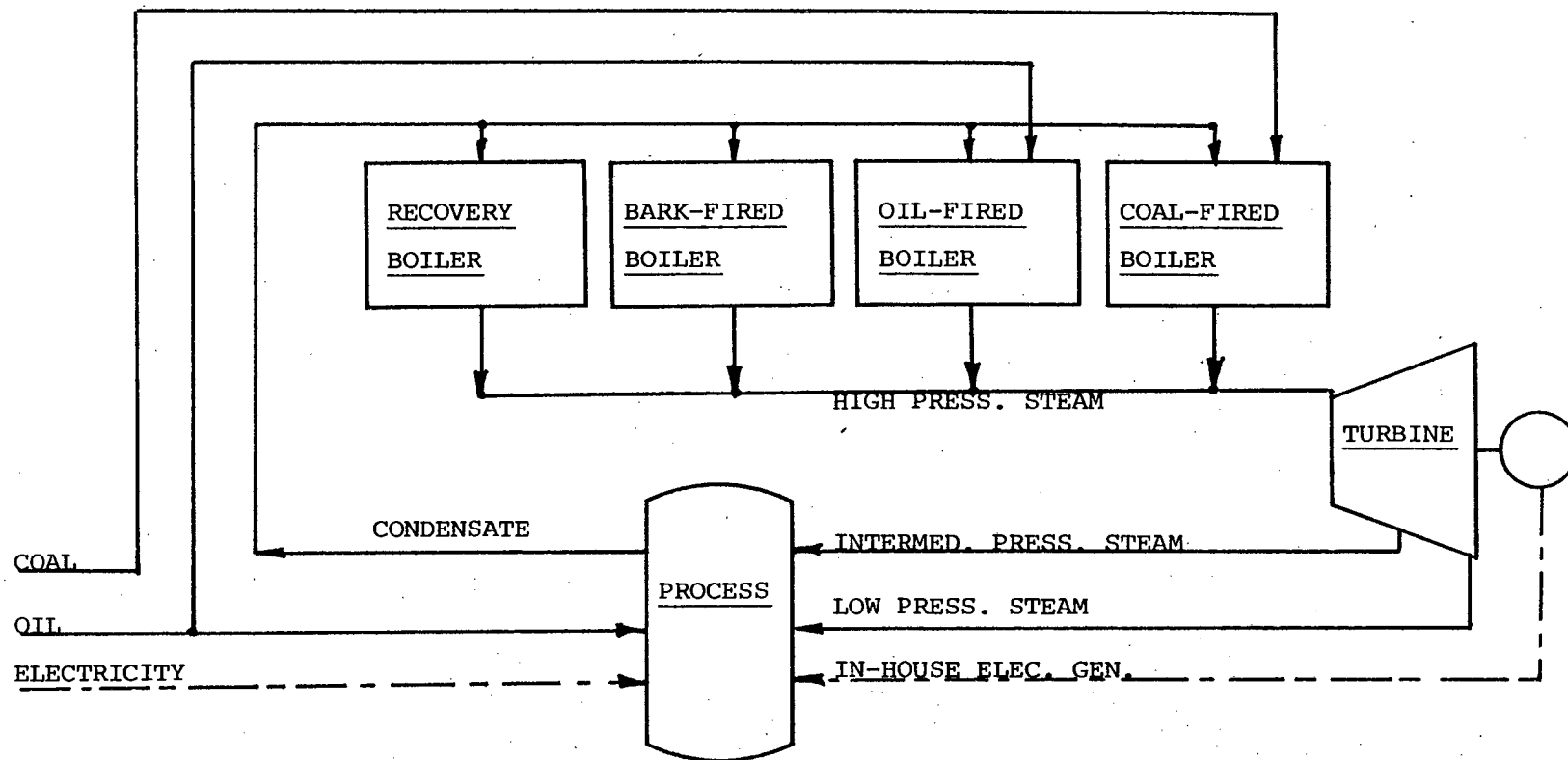


FIG 5.4

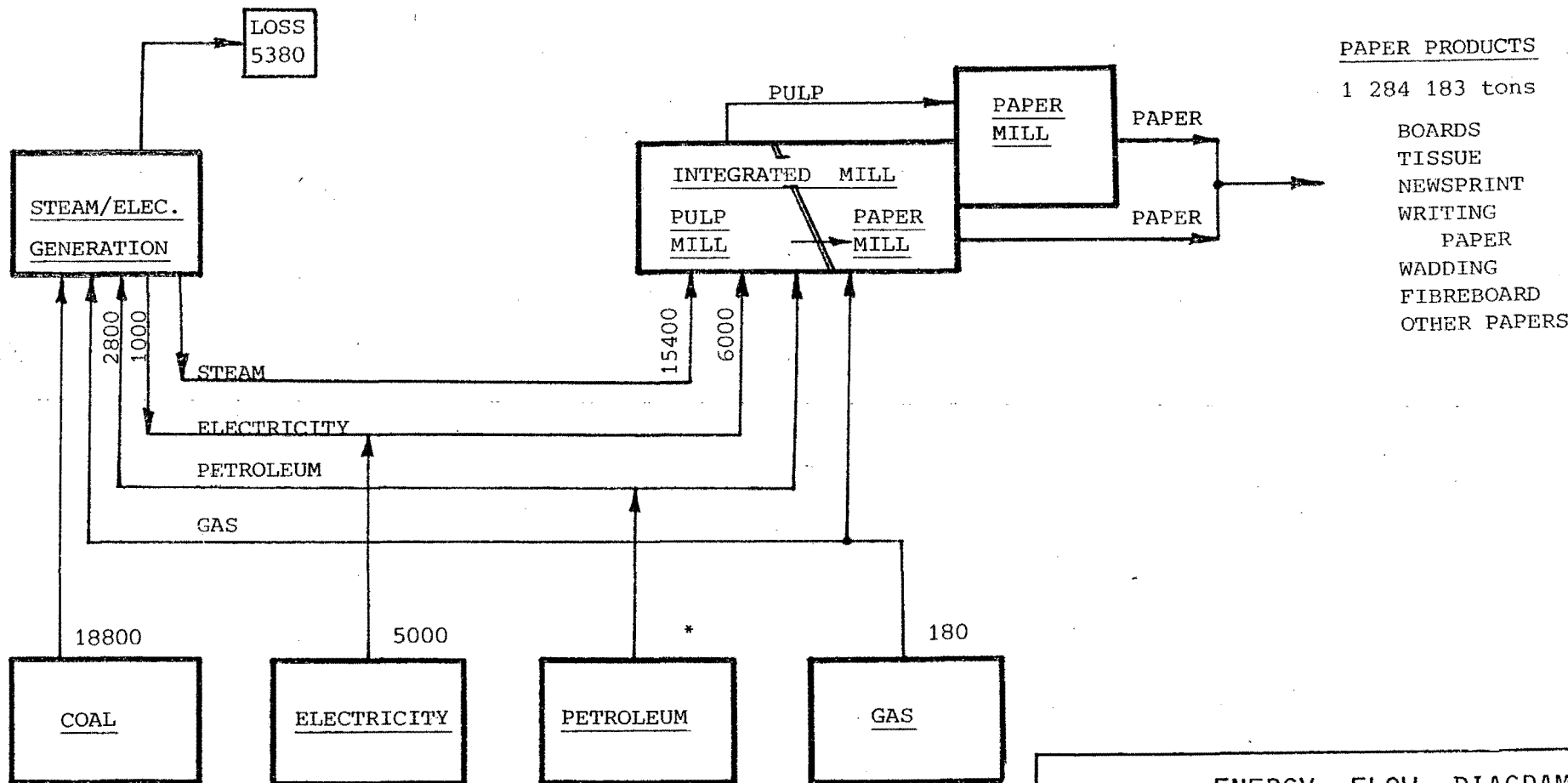
SOUTH AFRICAN URANIUM PRODUCTION 1952-1979

1000Tons treated (—) and Tons produced (---)



ENERGY SYSTEM IN A SULPHATE PULP MILL

Fig 6.1



ENERGY FLOW DIAGRAM
SOUTH AFRICAN PULP & PAPER INDUSTRY
 UNITS::: MEGAJOULES/TON PAPER PRODUCED
 (VALUES BASED ON 1978 SURVEY; 1980 OUTPUT
 ESTIMATED 1 284 183 TONS)

