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ENERGY OUTLOOK FOR SOUTH AFRICA: 2002

DEPARTMENT OF MINERALS AND ENERGY
ESKOM
ENERGY RESEARCH INSTITUTE,
UNIVERSITY OF CAPE TOWN

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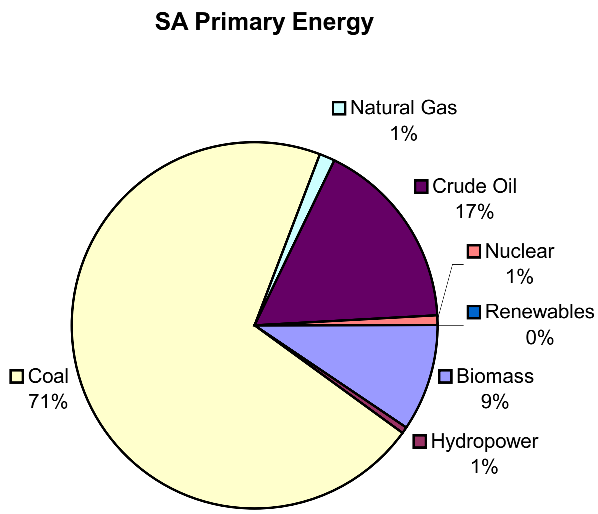
Note: The purpose of this document is to provide a background to energy supply and demand in South Africa as a base for the energy model. This is a preliminary draft. Revisions and alterations will be made according to the comments of the interested parties and to new data and information.

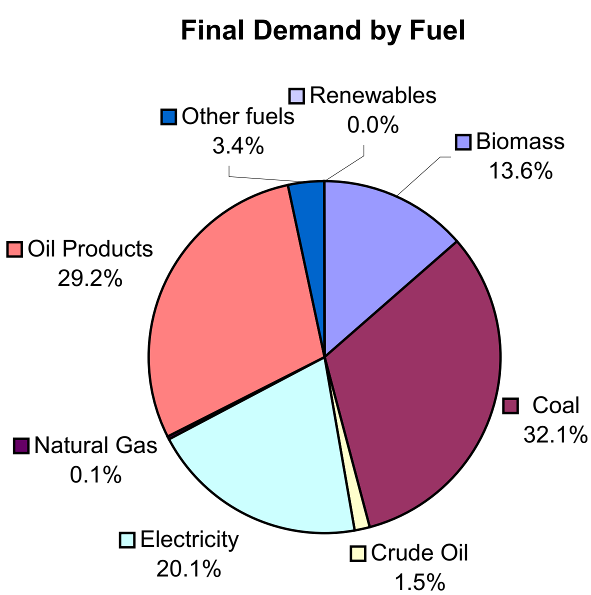
CONTENTS

EXECUTIVE SUMMARY

The South African economy is energy intensive: it uses much energy for every rand of value added. This is because it is still based on primary extraction and processing. South African energy is dominated by coal, which is plentiful and cheap, and this results in some of the lowest energy costs in the world, notably the cost of electricity. Apart from coal, which contributes 70% of primary energy, South Africa gets energy locally from biomass, such as wood and dung, natural gas, hydro-power, nuclear power, solar power and wind. South Africa has very little oil and 95% of our crude oil is imported. South Africa has fairly small gas fields off her south coast, which supply Mossgas. The figure below shows South Africa's primary energy supply for 2000. (Total: 4230 PJ).



Primary energy is that which enters the economy. Much of it this is transformed into more useable forms of final energy, which is then consumed by the final user. Examples of such transformation are coal to electricity in power stations, crude oil to liquid fuels in oil refineries, coal to liquid fuels in SASOL plants, and natural gas to liquid fuels in Mossgas. The figure below shows South Africa's final energy demand for 2000. (Total 3054 PJ)

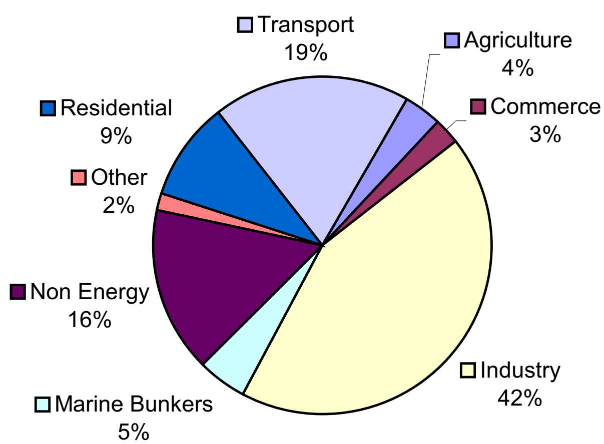


South Africa has very large reserves of coal and uranium; limited reserves of hydro-power; a large potential for solar power, especially in the Northern Cape; and considerable potential for wind in the coastal regions. African countries to our north have huge potential for hydro-power and very large gas reserves.

FINAL ENERGY DEMAND

For the purposes of energy demand, the South African economy may be considered to be divided into six sectors: industry, agriculture, commerce, residential, transport and other. The figure below shows the energy demand by sector for 2000. (Total: 3054 PJ)

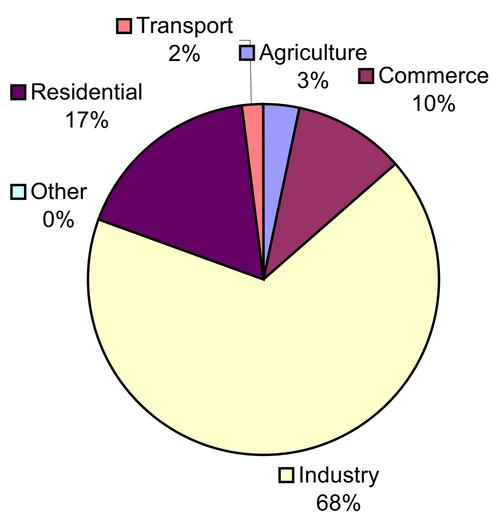
SA Final Energy Demand by Sector



"Non-energy" comprises of materials such as coal, oil and wood that could be used to produce energy but are actually used to make other materials such as chemicals, plastics and paper.

The figure below shows the electricity used by each economic sector in 2000 (total: 613 PJ)

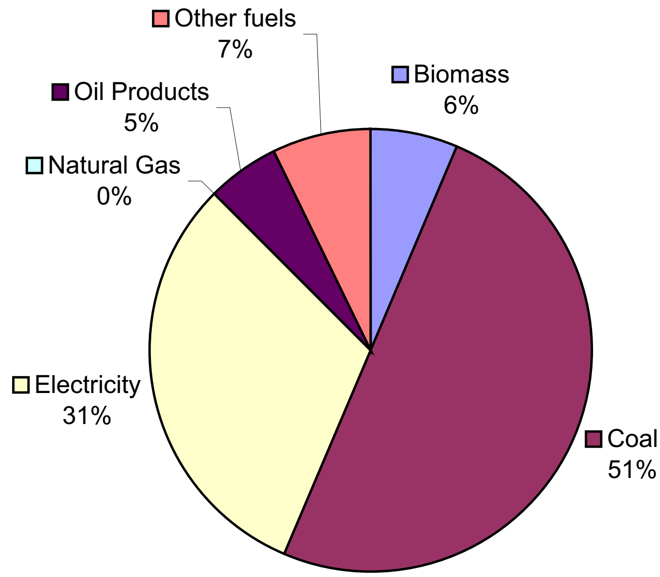
Electricity Demand by Sector



THE INDUSTRIAL SECTOR

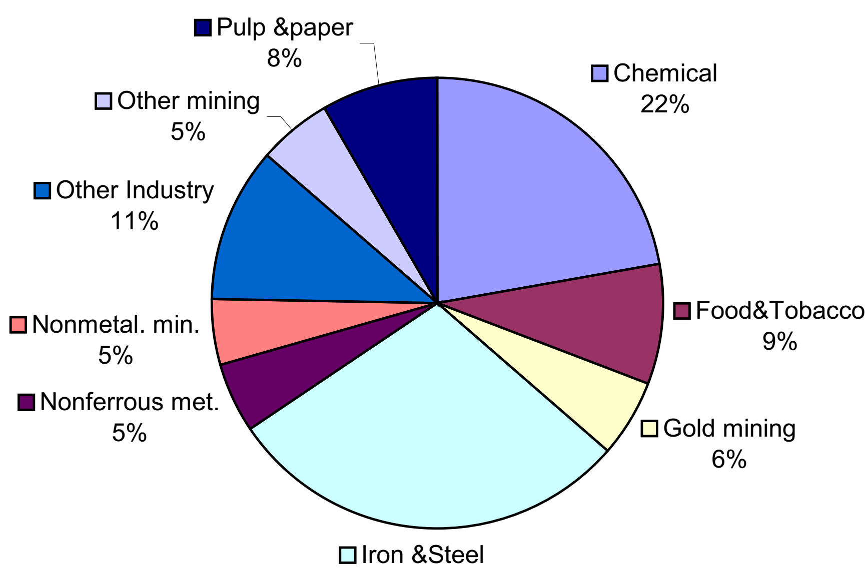
Industry is the largest user of energy and electricity in South Africa. The figure below shows the fuels used in industry in 2000. (Total: 1325 PJ).

Industrial Energy Demand by Fuel



Industry is divided into 8 sub-sectors: mining, iron and steel, non-ferrous metals, chemicals and petrochemicals, non-metallic minerals, pulp and paper, food and tobacco, and other. The figure below shows the energy demand for each of these sub-sectors in 2000. (Total: 1325 PJ.)

Industrial Final Energy Demand by Subsector



Mining

The discovery of gold and diamonds in the Nineteenth Century began South Africa's industrialisation. South Africa has vast mineral reserves. However the relative importance of mining within the economy has been declining since the 1930s. South African mining may be logically divided into gold mining and other mining.

Gold mining production is in decline because the richest ores have been worked out. However, increasing depths and worsening ore grades mean that more energy is required to produce each ton of gold. Other mining has better prospects and is likely to grow with the economy.

The table below shows the energy demand by fuel for mining in 2000.

Energy for Mining 2000 (PJ)			
	Gold Mining	**Other Mining**	**Total**
Coal	2.0	16.0	17.9
Diesel	3.3	15.3	22.5
Electricity	67.3	47.0	114.3
Fuel Oil	0.1	0.6	0.7
Hydrogen Rich Gas	0.4	0.3	0.6
LPG		0.1	0.1
Natural Gas		0.0	0.0
Paraffin		0.4	0.4
Total	73.1	79.6	152.7

Electricity, which already is the largest energy source for mining, is likely in future to increase its proportion of energy used.

Iron and Steel

South Africa all the minerals necessary for steel production except for coking coal. In 1996 she produced 6.5 million tons of finished steel which made her the world's twenty-first producer. South Africa exports a large fraction of her steel and in 1996 was the world's tenth biggest exporter. South Africa is increasing its production of stainless steel, which is becoming ever more important in the world economy. Steel prices are low and, with over-supply around the world, there is little prospect of their improving in the future.

Steel making is very energy intensive, especially in the first stage of converting iron ore to iron. This is usually done by blast furnaces, which require coke. Because South Africa lacks coking coal, she has turned to new methods of iron and steel making, notably the Midrex and Corex processes which use coal instead of coke. The new mill at Saldanha Bay uses these processes and promises to produce steel using less energy. Unfortunately the depressed steel market has affected Saldanha Steel.

The table below shows the fuels used in iron and steel production in 2000.

Energy for Iron & Steel Energy 2000 (PJ)	
Coal	54.7
Coke oven coke	11.2
Diesel	16.1
Electricity	33.5
Fuel Oil	6.7
Hydrogen Rich Gas	4.9
LPG	6.1
Methane Rich Gas	4.9
Natural Gas	0.0
Petrol	0.6
Paraffin	6.2
Total	**144.8**

It is likely in future that more steel will be produced in electric furnaces and that gas will be used instead of coal for making iron and steel.

It is expected that iron and steel production will grow more slowly than GDP.

Chemicals and Petro-Chemicals

This sub-sector produces chemical feedstocks, plastics, fertilizers, explosives, agrochemicals and pharmaceuticals. These chemicals can be made from oil, gas or coal. South Africa's special expertise and experience in making liquid fuels and chemicals from coal gives it a unique advantage in this field.

The table below shows the fuels used to provide energy for this sub-sector in 2000.

Energy for Chemicals 2000 (PJ)	
Coal	237.3
Electricity	50.3
Fuel Oil	0.6
Hydrogen Rich Gas	1.3
Methane Rich Gas	1.3
Natural Gas	0
Total	**290.8**

The prospects for chemicals are quite good and the sub-sector is likely to grow with GDP. The prospect of natural gas from Mozambique replacing coal as the feedstock will makes the processes more efficient and reduce pollution.

Non-Ferrous Metals

Aluminium and titanium are the two predominant metals in this sector. The winning of both is very energy intensive. South Africa has the world's largest reserves of titanium but no commercial reserves of aluminium. Her successful aluminium smelters at Richards Bay use imported ore and depend for their economic success on cheap electricity, which is a major production cost.

Various expansions of titanium and aluminium are being considered or are already in progress. Zinc smelters are also likely to be built. The prospects for this sub-sector are good and in the short term at least it is likely to grow more quickly than GDP.

The table below shows the energy use in non-ferrous metals in 2000.

Energy for Non-Ferrous Metals 2000 (PJ)	
Coal	1.5
Electricity	61.5
Hydrogen Rich Gas	1.4
Natural Gas	0.0
Total	**64.4**

As the table shows, electricity dominates the energy for non-ferrous metals and this domination will continue and probably even increase.

Non-Metallic Minerals

The main activities in the sub-sector are the manufacture of cement and bricks, both energy intensive. The graph below shows the energy used in this sub-sector for 2000.

Energy for Non-Metallic Minerals 2000 (PJ)	
Coal	32.7
Electricity	20.5
Fuel Oil	3.4
Hydrogen Rich Gas	6.5
Total	**63.0**

Demand for cement and bricks follows GDP quite closely and growth in this sub-sector is likely to be the same as that of GDP.

Pulp and Paper

South Africa has a well developed pulp and paper industry and in its forest areas good conditions for growing “hard wood” (pine) and even better for “soft wood” (eucalyptus). Unfortunately the area suitable for forests is small and this puts a limit on the size of this industry.

The table below shows energy consumption for pulp and paper in 2000.

Energy for Pulp & Paper 2000 (PJ)	
Coal	51.4
Electricity	24.4
Methane Rich Gas	0.4
Wood	34.4
Total	**110.6**

Pulp mills convert logs into pulp, the feedstock for paper making. The energy in the bark and in "black liquor" extracted from the wood chips is used to fire boilers for the mill to make process steam and electricity. Modern pulp mills are completely self-sufficient in energy. Paper making, though, will always require energy from outside.

South Africa's pulp and paper industry is likely to grow with GDP and to become more energy efficient in future.

Food and Tobacco

This sub-sector includes food, beverages and tobacco. The biggest energy user in it is the processing of sugar from sugar cane. The table below shows the energy used by this sub-sector in 2000.

Energy for Food & Tobacco 2000 (PJ)	
Bagasse	49.6
Coal	49.0
Electricity	12.7
Fuel Oil	1.3
Hydrogen Rich Gas	0.9
Total	**113.4**

Food and tobacco energy demand is likely to grow with the economy.

Other

"Other" is a large and various sub-sector which includes manufacturing (of motor vehicles, clothing, electrical goods etc).

The table below show the energy demand for this sub-sector in 2000.

Energy for Other 2000 (PJ)	
Coal	66.0
Electricity	33.5
Oil Products	35.6
Other fuels	9.7
Total	**144.8**

Since other contains most of the secondary industries that add value to our primary commodities, this sub-sector contains many of the hopes for the South African economy in the future. It is expected that energy demand here will grow more quickly than GDP.

THE COMMERCIAL SECTOR

This sector consists of government, office buildings, financial institutions, shops, recreation and education. This is the "service" sector of the economy. As countries advance economically, this sector produces an increasing share of the GDP.

The table below shows the energy used in this sector in 2000.

Commercial Energy Demand 2000 (PJ)	
Coal	6.2
Electricity	62.0
Fuel Oil	3.0
Hydrogen Rich Gas	0.8
LPG	2.4
Natural Gas	0.0
Paraffin	0.2
Town Gas	0.3
Total	**76.4**

The energy is used mainly for lighting, heating and air-conditioning although office machines such as computers, fax machines and printers are becoming more important as energy users. Most of the energy is electricity.

In future energy demand for this sector is likely to grow more quickly than GDP as this sector is likely to take an increasing share of GDP. There is large scope for improved energy efficiency here including better design of buildings, more efficient lights (especially changing from incandescent to fluorescent lighting), more efficient air conditioning and heating, and better management of energy use. Electricity is likely to take an even bigger share of energy for this sector in future.

THE AGRICULTURAL SECTOR

As economies mature, agriculture uses a smaller and smaller share of the national employment, large farmers replace smaller ones and agriculture produces an ever smaller fraction of GDP. This is already happening in South Africa and is likely to continue even if a more equitable land distribution is achieved.

The table below shows the energy used by the agricultural sector in 2000.

Energy for Agriculture 2000 (PJ)	
Coal	9.2
Diesel	58.9
Electricity	21.2
Fuel Oil	0.1
LPG	0.8
Petrol	3.6
Paraffin	3.0
Vegetable Wastes	10.8
Total	**107.6**

There are likely to be to contrary trends in South African agriculture. With land reform, many new small farmers are likely to arise, and these will almost certainly use traditional farming methods on small plots, including the use of vegetable wastes for energy. On the other hand, globalisation and commercialisation of farming is likely to lead to fewer commercial farmers with bigger farmers and increased exports and imports. This will lead to a search for more energy efficiency. The latter trend is almost certain to be more important for agricultural energy demand and it is expected that vegetable wastes will decline in importance and diesel and electricity will grow.

Total agricultural energy demand is expected to grow less than GDP.

THE RESIDENTIAL SECTOR

The extreme differences in South African society show themselves most vividly in the residential sector, where some people live in modern brick houses and obtain their energy for cooking and lighting by flicking an electricity switch while others live in shacks of tin and wood and obtain theirs by spending hours of each day collecting firewood. The burning of wood and coal in poor households is not only inefficient but has very severe health consequences: the air pollution from burning these fuels in rudimentary appliances kills and causes lung disease in a huge number of our children. Fires caused by paraffin stoves cause a major loss of life in South Africa.

Residential energy falls into three categories: (i) traditional, consisting of wood, dung and bagasse, (ii) transitional, consisting of coal, paraffin and LPG, and (iii) modern, consisting of electricity. The universal trend around the world is from (i) through (ii) to (i).

The table below shows the fuels used in the South African residential sector in 2000.

Energy for the Residential Sector 2000 (PJ)	
Coal	58.0
Electricity	106.9
LPG	4.7
Natural Gas	0.0
Paraffin	25.3
Solar	0.2
Vegetable Wastes	4.3
Wood	84.7
Total	**284.2**

South Africa has recently been following the world's most vigorous programme of electrification, spearheaded by Eskom. From 1994 to 2000, 3.1 million households a year were electrified. 70% of households now have electricity (about 80% in urban areas and 50% in rural). There are huge benefits here in terms of improved health, economics and opportunities to join the modern economy. There are also drawbacks, mainly because most of the newly electrified households cannot afford to buy enough electricity to make it profitable for the utility. They also cannot afford electrical appliances such as stoves and so continue to use coal and paraffin even when they have electricity.

There are five main uses of residential energy: space heating, water heating, cooking, lighting and other (such as refrigerators, radios and TVs).

The table below shows the use of residential energy in 2000.

Residential Energy Use 2000 (PJ)	
Cooking	113.4
Lighting	15.4
Other	35.1
Space heating	90.8
Water heating	29.5
Total	**284.2**

In future the trend from traditional fuels through transitional to electricity is likely to continue. Electricity allows for more efficient energy use than coal, wood and paraffin but more energy will be consumed for water heating. There will be a growth in energy demand for non-essential appliances such as TVs.

Residential energy demand is expected to grow at the same rate as the population.

THE TRANSPORT SECTOR

This sector deals with the transport of people and goods by land, sea and air. Energy for transport is completely dominated by liquid fuels, such as petrol, diesel and jet fuel. It is more difficult in this sector than any other to switch from fossil fuels to other sources of energy.

The table below shows transport energy by fuel for 2000.

Energy for Transport 2000 (PJ)	
Aviation Gas	1.1
Coal	0.6
Diesel	169.6
Electricity	12.4
Jet Fuel	61.0
Paraffin	0.4
Petrol	331.9
Total	**577.1**

Air transport uses jet fuel (very similar to paraffin) for gas turbine engines and aviation gas (petrol with a higher octane rating) for piston engines. However, today there are very few piston engines in the air. Marine engines today are nearly entirely diesel, and these use mainly heavy fuel oil (bunker oil) rather than diesel, which is only used for very small boats. Land transport is dominated by petrol and diesel with some electricity used by trains.

The table below shows the amounts of energy used by land, sea and air.

Transport Energy by Mode 2000 (PJ)	
Air transport	62.1
Land Passenger	385.6
Land freight	129.0
Other	0.4
Total	**577.1**

Looking at the two tables above, one can see that land transport takes the largest share of transport energy and within it passenger transport takes more energy than freight transport. Because at present land passenger transport is mainly by petrol engine, this explains why petrol is by far the biggest fuel for transport. Sea transport is included in “other”, which is only 0.4 PJ. This is because marine bunkers for ships travelling between South African ports and foreign ports have been excluded.

One of the most important questions in transport fuel is the proportions of petrol and diesel fuels. The refineries produce approximately equal fractions of each. The coal to liquid fuel process used by Sasol produces more petrol than diesel. At the moment, therefore, in order to produce enough petrol to meet her needs, South Africa produces an excess of diesel, which is exported.