Fig 6.2

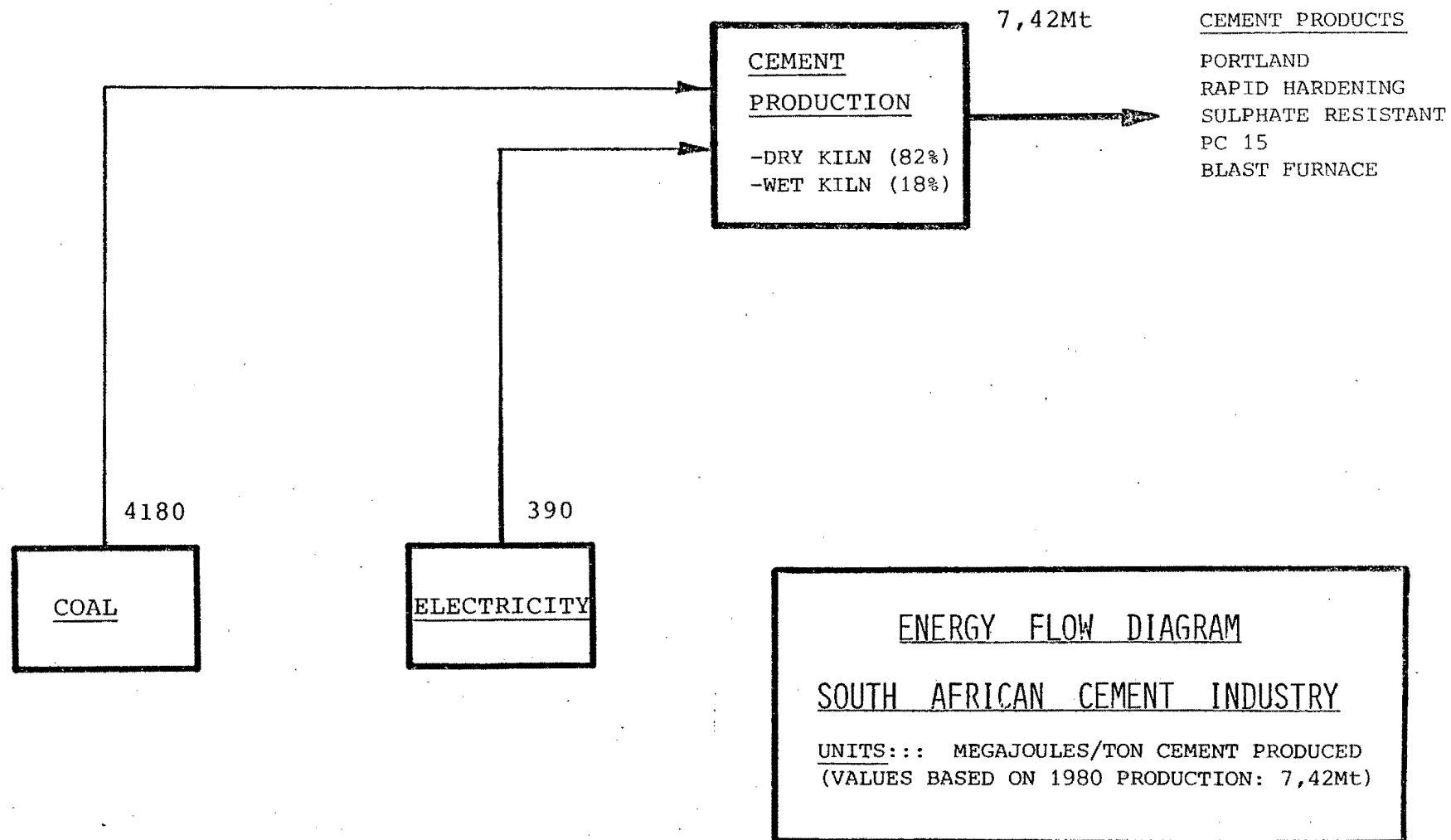
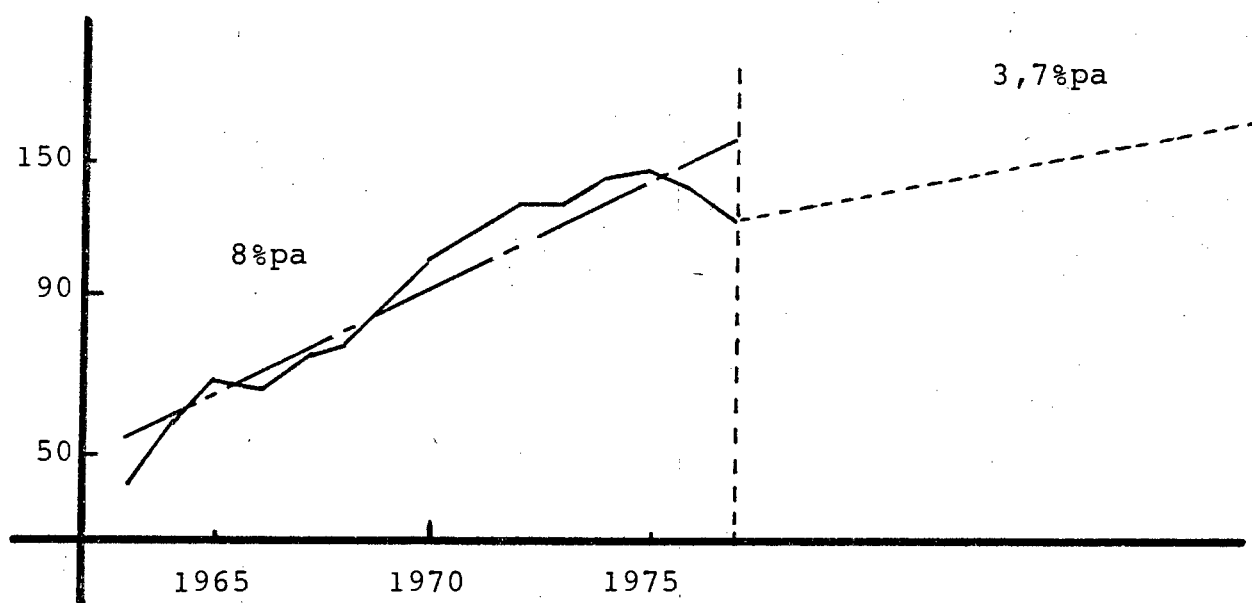


Fig 7.1

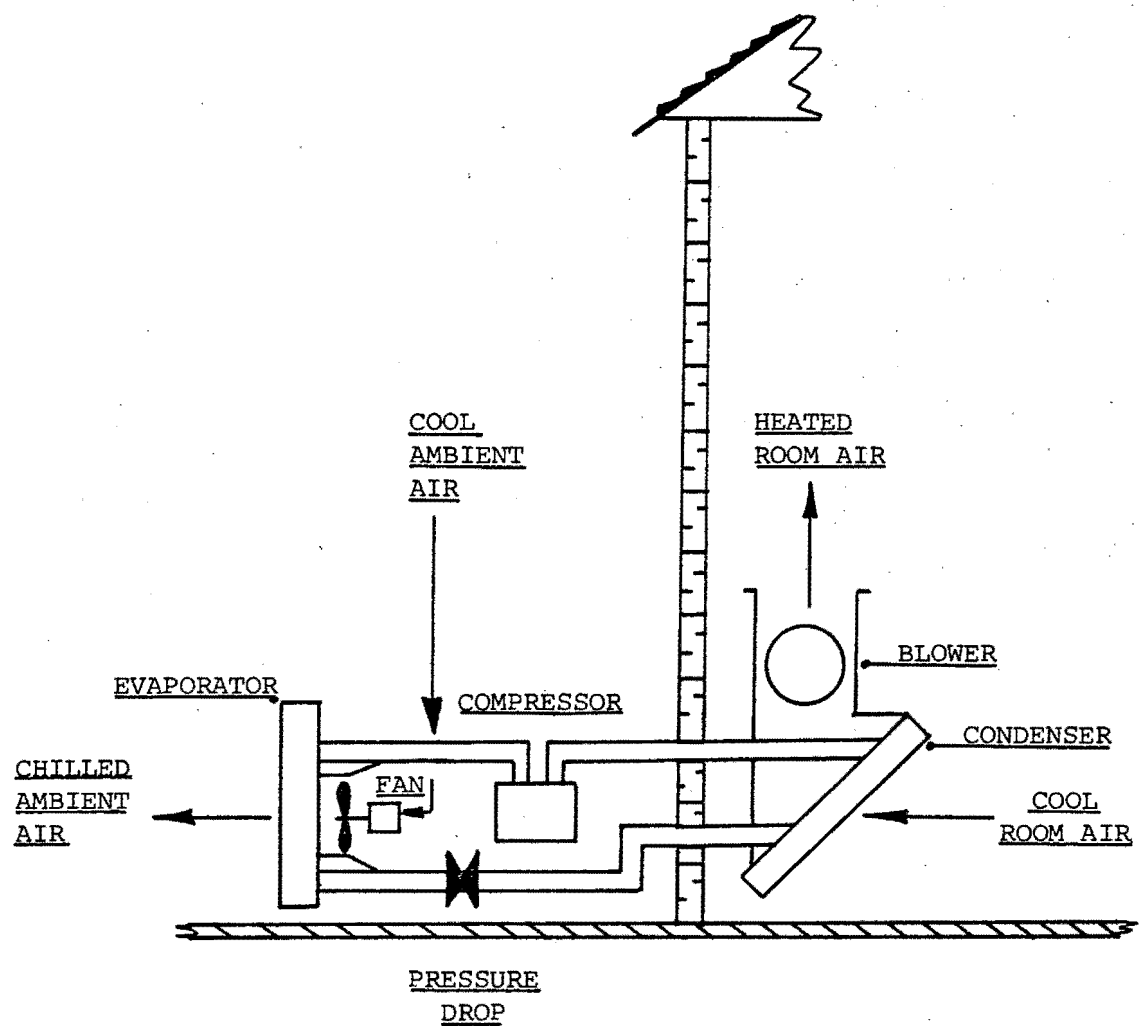


INDEX OF PHYSICAL VOLUME OF PRODUCTION

TOTAL CONSTRUCTION SECTOR

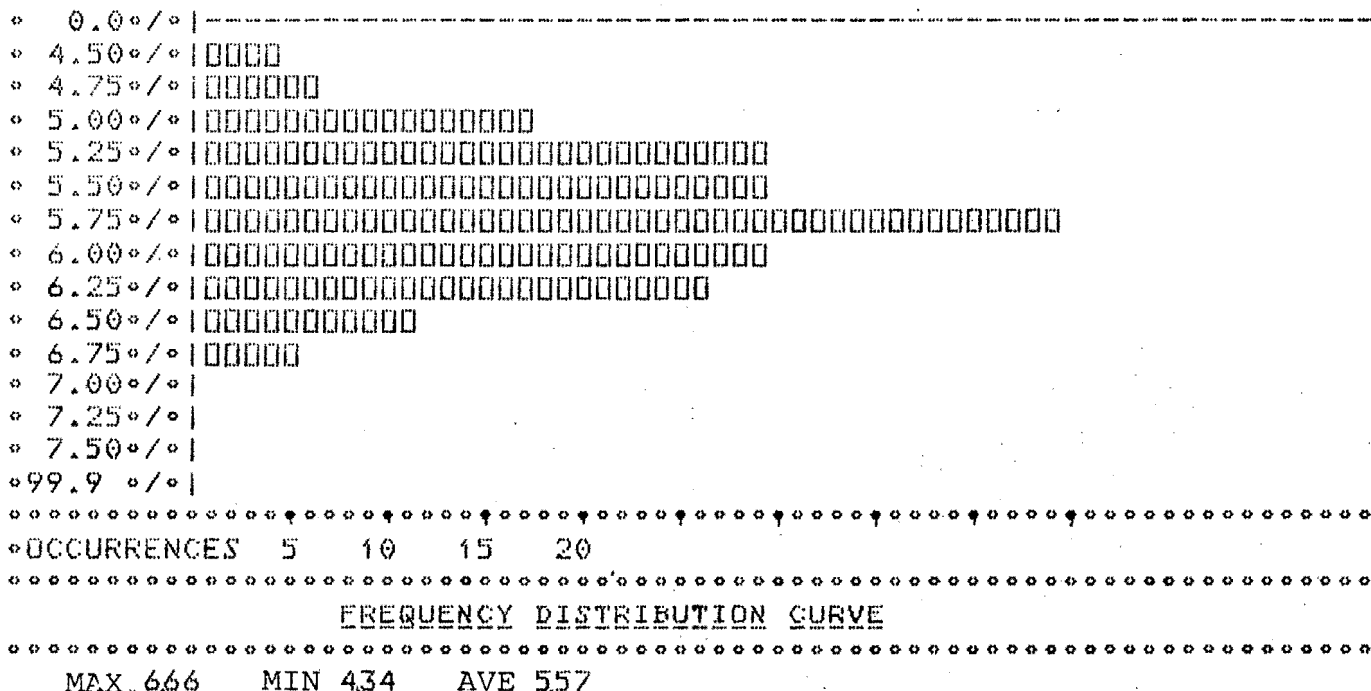
(POST 1977 ESTIMATED)

Fig 7.2



DOMESTIC HEAT PUMP INSTALLATION

FIG 9.1

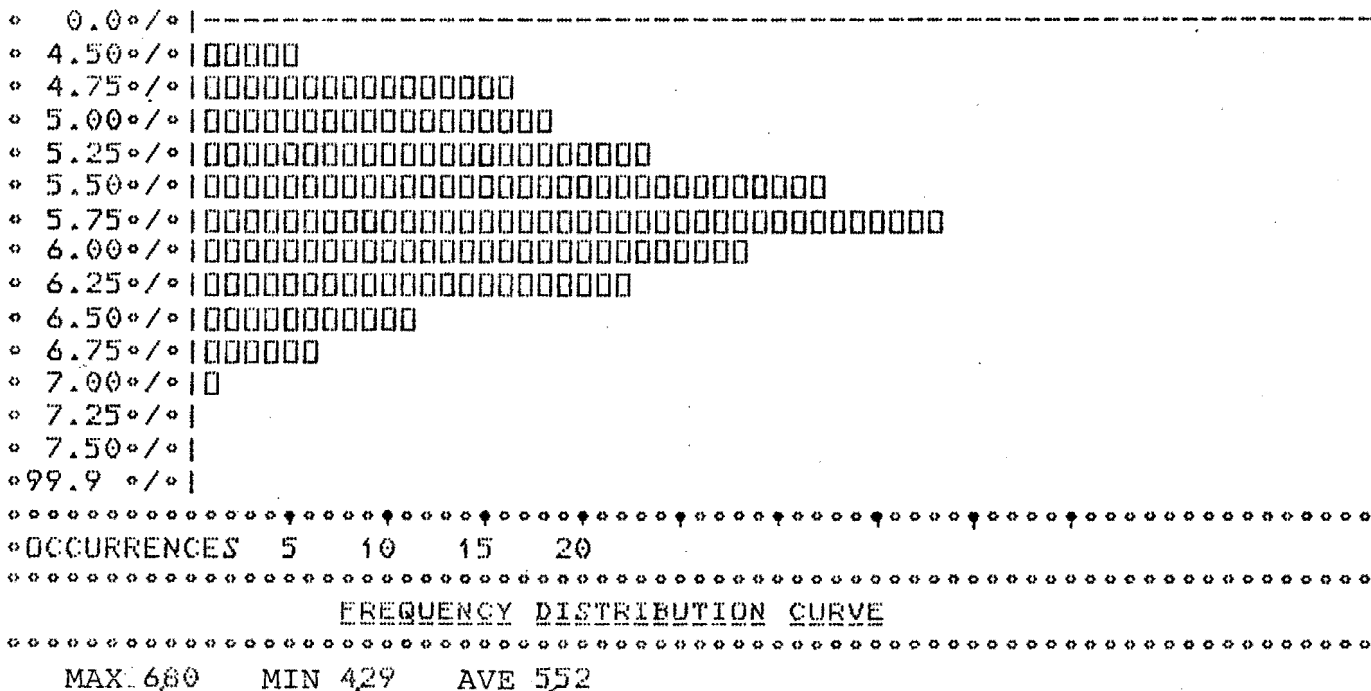


SIMULATION OUTPUT DISTRIBUTION

DOMESTIC COAL DEMAND ANNUAL GROWTH RATE

(PROBABILITIES: 20% HIGH/LOW, 60% LIKELY)

FIGURE 10.1



SIMULATION OUTPUT DISTRIBUTION

DOMESTIC COAL DEMAND ANNUAL GROWTH RATE

(PROBABILITIES: 33% HIGH, 33% LIKELY AND 33% LOW)

FIGURE 10.2

		ORE PREPARATION	CRUDE STEEL PRODUCTION	ROLLING/ FINISHING	OTHER USES
TOTAL COAL	kton	620,7	51,3	-	361,3
TOTAL COKE	kton	4403,3	9,1	-	0,3
ELECTRICITY	10 ⁶ kWh	1844,6	1493,5	1706,2	766,6
TOTAL GAS (coal equiv.)	kton	657,6	107,8	911,6	786,3
OXYGEN	10 ⁶ m ³	131,0	478,6	55,1	7,1
PETROLEUM PRODUCTS	kton	*	*	*	*
TOTAL ENERGY (coal equiv.)	kton	4928,1	1100,8	1796,7	1335,3

ENERGY CONSUMPTION

SOUTH AFRICAN IRON AND STEEL INDUSTRY :: 1979

TABLE 3.1

YEAR	STEEL OUTPUT Mt	ELECTRIC DEMAND 10 ⁹ kWh	HARD COAL DIRECT Mt	HARD COAL ELECTRIC. Mt	HARD COAL TOTAL Mt	COKING COAL Mt
1985	15	9,73	2,12	4,91	7,02	10,8
1990	22	14,28	3,10	7,2	10,3	15,8
1995	30	19,46	4,24	9,82	14,06	21,6
2000	38	24,66	5,36	12,4	17,76	27,3

PROJECTED ANNUAL ENERGY DEMAND

IRON AND STEEL INDUSTRY

(ILLUSTRATING COAL NEEDED FOR REDUCTION
AND FOR ELECTRICITY GENERATION)