In future this might well change. In Europe, with the advent of efficient, reliable and convenient diesel engines, motorcars are switching from petrol to diesel. South Africa is likely to follow suit. Moreover the government’s proposed taxi recapitalisation scheme would change the minibus taxi fleet from petrol to diesel. It could be that in future, there is an excess of petrol rather than diesel.

Motor vehicles are major culprits in air pollution. In Europe and America, the drive for fewer emissions from motor cars is forcing engine manufacturers to make more efficient engines. This is likely to happen in South Africa too.

Much of the future of transport will depend on government policy and regulation. The future of rail transport, passenger and freight, for example, will depend on subsidies of rail and taxation of road transport.

Experience around the world shows that as countries get richer, private vehicle ownership and air transport grows considerable more quickly than GDP. People like private vehicles not only for flexible personal transport but also as status symbols. In South Africa, even among the poorest of people, the desire for a motor car is very high, and as the economy advances, more and more people will own them.

In future, energy demand for land freight and sea transport is likely to grow at the same rate as GDP but energy demand for land passenger transport and air transport is likely to grow much more quickly.

ENERGY TRANSFORMATION

ELECTRICITY GENERATION

South Africa has advanced electricity generation, produces the world's cheapest electricity and generates over half of all electricity on the African continent. There is now a surplus of generation capacity but this will end by about 2007, when new capacity will be required. Eskom, the public utility, produces over 90% of our electricity with the rest coming from municipals power stations and auto-generators (industries which generate electricity for their own use).

The table below shows the operational generating capacity in South Africa by energy source:

Energy Source of Generation	Capacity (MWe)
Coal	32202
Nuclear	1840
Bagasse	105
Hydro	667
Gas Turbines	662
Pumped Storage	1580
Total	37056

COAL

Over 90% of South African electricity comes from coal power stations. Our huge reserves of coal, much of it mined in open cast mines, and a programme since the late 1960s of building large, standardised, six-unit coal stations has resulted in South Africa's having very cheap electricity. Our stations are conventional pulverised fuel (PF) stations with no flue gas desulphurisation.

Coal is the most polluting source of energy for electricity generation and produces the greatest amount of waste, which includes nitrogen gases, sulphur gases, carbon dioxide, organic compounds, heavy metals and radioactive elements. It is a significant cause of air pollution. However, the benefits our coal stations have brought have greatly outweighed these environmental costs. In future, though, particularly with the threat of penalties for emitting greenhouse gases, the environmental aspects of coal stations will become pressing.

A serious disadvantage of coal is that all our coal fields lie in the north east of the country. Because of their large coal requirements, the stations have to be built close to the fields and this means that the electricity has to be transmitted long distances to the rest of the country, which causes problems in the gird.

In future we might build more conventional coal stations or turn to new coal technologies. Desulphurisation is likely to be used for new conventional stations although this will considerably increase capital and running costs.

Some of the new technologies include:

(i) **Supercritical coal stations**, which gain extra efficiency from high steam pressures. These are unlikely to be built because of the higher capital costs.
(ii) **Fluidised Bed Combustion**, where combustion of the coal takes place in a moving bed of coal particles and inert particles. This allows for the burning of low grade coals and discard coal. If the inert particles include lime, it can remove sulphur from the flue gas. The disadvantage is that these units cannot be used for load-following and take a long time to start up. This technology is likely to be used in South Africa.
(iii) **Integrated Gasification Combined Cycle**, where coal is first gasified, then burnt in a gas turbine with the exhaust gases raising steam for a steam turbine. This can achieve high efficiencies. However, the technology is complicated and our coal is unsuitable for it. This is unlikely to be used in South Africa in the next 20 years.

HYDRO-POWER

South Africa itself is a dry country with few rivers suitable for hydro-electricity. Most of its small capacity has already been used up. However, Africa to the north, which already produces large amounts of electricity from hydro-power, has gigantic potential for more. One site on the Congo River alone has the potential to supply the whole of Africa twice over.

Hydro-electricity is relatively clean and, provided the river is dependable, extremely reliable. However, the capital costs are high and there are environmental and social problems associated with large dams.

Because of its enormous potential, it seems highly likely that South Africa will import large amounts of electricity from Africa within the next twenty years.

GAS TURBINES

At present South Africa has a number of small gas turbine power stations, which are used entirely for peak demand topping or stand-by power. These are simple, single-cycle stations, essentially using aeroplane engines. They have low capital costs and start up very quickly but they are very expensive to run and have no prospect of providing large scale electricity in future.

However, the Combined Cycle Gas Turbine (CCGT), which combines a gas turbine with a steam turbine (running off the exhaust gases from gas turbine), achieves high efficiencies. Its capital costs are low and its emissions are only carbon dioxide, water vapour and some nitrogen gases. If South Africa uses gas for power generation on a large scale, it will certainly be from this technology.

The uncertainty is over the availability and costs of the gas. South Africa herself has small gas fields. There are larger fields in Mozambique and off the coast from Namibia. Angola has huge fields. Imported natural gas feeding into CCGTs is likely to generate considerable electricity for South Africa in future.

NUCLEAR

Nuclear power is paradoxical. On the one hand it has the best safety record of any large scale source of electricity and is the only one to have procedures for storing its waste safely. On the other it is perceived as being dangerous and having a waste problem. Perceptions are the greatest obstacle for nuclear power.

Nuclear power generates large amounts of electricity from very small amounts of fuel. It releases no greenhouse gases in its operation. Because the fuel is so small, it can be transported easily and nuclear power stations can be situated anywhere.

South Africa has one nuclear power station, Koeberg, just north of Cape Town. It uses standard pressurised water reactors.

Capital costs for present designs of nuclear stations are higher than for coal or gas and this has been a handicap for nuclear power in the past. However, there are designs for a new generation of nuclear plants that are smaller, simpler, safer and cheaper than existing one and these could make nuclear power an economically attractive option in future. One of these is the Pebble Bed Modular Reactor (PBMR) being designed in South Africa.

SOLAR AND WIND

The Northern Cape has some of the world's best conditions for solar power, and much of South Africa's coastal region is suitable for wind power. Solar power and wind power have the advantage that the fuel is free and they are clean. They both have the disadvantage that their source of energy is dilute and intermittent. To produce reasonable amounts of electricity, you need not only to have very large collection areas but also storage against times when the sun is not shining or the wind is not blowing. This means that capital costs of wind and solar power are very high.

Electricity from the sun may either come from photovoltaic panels which convert sunlight directly into electricity, from thermal stations which use sunlight to heat water into steam to drive a turbine or by using the chimney effect to drive a air turbine from air heated by the sun. Photovoltaics are already used to provide electricity for houses, clinics and schools in rural areas. There are proposals for both a thermal power station and a solar chimney (or solar pipe) in the Northern Cape.

Wind power is growing rapidly in northern Europe and turbines are becoming larger and more efficient. There are proposed schemes both by Eskom and an independent consortium in the Darling area to build wind farms of about 5 to 20 MWe capacity.

BIOMASS

South Africa already generates a substantial amount of electricity from biomass, namely from bark and black liquor in the pulp mills and from bagasse in sugar refineries. This is all used by the industries themselves. Because of the lack of suitable arable land for increasing forest and cane fields, there seems little prospect of increasing this generation substantially to put useful amounts of electricity into the national grid.

STORAGE

The demand for electricity is not even during the day. There are peaks in the morning and evening. Providing extra generating capacity just to meet these peaks would be inordinately expensive. An alternative is to find some way of using the extra capacity during off-peak times to store energy which can be released in peak times. The most usual way of doing this is by "pumped storage", pumping water uphill during off peak and allowing it to run downhill through a turbine to generate electricity on peak.

South Africa has three pumped storage schemes: Drakensberg, Palmiet and Steenbras, with a combined capacity of 1580 MWe. In future, with increased peaks because of more residential electricity, there is a good chance of further such schemes.

LIQUID FUELS

South Africa produces liquid fuels, such as petrol, diesel and paraffin, by three methods: (i) crude oil refining, (ii) coal to liquid fuels, and (iii) natural gas to liquid fuels

The table below shows the capacities of South African facilities by barrels of crude oil or equivalent going in.

Facility	1000 barrels / day (Crude or equivalent)
Oil Refineries	
Calref (Cape Town: Caltex)	110
Sapref (Durban: BP/Shell)	165
Genref (Durban: Engen)	104
Natref (Sasolburg: Sasol/Total)	90
Coal to Liquid Fuel	
Sasol 2 & 3 (Secunda)	150
Gas to liquid fuel	
Mossgas	45
Total	664

CRUDE OIL REFINING

South Africa has four crude oil refineries: Sapref, Enref, Calref and Natref. The only one not at the coast is Natref, which is of a special design so as not to produce residual marine oil for ships' bunkers. The products of the refineries are petrol (about 35%), diesel (32%), residual fuel oil (20%), paraffin (4%), jet fuel (7%), avgas (0.7%), LPG (1%) and refinery gas (0.8%). The ratios of petrol to diesel can be altered slightly by changing operating conditions.

In the past, it was felt necessary for strategic reasons to have security of supply, and therefore a surplus of capacity. This is no longer the case now. To meet its petrol demand, South Africa produces more diesel than it can consume and this excess is exported. However, with a shift to diesel engines in land transport, this may well swap over.

It is unlikely that South Africa will build another oil refinery. In future, extra demand is likely to be met by imports.

COAL TO LIQUID FUELS

South Africa leads the world by far in converting coal to liquid fuels. Sasol has two large units at Secunda which produce diesel, petrol and other fuels from coal. The earlier unit at Sasolburg is now dedicated to making chemicals from coal. Approximately 23% of South Africa's liquid fuel is made from coal at Secunda. Secunda produces considerably more petrol than diesel.

The advantages of the coal to liquid fuel process is that it saves on foreign exchange since the feedstock is local. It has also stimulated a unique range of products which are sold around the world. The disadvantages are that the process is inherently inefficient and polluting, releasing large amounts of carbon dioxide.

A strong possibility for the future is that natural gas will be used as the feedstock instead of coal. This allows a cleaner, more efficient and more economic process. Already a pipeline is being planned to bring in natural gas from Mozambique to the Sasolburg plant, where it will be a feedstock for chemical production.

Sasol has developed a process to make exceptionally clean diesel from natural gas and is likely to exploit this around the world.

It is unlikely that any more coal to oil plants will be built in South Africa.

GAS TO LIQUID FUEL

The Mossgas plant on the south coast makes liquid fuels from an off-shore natural gas field. It produces about 7% of South Africa's liquid fuels. The fields are not large but there is the possibility that gas could be piped to Mossgas from elsewhere in Africa.

Similarly the coal to liquid fuel plants at Secunda could be converted to making liquid fuels from natural gas piped in from Africa.

ENERGY DEMAND: THE INDUSTRIAL SECTOR

1. INTRODUCTION

The "Industry Sector" in this report includes mining, manufacturing, construction and all processing except the processing of energy from one form to another, such as oil refineries which convert crude oil to petrol and other refined products and power stations which convert coal and other fuels to electricity. These processes fall under "Transformation".

The Industrial Sector is the biggest user of energy and the biggest user of electricity. In 2000 it consumed 43% of South Africa's final energy consumption and 66.9% of her electricity.

South African industry was founded on mining following the discovery of diamonds and gold in the last century. Huge mineral wealth and an abundance of cheap energy in the form of coal lead to an industry dominated by mining, processing and energy transformation on a large scale. Mining rose in relative importance in the economy until the 1940s and has been in steady relative decline since then. However industry is still dominated by large processing plants which are big users of energy, such as the iron and steel plants, the aluminium smelters, Sasol's coal to chemical feedstock plants and cement mills. The diversification into light manufacturing and high technology, which uses less energy per unit of value added, has not happened in South Africa to the same extent as it has happened in east Asian countries.

South African industry is energy intensive, that is, it uses large amounts of energy for every dollar of added value, compared with industries in the developed world. Final industrial energy consumption is dominated by coal (which produces 50% of all industrial energy) and electricity (31%). The next most important energy source is liquid fuel (5.3%). [(1)]

The biggest energy users in the Industrial Sector are (% for 2000 in brackets): chemical and petrochemical (22% of total industrial energy, 12.6% of total industrial electricity); iron and steel (29% of energy, 22% of electricity); mining (11.5% of energy, 29% of electricity); non-ferrous metals (4.9% of energy, 15.6% of electricity); non-metallic minerals (4.8% of energy, 5.0% of electricity); food and tobacco (8.6% of energy; 3.2% of electricity); and paper, pulp and print (8.4% of energy, 6.2% of electricity).[(1)] The rest of industry consists of a wide range of enterprises, including manufacturing and processing, which are usually on a much smaller scale.

Future energy demand in the industrial sector depends on various economic and political factors. Economic growth, export growth, the nature of South African industry, energy efficiency, selection of fuel and policy decisions in South Africa and in the international community. Growth in the gross domestic product will be the most important influence in energy demand. However, the big users of energy - mining, iron and steel, aluminium smelting, chemical and petrochemical - are big exporters, with iron and steel exporting up to half of its produce and the rest more than half, and these will be affected by the state of the world market outside South Africa. If South African industry remains concentrated on primary extraction and processing, it will continue to be a heavy user of energy; if it diversifies into higher technology manufacturing and processing, its energy intensity will come down.

In future electricity is likely to increase its share of industrial energy, an international trend. Synthetic gas, from the Sasol plants, and natural gas, imported from the fields in Namibia and Mozambique, are likely to grow in importance. Coal will probably decline in relative importance, although over the next thirty years it will still be a major final energy source, second only to electricity.

2. ENERGY CONSUMPTION IN INDUSTRY

In 2000, the South African Industrial Sector took 43.4% of South Africa's total final energy consumption (1325 PJ out of 3055 PJ) and 66.9% of her electricity (410 PJ out of 612 PJ). This makes the Industrial Sector the largest user of energy and the largest user of electricity. 31% of the energy for the Industrial Sector is electricity.[(1)] Figure 1 below illustrates these proportions.

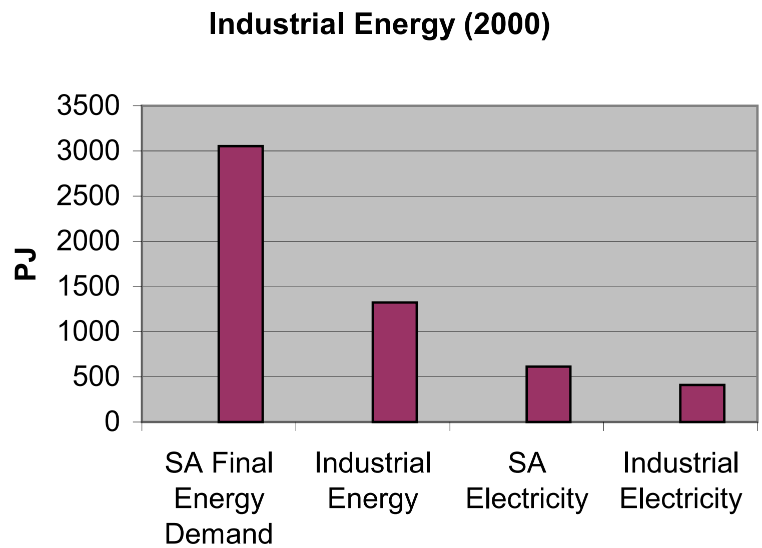


Figure 1. Energy Consumption in the Industrial Sector(1)

Table 1 below shows the energy consumption of the various divisions within the Industrial Sector in 1996. As the table shows the largest user was the chemical and petrochemical division which used 25% of industrial energy although only 3% of its electricity. This does not include the refining of crude oil to petroleum and other products nor the conversion of coal to liquid fuels, which comes under the Transformation Sector. The second largest user was the iron and steel division, which uses 21% of industrial energy and 18% of its electricity. In previous years, iron and steel had been the largest user (see figure 2 below). The third largest user was mining and quarrying with 17% of industrial energy; this was however the largest user of industrial electricity with 41% of the total. These are the big three industrial consumers. After them comes food and tobacco with 10% of energy and 7% of electricity, and paper, pulp and print with 10% of energy and 7% of electricity. Non-ferrous metals and non-metallic minerals, each use 5% of total industrial energy. The largest energy user in non-ferrous metals is aluminium smelting industry, where the energy is mainly electricity. The largest in non-metallic minerals is the manufacture of cement. (1)

After these large consumers, the Industrial Sector is spread over a wide range of small consumers which are so various it is difficult to categorise them or collect individual statistics for them. Hence the large division “Non-Specified” which consumes 7% of the total energy of the Industrial Sector.

Table 1. Energy Consumption of Industrial Divisions for 2000(1)

	Energy PJ	% of Industrial consumption
Iron & steel	385	29.1
Chemical & petrochem	291	21.9
Non-ferrous metals	64	4.9
Non-metallic minerals	63	4.8
Gold Mining	73	5.5
Other Mining	80	6.0
Food & Tobacco	113	8.6
Pulp & Paper	111	8.4
Other	145	10.9
Total	**1325**	**100.0**

However, these statistics for energy use for the various divisions of industry can change widely, and often against long term trends, according to events within the industry and according to the time the energy audits were taken. Figure 2 below shows the total energy use by the main industrial divisions, excluding Food and Tobacco and Paper, Pulp and Print, from 1992 to 1997.

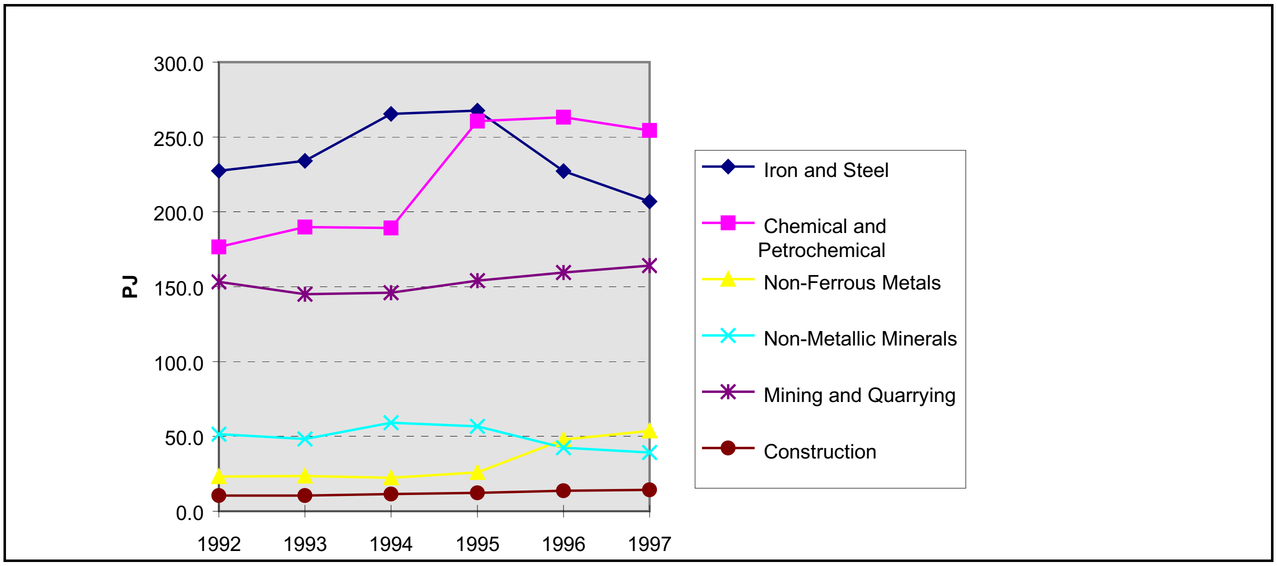


Figure 2. Industrial Energy Demand by Main Divisions from 92 to 97[3]

3. THE HISTORY AND NATURE OF SOUTH AFRICAN INDUSTRY

The discovery of diamonds and gold towards the end of the Nineteenth Century fundamentally changed the history of the South African economy and began the long dominance of mining in her industry. South Africa discovered a huge wealth of metals and an abundance of coal. The combination of mineral wealth and plentiful energy in the form of coal led to what has been called “the minerals-energy complex”. The progress of industrialisation in South Africa follows the same direction as that of other countries but the pace is different. In general, countries move from agriculture and mining (the primary sector) through heavy industry and manufacturing (the secondary sector) to light industry, information industries and services. The movement is towards diversification. In South Africa this diversification has been slow in coming. This is from a combination of causes, natural and manmade. Kimberly had electric street lighting before London (in 1882) but South Africa has yet no indigenous brand of motor car or washing machine; South Korea began industrialisation a few decades ago and has both.

Figure 3 below shows the relative contribution to the South African gross national product of mining, manufacturing and construction from 1912 to 1997.

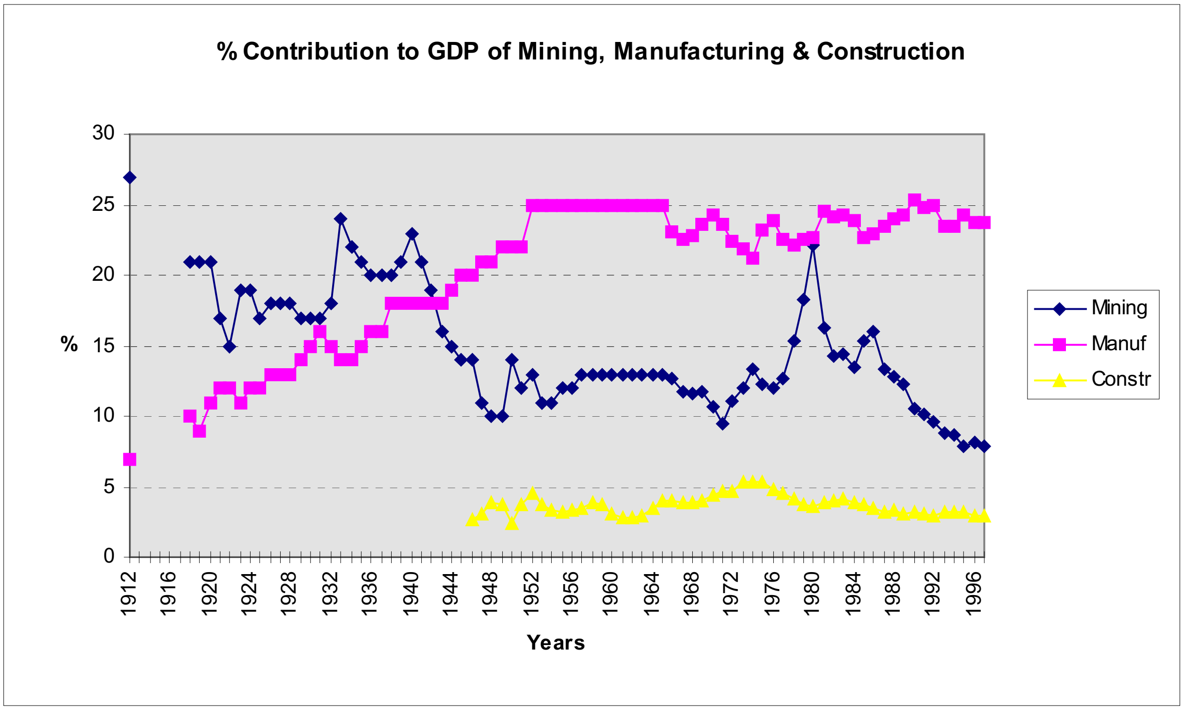


Figure 3. Contribution to GDP of Different Divisions of Industry[(4)] (Current prices)

The graph shows the reduction in relative importance of mining from 1912 to now, from 27% to 8%. The rise in the 1970's to a peak in 1980 was caused by the sudden increase in the gold price and the biggest ever production of gold; this skewed the national statistics at the time. Manufacturing rose from 7% in 1912 to 25% in 1952 where it has stayed for the last 45 years.

From 1916 to about 1980, the proportion of imported manufactured goods dropped from 53% to 15% and has remained at that level since. Import substitution was led by consumer non-durables, where the percentage imported dropped from 48% in 1916 to 6% in 1993, and followed by capital goods, where the percentage imported dropped from 70% in 1916 to 32% in 1993[(5)].

Figure 4 below shows the industrial growth rate of South Africa compared with some other countries at a similar stage of development from the year 1971 to the year 1991. In this figure and in figures 5 and 6 below it, "industry" includes energy transformation such as power stations and oil refineries. The acronym, OECD, stands for Organisation for Economic Co-operation and Development; it is a grouping of the world's most developed countries.

Figure 4 shows strong industrial growth in almost all of these developing countries, especially in East Asia. South Africa, unfortunately, is an exception with a poor growth of only 2.9% per annum from 1971 to 1991, making it the worst performer on the list. Figure 5 shows growth in industrial energy demand for the same countries and period. South Africa shows amongst the lowest growth in demand at 2.4% between 1971 and 1991. Figure 6 shows the percentage of energy intensive industry for these countries in the years 1971, 1981 and 1991.

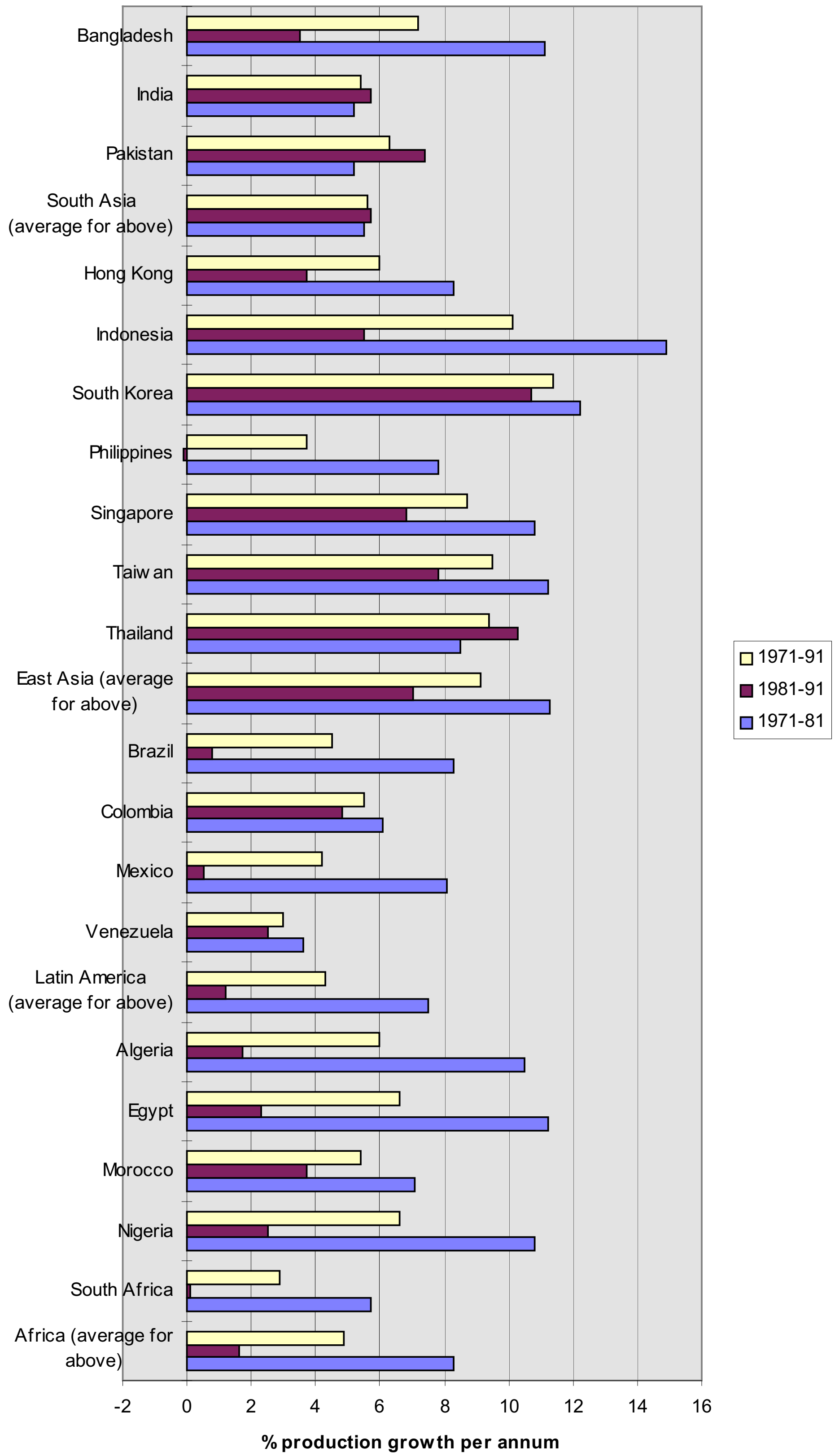


Figure 4. Industrial Production Growth Rates[(6)]. (% per year)

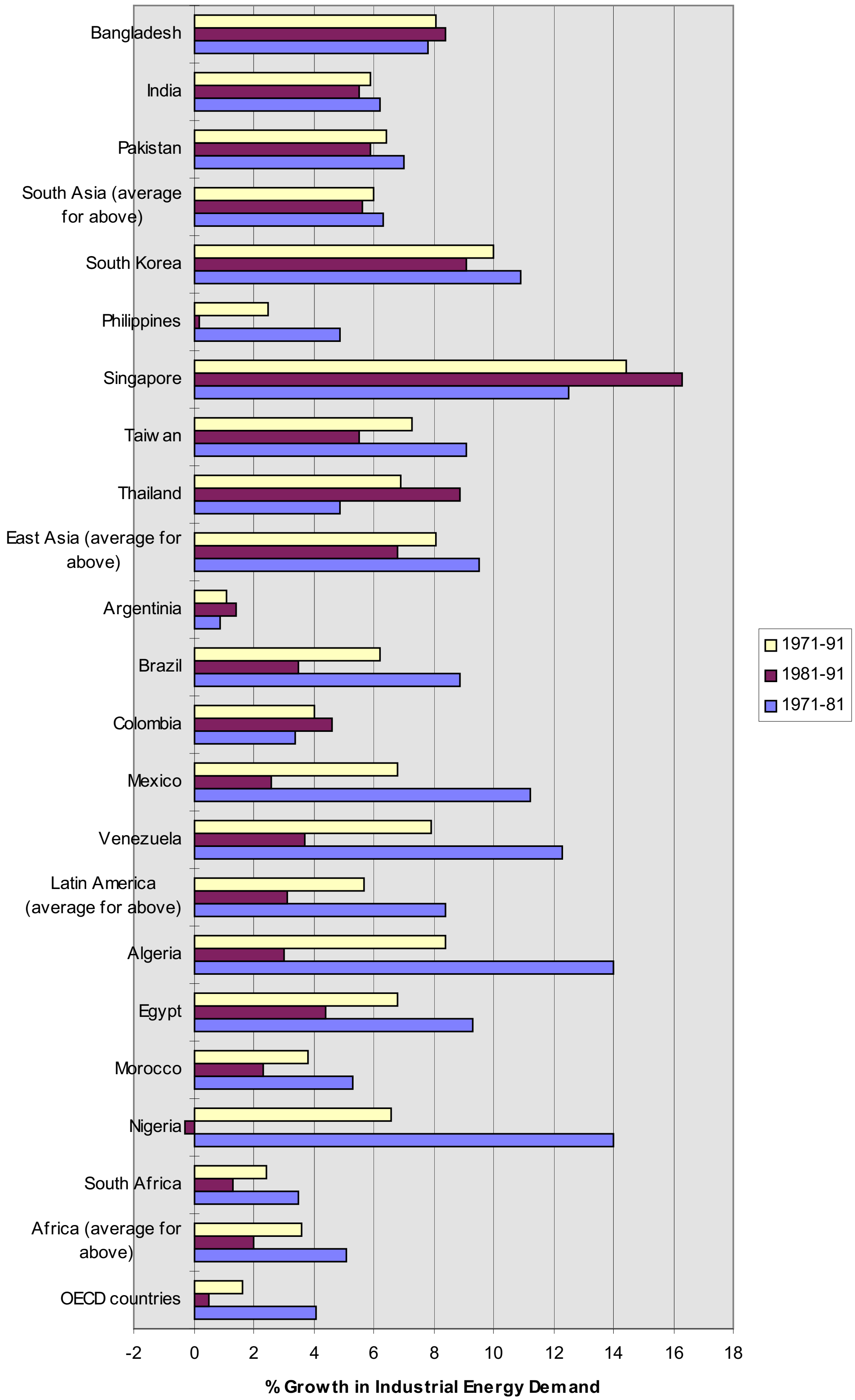


Figure 5. Industrial Energy Demand Growth in Developing Countries (7)

Figure 6 shows the share of energy intensive industry for these countries from 1971 to 1991.

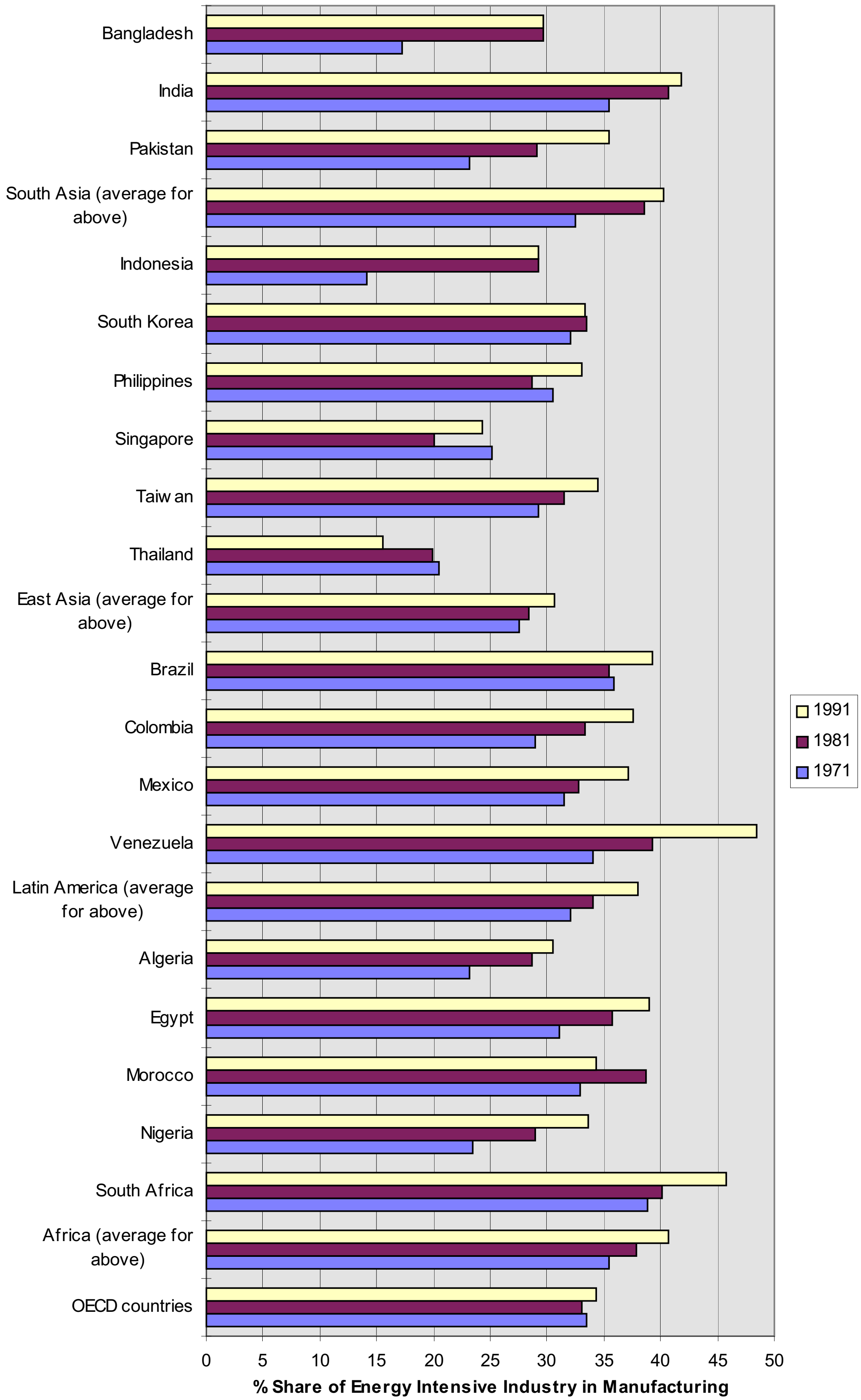


Figure 6. Share of Energy Intensive Industry in Manufacturing[(8)] (%)

The energy intensive industries are iron and steel, chemicals, non-ferrous metals, non-metallic minerals, and pulp and paper. The most energy intensive industrial activities are the melting of metals and the manufacture of cement, bricks and glass. Non-energy intensive industries are food, tobacco, textiles, leather, wood products, fabricated metal products, machinery and equipment and other non-specified industries. In nearly all of the countries considered there has been an increase in the percentage of energy intensive industries. South Africa, with 45.8% of its industry energy intensive in 1991, is the second highest in the list, surpassed only by Venezuela. The OECD countries have only 34.3% of their industry energy intensive and East Asia, with the most advanced economies among the developing countries, has 30.6%.

In summary, South African manufacturing has risen from 7% of GDP in 1912 to 25% in 1952, where it has remained since. The growth of production and energy demand in South African industry has been quite low from 1971 to 1991. South African industry is energy intensive, with an emphasis on minerals extraction and processing, and it has failed to diversify nearly as much as the newly developed economies of East Asia.

4. INDUSTRIAL DIVISIONS

4.1 Mining

Mining dominated South African industry from its beginnings. South Africa has vast mineral wealth, including the world's largest reserves of gold, chromium, manganese, platinum, titanium and vanadium, and huge amounts of copper, iron ore, lead, silver, fluorspar, uranium and coal. However, as Figure 3 shows, the relative importance of mining in the economy has been decreasing since the 1930's. Revenue from minerals, measured in USA dollars, has been declining for the last ten years.

In 2000 mining consumed 114 PJ of electricity, 18 PJ of coal and 18 PJ of diesel.(1) Mining is the biggest industrial consumer of electricity by far. In 2000 it consumed 29% of electricity and 12% of total energy in the industrial sector. The electricity is used for hoisting, milling, cooling and ventilation.

Gold is still the most important mineral mined in South Africa, earning R24.1 billion in 1998 compared with R17.7 billion for coal and R11.6 billion for platinum group metals, the next most important minerals.(9) However, gold is becoming less important both absolutely and relatively. The price of gold has declined from its peak in the 1970's. Production is also declining and the 1998 figure, 464 tons, was the lowest since 1955. This is because of declining gold ore concentrations, ever-increasing depths and declining prices.

Gold is by far the biggest energy user in mining. Although the tonnage of South African gold production is decreasing, the energy needed for each ton of gold is increasing. This is because the gold mines are going deeper and deeper, needing more energy for cooling, lifting and transporting. As the gold content of the ore available decreases, more tons of ore have to be dug, lifted and processed for each ton of gold recovered, and this uses more energy. Figure 7 shows these trends from 1967 to 1995.

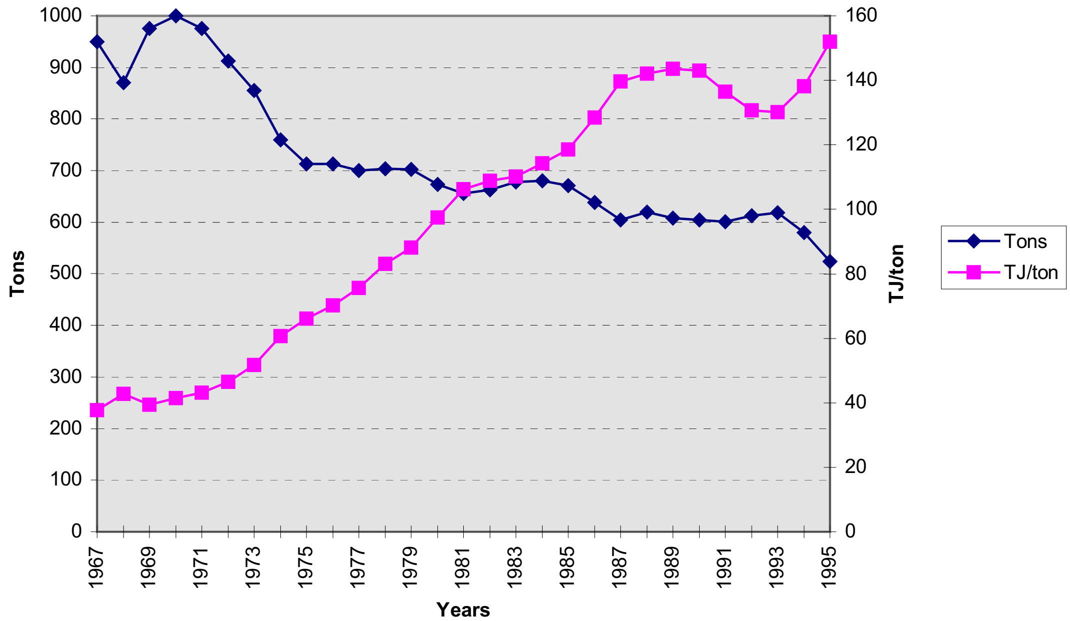


Figure 7. South African Gold Production and Electricity Intensity from 1967 to 1995 [10]

It must be pointed out that electricity is not the only energy used in mining gold although it is by far the most important one. It also must be pointed out that the electricity figures per ton of gold include the electricity for mining uranium. Uranium is found in company of gold and is extracted with it as a by-product.

The total amount of electricity used for mining gold increased from 1967 to 1988 and after that declined slightly. The electricity used in gold mining as a percentage of the electricity used in all mining declined from 88% in 1967 to 67% in 1995. Since then it has declined further. However, it still uses more electricity than all other mining put together. Indeed in 1996 it still used 12% of all the electricity consumed in South Africa, making it the biggest single user. These trends are shown in Figure 8 below.

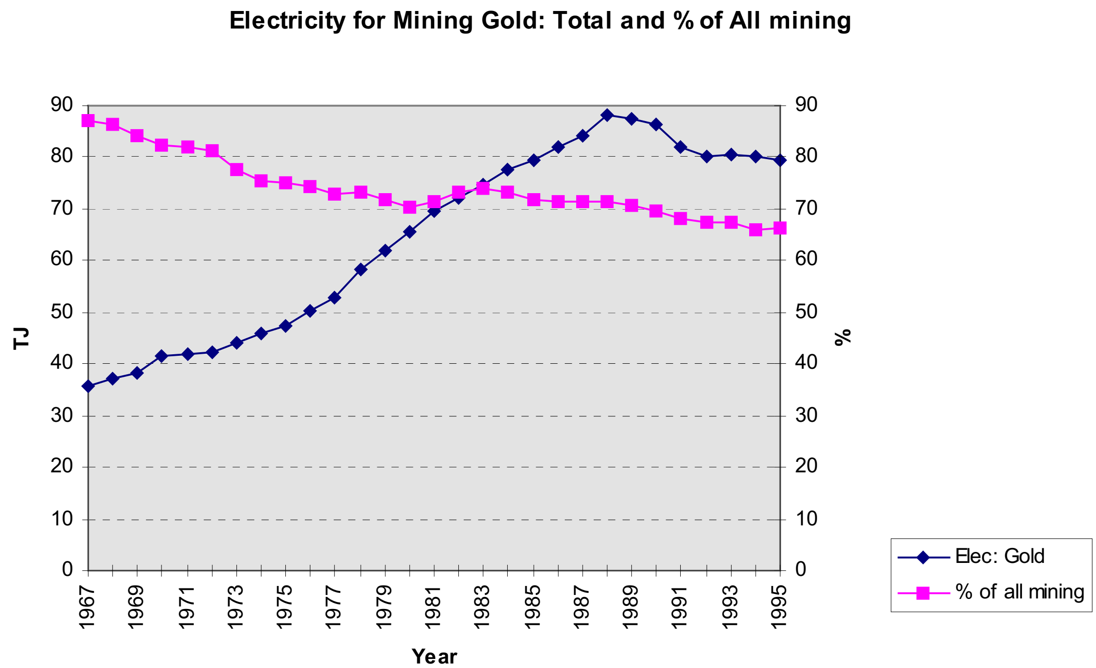


Figure 8. Electricity for Mining Gold: Absolute Consumption and % of All Mining [11]

Besides gold, South Africa mines a large range of minerals, precious, metallic and non-metallic, of which the most important are platinum, copper, chrome, iron ore, manganese, titanium, diamonds and coal. Until recently coal brought in the second biggest revenue after gold. Since then it has been surpassed by platinum and indeed in 2000 platinum exceeded gold with the highest value of foreign sales. This was due to the rapid increase in the price of platinum.