TABLE 3.2

SECTOR	1977 R million	1987	% CHANGE
Other mining	26	48	6,5
Other non-metallic mineral products	34	55	5,1
Iron and steel basic industries	336	642	6,7
Structural metal products	262	430	5,1
Other fabricated metal products	360	674	6,5
Agricultural machinery and equipment	37	68	6,4
Other machinery except electrical	190	345	6,1
Electrical machinery/apparatus	36	62	5,6
Motor vehicles	121	222	6,2
Motor vehicle parts	109	333	11,8
Railway equipment	84	113	3,0
Other transport equipment	18	30	5,3
Building construction	180	295	5,1
Civil engineering/construction	281	379	3,1
Other industries	107	197	6,3
TOTAL INTERMEDIATE DEMAND	2 180	3 892	6,0
Government expenditure	13	21	5,1
Inventory change	-79	42	
TOTAL DOMESTIC DEMAND	2 114	3 955	6,5

DOMESTIC CONSUMPTION OF IRON AND STEEL BASIC INDUSTRIES

TABLE 3.3

PRODUCT	EXPORT VALUE R. million
PIG IRON/CAST IRON	2,64
FERRO ALLOYS	206,93
BLOOMS, BILLETS, SLABS	54,04
BARS, RODS	49,61
ANGLES, SHAPES, SECTIONS	56,07
HOOP AND STRIP	9,19
SHEETS AND PLATES	141,66
IRON/STEEL WIRE	7,08
ALLOY, HIGH C STEEL	34,04
TRACK RAIL	3,44
WASTE FROM MANUFACTURE	23,71
OTHER	12,96
TOTAL	601,37

EXPORTS OF BASIC IRON AND STEEL PRODUCTS

1977 VALUES, F.O.B. CURRENT VALUE

TABLE 3.4

YEAR	STEEL PRODUCTION Mt	DRI PRODUCT. Mt	HARD COAL FOR DRI Mt	HARD COAL Mt	HARD COAL TOTAL Mt	COKING COAL Mt
1980	9,4	0	0	5,2	5,2	6,8
1985	13,2	0	0	7,3	7,3	9,5
1990	18,5	0	0	10,2	10,2	13,3
1995	25,9	0	0	14,2	14,2	18,6
2000	36,3	0	0	19,9	19,9	26,1
<u>IRON AND STEEL -- HIGH CASE</u>						
TABLE 3.5						
1980	9,3	0,5	1,7	5,1	6,8	6,3
1985	12,8	4,0	13,7	7,0	20,7	6,3
1990	17,5	8,7	29,8	9,6	39,4	6,3
1995	24,0	15,2	52,1	13,2	65,3	6,3
2000	32,9	24,1	82,7	18,1	100,8	6,3
<u>IRON AND STEEL -- LIKELY CASE</u>						
TABLE 3.6						
1980	9,0	0,2	0,7	4,9	5,6	6,3
1985	10,5	1,7	5,8	5,8	11,6	6,3
1990	12,1	3,3	11,3	6,6	17,9	6,3
1995	14,1	5,3	18,2	7,7	25,9	6,3
2000	16,3	7,5	25,7	8,9	34,6	6,3
<u>IRON AND STEEL -- LOW CASE</u>						
TABLE 3.7						

TABLES ILLUSTRATING STEEL AND DIRECT REDUCED IRON PRODUCTION,
AND COAL REQUIREMENTS FOR HIGH, LIKELY AND LOW CASES

IRON AND STEEL INDUSTRY

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*6L	10*9M*3	KT	COAL MT
1980	6.1	2.4	.0	*	.0	.0	6.3
1985	8.3	8.3	.0	*	.0	.0	6.3
1990	11.4	16.3	.0	*	.0	.0	6.3
1995	15.6	27.4	.0	*	.0	.0	6.3
2000	21.4	42.5	.0	*	.0	.0	6.3
2005	29.3	63.2	.0	*	.0	.0	6.3

ENERGY CARRIER FINAL DEMAND VALUES

FDS2 IRON AND STEEL INDUSTRY LIKELY CASE

TABLE 3.8

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*6L	10*9M*3	KT	COAL MT
1980	6.1	1.5	.0	*	.0	.0	6.7
1985	8.5	2.2	.0	*	.0	.0	9.5
1990	12.0	3.0	.0	*	.0	.0	13.3
1995	16.8	4.3	.0	*	.0	.0	18.6
2000	23.6	6.0	.0	*	.0	.0	26.1
2005	33.0	8.4	.0	*	.0	.0	36.6

ENERGY CARRIER FINAL DEMAND VALUES

FDS1 IRON AND STEEL INDUSTRY HIGH CASE

TABLE 3.9

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*6L	10*9M*3	KT	COAL MT
1980	5.9	1.9	.0	*	.0	.0	6.3
1985	6.8	4.3	.0	*	.0	.0	6.3
1990	7.9	7.2	.0	*	.0	.0	6.3
1995	9.1	10.5	.0	*	.0	.0	6.3
2000	10.6	14.3	.0	*	.0	.0	6.3
2005	12.3	18.7	.0	*	.0	.0	6.3

ENERGY CARRIER FINAL DEMAND VALUES

FDS3 IRON AND STEEL INDUSTRY LOW CASE

TABLE 3.10

SUBSECTOR	1977			1987		
	ELEC.	COAL	OUTPUT	ELEC.	COAL	OUTPUT
FERTILIZER	1	7	364	1	11	551
PLASTICS	0	2	263	0	5	541
BASIC IND. CHEMICALS	66	25	2446	340	47	3314
PHARMACEUT.	0	0	225	0	1	382
SOAP/CLEAN.	0	1	300	1	3	621
PAINT/EXPL.	1	3	654	1	5	1111

CHEMICAL SUBSECTOR OUTPUT; ELECTRICITY AND COAL INPUTS

R millions : 0 implies < 0,5

TABLE 4.1

PRODUCT	% OUTPUT (SYNTHOL)
CH ₄	10
C ₂ H ₄	4
C ₂ H ₆	4
C ₃ H ₆	12
C ₃ H ₈	2
C ₄ H ₈	9
C ₄ H ₁₀	2
C ₅ ⁺	51
Sol. Chemicals	5
Water Soluble Acids	1

PRODUCT OUTPUT - SYNTHOL PROCESS

Tuned to maximize light olefins

TABLE 4.2

SUBSECTOR	1977 R million	1987	%GROWTH (ANNUAL)
TOTAL PRODUCTION	3 845	6 218	4,9
Fertilizers	364	530	3,8
Plastic Materials	263	564	7,9
Basic Chemicals	2 083	3 127	4,4
Pharmaceuticals	225	365	4,9
Soap/Cleaners	300	576	6,7
Paints/ Explosives	654	1 056	4,9
IMPORTS	832	1 171	3,5
Fertilizers	38	62	5,1
Plastic Materials	196	249	2,4
Basic Chemicals	472	659	3,4
Pharmaceuticals	61	91	4,1
Soap/Cleaners	5	12	8,8
Paints/ Explosives	60	97	5,0
TOTAL SUPPLY	4 677	7 389	4,7
DOMESTIC DEMAND	4 258	6 578	4,4
INVENTORY CHANGE	-74	71	
EXPORTS	493	740	4,1
TOTAL DEMAND	4 677	7 389	4,7

PRODUCT FLOWS - CHEMICALS INDUSTRY

1977 - Actual R millions

1987 - Projected Values

Source - Economic Development

Program : 1980

TABLE 4.3

YEAR	ELECTRICITY 10 ⁹ kWh	COAL Mt	COKE kt	PETROLEUM PRODUCTS 10 ⁶ l	GAS 10 ⁶ m ³
1980	2,1	5,5	19		422
1985	2,7	7,0	25		541
1990	3,5	9,2	32		708
1995	4,4	11,4	40	*	883
2000	5,5	14,2	50		1100
2005	6,8	17,7	63		1371

LIKELY CASE

TABLE 4.4

1980	2,1	5,5	19		422
1985	2,9	7,6	27		589
1990	4,3	11,1	39		861
1995	5,9	15,2	54	*	1179
2000	8,1	20,9	74		1616
2005	11,0	28,6	101		2214

HIGH CASE

TABLE 4.5

1980	2,1	5,5	19		422
1985	2,5	6,4	23		498
1990	2,8	7,3	26		568
1995	3,3	8,5	30	*	659
2000	3,8	9,9	35		764
2005	4,4	11,4	41		885