The consumption of electricity for platinum mining increased from 2758 GWh in 1980 to 6613 GWh in 2000, an average growth of 8% a year.

Various expansions or new projects in mining are in progress, being planned or being considered. These include the South Deep gold mine, the Target gold mine, platinum mines, expansion of the Premier diamond mine, Iscor heavy mineral sands at the Wild Coast, expansion of the Nkomati nickel mine and mining of further titanium sands at Saldanha or Richards Bay. In the neighbouring countries the Skorpion zinc mine and refinery is likely to go ahead in Namibia and there might be a new copper mine at Haib in Namibia. The Corridor Sands project is likely to go ahead in Mozambique.

In real terms, the earnings from South African mining have been static for the last thirty years. The history of almost every commodity, including minerals, is that it drops in price in real terms. (This is a strong argument for beneficiation of our minerals.) However, South Africa has an abundance of mineral reserves for which there will be international demand and nearly 80% of earnings from minerals come from exports. So for the indefinite future mining is unlikely to decline and may even slightly increase. In the special case of gold, production is likely to decline but with increasing depths and poorer ores the amount of energy required will stay the same or increase. The increased working of mine dumps will to a small extent counteract this trend. The one possibility that could change the future for gold mining is ultra-deep mining, to depths down to 5000 m, which could extract again almost as much gold as has been mined in the past.[45] This is only likely to happen with a large and sustained increase in the price of gold.

New drilling technologies might well alter the nature of deep gold mining. At present most drilling is done by pneumatic drills using compressed air. They are noisy and inefficient. Hydraulic drills, using a head of water for power, have been introduced in some new mines. These are quiet and more efficient than the pneumatic drills but it is costly to install the high pressure water piping for them. A third possibility is electric drills and there are some indications that these might soon be developed for duty on the mines. They would probably be more efficient than either pneumatic or hydraulic drills and would only require electric cabling for installation but it remains to be seen whether they will be reliable.

Various expansions or new projects in mining are in progress, being planned or being considered. These include the South Deep gold mine and the Target gold mine. The Sun and Oribi gold projects will be considered over the longer term depending on the gold price.

Platinum is considered to have a very good future. Its use in catalytic converters is likely to saturate over time and the amount of material needed for catalytic reactions is likely to decline but platinum has various other applications some of them new, such as in fuel cells. A number of new platinum mines are being considered and so is a new smelter at Pietersburg. Energy consumption in platinum mines is expected to show significant growth in the medium term.

Southern Africa is rich in iron and titanium deposits, and there are plans for more iron and titanium plants, such as Iscor heavy mineral sands at the Wild Coast. Iskor is presently building its iron and titanium mine in Empangeni. There might be further mining of titanium sands at Saldanha or Richards Bay. The expansion of Anglo-American Namaqua sands is expected over the medium term.

Zinc mining is expected to get a boost from future zinc plants such as Gamsberg. A feasibility study is underway looking at a large-scale expansion of the Avmin/Nkomati nickel mine in Mpumalanga at a capital expenditure of around R1.6bn. There are also plans to deepen and extend the life of the Black Mountain Mine which produces mainly lead and zinc. In Namibia, the Skorpion zinc mine and refinery is likely to go ahead, and there is potential for copper mining over the longer term with the proposed new Haib copper mine.

Coal mining in South Africa is expected to show moderate growth. This includes a relatively small growth in exports.

The expansion of the Premier diamond mine near Cullinan is excepted to occur in the medium term.

The costs of energy are of major importance in mining. Recently (January 2002), Anglo-American has withdrawn from copper mining in Zambia, partly because of the low copper price but also because of the high operational costs, including the power costs, which were estimated to be 20% of total costs. A large part of the power demand was for the pumping of water. (Sunday Times, 27 Jan 02)

4.2 Iron and Steel

South Africa has in abundance all the natural resources needed for steel production with the exception of coking coal. She has 5.9 billion tons of iron ore (the eighth largest reserves in the world), 4 billion tons of manganese (80% of world's reserves), 12.5 million tons of vanadium (the largest in the world), 3.1 billion tons of chrome (68% of world reserves) and 11.8 million tons of nickel (10% of world reserves). She also has large coal reserves (35 billion tons). However, very little of this coal, probably only about 2%, is suitable for making coke, which is used for reducing iron ore to iron.[12]

In 1996 South Africa produced 6.5 million tons of finished steel. This is 1% of the world's production of 656 million tons and makes South Africa the world's twenty-first largest steel producer. Local consumption was 4 millions tons, of which 0.3 million was imported, and 2.8 million tons was exported, making South Africa the world's tenth largest steel exporter.[13]

With the world's largest reserves of chromium, South Africa is well placed to make ferrochrome and ferroalloys, and indeed stainless steel is now the fastest growing of South Africa's steel industries. From 1987 to 1997 stainless steel production grew at 9% per year compared with the world average of 6% per year. By 1997 South African production of stainless steel was 350 thousand tons, of which 80% was exported.[14] When the Columbus Stainless Steel plant is on full production, this will push production up to 600 thousand tons a year.[15]

Iron and steel making is very energy intensive and is the world's largest user in the industrial sector, accounting for 20% of the world's industrial energy consumption in 1993. In the OECD countries, from 1960 until 1973, a period of high world economic growth, GDP, industrial energy demand, industrial production and steel production were closely linked and all grew by about 4.8% per annum. From 1973 to 1993, however, while GDP and industrial production continued to grow strongly at the same pace, steel production and industrial energy demand both declined by about 0.4% per annum. In parts of the developing world, industrial energy demand and steel production have both grown strongly in this period.[16]

From 1960 until 1973, in both the developed countries and the developing countries, the tonnage of steel consumed per unit of GDP (the "steel intensity of the GDP") remained about the same; from 1973 until 1993 it declined markedly.[17]

Table 2 below shows the consumption of steel per capita and Table 3 the steel intensity of the GDP for a selection of developing and developed countries in the years 1973 and 1993.

Table 2. Apparent Consumption of Steel per Capita (kg of crude steel per capita.)[18]

	1973	1993
United States	737	400
Germany	621	401
Japan	822	646
China	35	110
India	13	22
Korea	84	606
Brazil	87	70
South Africa	223	120
World Average	177	133

"Apparent steel consumption" is steel production plus imports less exports. In all the countries considered, except China, India and Korea, the trend is markedly downward. In South Africa consumption has almost halved. The three exceptions are countries that have been strongly industrialising from a low base.

Table 3. Steel Intensity of GDP (kg of crude steel consumed per $1000 of GDP)[19]

	1973	1993
United States	51	22
Germany	77	33
Japan	97	43
China	47	66
India	16	17
Korea	41	77
Brazil	27	17
South Africa	65	39
World Average	54	33

Again the trend, including the South African trend, is downward with the same three exceptions. World steel intensity, that is, the tonnage of steel consumed per unit of GDP, has declined for the whole world since the mid 1970's. This is because of technological change: there has been more efficient use of steel, such as using thinner plate in motorcars, and there has been a replacement of steel with other materials, such as plastics and aluminium in motorcars. This decline is expected to continue.

The world's pattern of steel production and of steel exports and imports is changing. World steel production only grew at 0.3% per annum between 1973 and 1993. In the OECD countries steel production reached a peak in the mid 1970's, declined by an average of 2.9% per annum from 1973 to 1983 and then increased by an average of 1.1% until 1993. In developing countries steel production increased rapidly in these years and in the Far East, for example, it increased by an average of 12.5% per annum from 1973 to 1993. In 1973 the OECD countries produced 67% of world steel; by 1993 they produced 52%.[20] Table 5 below shows the main net exporters and importers of steel in 1993.

Table 4. Net Exports and Imports of Steel for Selected countries in 1993 (million tonnes)[21]

Net Exporters		Net Importers	
OECD Europe	32	China	40
Japan	19	East Asia excluding Korea	39
Former Soviet Union	17	USA	14
Brazil	14	Middle East	8
Eastern Europe	13	Africa excluding South Africa	7

The Table 4 shows some anomalies; on the one hand the advanced economies of OECD Europe and Japan are net exporters of steel but on the other the advanced economy of the USA is a net importer. In fact Japan's ratio of steel exports to imports has been declining since about 1978 while those of OECD Europe and the USA have not changed. Among developing countries the trends are different. South Africa, Korea and Brazil have increased their production to consumption ratios from 1973 to 1993 - from 1.0 to 1.8 in the case of South Africa. [22]

There are conflicting trends in steel production: GDPs are going up around the world but steel intensity of GDP is declining; steel production is growing slowly or not at all in most developed countries but growing rapidly in some developing countries, including South Africa. Steel production is often supported by governments, who have a nationalist desire for self-sufficiency in steel, and so steel production is not just determined by market forces.

The projection of the International Energy Agency is that steel production until 2010 will grow at 1% per annum for the OECD countries, 2% for the former Soviet Union and eastern Europe and 3% for the developing countries.[23] The SA Department of Mineral and Energy Affairs in 1992 gave three projections for steel production until 2015: (i) "survival" at 1.5% growth per annum (ii) "moderate" at 2.7%, and (iii) "fast growth" at 5.0% [24]

As mentioned above, steel making is very energy intensive. However, the energy intensity of steel production, measured in energy used per ton of steel produced, is coming down all over the world thanks to improved technologies. This meant that for the OECD countries, total energy demand for steel making actually declined from 1973 to 1993 while steel production increased. In the case of the developing countries, though, the energy demand considerably increased. Table 5 below shows the energy intensity of steelmaking in selected countries in 1971, 1981 and 1991.

Table 5. Energy Intensity in Steel Production (TOE per ton of crude steel)[25]

	1971	1981	1991
India	0.97	1.10	0,94
South Korea	na	0.42	0.34
Taiwan	0.73	0.42	0.33
Brazil	0.39	0.37	0.41
South Africa	0.95	0.74	0.71
United States	0.51	0.39	0.28
Japan	0.50	0.38	0.33

There is a downward trend in all countries except Brazil and India. The reduction in energy intensity is because of improved technologies. South Africa, although it improved considerably over the 20 years, has a high energy intensity compared with other countries.

The high energy intensity of steel production in South Africa is caused by various factors, technical and natural. Her raw materials for steel making have poor qualities for energy efficiency: the coal has high ash and volatile content, the coking coal has low strength, the iron ore has high alkali content, and there is a low proportion of sinter and no pellets in the blast furnaces. A large part of her electric furnace steel production uses directly reduced iron (DRI) rather than scrap, which increases energy use. In the older steel plants a low proportion of off-gas and waste heat is recovered and used. The cheapness of energy compared with the high capital costs of South African steel plants made energy efficiency a low priority in the past.[26] However, South Africa now is using a new steel-making process, Corex, which will improve energy efficiency and when used in an integrated plant will make use of the off-gas.

Steel is made in two steps: first iron ore is reduced to iron (by removing oxygen) and then iron is refined into steel (by removing impurities and setting fixed quantities of carbon and other additive elements). The iron produced in the first step may be either liquid iron or directly reduced iron (DRI), which is in solid state. The DRI may be in the form of “sponge iron” or of “hot briquetted iron” (HBI) where directly reduced iron fines are compacted into briquetts. This first step, iron ore to iron, uses more energy than the second, iron to steel. Until recently there were four routes from iron ore to steel, which used coal, coke, electricity and gas. They were: (i) blast furnace and open hearth furnace, (ii) blast furnace and basic oxygen furnace, (iii) direct reduction furnace and electric arc furnace, and (iv) electric arc furnace using scrap metal. The blast furnace uses coke. The basic oxygen furnace is a more recent technology than the open hearth furnace and uses less energy per ton of steel.

The shortage of coking coal has prompted South Africa to move into new technologies of steel-making which do not need it, notably the Midrex process and the Corex process. The Midrex process produces DRI using either coal or gas as a reductant. 90% of the DRI around the world uses gas but in South Africa it is made using coal, either directly or after gasification.

In the Corex process, which use coal lumps, iron ore is reduced to DRI in a reduction shaft and then made into liquid iron in a melter-gasifier. Iscor at Pretoria had the world’s largest Corex plant, producing over 300,000 tons a year of iron, but it was mothballed because of the poor market. It has built another Corex plant at Saldanha Bay for special steels which was commissioned in 1998. It was built in tandem with a Midrex plant and together they have a capacity of 1 240 000 tons of hot-rolled coil steel a year.

The Corex process releases large quantities of useful gas called “top gas” or “export gas” or “Corex” gas. It has a typical composition of 44% CO, 32% CO_2, 16% H_2, 5% N_2, 1.5% CH_4 and 1.5% H_2O. Its heating value is about 8 MJ per cubic metre. A Corex plant producing 1000 tons of steel a day releases enough gas to generate 60 MW electricity.(27) At Saldanha, a Midrex plant has been built alongside the Corex plant and will use its Corex gas as its source of energy. The gas from the Corex plant goes first to a vacuum pressure swing adsorption plant (VPSA) to reduce its carbon dioxide content from 32% to 6% and then it is sent to the Midrex plant.

When the plant is on full production, 756 000 tons a year of coal and 935 tons per year of iron ore are fed into the Corex plant to produce 650 000 tons per year of liquid iron. The Midrex plant receives 805 000 tons per year of iron ore and 345 000 tons per year of iron pellets and its entire energy supply comes from the Corex gas. Its full production is 804 000 tons per year of directly reduced iron.(28) This combined plant design improves energy efficiency and should produce liquid steel at an energy intensity of about 16.2 GJ / ton (0.62 TCE with coal at 26 GJ / ton).(29) Table 6 below shows the energy used in SA steelmaking in 2000

Table 6. Energy Used In South African Iron and Steel Production in 2000(1)

Energy for Iron & Steel PJ (2000)	
Coal Commercial	143.2
Coke Oven Gas	59.7
Coke oven coke	53.7
Electricity	87.5
Fuel Oil	8.9
Hydrogen Rich Gas	10
Natural Gas	0
Total	**363.1**

However, as Figure 2 above shows, in previous years the energy consumption of steel was greater and in those years iron and steel consumed more energy than chemical and petrochemical and was the biggest user in the industrial sector. The consumption has dropped because of the shutting down of a steel making plant in Pretoria and the rationalisation of the Vanderbijl Park works.

World steel production grew at 3.6% from 1910 to 1944, 7.1% from 1945 to 1970 and only 0.6% from 1971 to 1991. Growth over the last 10 years was very much the same. This slowing down of production since 1971 is because steel is being replaced by other materials and is itself being used more efficiently (the same job being done by less steel). However it is still the world's most important engineering metal by far, and is likely to remain so for the period being considered

Since 1976, South African production capacity has exceeded local demand and exports have taken up as much as 50% of her production. Between 1980 and 1995, the world's consumption of finished steel increased by about 1% per annum but South African steel consumption dropped by 1.2% per annum. A regression analysis between GDP and steel consumption from 1970 to 1997 shows that steel consumption will decline if the South Africa GDP grows at less than 1.79% per annum.(47) So the future growth of South Africa steel depends on the local market, which has been weak for nearly three decades, and the world market which has been better but still sluggish.

The Saldanha steel plant was commissioned in 1998 and although it currently has financial difficulty it is still expected that phase 1 will reach its full capacity in the short term. This is a modern plant that produces an excellent quality of flat steel coil. Phase 2 is still a possibility over the medium term depending on future commodity prices. The Duferco Steel mill that processes one third of Saldanha's output has been running since 1999 and has the potential for future expansion.

Iskor closed its stainless steel plant in Pretoria in 1997. The possible Coega project includes a stainless steel plant. Instead of Port Elizabeth, the plans appear to locate it near Columbus (Middelburg). Columbus still has the potential to increase its cold rolled facility. This would require expansions to the annealing and pickling capacities.

Various reports have been published on the proposed new Maputo iron and steel plant (which would draw about 340MW of electricity). Iron would be produced from magnetite (iron rich copper tailings) from Palaborwa for the export market.

South Africa is a major producer of ferrochrome, the essential ingredient of stainless steel. Ferrochrome production is very energy intensive. Production in South Africa has increased significantly in recent years and despite the current drop in the world price a number of new plants are being considered for the medium to long term.

Ferrosilicon and ferromanganese sectors are also very energy intensive. The products are used in carbon steel among other things, and future demand is expected to show moderate growth in the medium to long term.

With improved technologies the energy intensity of steel production is dropping in the developed countries. There is a trend towards DRI and smaller electric-furnace steel plants and away from the larger but highly polluting blast furnaces and their associated coking plants. It is unlikely that South Africa will ever build another blast furnace.

The present mixture of fuels used for steel-making is likely to change. Coke from coking coal, required for blast furnaces, is likely to decline relatively. Bituminous coal, used by the Corex and Midrex processes will increase as their production increases. Electric arc furnaces, which use DRI or scrap iron, are likely to increase in production and so the demand for electricity will increase. Gas, whether natural gas, Sasol gas or methane bed gas, can be used in the Midrex process to make DRI and so there is a good chance that this will be used for steel making in future.

A possibility, which would have a great effect on South Africa, is that developed countries might consider relocating there steelmaking to developing countries such as South Africa.

4.3 Chemical and Petrochemical

In 2000, the chemical and petrochemical division was the second biggest user of energy in the industrial sector after iron and steel. Coal is the dominant form of energy. Over two-thirds of the coal in this division is used by the Sasol plants. Table 7 shows the energy used for chemicals in 2000.

Table 7. Energy for Chemicals in 2000[1]

Energy for Chemicals 2000 (PJ)	
Coal	237.3
Electricity	50.3
Fuel Oil	0.6
Hydrogen Rich Gas	1.3
Methane Rich Gas	1.3
Natural Gas	0.0
Total	**290.8**

The "energy consumption" of the petrochemical and chemical division needs to be qualified. It includes the conversion of fossil fuels into chemicals, where the fuels are feedstocks rather than energy providers. In fact the greater part of the potential energy ends up this way. (It does not include the conversion of one form of energy into another, say coal to petrol, which comes under "Transformation" rather than consumption or demand.) This accounting of coal into chemical feedstock, provider of process energy and conversion into other forms of energy is never exactly accurate. The processes are complicated and interwoven.

Petrochemicals and chemicals can be divided into four broad groups according to their products. The first are petrochemicals which convert fossil fuels into feedstocks for the rest of the chemical industry. The most important petrochemical products are ethylene, propylene, styrene and aromatics. This group has large volumes and low prices. The second group are plastics, consisting mainly of polyethylene, polyvinyl chloride, polypropylene and polystyrene. The third are inorganic bulk materials, such as ammonia, most of which are used to make nitrogenous fertilisers and explosives. These latter two groups produce higher priced products than the petrochemicals. The last group are the fine chemicals such as agrochemicals and pharmaceuticals, which have small volumes and high prices.

Table 8 below shows the energy intensity in 1971, 1980 and 1989 of the chemical industry in some developed and developing countries, including South Africa. Energy intensity here is measured in toe per $1000 of value added.

Table 8. Energy Intensity in the Petrochemical and Chemical Industry (Toe/$1000)[31]

	1971	**1980**	**1989**
India	1.74	4.04	4.05
South Korea	na	1.47	0.63
Taiwan	0.66	0.87	0.56
Brazil	4.64	4.59	4.21
South Africa	0.86	1.36	1.62
United State	0.61	0.39	0.26
Japan	0.46	0.45	0.30

South Africa is an intermediate case with an energy intensity higher than that of developed countries such as the USA and Japan but lower than that of Brazil and India. South Africa's energy intensity increased during these years.

This is because of the Sasol plants. These all use coal as a raw material to make liquid fuels and chemicals. Sasol 1 at Sasolburg began making petrol in 1955. Sasol 2 and 3 at Secunda, each ten times bigger, went on stream in 1980 and 1982 respectively. All three plants use the Fischer-Tropsch process.

The first step in this process is to produce syngas ("synthesis gas"), a mixture of carbon monoxide and hydrogen. You can do this using either coal or methane as the raw material. Sasol uses coal. Of each 100 tons of coal entering the process, about 33 tons are burnt to provide steam for process heat and electricity. The remaining 67 tons are used as raw material to make the syngas. The coal is combined with oxygen and steam to produce the syngas. There are two main reactions: (i) carbon plus water goes to carbon monoxide and hydrogen (syngas); this is strongly endothermic, absorbing energy (ii) carbon plus oxygen goes to carbon dioxide; this is strongly exothermic, releasing the energy that forces reaction (i). Half of the 67 tons of carbon goes to each of (i) and (ii). The process is inherently inefficient because of the thermodynamics of its chemistry. This leads to its high energy intensity.

The process necessarily produces a lot of methane, approximately 8 tons for each 100 tons of coal at the beginning. The methane itself, which is quite stable, is not suitable to be used for building up more valuable chemicals. It can be burnt for energy or it can be used as a raw material for making syngas. SASOL exports a lot of methane in its "methane rich" gas stream.

The oxygen needed to make the syngas is itself separated out from air by refrigeration. The nitrogen separated from it is then used to make ammonia, a feedstock for fertilisers and explosives.

A wide range of fuels and chemicals are made from the syngas by joining the carbon atoms in chains of varying lengths. The products includes diesel, petrol, waxes, ethylene, ethane, polyethylene, propane, butane, fuel oil, alcohol and acetone. Sasol diesel is of high quality because of the low sulphur and straight chain molecules (cetanes).

Sasol 1 is now called Sasol Chemical Industries. The plant no longer manufactures petro-chemicals but was converted to manufacture wax, heavy furnace oil and other specialised chemicals.

The Sasol plants were built for political and strategic reasons. The thinking was that South Africa had no oil and was dependent on oil imports. This made her very vulnerable to trade boycotts, especially in the light of her increasingly unpopular apartheid policies. On the other hand she had a lot of coal. The Sasol plants were built primarily as a strategy to make South Africa self-sufficient in energy supply. Their capital costs were very high, their economics doubtful and their emissions high but they have been technically successful, making a wide range of useful products. Some of these are unique and others, such as the diesel, of very high quality.

Coal is now used to produce syngas (carbon monoxide and hydrogen), which is the first step of the process of making liquid fuels and chemicals. However, it can also be done using methane and this is cheaper, cleaner, more efficient and produces less carbon dioxide. Using coal to make syngas, 50% of the incoming carbon is lost as carbon dioxide; using methane, only 20% is lost. The capital costs of the equipment needed when using methane as the raw material are much less than when using coal and the operation is simpler and easier.

The strategic reasons for Sasol using coal as a raw material have fallen away now that South Africa is part of the world economy. And although South Africa is not now one of the Annex 1 countries required by the Kyoto protocol to reduce carbon dioxide emissions, it is likely in the near future that she will be obliged to do so. Natural gas consists mainly of methane, typically over 90% by volume, and there are large reserves around the world. It is estimated that the world has energy reserves in the form of methane one and a half times that in the form of oil. Methane is often found in oil fields and in coal beds. Much of this methane is now being discarded, often flared off to convert it to carbon dioxide because the global warming potential of carbon dioxide is 21 times less than that of methane.

Sasol has developed a new process, Sasol Slurry Phase Distillate (SSPD), that makes diesel, kerosene and naptha from natural gas. With additions from iso-cracking, this diesel can be made cleaner than conventional diesel. In July 1997 Sasol signed a Memorandum of Agreement to build a gas-to-liquids plant at Ras Laffan in Qatar in the Middle East. It will convert gas to naptha and diesel at the rate of about 20 000 barrels a day and could be onstream by 2002.

Sasol Chemical Industries at Sasolburg will within the near future be using natural gas instead of coal. The plant at Secunda will probably continue to use coal however it is expected that any expansions will make use of natural gas as a compliment.

South Africa has estimated coal bed methane reserves of about 90 billion cubic metres (3300 PJ), with the most promising field being at Waterberg. There is natural gas at Mossgas and at the Kudu field off Namibia and the Temane and Pande fields in Mozambique. The possibilities of using this methane and the threat of penalties against carbon dioxide emission strongly suggest that Sasol will not build another coal to oil or coal to chemical plant again, certainly not in the next 30 years. However, Sasol might well in the future build plants for converting methane to oil and chemicals, either here or abroad.

There is huge potential for saving energy at the Sasol plants by making them more efficient. The plants were built at a time when energy was cheap and plentiful and energy efficiency was not a high consideration in plant design. It has been estimated that by using pinch technology (optimising heat flows by heat exchangers) one could save 300 MW at each of Sasol 2 and 3.[48] However the huge capital costs required for these modifications would probably not make it economic.

Sasol is considering a number of expansions and new projects including an acrylic plant at Sasolburg and a detergent alcohol plant at Secunda. At Sasolburg it is considering replacement of its own generation.

4.4 Non-Ferrous Metals

In 2000, the processing of non-ferrous metals consumed a total of 64 PJ of energy, of which 61 was electricity, 1.5 coal and 1.4 hydrogen rich gas. [1] The biggest component of this consumption was aluminium smelting, which accounted for about half of it. The next biggest was the production of titanium slag. The rest, including the processing of zinc, nickel and copper are minor in comparison.

After steel, aluminium is the second most widely used metal in the world. Twice as much of it is used as the next two metals, copper and manganese, put together. Aluminium's main use is in transport, building and construction and packaging. It is replacing steel in many applications such as motor cars and window frames. It is also replacing copper as an electrical conductor and one of South Africa's largest uses of it is in electrical engineering.

In 1998 the world's production of aluminium was 22,690 kilotons (kt). This was dominated by the USA, Russia, China, Canada, Australia and Brazil.[32] Production of aluminium is shifting from Western Europe, North America and Japan to South America, China, Australia and South Africa. Japan's production, for example, fell from 1500 kt in 1973 to 35 kt in 1990 where Australia's production climbed from less than 100 kt to 1200 kt in the same period.[33]

Aluminium production in South Africa is an unusual industry for the country in that the raw material, aluminium ore (bauxite), has to be imported since no economically recoverable bauxite has been found here. South Africa imports the aluminium raw material in the form of alumina, which has been converted from bauxite ore in the Bayer process. In the Hall-Heroult process the alumina is dissolved in molten sodium aluminium fluoride (cryolite) and electrolysed to extract aluminium metal. The two aluminium production plants, belonging to BHP-Billiton at Richards Bay, which enjoys a good bulk handling port for bringing in the alumina and exporting aluminium metal.

South Africa has two aluminium smelters, both at Richards Bay. The Bayside smelter, commissioned in 1971, has a capacity of about 170 kilotons a year and uses about 400 MWe at this production. The Hillside smelter, commissioned in 1996, has a capacity of 500 kt a year and uses about 850 MWe at this production. From 1997 on, South African aluminium production has been about 670 kt of aluminium a year. [35]

Aluminium smelting is very energy intensive. It typically requires more than five times more energy to produce a ton of aluminium than a ton of steel. 90% of the energy is electricity for the smelting. The rest is used for baking the anodes and for the cast-house furnaces; usually this energy comes from natural gas or liquid fuels but in South Africa it comes from producer gas made from coal.

In 1991 the energy intensity of aluminium production in South Africa was 67 GJ/t of which 59 GJ was electricity and 8 GJ producer gas from coal.[36]. In 1998 the new Hillside smelter at Richards Bay was reported to be smelting aluminium at 13.4 MWh / ton (48.2 GJ/t) [37] This is among the best in the world. By the end of 1998, the gross energy consumption of the aluminium smelting industry was about 36 PJ.

South Africa aluminium production is viable almost entirely because of her cheap electricity. Indeed it has been said of South Africa's aluminium exports that she is "exporting electricity". For the new Billiton Hillside smelter at Richards Bay, a 25 year contract was signed between Eskom and BHP-Billiton linking the price of electricity paid by BHP-Billiton to the price of aluminium on the London Metal Exchange. (Price of electricity in USA cents = 2 / 1800 * price of aluminium on LME in $ USA per ton.) [38]

The next largest consumer of energy in this division is titanium. South Africa has the world's largest reserves of titanium, which are found in beach sands from East London to the Mozambique border and on the west coast about 300 km north of Cape Town. Titanium is a light, strong metal which is inert to a range of corrosive chemicals. It is used in aircraft, ships and spacecraft and in the chemical industry. However, there is a much bigger market for titanium dioxide, a pigment which is used as a whitening agent for paints and a cover for welding rods. South Africa does not yet produce titanium metal but produces titanium dioxide slag. South Africa is the second largest supplier of titanium (in the form of titanium dioxide) after Australia. In 1998 South Africa produced 1043 kilotons of titanium of which 526 kt were exported. [39]

Titanium is mined just north of Richards Bay (Richards Bay Minerals) and north of Saldanha Bay on the west coast (Namaqua Sands). The 3rd furnace at Namaqua Sands in currently in the feasibility stage. The probability of the smelting plants for Iskor's iron and titanium near Empangeni has increased with the signing on of a partner (Ticor). Further titanium plants at the wild coast, and either Richards Bay or Saldanha are being investigated. In Mozambique a number of iron and titanium projects are being investigated such as the Corridor Sands project.

Production of the slag is energy intensive at about 20 GJ / ton. In the South African process the energy comes from electricity (55%) and anthracite (45%). In 1996 titanium dioxide production was a gross consumer of approximately 18.6 PJ.

The prospects for non-ferrous metals are good. South Africa's aluminium plants are world leaders and the market for aluminium is growing. The two big provisos for aluminium are future electricity pricing and greenhouse gas legislation. Aluminium is energy intensive, using large amounts of electricity. The Hillside smelter at Richards Bay is economic because of its 25 year electricity contract with Eskom. That electricity is generated mainly from coal, the worst carbon dioxide emitter of all fuels. Increased electricity prices in future and international penalties against aluminium produced from electricity generators that release a lot of carbon dioxide would completely change the prospects for South African aluminium.

Both the Bayside and Hillside plants will be upgraded over the medium term which will result in increased production and increased demand for energy. Hulletts Aluminium have expanded their aluminium mill at Pietermaritzburg and a further upgrading has been planned to take place within the next 5 years.

Beyond our borders, the new 250kton/annum, 420 MWe, BHP-Billiton Aluminium plant (pot line 1) in Mozambique was commissioned in 2000. The construction of the 2nd pot line was approved during June 2001 and commissioning is expected to start during the 4th quarter of 2004 with full production on 2005. This is expected to add a further 420 MW. The new smelter will increase the capacity to 500ktons/annum.

The prospects for titanium are also good as there is promise of a widening application for the use of titanium metal out of its present rather specialist niche and as South Africa has the world's biggest reserves of the ore

The 3rd furnace at Namaqua Sands is currently in the feasibility stage. The probability of the smelting plants for Iskor's iron and titanium near Empangeni has increased with the signing on of a partner (Ticor). Further titanium plants at the wild coast, and either Richards Bay or Saldanha are being investigated. In Mozambique a number of iron and titanium projects are being investigated such as the Corridor Sands project.

The proposed new Anglo-American Gamsberg zinc smelter has been delayed due to the decline in the zinc prices. However, it is expected that this project will go ahead during the medium to long term. The proposed new BHP-Billiton zinc smelter that was planned for Coega near Port Elizabeth has been put off and may only be built over the long term. The Scorpion zinc project in the southern part of Namibia has received the go ahead and is expected to be commissioned during the latter part of 2003.

Over the longer term there is the possibility of a copper smelter, at the Haib copper mine north of the South African/Namibian border.

4.5 Non-Metallic Minerals

This division includes the making of cement, lime, bricks and glass. The biggest energy consumer is cement making. These are products that are made and used locally, with little import or export, and are therefore closely linked to economic growth, particularly growth in building and large projects. In 2000 this division consumed 63 PJ of energy, of which 33 PJ was coal, 20.5 PJ electricity, 3.4 PJ fuel oil and 6.5 PJ methane rich gas. [1]

South Africa's cement kilns tend to be large and modern, and use the newer and more energy efficient method of dry manufacture. However 60% of bricks are made in "clamp kilns", which are labour intensive and not as energy efficient as non-clamp kilns, so this is an area for improvement.

The products for this division are almost entirely for domestic consumption and so its growth will depend largely upon the growth in the GDP.

4.6 Pulp and Paper

South Africa has a substantial pulp and paper industry which exports around the world. She makes pulp from both softwood (pine) and hardwood (eucalyptus), both of which grow more quickly in South Africa than in Europe. The conditions here are particularly suited to hardwood, which is good for tissue paper. South Africa produces annually approximately 1.9 million tons of pulp and 2.3 millions tons of paper and board.[40]

The main energy sources for pulp and paper manufacture are coal, electricity and biomass. Coal is brought in to the mills. The biomass comes from the timber which is the feedstock for pulp production. The bark from the softwood logs is removed in debarking drums and used to fire boilers which produce process steam and steam for electricity generation. In the digestors, the fibres for the pulp are separated out from the lignin and other components of the wood. This residue forms "black liquor" which is concentrated and then fired in a "recovery boiler" to raise steam for electricity generation and processes. Some electricity for pulp manufacture is brought in from Eskom and some is generated by the mill on coal, bark or black liquor. The Mondi pulp mill at Richards Bay, for example, 70% of the electricity used is generated in the mill and 30% is bought from Eskom. Modern pulp mills in Scandanavia are completely self-sufficient in energy. Mills making paper from pulp do not have this biomass energy source and have to import their energy.

Exact energy consumption statistics for pulp and paper are difficult to come by because of the large auto-generation of the pulp mills and difficulties in getting the figures for coal. However an estimate of annual fuel consumption for recent years is in table 9 below:

Table 9. Estimated Energy Consumption of Pulp and Paper in 2000[1]

Energy for Pulp & Paper 2000 (PJ)	
Electricity	24.4
Coal	51.4
Wood	34.4
Methane Rich Gas	0.3

The pulp and paper industry has been characterised by violent cycles in price. In the past there were fears that the world would enter a long term period of over-capacity. This does not seem to be the case. Since 1989 there has been an average 3.3% increase in demand for pulp and paper, and this is expected to continue for the next 15 years at least. Demand from developing countries is expected to be even higher. South Africa's two main pulp and paper companies, Mondi (which is part of the Anglo American Industrial Corporation) and Sappi, have bought mills overseas, and the chances of their building new pulp or paper mills in South Africa during the period being studied look low.

Probably more important than any of these economic factors is the physical limit imposed by South Africa's plantation forests. South Africa has a forested area of 1.49 million hectares, which is about 1.2% of her total land area.[51] The only proposed new plantation forest area is in the Eastern Cape, would only add 70 thousand hectares. The new water licensing system will make it difficult to expand the area of commercial forests. However, at the moment 1.7 million tons of wood chips are exported from South Africa every year. This would be enough to make about 0.425 million tons of pulp. In their Spatial Development plans, the Department of Trade and Industry listed a proposed new paper and pulp mill at the Wild Coast. However, whether another pulp mill will be built or whether existing mills will just expand their capacity remains to be seen.

4.7 Food, Beverages and Tobacco

The food, beverages and tobacco division includes sugar mills, food processing, breweries and tobacco processing. The biggest single component is the sugar industry which in the year 1997/8 reaped 22 million tons of sugar cane to produce 2.4 million tons of sugar.[42*] Sugar cane consists of approximately 10% sugar (sucrose), 35% fibre and 55% water. The fibre is known as “bagasse” and most of it is fired in boilers to make steam for electricity generation or process heat. (Some of it is used as a feedstock for paper mills.) The calorific value of dry bagasse is approximately 14 MJ / kg.

This division is various and includes a large number of small processing plants. Moreover it uses a lot of energy from biomass, which is hard to quantify. This makes an exact energy balance difficult to make. However, table 10 below gives the estimated energy annually.

Table 10. Estimated Fuel Consumption in Food and Tobacco in 2000 [1]

Energy for Food & Tobacco 2000 (PJ)	
Bagasse	49.6
Coal	49.0
Electricity	12.7
Fuel Oil	1.3
Hydrogen Rich Gas	0.9
Total	**113.4**

The growth in food and tobacco is likely to follow the growth in GDP.

4.8 Other

The rest of the industrial sector consists of a wide range of disparate industries, mainly in manufacturing. There is construction, motor vehicles, wood products, textiles, clothing and leather, and various other manufacturing and processing concerns. In 2000, the energy consumption for this grouping was 144.8 PJ of which 66 PJ was coal, 34 PJ electricity, 36 PJ oil products and 9.7 PJ other fuels.[1] Statistics are poor for this grouping but it can be expected to contain the small enterprises and informal enterprises which it is hoped will grow in number and importance in the future.

Good growth has been experienced in areas such as motor vehicle exports and motor parts. The proposed Coega industrial zone offers a potential for these industries to expand. New textile clusters have been suggested in both Botswana and Lesotho.

5. FUTURE INDUSTRIAL ENERGY DEMAND

Future energy demand in South African industry depends on economic growth, the changing structure of the economy, and the volumes and nature of our exports. It also depends on policy decisions. Energy liberalisation, energy subsidies, energy regulation, tariffs on energy imports and environmental legislation will all have important effects on energy supply and demand. So will decisions by the international community, particularly on environmental issues such as greenhouse gases.

Economic growth in South Africa has been disappointingly low in recent years, especially in the Industrial Sector. There are few signs of South Africa’s diversifying her industry from primary processing into beneficiation and higher technological manufacturing. Indeed most of the big industrial projects of recent years have been in primary or secondary processing, such as steel making and aluminium smelting. These are high energy users.

Some of these big projects have been undertaken because South Africa has plentiful, cheap energy. One of them, the Hillside aluminium smelter at Richards Bay, was built partly to exploit Eskom's surplus of generating capacity. In our neighbouring country, Mozambique, the large surplus generating capacity at Cabora-Bassa and the discovery of natural gas have prompted the search for industries to consume this energy. This has led to the Mozal project and perhaps a new iron and steel plant in Mozambique.

The balance between the types of energy seems likely to change but, with one exception, it seems unlikely that we will see any new types of energy. That one exception is gas. There are several actual or potential sources. Synthetic gas from Sasol (both "methane rich" and "hydrogen rich) is already being piped to industrial customers. There is local natural gas from the Mossel Bay area (Southern Cape) and the West Coast. A pipeline will soon bring natural gas from Mozambique to South Africa, and in future another one could bring gas from the Kudu field offshore from Namibia to the Western Cape. There are much larger gasfields in Angola and in the further future pipelines could bring this gas to South Africa or it could be shipped in in the form of liquefied natural gas (LNG). Finally there are sizeable fields of coal bed methane in the Waterberg area.

Gas is cleaner and easier to use than coal or oil and releases less carbon dioxide per unit of energy. The mildness of the South African winters, the large size of the country and the low density of housing will probably make it uneconomic to develop a piped gas grid for residential or commercial use. However, industry, which is a large user of energy and which has concentrations in big plants, is well suited to use natural gas.

It is very likely that, as in other countries, electricity will take up an increasing fraction of industrial energy. Coal use will probably increase absolutely for another ten to twenty years and then steady out or decline. The use of coke from coking ovens will probably decline further, given our poor reserves of coking coal. Liquid fuels are likely to be increasingly expensive in real terms in the medium term future.

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ENERGY DEMAND: THE COMMERCIAL SECTOR

1. INTRODUCTION

The Commercial Sector or Services Sector consists of government, office buildings, financial institutions, educational facilities and places of entertainment. As the economies of countries mature, this sector becomes proportionally more important and contributes an increasingly large share of the GDP. South Africa is probably at the stage where this sector will grow more rapidly than any other sector of the economy. In 2000 the Commercial Sector consumed 76 Petajoules of energy of which 62 PJ were electricity and 6.2 PJ coal. Partly for environmental reasons, coal is likely to decline and gas, coming from SASOL or the gas fields of Pande and Kudu, is likely to increase. Energy is not used efficiently in the South African Commercial Sector and considerable savings in energy could be made here.

2. COMMERCIAL ENERGY CONSUMPTION

The “Commercial” or “Service” Sector of the economy is not clearly defined. It often simply means anything that is not included in the Industrial, Transport, Agriculture and Residential Sectors. It includes government, education, shops, hotels, restaurants, repair of goods, financial institutions, business services, entertainment, hospitals, libraries and museums. The statistics for the Commercial Sector are not good mainly because it is so difficult to delimit.

In 2000, the Commercial Sector consumed 2.5% of South Africa’s total final energy consumption (76 PJ out of 3055 PJ) and 10% of her total electricity consumption (62 PJ out of 612 PJ) [1]

Table 1 gives the energy consumption by fuel in the Commercial Sector in 2000.

Table 1. Fuels consumed in Commercial Sector in 2000[2]

Energy for the Commercial Sector 2000 (PJ)	
Electricity	62
Coal	6.2
Diesel	1.5
Fuel Oil	3.0
Hydrogen Rich Gas	0.8
LPG	2.4
Natural Gas	0.0
Paraffin	0.2
Town Gas	0.3
Total	**76.4**

Electricity is the most important source of energy for the Commercial Sector, providing 81% of its energy. Eskom, by far the biggest electricity provider, supplies it through the municipalities and so there are no central Eskom statistics for electricity use in the Commercial Sector. The National Electricity Regulator (NER) gives a breakdown of electricity sales by economic sector. A study was done by the Department of Mineral and Energy Affairs of commercial electricity in Cape Town from August to October 1991[3]. This gives a guide as to the use of electricity in South African cities. Table 2 gives the study’s estimate of the use of electricity among the different sectors in Cape Town in 1992.

Table 2. Estimated Consumption of Electricity in Cape Town by Sector[4]

	Weekly Consumption (MWh)	% of Total
Feb 92		
Cape Town	263667	100
Domestic	105085	40
Commercial	71190	27
Industry & other	87392	33
Jul 92		
Cape Town	318579	100
Domestic	149346	47
Commercial	63716	20
Industry & other	105517	33

This study estimates that 15.2% in summer and 9.3% in winter of the total electricity consumption of Cape Town is for air-conditioning. These figures are likely to be higher in Johannesburg and Durban which have greater temperature extremes than Cape Town. Lighting uses 8.4% of total electricity in summer and 8.1% in winter. For office building 74% of summer electricity consumption was from air-conditioning. Table 3 gives the proportions of electricity consumed by big users in the Commercial Sector in Cape Town.

Table 3. Ratio of Electricity consumed by Commercial Sector in Cape Town[5]

office blocks	60%
hotels	4%
hospitals	18%
shopping malls	18%

Table 4 shows some energy intensities from Commercial Energy in Cape Town.