LOW CASE

TABLE 4.6

ENERGY CARRIER FINAL DEMAND VALUES

CHEMICALS INDUSTRY:::::LIKELY CASE
HIGH CASE
LOW CASE

COAL FIELD	CALORIFIC VALUE MJ/kg	VOLATILE MATTER %	ASH %	SULPHUR %
WITBANK				
Blend coking	28-32	28-37	5-15	0,4-0,6
Other	21-30	21-33	10-30	0,4-2,0
EASTERN TRANSVAAL	21-30	20-36	12-24	0,5-2,5
SOUTH RAND / OFS	17-21	20-23	25-36	0,2-1,1
NATAL				
Anthracite	26-32	4-15	8-22	0,4-2,0
Bituminous	23-31	11-31	9-25	0,5-2,8

CHARACTERISTICS OF COAL PRODUCED IN SOUTH AFRICA

TABLE 5.1

YEAR	BITUMINOUS Mt	ANTHRACITE Mt	TOTAL Mt
1976	4431	1530	5961
1977	10478	2224	12702
1978	12861	2528	15389
1979	19997	3364	23341

COAL EXPORTS FROM SOUTH AFRICA

1976 - 1979

TABLE 5.2

YEAR	GOLD PRODUCTION ton	ORE MILLED Mton	ELECTRICITY 10 ⁹ kWh	COAL Mton	PETROLEUM Ml
1980	674	89,3	16,5	0,54	
1985	656	89,3	16,5	0,54	
1990	638	89,3	16,5	0,54	
1995	621	89,3	16,5	0,54	*
2000	605	89,3	16,4	0,54	
2005	589	89,3	16,4	0,54	

LIKELY CASE

TABLE 5.3

1980	674	89,3	16,5	0,54	
1985	656	114	20,9	0,69	
1990	638	146	26,6	0,88	
1995	621	186	33,8	1,12	*
2000	605	237	43,0	1,43	
2005	589	302	54,7	1,82	

HIGH CASE

TABLE 5.4

1980	674	89,3	16,5	0,54	
1985	356	77	14,0	0,46	
1990	188	66	12,0	0,40	
1995	99	57	10,2	0,34	*
2000	52	49	8,8	0,29	
2005	27	42	7,5	0,25	

LOW CASE

TABLE 5.5

ENERGY CARRIER FINAL DEMAND VALUES

GOLD PRODUCTION:::::LIKELY CASE
HIGH CASE
LOW CASE

YEAR	EXPORT VALUE		
	HIGH ton	LIKELY ton	LOW ton
1980	6093	6093	6093
1985	9812	7785	6734
1990	15803	9936	7435
1995	20169	12681	8210
2000	25741	16185	9064
2005	32847	20656	10008

URANIUM EXPORT CASES

TABLE 5.6

YEAR	EXPORT VALUE		
	HIGH Mton	LIKELY Mton	LOW Mton
1980	23,3	23,3	23,3
1985	39,6	39,6	39,6
1990	56,4	53,1	46,9
1995	76,9	67,1	50,8
2000	105,0	84,8	55,0
2005	143,0	107,2	59,5

COAL EXPORT CASES

TABLE 5.7

	%	10 ⁹ MJ	
ELECTRICITY	17,1	6,43	1,79 x10 ⁹ kWh
COAL	64,1	24,1	1,01 Mt
PETROLEUM PRODUCTS	*	*	* x10 ⁹ l
GAS	0,6	0,23	0,012x10 ⁹ m ³

ENERGY INPUTS -- PULP AND PAPER INDUSTRY

(BASED ON ESTIMATED 1980 PRODUCTION OF 1 284 183t)

TABLE 6.1

YEAR	ELEC.	COAL	COKE	PETRO. PROD.	GAS	URAN.	COKE COAL
	10*9KWH	MT	MT	10*6L	10*6M*3	KT	MT
1980	1.8	1.0	.0	*	12.2	.0	.0
1985	2.2	1.3	.0	*	15.3	.0	.0
1990	2.8	1.6	.0	*	19.2	.0	.0
1995	3.7	2.1	.0	*	25.5	.0	.0
2000	5.0	2.8	.0	*	33.8	.0	.0
2005	6.6	3.7	.0	*	44.8	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS11|PULP AND PAPER INDUSTRY-----LIKELY CASE-----vvvvvvvv

TABLE 6.2

YEAR	ELEC.	COAL	COKE	PETRO. PROD.	GAS	URAN.	COKE COAL
	10*9KWH	MT	MT	10*6L	10*6M*3	KT	MT
1980	1.8	1.0	.0	*	12.2	.0	.0
1985	2.4	1.3	.0	*	16.1	.0	.0
1990	3.1	1.8	.0	*	21.4	.0	.0
1995	4.2	2.3	.0	*	28.3	.0	.0
2000	5.5	3.1	.0	*	37.6	.0	.0
2005	7.3	4.1	.0	*	49.8	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS11|PULP AND PAPER INDUSTRY-----HIGH CASE-----vvvvvvvvvv

TABLE 6.3

YEAR	ELEC.	COAL	COKE	PETRO. PROD.	GAS	URAN.	COKE COAL
	10*9KWH	MT	MT	10*6L	10*6M*3	KT	MT
1980	1.8	1.0	.0	*	12.2	.0	.0
1985	2.1	1.2	.0	*	14.6	.0	.0
1990	2.6	1.4	.0	*	17.5	.0	.0
1995	3.2	1.8	.0	*	22.1	.0	.0
2000	4.1	2.3	.0	*	28.0	.0	.0
2005	5.2	2.9	.0	*	35.3	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS11|PULP AND PAPER INDUSTRY-----LOW CASE-----vvvvvvvvvvvv

TABLE 6.4

	WET PROCESS MJ/kg	DRY PROCESS MJ/kg
HEAT OF REACTION	1,676	1,676
LOSS OF HEAT IN EXIT GASES	0,335	0,545
LOSS OF HEAT IN EVAPORATION	1,844	0,021
RADIATION LOSSES	0,419	0,251
COOLING LOSSES	0,251	0,545
<u>TOTAL</u>	4,525	3,038

WET AND DRY CEMENT MANUFACTURING PROCESSES
MINIMUM ENERGY INPUT FIGURES OBTAINABLE IN PRACTICE

TABLE 7.1

TYPE	1970 %	1975 %	1979 %
PORTLAND	84,92	83,92	86,97
RAPID HARDENING	3,87	5,50	3,66
BLAST FURNACE	8,59	4,36	3,21
SULPHATE RESISTANT	-	0,12	1,77
PC 15	2,62	6,10	4,39
	100	100	100

TYPES OF CEMENT AND MARKET SHARE

TABLE 7.2

PRODUCT	RELATIVE ENERGY COST
PORTLAND CEMENT	1
GLASS	1,3
ALUMINIUM	35
STEEL	20
POLYSTYRENE	5

ENERGY COST OF PRODUCTION OF MATERIALS
PER UNIT VOLUME, RELATIVE TO CEMENT

TABLE 7.3

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
				PROD.			COAL
	10*9KWH	MT	KT	10*6L	10*6M*3	KT	MT
1980	.8	1.3	.0	.0	.0	.0	.0
1985	.9	1.4	.0	.0	.0	.0	.0
1990	1.0	1.6	.0	.0	.0	.0	.0
1995	1.1	1.8	.0	.0	.0	.0	.0
2000	1.2	2.0	.0	.0	.0	.0	.0
2005	1.4	2.2	.0	.0	.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS14 CEMENT INDUSTRY LIKELY CASE

TABLE 7.4

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
				PROD.			COAL
	10*9KWH	MT	KT	10*6L	10*6M*3	KT	MT
1980	.8	1.3	.0	.0	.0	.0	.0
1985	1.0	1.6	.0	.0	.0	.0	.0
1990	1.2	2.0	.0	.0	.0	.0	.0
1995	1.6	2.5	.0	.0	.0	.0	.0
2000	1.9	3.1	.0	.0	.0	.0	.0
2005	2.4	3.9	.0	.0	.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS14 CEMENT INDUSTRY HIGH CASE

TABLE 7.5

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
				PROD.			COAL
	10*9KWH	MT	KT	10*6L	10*6M*3	KT	MT
1980	.8	1.3	.0	.0	.0	.0	.0
1985	.9	1.4	.0	.0	.0	.0	.0
1990	.9	1.5	.0	.0	.0	.0	.0
1995	1.0	1.6	.0	.0	.0	.0	.0
2000	1.0	1.7	.0	.0	.0	.0	.0
2005	1.1	1.8	.0	.0	.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS14 CEMENT INDUSTRY LOW CASE

TABLE 7.6

	OIL AS % OF PRIMARY ENERGY	OIL % USED FOR TRANSPORT
EEC	62	28
OECD	64	28
CANADA	54	41
USA	46	52
JAPAN	78	20
AUSTRALIA	50	52
NEW ZEALAND	56	55

CONTRIBUTION OF OIL TO PRIMARY ENERGY AND TRANSPORTATION
FOR SOME COUNTRIES (OECD 1978)