Table 4. Energy Intensities in Cape Town[6]

	kVAh / square metre
offices	27
shopping complexes	30
air conditioning: offices	21
process: hotels	10
process: shopping complexes	6

3. FUTURE COMMERCIAL ENERGY CONSUMPTION

Among the rich countries of the Organisation of Economic Co-operation and Development (OEDC), the Service Sector of the economy is becoming a larger proportion of the total economy at the expense of agriculture and heavy industry. This trend seems to be followed by all countries on the path of economic development, and there are signs that it is being followed by South Africa, whose economy in the past has been dominated by agriculture, mining and heavy industry.

Since the early 1970s, in the USA, Japan, France, Italy, Britain, Denmark and Sweden, Service Sector GDP has grown and so has its share of the total GDP. The trend in these countries has been for the service floor area per capita and for the service GDP per unit of floor area to increase; that is, more floor area is taken by the service sector and it is making more wealth. There has been a shift in energy sources from oil to electricity and gas[7].

In these countries, the primary energy use in the Service Sector per unit of total GDP has fallen slightly. Electricity intensities in the Service Sector, consumption per unit of floor area and per unit of sector GDP, are increasing; but the heating energy per unit of floor area is decreasing. This is because buildings are becoming more efficiently insulated and designed, because of the change from oil to gas and electricity and because of the increase in the number of electrically powered appliances such as fans, air-conditioners and computers. These electrical appliances themselves give off heat so reducing the need for space heating. Of course this is likely to increase the need for cooling[8].

In South Africa, following the example of the OECD countries, the Service Sector is likely to grow more rapidly than the economy as a whole. It seems reasonable to expect an increase of about 1.5% in Service Sector growth for every 1% increase in total GDP growth.

In Cape Town, as can be seen above, the Commercial Sector energy demand is greater in summer than in winter. This will be verified for Johannesburg and Durban. This is because of cooling loads on air-conditioners in summer. These loads will be greater in Johannesburg and Durban because of their hotter summers. So for South Africa the OECD trend of lower heating demand but higher electrical intensities in the Commercial Sector should be exaggerated.

As can be seen above, South Africa, unlike Europe and the USA, used very little gas in the Commercial Sector. From its primary energy source, gas is far more efficient for heating than electricity; but this does not apply for cooling. Synthesised gas from SASOL and natural gas from the Kudu field in Namibia and the Pande field in Mozambique might soon be available for energy in the Commercial Sector. This will almost certainly displace coal, as it did oil in the OECD countries, and might to some extent displace electricity for heating.

In the OECD countries the economic sectors that have showed most improved energy efficiency are the Industrial Sector and the Residential Sector. The Transport Sector has shown little improvement and the Commercial Sector has shown mixed improvements. In South Africa there is great scope for increased energy efficiency in the Commercial Sector. A lack of concern for energy efficiency, helped by cheap energy, is prevalent in the South African Commercial Sector. Poor thermal insulation, badly matched air-conditioning units, badly designed buildings and bad maintenance add to a problem which is technically easy to solve. Lights, heating and air-conditioning are left on in empty buildings. Heat pumps could give energy savings of 67% against electrical resistance heaters[9]. Better building design, using natural lighting, natural ventilation and good thermal insulation, would great reduce energy demand. The change from incandescent light bulbs to fluorescent tubes would greatly reduce electrical demand for lighting.

A significant portion of electricity provided in the electrification programme will actually be used for commercial purposes. Much of this is by prepayment.

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ENERGY DEMAND: THE AGRICULTURAL SECTOR

1. INTRODUCTION

In this study agricultural energy includes energy used by large established farmers and smaller dedicated farmers. Energy used for subsistence farming is included with residential energy. Subsistence farming is not mechanised and relies predominantly on human and animal power, and therefore subsistence farming energy is small compared with commercial farming energy.

Only 12 to 14% of South Africa's land area is arable, and only 1 to 3% is irrigable[(1)]. About three thousand large commercial farmers produce 40% of the agricultural output, ten thousand farmers are surviving economically producing a further 40% of the agricultural output, and forty to sixty thousand full-time struggling farmers produce the remaining 20% of agricultural output[(1)].

The agricultural sector now employs 13% of the workforce[(2)].

Table 1 compares agricultural GDP with total GDP for the period 1960 to 1994. Using constant 1990 prices, agriculture's contribution to total GDP has decreased marginally from 6.8% to 5.1%. Using current prices, agriculture's contribution to total GDP has decreased sharply from 12.4% to 4.7%. The reason for this discrepancy is not known although changes in the way GDP is calculated might be responsible for at least some of it.

Table 1. Contribution of agriculture to total GDP for the period 1960 to 1994[(5)]

	GDP (constant 1990 prices)			GDP (current prices)		
Year	Agriculture (Rmillion)	Total (Rmillion)	Agriculture (%)	Agriculture (Rmillion)	Total (Rmillion)	Agriculture (%)
1960	6166	90755	6.79	599	4839	12.38
1965	6246	121118	5.16	736	7261	10.14
1970	7250	155692	4.66	923	11638	7.93
1975	8907	184824	4.82	2127	25136	8.46
1980	10869	215659	5.04	3915	56379	6.94
1985	10907	230690	4.73	6526	112448	5.80
1990	13055	247315	5.28	13055	247315	5.28
1994	12606	246855	5.11	17930	382561	4.69

2. PAST AND PRESENT ENERGY CONSUMPTION

2.1 Past trends in energy consumption

Figure 1 shows a breakdown of energy consumption from 1970 to 1990. It is evident that liquid fuels, comprising mostly diesel, are the main energy source for agriculture, accounting for 69% of agricultural commercial energy consumption. The rest is electricity 24% and coal 7%. Increased mechanisation has resulted in increasing electricity use. Coal consumption is small, and although its contribution may appear to be increasing in recent years, this may be due to lack of accuracy in statistics in the past. No information is available on biomass energy use in agriculture. It is estimated that presently biomass accounts for 10% of agricultural energy consumption and comprises mainly agricultural residues.

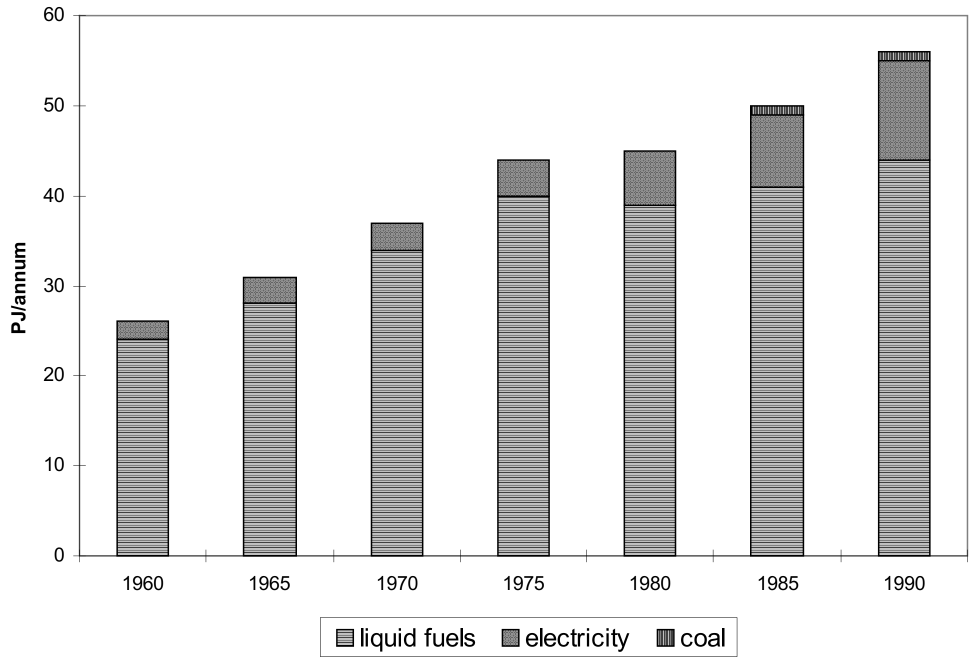

Figure 1. Energy consumption by agriculture: 1960-1990[3]

2.2 End-uses of agricultural energy

Agriculture uses energy both directly and indirectly. Only direct use of energy is included in the agricultural sector. Activities which make use of energy directly are:

- preparing the land
- irrigating the land
- applying nutrients, pesticides and herbicides
- harvesting
- primary processing

Agricultural activity also gives rise to the following indirect uses of energy which are not included under agriculture:

- production of fertilisers
- production of farming equipment
- transport of agricultural produce
- final processing of agricultural produce

Table 2 highlights the importance of indirect energy use by agriculture. Fertilisers alone are responsible for about a third of energy input into maize production.

Table 2. Energy consumption for modern maize production[4]

Input	Energy (MJ/ha)
Machinery and implements	4 200
Fertilisers	11 191
Seeds	621
Insecticides and herbicides	220
Fuel for machinery	8 240
Irrigation energy	351
Drying energy	1 239
Electricity	3 248
Transport energy	724
Total	30 034

Energy use in agriculture can be divided into the following end-uses:

(i) Tractors, which use diesel, or animal draft power (not accounted for in this study) for land preparation.

(ii) Irrigation, which consists of two basic types: gravity flow irrigation, by which dams or water diversion structures and channels transfer water to the fields; or pump irrigation, by which water is either pumped from groundwater or surface sources. Electricity sources for pumping include diesel, petrol, electricity, and wind.

(iii) Harvesters which use diesel.

(iv) Transport of harvested crops (diesel).

(v) Raw processing equipment which uses electricity.

(vi) Production of heat for incubators, warm water for dairies, and drying certain crops.

(vii) Miscellaneous energy applications such as refrigeration of perishables and lighting.

2.3 Current energy consumption

The energy used by agriculture in 2000 is summarised in Table 3 below.

Table 3. Agricultural energy consumption for 2000[(6)]

Energy for Agriculture 2000 (PJ)	
Coal	9.2
Diesel	58.9
Electricity	21.2
Fuel Oil	0.1
LPG	0.8
Petrol	3.6
Paraffin	3.0
Biomass	10.8
Total	**107.6**

3. FUTURE ENERGY CONSUMPTION

3.1 Top-down analysis

Figure 2 below shows that there is a strong correlation between annual agricultural energy consumption and agricultural production, and Figure 3 below shows that there is a strong linear correlation between agricultural production and national GDP. Due to data inconsistencies between the 1995 data and historical data, the historical data was scaled accordingly, and estimated biomass use added. A ‘best fit’ empirical equation was calculated to correlate agricultural energy consumption with national GDP:

$$\text{agricultural energy consumption (PJ/annum)} = 2.2 \times (\text{GDP index, constant 1990 prices})^{0.8}$$

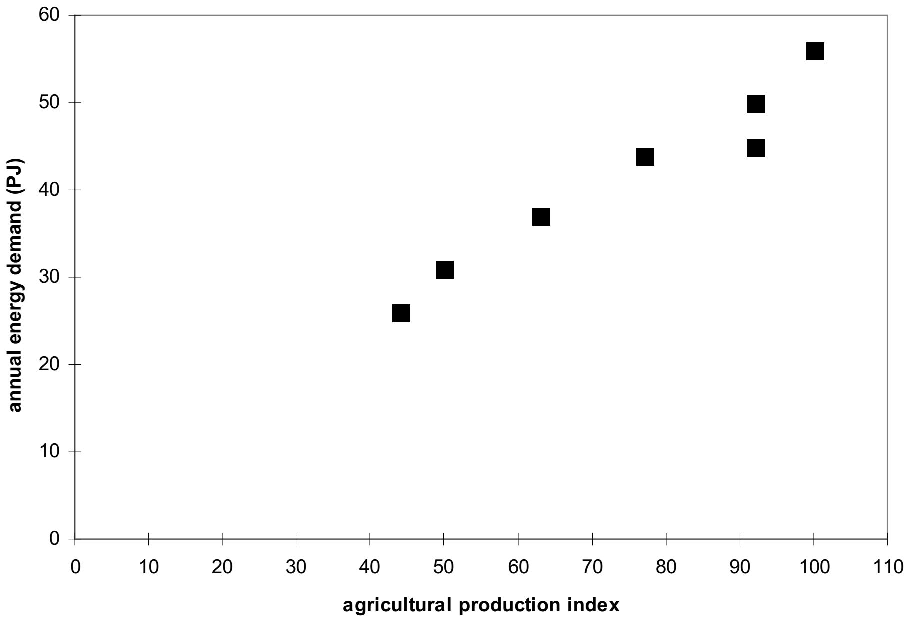

Figure 2. Correlation between agricultural energy consumption and the volume of agricultural output for the period 1960 to 1990

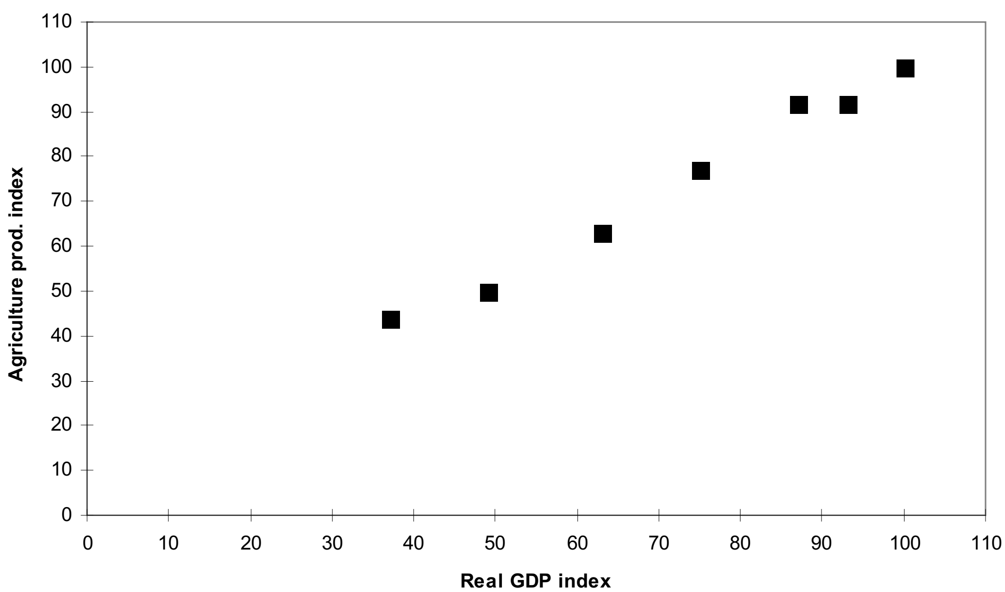

Figure 3. Agricultural production index vs real GDP index (1960-1994)[(5)]

It is assumed that between 1995 and 2020 the liquid fuel share will decrease marginally, the electricity share will increase marginally, and the coal and biomass share will remain similar. Using these principles and the 'best fit' equation, Figure 4 shows a prediction of energy consumption by agriculture.

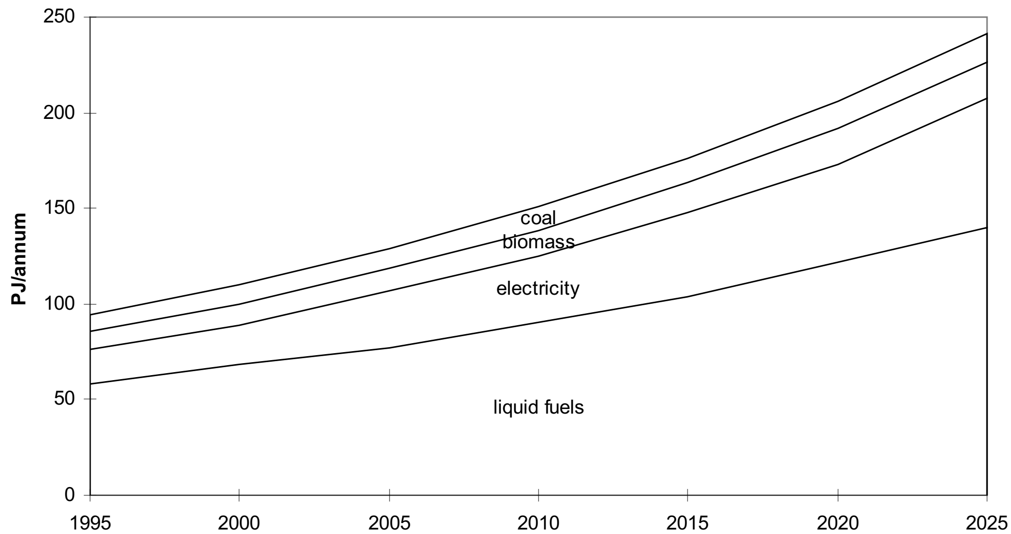

Figure 4. Predicted energy consumption of agriculture (1995 - 2020)

3.2 Bottom-up analysis

Factors to consider in predicting future agricultural energy consumption are:
(i) Increase in local demand for agricultural produce.
(ii) Increase in agricultural imports and exports, which will be influenced by trade agreements and the exchange rate.
(iii) Saturation of arable and irrigable land.
(iv) Restrictions on water availability.
(v) Conversion of traditional agriculture to commercial agriculture, resulting in more commercial fuels being used per unit of agricultural output.
(vi) Fuel switching.
(vii) Weather patterns.

Analysis of the above factors is complex and is beyond the scope of this study. However, restrictions on water availability is probably the most important influencing factor in the longer term. In the absence of a detailed analysis of water availability, the empirical equation based on past correlations is used to predict future agricultural energy consumption.

4. ENERGY SUPPLY OPTIONS

Supply options for agriculture include:
(i) Accessibility to diesel by small-scale farmers is poor. This is the most important fuel in the agricultural sector and therefore improved diesel distribution will assist in agricultural development. However, the price of diesel is even more important.
(ii) Agricultural residues can be used to a greater extent for energy production.
(iii) Non-grid electrification, such as mini-hydro.

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ENERGY DEMAND: THE RESIDENTIAL SECTOR

1. INTRODUCTION

South Africa is a country of extremes and a country in transition. Islands of a rich modern economy lie in a sea of deprivation and poverty, and both are being swept by an unstoppable but uneven tide of change. The problems of uplifting the poor and advancing the economy merge together. Poor living conditions, the diseases of poverty, poor education, unemployment, large numbers of children, degradation of the environment - all of these deprivations affect each other. There is probably no area where the problems can be more vividly seen than in the area of residential energy - energy for the people. And there are few other areas where sensible policies and the use of the proper technologies can have such universal benefit, doing more than almost anything else to transform and improve the lot of the poor.

South African residential energy consumption is just over a tenth of the total energy consumption. The rich turn on electrical power at the flick of a switch for their lights, ovens, CD players and dishwashers. The poor spend six hours a day collecting firewood to cook their food, and use candles to light their huts at night. Domestic energy comes to the house as electricity, coal, paraffin, LPG, petrol, candles, wood, bagasse and dung. South Africa generates over half of the electricity on the continent, but until recently the majority of her people were without it. Now, however, a vigorous programme of electrification is bringing electric power to almost half a million households a year. This and other changes in energy consumption will have effects on the economy, employment, pollution and health.

2. RESIDENTIAL POPULATION

2.1 Number of people and households

In 2000, Statistics South Africa put the South African population at 43.5 million.

The 1996 Census divided the population into provinces and into urban and non-urban parts. Their figures are given in Table 1.

Table 1. South African population by Province in 1996[1]

	Urban	Non-Urban	Total
KwaZulu-Natal	3341	4331	7672
Gauteng	6911	260	7171
Eastern Cape	2188	3677	5865
Northern Province	490	3638	4128
Western Cape	3703	415	4118
North West	1060	1983	3043
Mpumalanga	1014	1632	2646
Free State	1718	752	2470
Northern Cape	535	211	746
South Africa	20960	16899	37859

2.2 Economic groups

South Africa is a diverse country with different races, communities at widely different stages of development, and extremes between rich and poor. Race, which defined population differences under apartheid, is being replaced by wealth as the most important criterion for distinguishing one section of the population from the other for the purposes of economic, social or industrial policy. However, differences by race are still large and important. This study is concerned with the energy requirements and consumption of the South African people and so is interested in whether they are electrified or not, whether they gather firewood or buy coal, and whether they live in shacks in a squatter camp or brick houses in a suburb. All of these differences are because of differences in wealth. The only other important division is between rural people and urban people, although this too is influenced by wealth.
The population is 78% African, 10% White, 8.7% Coloured and 2.5% Indian[2].

Estimates of the number of households in South Africa at the end of 1996 vary between 8.26 million(3) and 9.17 million(4).

55% of the population lives in the urban areas and 45% in the rural(5). There is a heavy concentration of the urban population in just four areas, Gauteng, Durban/Pinetown, Cape Town and Port Elizabeth / Uitenhage, which together hold 18.3 million people, 48% of the South African population. Gauteng is by far the largest with a population of 7.2 million. Seven to 8 million people live in informal settlements in the urban areas(6).

Of the total population in 1996, 49% had no electricity, 46% had grid electricity and 5% non-grid electricity. Forty-three percent lived in huts or shacks, 19% in small “matchbox” brick houses and 36% in flats or suburban houses(7).

3. RESIDENTIAL ENERGY CONSUMPTION

3.1 Total consumption

In 2000, the Residential Sector consumed 284 PJ, which is 9.3% of South Africa’s final energy demand. It consumed 107 PJ of electricity, which is 17.5% of the total electricity demand.

Table 2 below shows residential energy by fuel and Table 3 shows it by activity.

Table 2. Residential Energy by Fuel for 2000 (9a)

Residential Energy by Fuel 2000 (PJ)	
Coal	58.0
Electricity	106.9
LPG	4.7
Natural Gas	0.0
Paraffin	25.3
Solar	0.2
Vegetable Wastes	4.3
Wood	84.7
Total	**284.2**

Table 3. Residential Energy by Activity for 2000

Residential Energy by Activity 2000 (PJ)	
Cooking	113.4
Lighting	15.4
Other	35.1
Space heating	90.8
Water heating	29.5
Total	**284.2**

3.2 Consumption by fuel type, province and economic group

Table 4 below shows the residential energy consumption in the provinces by fuel types. The figures for biomass are the most uncertain. They have been taken as 70% of the “estimated potential production” found by “The Biomass Initiative”. The conversion from mass to energy has been taken at 17 MJ/Kg for dry wood.

Residential electricity consumption, which now stands at about 16% of total electricity consumption, has been very steady at this percentage since 1964. However, it is likely to increase in the future, with a rapid programme of residential electrification and with a transition of the economy from primary industry with high energy density to more advanced manufacturing, service and commercial sectors with lower energy density.

Table 4. Residential energy consumption by province and fuel for 1996[11]

Province	**Coal TJ**	**LPG TJ**	**Paraffin TJ**	**Electricity TJ**	**Biomass TJ**	**Total TJ**
Northern Province	682	70	2052	2758	21982	27543
Eastern Cape	0	471	6363	4820	14663	26317
North West	682	235	2220	5389	17783	26309
KwaZulu-Natal	13640	862	5452	13079	21637	54669
Mpumalanga	13640	54	1171	2318	5111	22295
Free State	12276	167	1800	4334	250	18828
Northern Cape	0	67	302	1490	0	1859
Western Cape	0	294	1445	13925	0	15664
Gauteng	27280	583	4415	23461	0	55739
Not Specified	0	0	0	17111	0	17111
Total	68200	2802	25220	88686	81425	266333
% of total	26%	1%	9%	33%	22%	100%

3.3 Uses of energy

Table 5 below shows the number of households in South Africa using various fuel types for heating, cooking and lighting. This does not give quantities of fuel for each use. If a household uses, say, paraffin for cooking and lighting, it will be shown under both. The table is based on sample surveys, and the percentages have then been multiplied by number of households in the provinces.

Table 5. South African households: fuels and uses[12] ***(SAZ 1996)***

Units: Thousands of households

	Electricity	**Coal**	**Wood**	**Paraffin**	**Gas**	**Candles**	**Batteries**
Heating water	3364	441	2358	2565	242	0	0
Heating dwellings	2437	753	2264	1548	121	0	0
Cooking	3346	783	2741	3370	673	0	0
Lighting	3812	0	0	1901	158	3245	125
Total	12959	1977	7363	9384	1194	3245	125

Appendix 1 gives the fuels used in each province.

The poorest households, which use traditional fuels like fuelwood and dung, consume energy only for basic needs such as cooking, heating the dwelling and lighting. The richer use it too for heating water for bathing and for modern appliances such as TV's, refrigerators, Hi-Fi's, radios and hair-dryers.

3.4 Trends in energy use

The main changes in residential energy use are among the poorer people. Among the richer, grid electricity is the settled and dominant source of energy and is likely to remain so indefinitely. Rural people and people living in informal urban settlements and townships of small houses are moving through an uneven transition in their patterns of energy consumption. The trend is from traditional sources of energy, such as wood and dung, to transitional energy, such as coal, candles, paraffin and LPG, and then to electricity.

From about 1991, South Africa began what is probably the world's most vigorous programme of electrification. This was undertaken by Eskom and local governments. During the years 1994 to 1997, Eskom was making about 280 000 connections a year and local governments about 150 000 a year. By the end of 1999, 66.3% of all household had grid electricity. [14]

Electrification should bring unqualified benefits. It provides cheaper, cleaner, safer, more convenient and more versatile energy. It improves the health of people, especially children, by removing indoor air pollution and greatly reducing fires and accidents. It relieves women of hours of burden in collecting wood, paraffin or coal, so allowing them more time to look after their children. It brings people into the modern economy, and through TV and radio offers educational opportunity and raises their expectations. However, there are problems. The main one is that the poor people cannot afford the cost of an electrical connection and do not use enough electricity to make it economic. Therefore they have to be subsidised. Furthermore, they often cannot afford to buy electrical appliances such as stoves, and so continue to use wood and coal.

Table 7 shows the status of electrification by province.

Table 7. Percentage of households electrified at end of 1999[15]

	Rural	Urban	Total
Eastern Cape	32	84	53
Free State	60	83	76
Gauteng	54	75	74
KwaZulu-Natal	30	80	57
Mpumalanga	75	67	72
North West	54	86	66
Northern Cape	75	83	80
Northern Province	51	86	55
Western Cape	65	86	84
South Africa	46	80	66

If the population increases at the rate predicted and if electrification continues at the rate of the last five years, the whole population will have electricity by the year 2014. This seems unlikely as the remaining households without electricity will become increasingly remote and fragmented and the costs of electrical connection to the grid will rise. However there would be 90% electrification by the year 2008, which seems reasonable.

Among those households that do not have electricity there is a transition from traditional fuels such as wood, dung and bagasse to commercial fuels such as coal, paraffin and LPG and then finally to electricity. This move depends on income and the availability of traditional and commercial fuels, which depends on location, as can be seen from Table 4. For example, coal is plentifully available in Gauteng, Mpumalanga, the Free State and KwaZulu-Natal but not in the Western Cape, Eastern Cape or Northern Cape; wood is abundant in the Northern Province and KwaZulu-Natal but scarce in the Western Cape or the Northern Cape. Households getting electricity for the first time continue to use coal, paraffin and wood for heating and cooking. This is because of the high cost, relative to their income, of electrical appliances such as stoves, when they already have paraffin, coal or wood burning appliances. Typically, newly electrified households use electricity immediately for lighting, and then buy electrical appliances such as TV's, refrigerators and radios, but may take as long as twenty years to change to electricity from wood, coal and paraffin for heating and cooking[16].

4. ENVIRONMENTAL EFFECTS

Residential energy consumption has dispersed and local effects, of which the latter are more severe. Electrified households typically get their primary energy from coal burnt in a large Eskom power station with electric precipitators to remove most of the particles and high stacks to disperse the SO_X and NO_X over a large area. There are local effects from coal-powered electricity - air pollution in the vicinity of the power station and respiratory disease in the vicinity of opencast coal mines caused by dust[17] - but the local effects from domestic burning of fuel are much more serious. Coal burnt in poor households for cooking and heating discharges pollutants, unfiltered and concentrated, into their dwellings for adults and children to breathe in. Moreover, it is burnt at low temperatures resulting in incomplete combustion and high pollution[18].

In South Africa about 24 million people are exposed to air pollution that can be compared with the London smog of 1952 which is estimated to have killed over 3000 people from respiratory disease[19]. The mortality rate for acute respiratory infections is 270 times greater for children in South Africa than those in western Europe[20]. The risks to children from these air pollutants are particularly grave. A report by A. Williams[21] gives acute respiratory infection as the number two cause of death in SA children after gastro-illness. Children aged between 8-12 exposed to wood or coal smoke during winter had a 290% increased risk of developing upper respiratory illness and 420% for lower respiratory illness[22].

The transition from traditional fuels to commercial fuels to electricity is also a transition towards more environmentally benign energy. A report by the DME found that rural populations using wood rather than coal for cooking and heating their dwellings were 4.7 to 7.3 times more at risk from upper and lower respiratory disease[23]. In urban populations, coal has 8 times higher risk for upper respiratory illness and lower respiratory illness than paraffin. Paraffin in turn has a higher risk than electricity.

The main danger from residential air pollution through burning fuel is particulates (smoke). The lowest level at which health effects are observed was documented by the WHO as 180 $\mu g/m^3$ and the USA 24 Health Standard was 260 $\mu g/m^3$. A study in two townships in the Vaal Triangle found that children there were exposed to levels higher than the WHO levels 100% of the time and higher than the USA levels 99% of the time[24]. Table 10 below shows average 12 hour exposures to particulates in Gauteng.

Table 8. Average 12 hour exposures to total suspended particulates in Gauteng Industrial Area[24]

Residents/Safe Levels	$\mu g/m^3$
WHO	180
EPA	260
White,electrified,winter	320
Black, electrified, summer	390
Black, not electrified, summer	620
Black, electrified, winter	1150
Black, not electrified,winter	1250

These tables are for total suspended particles, including those more than 10 μm in diameter, which are not harmful. So they are not exactly related to ill effects on health, but they give a good indication.

The benefit from electrification is clear, but even with it air pollution remains a problem in Gauteng. This is almost certainly because of the close proximity of non-electrified to electrified areas. An additional transition fuel to be considered is low-smoke coal, where the coal is processed into briquettes which release fewer particulates when burnt. Table 9 shows some of the pollutants from household fuels.

Table 9. Some pollutants from domestic fuels[25]

Pollutant (Kg/TJ delivered)	Coal	Wood	Natural Gas
SO_2	2200	30	negligible
Total & respirable suspended particulates	280	2700	0.5
Nitrogen oxides	460	100	10
Hydrocarbons	2200	6800	5
Carbon monoxide	27000	17000	250

This table is based on a coal-burning stove with 20% efficiency, a wood stove with 50% and a gas stove with 80%.

Apart from air pollution there are other health hazards from domestic fuels which include paraffin poisoning and, more important, burns. A small study found that 4% of rural children and 1% of urban children suffered from paraffin poisoning, and 14% of rural children and 6% of urban children suffered accidental burns[26]. Seventy-five percent of child fatalities by burning from Jan. 1990 to Dec. 1991 in Cape Town were caused by residential fires[27].

Besides having bad effects on health, the use of tradition fuels also has bad social effects. Women may spend as many as six hours a day collecting firewood. This tires them and uses up time that could be spent on the education of their children.

Wood for fuel is taken from both dead wood on the ground and also from cutting down live trees. This can lead to land degradation. In several areas, including the Northern Province and parts of Mpumalanga and the Eastern Cape, the harvesting of live trees for fuelwood seems to be exceeding the rate at which new ones will grow. Indeed the lack of available fuelwood is one of the forces driving rural people to the urban areas.

5. FUTURE RESIDENTIAL ENERGY DEMAND

5.1 Population changes

The South African population is following general well-established trends. The population growth among Blacks is larger than among Coloureds, which in turn is larger than among Whites, but the growth for all races is slowing down. Table 10 below shows estimated population growth rates for the different races in South Africa.

Table 10. Predicated population growth rate[28]

Units: % increase per year

	1980-85	1985-90	1990-95	2000-05	2005-10	2010-15	2015-20
Whites	1.2	0.6	0.6	0.5	0.4	0.3	0.2
Blacks	3.4	2.8	2.8	2.6	2.5	2.3	2.1
Coloured	1.7	1.8	1.7	1.2	1	1	0.9
Asian	1.2	0.6	0.6	0.5	0.4	0.3	0.2

This slowing down of population growth is happening all over the world. The richer and more educated the people, the fewer children they tend to have. Studies have shown that the fertility rate of women has a strong negative correlation with their years of education - the more education, the fewer children[29]. There is a strong movement of people from the rural areas to the urban areas, and the fertility rate among women in the urban areas is less than in the rural areas; so urbanisation has the effect of slowing down population growth. The more successful the economy and the more rapid industrialisation, the more the population growth will slow down. There is much dispute about the effect of AIDS on the population of the future. Immigration, especially from the rest of Africa, is another variable in population growth. The estimates are that about 100 000 illegal immigrants enter South Africa every year[31]. Table 10 above predicts a total SA population in 2020 of 61.6 million. Extrapolating, using the growth rates in Table 10, gives a population of 68.5 million in the year 2025.

The trend towards greater urbanisation will continue and it has been suggested by the Development Bank of Southern Africa that the rural population of South Africa has reached a zenith and from now on will either remain as it is or decline[32]. This suggestion depends to some extent on the definitions of "rural" and "urban", and on the classification of peri-urban areas and dense settlements in formerly rural areas now not earning an income from agriculture. For the purposes of energy consumption it seems sensible to classify both of these as urban and to accept the proposal that the rural population will not grow any more. All future population growth will be in the urban areas.

5.2 Changes in energy demand/changes in fuel types/changes in use of energy

Patterns of energy consumption, like those of population growth, seem to be following general trends although with more variation. The energy patterns will depend on economic growth and in turn will influence economic growth. The population is growing, so there will be a consequent increase in demand for energy. The transition from wood and dung through coal and paraffin to electricity is proceeding all over the country, although at different rates dependent on income, culture and location, and influenced by the movement of people from rural to urban areas. As people move through the energy transition they will obtain more appliances, and studies show that electricity consumption per household increases with the number of appliances per household[33]. This is countered by the fact that electrical appliances use energy more efficiently than non-electrical ones: Electric stoves and kettles have efficiencies of about 90% compared with less than 20% for wood-burning ones. (This is in terms of energy entering the household. Of course the thermal efficiency of the power station which makes the electricity is typically only about 30%.)

As future population increase will be in the urban areas, and as in many rural areas the sustainable level of fuelwood harvesting is already being exceeded, the total amount of biomass consumed will not increase and will probably decrease. Total consumption of the transition fuels, coal and paraffin, will rise and then fall as people pass through them on their energy journey from traditional fuels to electricity.

6. OPTIONS

6.1 Electrification

The most important change in domestic energy consumption is the advance of electrification. Electrification is an almost unmitigated good. It gives households clean energy, improving the health of the householders. It reduces the amount of disposable income they spend on energy. It eliminates the time spent on energy collection, so allowing householders the opportunity for more fruitful activity. It stimulates the growth of new jobs: it is estimated that 100 connections lead to 5-25 new jobs[35]. It boosts the economy by introducing new customers into the modern market place, especially at first of electrical appliances. It is versatile and introduces to households a new range of appliances such as TV and radio which can have educational benefits. It makes life more comfortable and convenient. It benefits the environment by reducing the number of trees cut down for fuelwood. By relieving women of physical labour, giving them more time to educate their children and themselves, and by bringing them into the modern economy, it elevates them socially and reduces the number of children they have.

Eskom is the driving force behind electrification. Eskom's programme is not based purely on business principles. It chooses the areas to be electrified on financial and social grounds, seeking to bring about upliftment of customers as well as profit for itself. The true costs of electrifying an urban and a rural household are about R1000 and R3900 respectively. Eskom charges less than this and covers the difference by increased charges for kWh or charging other customers more. The whole question of subsidising electrification is difficult but important. Should it be done at all? If yes, should it be done by Eskom charging rich householders and industrial customers more than the real costs to allow it to charge poor householders less? Or should it be done through the government by taxation and grants?

It has even been suggested that the sale of electrical appliances, such as electric stoves and geysers, should be subsidised to poor households when they are electrified[36]. Eskom estimates that a householder needs to use 400 kWh/month to break even on the costs of connection and in fact newly electrified householders may use as little as 50 kWh/month. The reason for the low consumption is that these householders cannot afford the capital costs of electrical appliances. Subsidising the sale of electrical appliances would mean that households could replace coal and paraffin with electricity, which is cheaper, thus saving them money and also making the connection financially worthwhile for Eskom. But again there is the question of where the subsidy should come from.

For remote communities far from the main power cables there are schemes for non-grid electricity. These include photovoltaic panels. Unfortunately the local people view the PV panels as inferior to grid electricity, and believe, correctly, that accepting a PV scheme means delaying grid electrification. They regard the PV as not only practically inferior, providing less power, but also as socially inferior, implying that they are not as good as the people connected to the grid. Other possibilities include generators running off natural gas in those areas where it is cheaper to pipe in the gas than to bring in the electric cable.

The possible privatisation of electricity supply will have a profound effect on electrification. A private electricity company will not electrify any household unless it can make money out of it. Would private companies receive government subsidies for electrification? Would they only be licensed to operate if they agreed to undertake electrification? Such questions will have to be addressed if liberalisation of electricity happens.

6.2 Change from traditional to commercial fuels

The change from traditional fuels to transitional commercial fuels brings health and economic benefits, but in many areas the means of distributing these fuels is poor or non-existent. An option is to subsidise the transport of the fuels.

Substituting ordinary coal with smokeless fuel would have health and environmental benefits and there is a good case for promoting their manufacture and distribution.

In place of the gathering of wood from wild trees, schemes of specially grown woodlots for fuelwood, on a co-operative or commercial basis have been suggested. The problem with this is the relatively long time from planting to harvesting, five to ten years, which might be difficult for poor people with immediately energy requirements to manage. They could perhaps be run by local business contractors on a purely commercial basis.

6.3 Demand management and energy conservation

There are various ways to plan and control the demand for household energy and to use it more efficiently. There could be differential electricity tariffs, charging more at peak load times, to encourage householders to flatten the demand curve. These would have to be explained clearly to consumers. Electric geysers could be fitted with timers to use electricity only in off-peak periods.

Electricity could be used more efficiently for lighting if there were a change from incandescent light bulbs to compact fluorescent light tubes. Wood and coal could be burnt more efficiently with properly designed stoves. Houses with proper thermal insulation would greatly reduce the energy demand for space heating.

All of these measures need to be carefully thought out and systematically implemented.

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APPENDIX 1: FUELS FOR DOMESTIC USES IN DIFFERENT PROVINCES

Heating Water

	No of households (thousands)				
	Electricity	Coal	Wood	Paraffin	Gas
Northern Province	101	46	677	137	9
Eastern Cape	244	13	488	591	24
North West	165	49	189	244	37
KwaZulu-Natal	629	13	414	645	83
Mpumalanga	130	80	220	140	10
Free State	154	85	170	250	27
Northern Cape	84	0	25	8	8
Western Cape	651	0	72	154	27
Gauteng	1206	155	103	396	17
TOTAL:SA	3364	441	2358	2565	242

Heating Dwelling

Northern Province	64	55	522	110	9
Eastern Cape	129	26	540	501	13
North West	153	134	208	141	4
KwaZulu-Natal	347	33	380	182	17
Mpumalanga	120	110	185	25	0
Free State	133	106	181	149	16
Northern Cape	66	4	21	10	1
Western Cape	443	9	72	172	27
Gauteng	982	276	155	258	34
TOTAL:SA	2437	753	2264	1548	121

Cooking

Northern Province	111	73	723	238	27
Eastern Cape	231	13	578	964	141
North West	165	104	232	299	67
KwaZulu-Natal	645	50	480	860	198
Mpumalanga	120	115	240	130	15
Free State	159	149	202	260	48
Northern Cape	92	3	33	8	7
Western Cape	651	0	81	163	118
Gauteng	1172	276	172	448	52
TOTAL:SA	3346	783	2741	3370	673

Lighting

Northern Province	174	339	18	595	0
Eastern Cape	283	822	26	360	39
North West	189	104	18	367	12
KwaZulu-Natal	678	248	66	860	17
Mpumalanga	150	115	20	260	5
Free State	165	100	10	309	15
Northern Cape	106	3	0	25	0
Western Cape	723	118	0	90	2
Gauteng	1344	52	0	379	35
TOTAL:SA	3812	1901	158	3245	125

Source: SAZ 96

ENERGY DEMAND: THE TRANSPORT SECTOR

1. INTRODUCTION

The aim of this report is to establish the links and trends in transport energy demand in South Africa. The transport sector is divided into two distinct sections, namely, freight transport and passenger transport. The modes employed by the sector discussed in the report are road, rail, maritime and air. The fuels consumed include various petroleum fuels (gasoline, diesel, aviation gas and jet fuel) and small quantities of coal and electricity.

2. PRESENT AND PAST TRANSPORT ENERGY

Globally the transport sector is the biggest consumer of oil. The IPCC estimates that 58% of all oil products are consumed by this sector. In terms of energy demand, 95% of the transport sector is satisfied by oil, with small quantities of electricity, gas and coal constituting the remainder. There is little opportunity for rapid fuel switching and, in global terms, therefore, the transport sector is highly dependent on oil supply. As a sector, it is important in terms of increasing petroleum demand. The transportation market has been virtually the only growth sector for the oil industry over the past 20 years(1).

In 2000, the Transport Sector consumed 577 PJ, which is 19% of total South African final energy demand. Table 1 below shows transport energy by fuel and Table 2 shows it by mode.

Table 1. Energy for Transport in 2000 by Fuel(2)

Energy for Transport by Fuel 2000 (PJ)	
Aviation Gas	1.1
Coal	0.6
Diesel	169.6
Electricity	12.4
Fuel Oil	0.0
Jetfuel	61.0
LPG	0.0
Paraffin	0.4
Petrol	331.9
Total	**577.1**

Table 2. Energy for Transport in 2000 by Mode

Energy for Transport by Mode 2000 (PJ)	
Air transport	62.1
Land Passenger	385.6
Land freight	129.0
Other	0.4
Total	**577.1**

In the tables above, marine bunkers, used for ships travelling between South African and foreign lands, are not included.

In the OECD, when excluding international maritime traffic, road transport dominates oil demand. In 1990, the split for oil consumption was as follows. Road: 82.5%, air: 13.3%, rail: 1.8, internal navigation: 2.8%, and other: 0.3%.

Growth in transport demand has been a global trend, rates differing from region to region. During the period 1972 to 1995, the developing world had a transport growth rate of almost double the developed world. Despite the OECD having a growth in transport energy of just under 2%, the OECD still accounts for about two-thirds of total demand. This growth is linked strongly to economic activity, amongst other things. It is interesting to note that during the period mentioned there were two spikes in crude oil price that have not reversed oil growth in this sector.

Transport energy demand is dominated by road vehicle consumption. There is a strong link between vehicle population and energy demand, especially where average trip lengths and efficiencies do not change excessively with time. Therefore a crude indicator of passenger oil demand per person is the number of private vehicles (especially larger than motorcycles) per 1000 of the population. In South Africa, this figure was 107(3) in 1993, while the global average was 115. The latter figure varies from one vehicle per thousand for Bangladesh to 769 for the United States of America(1).

3. TRANSPORT ENERGY MODELLING

Models that are used to predict transport energy demand on macro level, use drivers such as GDP, vehicle population and fuel costs to predict demand. Two common models are often employed, the first being a standard econometric regression and the second a more 'bottom-up' model based on vehicle population growth rates, average trip lengths and efficiencies.