TABLE 8.1

VEHICLE TYPE	VEHICLE POPULATION	AVERAGE CONSUMPTION l/100km	AVERAGE DISTANCE km	TOTAL CONSUMPTION 10 ⁶ l
CARS	2389,5	10	14000	
COMMERCIAL VEHICLES	892,1	17	26000	
BUSSES & MINIBUSSES	96,8	20	25000	*
MOTORCYCLES	200,3	5	9500	
TRACTORS	49,0	39	900	
<u>TOTAL</u>	3627,7			*

MOTOR VEHICLE CHARACTERISTICS -- 1980

TABLE 8.2

	<u>TRACTION MODE</u>			
	COAL	ELECTRIC	DIESEL	TOTAL
	10 ⁹ MJ	10 ⁹ MJ	10 ⁹ MJ	10 ⁹ MJ
1980 VALUE	44,5	15,5	*	
EFFICIENCY	(3%)	(60%)	*	
TRACTIVE ENERGY	1,335	9,03	*	16,785
YEAR 2000 VALUE AT 2,5% PA				27,5
DIESEL 1% INCREASE				
COAL 7% DECREASE	0,34		*	
ELECTRIC REQUIREMENT		19,33		
GROWTH RATE		(3,88%)		

TABLE 8.3

YEAR 2000 VALUE AT 2% PA				24,94
DIESEL 1% INCREASE			*	
ELECTRIC REQUIREMENT		16,76		
GROWTH RATE		(3,14%)		

TABLE 8.5

YEAR 2000 VALUE AT 3% PA				30,32
DIESEL CONSTANT			*	
ELECTRIC REQUIREMENT		23,55		
GROWTH RATE		(4,9%)		

TABLE 8.4

CALCULATION OF GROWTH RATE FOR ELECTRIC TRACTION
USING ASSUMPTIONS FOR TRACTIVE ENERGY AND
DIESEL CONTRIBUTION GROWTH RATES

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE/COAL
	10*9KWH	MT	MT	PROD. 10*9L	10*6M*3	KT	MT
1980	4.2	1.8	.0	*	.0	.0	.0
1985	5.1	1.3	.0	*	.0	.0	.0
1990	6.1	.9	.0	*	.0	.0	.0
1995	7.4	.6	.0	*	.0	.0	.0
2000	9.0	.4	.0	*	.0	.0	.0
2005	10.9	.3	.0	*	.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES
 FDS12 | TRANSPORT SECTOR -----LIKELY CASE-----▽

TABLE 8.6

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE/COAL
	10*9KWH	MT	MT	PROD. 10*9L	10*6M*3	KT	MT
1980	4.2	1.8	.0	*	.0	.0	.0
1985	5.3	1.3	.0	*	.0	.0	.0
1990	6.8	.9	.0	*	.0	.0	.0
1995	8.6	.6	.0	*	.0	.0	.0
2000	10.9	.4	.0	*	.0	.0	.0
2005	13.9	.3	.0	*	.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES
 FDS12 | TRANSPORT SECTOR -----HIGH CASE-----

TABLE 8.7

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE/COAL
	10*9KWH	MT	MT	PROD. 10*9L	10*6M*3	KT	MT
1980	4.2	1.8	.0	*	.0	.0	.0
1985	4.9	1.3	.0	*	.0	.0	.0
1990	5.7	.9	.0	*	.0	.0	.0
1995	6.7	.6	.0	*	.0	.0	.0
2000	7.8	.4	.0	*	.0	.0	.0
2005	9.1	.3	.0	*	.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES
 FDS12 | TRANSPORT SECTOR -----LOW CASE-----

TABLE 8.8

	tons per annum	MJ per annum
AVERAGE HIGHVELD HOUSEHOLD	3,6	93600
AVERAGE COASTAL HOUSEHOLD	0,175	4550
COUNTRY AVERAGE	2,813	73138
TOTAL COAL DEMAND	1 740 000	45,2x10 ⁹

COAL DEMAND, BLACK HOUSEHOLDS

INLAND AND COASTAL AREAS OF SOUTH AFRICA

TABLE 9.1

AMBIENT TEMP °C	HEAT OUTPUT kW	POWER CONSUMED kW	COP PRACTICAL	COP THEORETICAL
+13	7,4	2,9	2,55	6,32
-1	4,6	2,25	2,04	4,59
-7	3,6	2,03	1,77	4,0

PERFORMANCE FIGURES FOR A TYPICAL HEAT PUMP

TABLE 9.2

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	KT	PROD.	10*9L 10*6M*3	KT	COAL
							MT
1980	13.9	3.5	1.0	*	25.0	.0	.0
1985	19.1	2.8	1.0	*	25.0	.0	.0
1990	26.3	2.2	1.0	*	25.0	.0	.0
1995	36.3	1.7	1.0	*	25.0	.0	.0
2000	49.9	1.3	1.0	*	25.0	.0	.0
2005	68.7	1.1	1.0	*	25.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS13

DOMESTIC SECTOR

----- LIKELY CASE

TABLE 9.3

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	KT	PROD.	10*9L 10*6M*3	KT	COAL
							MT
1980	13.9	3.5	1.0	*	25.0	.0	.0
1985	21.1	2.8	1.0	*	25.0	.0	.0
1990	32.0	2.2	1.0	*	25.0	.0	.0
1995	48.6	1.7	1.0	*	25.0	.0	.0
2000	73.7	1.3	1.0	*	25.0	.0	.0
2005	111.9	1.1	1.0	*	25.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS33

DOMESTIC SECTOR

----- HIGH CASE

TABLE 9.4

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	KT	PROD.	10*9L 10*6M*3	KT	COAL
							MT
1980	13.9	3.5	1.0	*	25.0	.0	.0
1985	18.4	2.8	1.0	*	25.0	.0	.0
1990	24.4	2.2	1.0	*	25.0	.0	.0
1995	32.4	1.7	1.0	*	25.0	.0	.0
2000	42.9	1.3	1.0	*	25.0	.0	.0
2005	56.9	1.1	1.0	*	25.0	.0	.0

ENERGY CARRIER FINAL DEMAND VALUES

FDS43

DOMESTIC SECTOR

----- LOW CASE

TABLE 9.5

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*9L	10*9M*3	KT	COAL MT
1980	35.0	2.9	.3	*	1.9	.0	.5
1985	46.8	3.7	.3	*	2.3	.0	.6
1990	62.7	4.6	.4	*	2.9	.0	.8
1995	83.9	5.7	.5	*	3.6	.0	1.0
2000	112.2	7.1	.6	*	4.5	.0	1.2
2005	150.2	8.8	.8	*	5.7	.0	1.5

ENERGY CARRIER FINAL DEMAND VALUES

FDS15] UNSPECIFIED (GENERAL) SECTORS ---- LIKELY CASE

TABLE 10.1

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*9L	10*9M*3	KT	COAL MT
1980	35.0	2.9	.3	*	1.9	.0	.5
1985	49.1	3.7	.3	*	2.4	.0	.6
1990	68.9	4.8	.4	*	3.1	.0	.8
1995	96.6	6.1	.5	*	3.9	.0	1.0
2000	135.4	7.8	.7	*	5.0	.0	1.3
2005	190.0	9.9	.8	*	6.4	.0	1.7

ENERGY CARRIER FINAL DEMAND VALUES

FDS35] UNSPECIFIED (GENERAL) SECTORS --- HIGH CASE

TABLE 10.2

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
	10*9KWH	MT	MT	PROD. 10*9L	10*9M*3	KT	COAL MT
1980	35.0	2.9	.3	*	1.9	.0	.5
1985	44.7	3.5	.3	*	2.2	.0	.6
1990	57.0	4.2	.4	*	2.7	.0	.7
1995	72.8	5.0	.4	*	3.2	.0	.8
2000	92.9	5.9	.5	*	3.8	.0	1.0
2005	118.5	7.1	.6	*	4.6	.0	1.2

ENERGY CARRIER FINAL DEMAND VALUES

FDS45] UNSPECIFIED (GENERAL) SECTORS --- LOW CASE

TABLE 10.3

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
				PROD.			COAL
	10*9KWH	MT	MT	10*9L	10*9M*3	KT	MT
1980	80.4	42.3	.3	*	2.3	6.1	6.8
1985	101.7	65.8	.3	*	2.9	7.8	6.9
1990	130.4	89.9	.4	*	3.7	9.9	7.1
1995	168.9	118.3	.5	*	4.6	12.7	7.3
2000	220.6	155.7	.7	*	5.7	16.2	7.5
2005	290.3	204.7	.8	*	7.1	20.7	7.8

ENERGY CARRIER FINAL DEMAND VALUES

FDS99 TOTAL FINAL DEMAND***** ALL ASSUMPTIONS LIKELY

TABLE 10.4

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
				PROD.			COAL
	10*9KWH	MT	MT	10*9L	10*9M*3	KT	MT
1980	80.4	41.4	.3	*	2.3	6.1	7.2
1985	111.3	60.8	.3	*	3.0	9.8	10.1
1990	154.9	83.0	.4	*	4.0	15.8	14.1
1995	215.9	110.8	.6	*	5.1	20.2	19.6
2000	302.1	148.9	.7	*	6.7	25.7	27.4
2005	424.2	201.1	.9	*	8.7	32.8	38.3

ENERGY CARRIER FINAL DEMAND VALUES

FDS98 TOTAL FINAL DEMAND***** ALL ASSUMPTIONS HIGH

TABLE 10.5

YEAR	ELEC.	COAL	COKE	PETRO.	GAS	URAN.	COKE
				PROD.			COAL
	10*9KWH	MT	MT	10*9L	10*9M*3	KT	MT
1980	80.2	41.7	.3	*	2.3	6.1	6.8
1985	94.3	60.9	.3	*	2.8	6.7	6.9
1990	113.3	71.9	.4	*	3.3	7.4	7.0
1995	138.7	80.8	.5	*	3.9	8.2	7.2
2000	171.9	91.1	.5	*	4.6	9.1	7.3
2005	215.0	103.0	.6	*	5.5	10.0	7.5

ENERGY CARRIER FINAL DEMAND VALUES

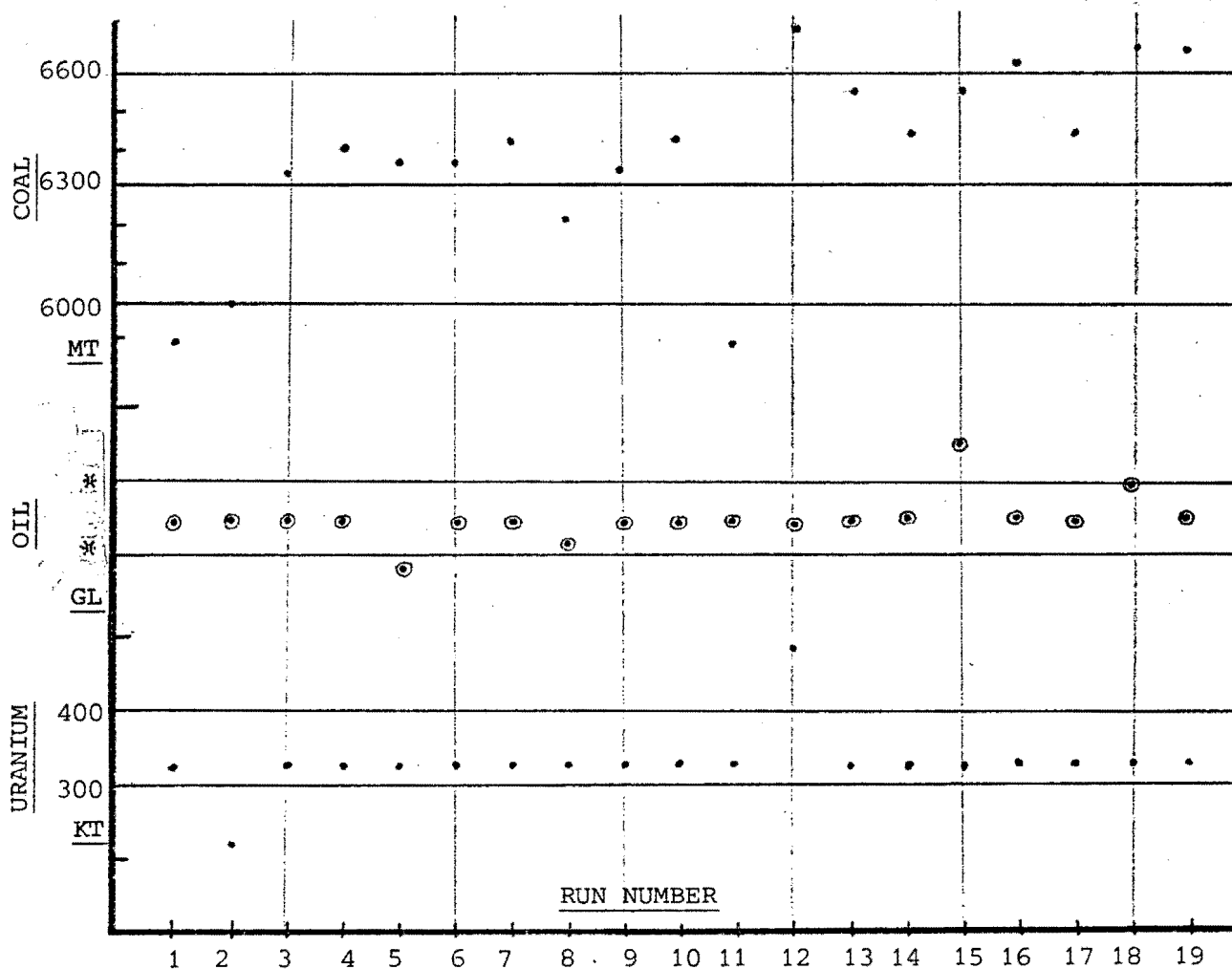
FDS97 TOTAL FINAL DEMAND***** ALL ASSUMPTIONS LOW

TABLE 10.6

RUN NO.	CUMULATIVE URAN.	COAL	OIL	DESCEND. QTY. RUN
	KT	MT	GL	SEQUENCE NUMBER
1.0	325.6	5914.6		12.0 12.0 15.0
2.0	219.6	6007.0		19.0 18.0 18.0
3.0	326.1	6344.0		18.0 19.0 16.0
4.0	326.1	6414.5		16.0 16.0 19.0
5.0	326.0	6369.3		15.0 15.0 14.0
6.0	325.8	6374.5		13.0 13.0 13.0
7.0	326.1	6424.3		11.0 17.0 12.0
8.0	325.2	6215.6		17.0 14.0 11.0
9.0	325.7	6349.9		14.0 10.0 17.0
10.0	326.1	6431.0		10.0 7.0 10.0
11.0	326.2	5892.1		7.0 4.0 7.0
12.0	485.5	6733.6		4.0 6.0 3.0
13.0	326.3	6558.3	*	3.0 5.0 6.0
14.0	326.2	6443.0		5.0 9.0 2.0
15.0	326.4	6568.0		6.0 3.0 9.0
16.0	327.2	6625.0		9.0 8.0 4.0
17.0	326.2	6453.8		1.0 2.0 1.0
18.0	327.3	6677.4		8.0 1.0 8.0
19.0	327.4	6675.0		2.0 11.0 5.0

CUMULATIVE COAL, OIL AND URANIUM FOR
VARIOUS FINAL DEMAND COMBINATIONS

TABLE 10.7



TOTAL OUTPUT SENSITIVITY TO FINAL DEMAND

COAL, OIL AND URANIUM

TABLE 10.8

BLANK

APPENDIX 1

CAPITAL INVESTMENT VALUES

APPENDIX 1

CAPITAL INVESTMENT VALUES

The following values were used for assessing the investments in each of the 16 energy industries:

<u>INDUSTRY</u> (see chap. 1)	<u>INVESTMENT</u> $10^6 \text{ R}/10^9 \text{ MJ}$ (1980)	<u>DERIVATION</u>
ED	15	Assume approx. 50% coal gen.
CG	29	R650/kW, 70% load factor (1)
HG	20	Estimate. NB depends on load factor
OG	20	Estimate. NB depends on load factor
NG	52	$R1500 \times 10^6$ for 1850MW, 50% load factor. Also (2)
UM	0,5	$R250 \times 10^6 / 100\ 000 \text{ t pa}$ ~ 1% grade
UP	1,44	$R4 \times 10^9$ for 5000 t SW pa $555 \times 10^6 \text{ MJ/ton}$
CM	1,25	R30/ton (annual) (3)
CP	1	Estimate
GD	1	Estimate
FD	1	Estimate
OR	1,1	$R100 \times 10^6 / 2,5 \times 10^9 \text{ l pa}$
SC	27	$R2503 \times 10^6 / 2,5 \times 10^9 \text{ l pa}$
GP	1	Estimate
CC	1,25	Same as Coal Mining, CM
MP	22	80% Sasol costs (4) (5) (6)

NOTES

1. Escom, private communication.

2. Mooz, W.E. Cost Analysis for Light Water Reactor Power Plants . Energy, Vol 6 No 3 (March 1981) p 197.
3. Minerals Bureau, private communication.
4. Hughes, D.O. Methanol, the Chemical of the Future. Chemsa (October 1980) p 182.
5. Anon. One for the Road - Alcohol Fuels. Financial Mail (April 11, 1980) p 144.
6. Energy Research Institute. Energy Policy 1980. University of Cape Town (1980) p 72.

APPENDIX 2

ENERGY SUPPLY SYSTEM MATRICES

ECOEFFICIENTS

ECOEFFN4S

ECOEFFN4SM

ECOEFFIND

▽ ECOEFFICIENTS

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[1] EN1← 4.3 4.1 0.1 0.1 0.00004 0.9 0.00006 1.09 0 0 0 0.4
[2] EN1←EN1, 0.000828 0 0.062 0.00001 59.55
[3] EN1←EN1×FACT[1]
[4] EN2←FACT[2]× 72.8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[5] EN3←FACT[3]× 1.6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[6] EN4←FACT[4]× 0.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[7] EN5←FACT[5]× 0.00071 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[8] EN6←FACT[6]× 0 0 0 0 0 0 0.0000197 0 0 0 0 0 0 0 0 2.737
[9] EN7←FACT[7]× 0 0 0 0 0.0038 0 0 0 0 0 0 0 0 0 0 0
[10] EN8← 0 41.8 0 0 0 0.075 0 0.026 1.25 0 0 0 0.00062 2.9 0.002
[11] EN8←FACT[8]×EN8, 0.00042 19.95
[12] EN9←FACT[9]× 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
[13] EN10←FACT[10]× 0 0 0 0 0 0 0 0 0 0 0 0.8 0 0 0 1.9
[14] EN11←FACT[11]× 0 0 0 0.15 0 0 0 0.046 0 0 0 0.3 0 0 0.002 0 13.4
[15] EN12←FACT[12]× 0 0 0 0 0 0 0 0 0 0 13.9 0 0 0 0 0 0
[16] EN13←FACT[13]× 0 0 0 0 0 0 0 0 0 7E-6 0.0002565 0 0 0 0 0 0
[17] EN14←FACT[14]× 0 0 0 0 0 0 0 0 0 2.7 0 0 0 0 0 0 0
[18] EN15←FACT[15]× 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3.12
[19] EN16←FACT[16]× 0 0 0 0 0 0 0 0 0 0 0.000278 0 0 0 0 0 0
[20] EN20←EN10, EN11, EN12, EN13, EN14, EN15, EN16
[21] EC← 16 17 p (EN1, EN2, EN3, EN4, EN5, EN6, EN7, EN8, EN9, EN20)
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[22] TOP←+/EC
[23] EC←(16 16 ↑EC)÷(16 16 p+/EC)

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▽

▽ ECOEFFN4S

[1] aECOEFFS FOR 10%*N, 40%*SASOL CC; ALL EFFECIENCIES CONSTANT::YEAR1986

[2] EN1← 4.3 3.7 0.1 0.1 0.4 0.9 0.6 1.09 0 0 0 0.3 8.28 0 0.062

[3] EN1←FACT[1]*EN1, 0.00001 50.77

[4] EN2←FACT[2]* 65.7 0 0 0 0 0 0 0 0 0 0 0 0 0 0

[5] EN3←FACT[3]* 1.6 0 0 0 0 0 0 0 0 0 0 0 0 0 0

[6] EN4←FACT[4]* 0.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0

[7] EN5←FACT[5]* 7.1 0 0 0 0 0 0 0 0 0 0 0 0 0 0

[8] EN6←FACT[6]* 0 0 0 0 0 0 0.197 0 0 0 0 0 0 0 2.54

[9] EN7←FACT[7]* 0 0 0 0 38 0 0 0 0 0 0 0 0 0 0

[10] EN8← 0 37.7 0 0 0 0.075 0 0.026 1.25 0 0 0 18.4 2.57 0.002 0.00042
5.98

[11] EN8←FACT[8]*EN8

[12] EN9←FACT[9]* 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1

[13] EN10←FACT[10]* 0 0 0 0 0 0 0 0 0 0 0 0.5 0 0 0 2.2

[14] EN11←FACT[11]* 0 0 0 0.15 0 0 0 0.046 0 0 0 0.3 0 0 0.002 0 13.4

[15] EN12←FACT[12]* 0 0 0 0 0 0 0 0 0 0 8.34 0 0 0 0 0

[16] EN13←FACT[13]* 0 0 0 0 0 0 0 0 0 0.16 5.56 0 0 0 0 0

[17] EN14←FACT[14]* 0 0 0 0 0 0 0 0 0 2.38 0 0 0 0 0 0

[18] EN15←FACT[15]* 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3.12

[19] EN16←FACT[16]* 0 0 0 0 0 0 0 0 0 0 0.000278 0 0 0 0 0

[20] ECF←EN10,EN11,EN12,EN13,EN14,EN15,EN16

[21] ECF← 16 17 p(EN1,EN2,EN3,EN4,EN5,EN6,EN7,EN8,EN9,ECF)

[22] ECF←(16 16 ↑ECF)÷(16 16 p+↑ECF)

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      ▽ EDCOEFFN4SM
[1]  AEDCOEFFS FOR 10%/N,40%/SCC,10%/M:EL GEN,SCC EFFIC IMPROVED::YEAR2005
[2]  EN1← 4.3 3.7 0.1 0.1 0.4 0.9 0.6 1.09 0 0 0 0.2 8.28 0 0.062 0.1 50.77
[3]  EN1←EN1×FACT[1]
[4]  EN2←FACT[2]× 65.7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[5]  EN3←FACT[3]× 1.6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[6]  EN4←FACT[4]× 0.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[7]  EN5←FACT[5]× 7.1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[8]  EN6←FACT[6]× 0 0 0 0 0 0 0.197 0 0 0 0 0 0 0 0 2.54
[9]  EN7←FACT[7]× 0 0 0 0 38 0 0 0 0 0 0 0 0 0 0 0
[10] EN8← 0 32.1 0 0 0 0.075 0 0.026 1.25 0 0 0 14.2 2.57 0.002 4.2 11.58
[11] EN8←FACT[8]×EN8
[12] EN9←FACT[9]× 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
[13] EN10←FACT[10]× 0 0 0 0 0 0 0 0 0 0 0 0.4 0 0 0 2.3
[14] EN11←FACT[11]× 0 0 0 0.15 0 0 0 0.046 0 0 0 0.3 0 0 0.002 0 13.4
[15] EN12←FACT[12]× 0 0 0 0 0 0 0 0 0 0 6.95 0 0 0 0 0
[16] EN13←FACT[13]× 0 0 0 0 0 0 0 0 0.16 5.56 0 0 0 0 0 0
[17] EN14←FACT[14]× 0 0 0 0 0 0 0 0 2.38 0 0 0 0 0 0 0
[18] EN15←FACT[15]× 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3.12
[19] EN16←FACT[16]× 0 0 0 0 0 0 0 0 2.78 0 0 0 0 0 0 0
[20] ECF←EN10,EN11,EN12,EN13,EN14,EN15,EN16
[21] ECF← 16 17 p(EN1,EN2,EN3,EN4,EN5,EN6,EN7,EN8,EN9,ECF)
***
[22] ECF←(16 16 ↑ECF)÷(16 16 p+ /ECF)

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▽

▽ ECOEFFIND

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[1]  #ECOEFFS FOR 10%*N,50%*SCC,50%*M:EL GEN,SCC EFFIC IMPROVED::YEAR2005
[2]  # COAL MINING INCREASED 20%* TO BALANCE FLOWS
[3]  EN1← 4.3 3.7 0.1 0.1 0.4 0.9 0.6 1.31 0 0 0 0.00002 10.35 0 0.62
[4]  EN1←EN1, 0.53 48.25
[5]  EN1←EN1*FACT[1]
[6]  EN2←FACT[2]* 65.7 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[7]  EN3←FACT[3]* 1.6 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[8]  EN4←FACT[4]* 0.5 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[9]  EN5←FACT[5]* 7.1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[10] EN6←FACT[6]* 0 0 0 0 0 0 0.197 0 0 0 0 0 0 0 0 2.54
[11] EN7←FACT[7]* 0 0 0 0 38 0 0 0 0 0 0 0 0 0 0 0
[12] EN8← 0 32.1 0 0 0 0.075 0 0.03 1.25 0 0 0 17.7 2.57 0.002 22.3 3.81
[13] EN8←FACT[8]*EN8
[14] EN9←FACT[9]* 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
[15] EN10←FACT[10]* 0 0 0 0 0 0 0 0 0 0 0 0.00004 0 0 0 2.7
[16] EN11←FACT[11]* 0 0 0 0.15 0 0 0 0.06 0 0 0 0.00003 0 0 0.002 0 13.7
[17] EN12←FACT[12]* 0 0 0 0 0 0 0 0 0 0 0.000695 0 0 0 0 0
[18] EN13←FACT[13]* 0 0 0 0 0 0 0 0 0.2 6.949 0 0 0 0 0 0
[19] EN14←FACT[14]* 0 0 0 0 0 0 0 0 2.3 0 0 0 0 0 0 0
[20] EN15←FACT[15]* 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3.12
[21] EN16←FACT[16]* 0 0 0 0 0 0 0 0 0 0 14.78 0 0 0 0 0
***
[22] ECF←EN10,EN11,EN12,EN13,EN14,EN15,EN16
[23] ECF← 16 17 p(EN1,EN2,EN3,EN4,EN5,EN6,EN7,EN8,EN9,ECF)
[24] ECF←(16 16 ↑ECF)÷(16 16 p+↑ECF)

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