The first model relates fuel demand to fuel price and GDP growth and includes a time-lagged effect, consistent with observed price-consumption trends. This is a top-down approach, and as such does not need any examination of transport characteristics such as fleet compositions, trip lengths, efficiency changes or life-style norms. The equation constants, that aggregate all the latter effects, have been calculated based on historical data for South African passenger transport. The structure of the equation allows for a close fit to the data considered (Appendix, page 8). The second model widely employed is given in Table 3.

Table 3. A second macro energy model

Fuel demand	=	Vehicle population	*	Average trip length	*	1/Efficiency

Energy demand growth is thus determined by changes primarily in vehicle population, trip lengths and fleet efficiency for average drive-cycles. The above is given per fuel type and therefore total demand is calculated by adding projections for each fuel. Interrelated important 'drivers' influencing important terms in this equation are summarised below:

Table 4. Energy drivers

Vehicle population	-	Economic growth, demographics, regulation, life-style/industrial norms, transport infrastructure & costs.
Average trip lengths	-	Regulation, costs, economic growth, life-style/industrial norms, demographics & spatial patterns.
Efficiency	-	Technology, life-style/industry norms, regulation & costs.

It is also useful to group the product of vehicle population and average trip lengths to determine 'energy demand' where more detailed information is not available. This is particularly true in the South African situation where minibus taxis, consuming gasoline quantities that cannot be clearly separated from demand by passenger motorcars, are included with passenger motorcars. Also incorporated in this term is the large fluctuation in distances travelled between the rich and poor, economically active and retired, and settlement location (i.e. suburb, outlying urban sprawl or township). In the case of freight transport all three components of demand are aggregated and a direct correlation between GDP growth (which affects trip lengths), vehicle population and efficiency, and fuel demand is assumed. It is impossible to clearly separate these influences as they are all related and overlap. This makes their discussion, under separate titles below, a little artificial.

4. FACTORS AFFECTING TRANSPORT ENERGY DEMAND

4.1 Economic trends

A primary driver of the transport system is economic (GDP) growth. In the case of freight transport, the direct correlation between increases in freight fuel demand and GDP growth are well observed.

For surface passenger travel, GDP growth implies increased commuting needs and personal wealth, often both in terms of number of wealthier people and expendable incomes. This results in more money being available for motorcar purchasing and leisure activities, which in turn increases the demand for transport and transport fuel.

In South Africa the majority of households earning more than R3500 per month own a motorcar(4). Most of the population, however, is dependent on minibus taxis and other public transport, and foot.

Globally there has been a rapid rise in air transport both for goods (freight) and passenger movements. The growth in jet fuel demand has averaged as much as twice the economic growth in many countries. This trend is associated with the rapid expansion of the tourist industry, liberalization of markets, business conferences and the rapid transport of smaller goods. In recent years, South Africa has experienced high growth in the demand for aircraft fuel. The primary driver for this is increased tourism.(1) It is likely to remain the key driver, with the prediction that tourism will account for an increased share of GDP.(5)

4.2 Demographics

Linked to economic growth and life-style norms, a country's demographic trends are important for projecting transport energy demand. With the needs and norms of commuting, leisure travel and status, population acts as a measure of demand for transport. Population statistics can thus be used in deducing a ceiling to demand. As a driver for motorcar ownership, population is linked to, among other things, economics. Wealth empowers people to purchase. However, it has been observed that, when economic growth is slower than population growth, the latter and private vehicle ownership are (in more marginal cases such as South Africa) still closely proportional. Several other factors contribute to this, such as the wealthy owning more vehicles per capita and an ever growing, more affordable second-hand motorcar market. What is clear though is that population is an important driver for transport energy demand.

An important aspect to be taken into account when using population-transport indicators is age distribution. In many developing countries, large proportions of the population are less than 15 years old. These countries therefore have a potential transport energy demand far below what is suggested from gross population as, although there is a need for transport, they are not potential drivers or motorcar owners. In more developed regions, such as North America, Europe or Japan, population growths are slowing, and larger proportions of the population are pensioners over 65 years of age with no need for commuting. Therefore travel demands and energy consumption change. Thus, indicators such as motorcar ownership/1000 people are to be contextualised. In addition, for longer term projection, assumptions regarding the age distribution of population may become more important.

Related to age distribution is average household size. While the 'need' for individual transport increases the demand for vehicles due to specific family relationships, individual preferences are restricted by the family size. Thus the larger the household, the smaller the demand for vehicles. While the preceding discussion relates to life-style norms, the average size of households is an important demographic indicator.

4.3 Fuel accessibility and supply

According to the US Energy Information Administration(6), oil resources are not expected to constrain substantial increases in oil demand through 2020, although political and economic events could cause price fluctuations. Oil use will continue to dominate transportation energy markets. This view is shared by both the International Energy Agency's 'World Energy Outlook'(7) and the World Energy Council's transport modeling[1]. It is expected however that shortly after this period alternative transport fuels will receive more general use due to fuel supply constraints.

Due to its current high dependence on petroleum, the transport sector is particularly vulnerable to oil shortages. Such shortages took place for political reasons when the OPEC Middle Eastern oil producers reduced supplies in 1973 and 1980. South Africa, which was at risk of oil embargoes due to international sanctions in the 1980's, is in a unique situation in this regard. Large quantities of transport oil are produced by the SASOL coal-to-oil installation (approximately 22% of demand). Smaller quantities of synthetic petrol and diesel are produced by Mossgas from natural gas reserves.

It is interesting that the aforementioned oil shocks, which saw record drops in crude supply, did not change the global face of the transport sector. With a few exceptions, instead of fuel switching, moves were made to increase non-OPEC oil supply. This has resulted in the steady depletion of the much smaller non-OPEC reserves. Currently, the North Sea fields are showing signs of depletion. It is unlikely however, according to the WEC, that OPEC will again force another oil shock but will rather opt for increased profit based on high volume supply for the following reasons:

- It is a low-risk strategy.
- It will yield a steady income growth for those countries with a potential to increase production.
- The allocation of growing quotas will reduce stress on OPEC.

South Africa's oil supply will continue to consist of crude imports and synthetic fuel production. SASOL is likely to continue supply towards the end of the scenario period, though the mix of products will push towards greater production of diesel. Currently, more than twice the amount of synthetic gasoline is produced compared with synthetic diesel. The shift is probable, due to SASOL's drive to increase chemical production. This requires more heavy oil products from the gasified coal. (Within the scenario period much of the coal used for gasification will be replaced by natural gas from the Mozambican Pande fields and Waterburg coal-bed methane[8].) The heavier oil products produced during synthesis would be more suited to produce diesel, due to lower energy requirements of the process.

While final gasoline:diesel proportions are not known from SASOL, an existing problem in the supply of local transport fuels is an imbalance in this gasoline:diesel ratio produced by refineries. Where proportions deviate from 50:50, using current crude feedstocks, refining changes and requires increased crude processing. In this light, there is an excessive gasoline demand due to previous government policies that regarded diesel as a strategic military commodity. South Africa is now exporting diesel to neighboring countries, thereby reducing national profits. As military considerations are no longer paramount, within the scenario period this imbalance will be addressed[9]. Historical evidence from the 1980's suggests that policies such as levies would work adequately[11].

4.4 Costs

Both transport fuel and operating costs affect passenger transport fuel demand. The relative extents of these impacts are determined by wealth and life-style norms. In the case of freight transport, fleet maintenance and thus the environment and fleet efficiencies are affected by the demand for low-cost transport.

In South Africa the freight transport system was deregulated in 1989. Since this deregulation road freight transport volumes have grown at the expense of rail. A number of small haulers quickly entered the market after the new policy. Due to inadequate regulations, the subsequent poor enforcement of these regulations, and a market where capacity now exceeded demand, fleet owners kept costs as low as possible, with negative results. The average age of the current fleet is about fourteen years. The fleet is poorly maintained and vehicles are often overloaded. The result, especially in older vehicles, is significant decreases in efficiency and increased emissions.

Due to economic conditions, private vehicles are in high demand in South Africa. Hence there is high growth in the used-car market and the average fleet age is increasing by 0.6 years annually. As incomes rise so too will the extent of motorcar ownership. Currently the majority of households earning over R3500 own a registered motorcar. Thus, if income distributions do not change rapidly, for certain scenarios private vehicle ownership will follow population growth. If economic growth is sufficiently greater than population growth, it is likely that GDP will drive passenger energy demand. This will result when motorcar ownership and/or increased recreational trips become affordable.

Nationally, disposable incomes are relatively low. Thus even with motorcar owners, there is significant scope for government to use levies on fuel and vehicles as an effective policy instrument to affect fuel demand. This was successfully accomplished during the last decade where tariffs were used to rapidly alter diesel and gasoline consumption proportions for strategic reasons. The trend has been observed in several other countries[(11)].

In terms of total fuel demand, studies of the effect of price changes on gasoline demand indicate that increases in fuel price have variable short and longer-term effects. It was found that a 10% increase in fuel price leads to a 1-3% reduction in short-term demand and, due to the adoption of more efficient motorcars, a longer term saving could vary between 7 and 15 percent[(12)]. The latter is thus dependent on a high turnover of motorcar stock, which is less applicable where the demand for low-cost motorcars is high and their usable life is not reduced by regulation or enforced maintenance levels. It was also found that fuel price, Michaelis[(11)], had no significant effect on vehicle ownership.

Vehicle ownership trends, which are affected by cost, have been found to affect transport energy demand. Studies show that a 10% increase in vehicle price leads to a 1 to 5% decrease in fuel consumption[(11)]. This is not due simply to a slowing of motorcar purchases but also to changes in the average engine size. Smaller engine motorcars are generally cheaper to buy. It has been shown[(13)] that so-called ‘freebates’ taxes or subsidies to encourage the purchase of smaller engine vehicles is one of the most effective ways of encouraging fuel economy.

4.5 Environment

The influence of the environment on transport energy demand is significant and may play a more important role in the future. Energy use, amongst other human activities, affects the environment. Where the environment is affected undesirably in terms of aesthetics, economic or personal damage, attitudes and policy result so as to resist or reverse this change.

The effect of the transport system on the environment can be divided into three categories[(1)].

- Those caused directly by fuel use, such as gaseous emissions.
- Effects caused by vehicle use such as congestion, noise and accidents.
- Those caused by transport infrastructure, such as land-use, concerns with the building of new highways, or the visual intrusion of a new airport.

Attempts therefore to change the effect of the transport system on the environment may affect fuel demand. For example, better town planning to reduce congestion could increase city motorcar traffic and thus fuel demand.
It is interesting to note the close relationship between the environment, life-style norms and regulation. Of itself, the environment could act only as a limiting agent to transport. A mountain may necessitate the redirection of a proposed road. The negative effects, or externalities, referred to differ in magnitude depending on social and economic norms. Attitudes either affect the system directly (which are then reflected in fuel demand) or via policy changes.

This report is concerned with fuel demand from the transport sector and important emissions from its use. These emissions affect both the local and global environment. Emissions that are of concern at the local level include: CO, NO_X, HC_X, O_3, Pb and particulates (particularly PM_{10} and $PM_{2.5}$). Important quantifiable emissions from the transport sector that either directly or indirectly contribute to the greenhouse effect include: CO_2, CH_4, HC_X, N_2O, NO_X, CO and SO_2. Important emissions and their effects in terms of global warming potential (GWP) and health effects from transport fuel use are summarised in Table 5.[(14)]

Table 5. Transport pollutant effects

Pollutant	GWP	Other effects
CO	(I)	Slows reflexes, drowsiness
NO_X	(I)	Reduced resistance and lung infection
HC_X	(I)	Drowsiness, eye irritation and coughing
O_3	(I)	Reduced lung function
Pb		Affects circulatory system & nervous system
Particulates		Carcinogenic
SO_2	(I)	Acid rain; lung disease
CO_2	1	Greenhouse gas
CH_4	64	Greenhouse gas
N_2O	270	Greenhouse gas

(I) – Refers to indirect greenhouse gas

An important consideration is that currently emissions from the transport sector account for about 23%[15] of CO_2 emissions from South Africa's final energy use. In South Africa, transport emissions on a cradle-to-grave basis are high due to the high percentage of gasoline and diesel produced by SASOL from coal. The synthetic fuel manufacture is about 33% efficient. Of South Africa's total CO_2 emissions, transport (cradle-to-grave) emissions account for 11% of the total[16].

At national and local level large quantities of particulates are responsible for smog formation. Recent studies such as the Cape Town Brown Haze[17] project and the DMEA[4] particulate source apportionment studies bear this out. It has been estimated that in Soweto, where background domestic emissions are known to be high, traffic emissions account for between 25 and 47% of ambient particulate concentrations from winter to summer.[4] There are also environmental effects associated with South Africa's switching from leaded to unleaded fuel. Most motorcars in the current fleet are old and not equipped with catalytic converters. In fact, most new motorcars are not equipped with these either. Thus, with the introduction of relatively cheaper (due to policy) unleaded gasoline, there is increased pollution potential and possible engine wear, decreasing emission qualities even further.

4.6 Spatial structure and transport infrastructure

Through the evolution of social and economic systems, various spatial patterns and transport infrastructures have emerged. As transport is concerned with movement, the distances, routes, settlement types, manufacturing, market and suburb locations, and infrastructure will all have important bearings on fuel demand. Due to current trends in life-style and economic norms, much of the spatial patterns and transport infrastructure has often encouraged greater fuel consumption.

Local and national business and leisure centres are becoming increasingly decentralised, thereby increasing the need for mobility. Accessible international markets encourage longer distance freight and passenger travel. The result is increased trip lengths. Generally, this reinforces popular modes of travel, which requires the upgrading of existing infrastructure.

Passenger transport is also affected by settlement patterns characterised by urban sprawl and inherited apartheid planning. 'Urban sprawl' refers to the development of low-density suburbs on the peripheries of towns and cities. This phenomenon increases the need for personal mobility, private motor vehicles and thus fuel. More energy-efficient forms of transport, such as mass transport systems, become less competitive as pick-up points become less convenient with lower housing density. Apartheid planning has resulted in large townships away from economic hubs, thus increasing travelling distances and times for the majority of workers and straining existing road and rail routes to and from centres. Approximately 40% of workers commute for more than two hours per working day[(14)].

While infrastructure can limit personal freedom, and thus increase energy demand, the lack of bicycle-paths also encourages the use of motorised transport. Infrastructure (often temporarily) limits or retards overall transport movement. Currently, about 8% of South Africans have no access to any form of motorised transport, either public or private[(4)]. Also, access to public transport is often difficult, with less than 45% of South Africans having access to either train or bus services[(14)]. This encourages the use of less efficient (in terms of fuel per passenger-kilometre) private vehicles, often in poor communities. Motorcar maintenance and quality (in terms of emissions and efficiencies) are then reduced as the demand for 'low-cost' private vehicle rise.

Another important influence on the demand for transport is the rate of urbanisation, resulting in large numbers moving from rural areas to find employment. Because of the nature of urban life, transport is a necessity and demand increases further.

4.7 Intermodal competition

Intermodal competition and resulting competition for freight and passenger transport have important implications associated with them. Passenger transport modes have associated effects in terms of fuel consumption, congestion potential, consumer costs and environmental emissions. While certain options appear to have distinct advantages in terms of what is considered sustainably desirable, consumer demands have tended to push the system toward greater emissions, congestion and fuel consumption. While closely linked to life-style norms, and hence consumer demands, low-occupancy motor vehicles and road freight transport have a competitive edge over other modes in modern economies. As clearly illustrated below in Table 6, the use of motorcars for passenger transport is the least efficient per passenger in terms of all the criteria mentioned: congestion, energy consumption and emissions[(18)].

Table 6. Characteristics of different transport modes

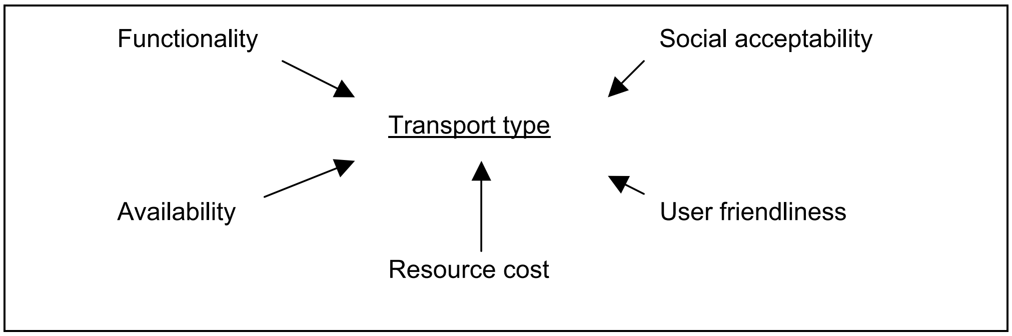
Mode of transport	Persons per hour per lane	Energy consumption per seat-km	Total cost per person-km (US cents)	Total emission per passenger-km(grams)
Walking	1800	0.04	Negligible	None
Bicycling	1500	0.06	0.2	None
Motorcycle	1100	N/A	N/A	27.497
Motorcar	440-800	0.29	8.6	18.965
Bus: Mixed traffic	10000	0.12	1.4	1.02
Bus: Busway	1900	0.09	0.9	0.89
Light rail transit	1800	N/A	N/A	Coal: 4.35 Gas: 0.19 Fuel oil: 0.62
Rapid rail transit	54000	0.15	2.4	Coal: 4.97 Gas: 0.23 Fuel oil: 0.71

The freight transport trends towards road transport are also self-enforcing as this encourages production and supply, decreasing storage needs and therefore storage capacity. The result is that rail transport, which is often slower and less flexible and necessitates storage facilities, cannot compete. Where this is not necessary and stockpiling does not constitute a decrease in speed and efficiency, such as mineral ore or coal movement, rail transport has maintained its niche.

4.8 Life-style and industry norms

The mode of transport employed by business and individuals is dictated by concepts such as convenience and acceptability. What constitutes these concepts is however dynamic. These exist at different levels for freight and passenger transport. The following diagram is from the work of Tengstrom[19] and illustrates the major influences in the choice of transport type.

Table 7. Influences on the type of passenger transport employed



Life-style norms have had a great impact on the type of passenger transport used by the general public. The motorcar has come to be a status symbol and means freedom to travel. Ownership is thus not based entirely on economic choices. Vehicle fleets in many countries have decreased in efficiency over time. This is not due to technical limits to efficiency, but rather due to choice of engine size. The larger the engine, generally the higher the status of the motorcar and its performance. This trend occurred after the average efficiencies of new motorcars improved following the two OPEC oil shocks mentioned earlier.

Thus, as in the case of South Africa, vehicle ownership growth may outstrip economic growth.

Interestingly, while expendable income will affect leisure activities, it has been found in developed countries that average travelling time is an important factor in determining fuel demand[11]. On average in western countries, people spend about 70 to 80 minutes travelling per day. If these people travelled by bus or on foot, when they obtain a motorcar they would still spend the same amount of time travelling. In some cases it would take more time, though they may perform all the tasks they did previously well within 70 minutes. More time is spent on leisure travel. Another effect is that home and employment places may be further away from each other. This influences settlement patterns, encouraging urban sprawl and remote shopping malls. Thus preferences such as lower density housing, shopping and leisure options are increased, further entrenching private vehicles as the passenger transport mode of choice.

Demographic trends, such as average household sizes, influence the extent of an individual's desire to own a vehicle. Where households are become smaller in size (persons per dwelling), the demand for transport increases.

The influence of company motor vehicles and subsidies also significantly increases transport fuel demand. In 1990, about 12-13% of passenger vehicles were registered under the name of companies. Most of these are also used extensively for private purposes. An individual with a company motorcar travels 10% more than one with a private vehicle. Additionally, about 25% of company motorcar drivers receive an allowance, which results in 20% more travel in company vehicles. It is estimated that nationally transport fuel consumption is increased by 7.8% due to these 'benefits'[4].

Other influences, such as congestion, can decrease motorcar use and even ownership in certain areas. Thus in many high-density areas, trends of fuel consumption per person are inversely related to the number of persons per hectare. For example, in Hong Kong, with 300 persons per hectare, less than 5 GJ of petrol per person was consumed per year, compared to Houston, USA, with 10 persons per hectare resulting in an average gasoline consumption of 75GJ per person[20]. Another influence that reduces consumption is saturation of motorcar demand. This has been observed in the United States, where growth is rapidly decreasing. In the 1960's vehicle growth was 3.9%, in the 70's it was 3.6% and it moved down to 1.9% in the 80's[1].

While the above effect is well established and self-entrenching, the influence of ‘new norms’ on society may have an ever-important effect on passenger transport energy. Such an example is that of ‘telecommuting’ where work is done from a ‘home-office’, and the company (where applicable) is accessed via computer networks. Such trends would have a drastic effect in reducing commuting, especially in the commercial sector. However, in South Africa there might not be a sufficiently large number of people engaged in the modern economy for it to make a significant difference here.

While norms and standards are changing for passengers, so too are trends relating to norms in the freight transport industry. As economies change goods are becoming more processed and require more components. This results in increased processing steps. As road freight transport allows for fast convenient movement, competition is increased for goods movement from processing at different locations to complete goods movement. Thus, modal shifts from rail-freight have taken place globally. Another factor contributing to this shift has been government deregulation of state rail systems. This trend is again self-entrenching and smaller vehicles (less efficient in terms of fuel per ton of goods moved) are employed. Aided by fast and flexible transport industry has moved towards ‘just in time production’ (JIT). Now computers and advanced stock tracing reduces the need for depot and storage. This favours smaller, more frequent deliveries. There may however be a slowing or reversal of this trend if congestion prevents effective road movement. Thus transport ton-km's have increased beyond predictions from the 1980’s in the developed world, and are likely to follow suit in developing countries.

4.9 Regulation

Regulation in the transport sector is important in terms of protecting and pursuing short, medium and long-term interests. These are related to fuel supply considerations, life-style norms and longer sustainable growth, which is generally linked to the environment. Most of these will have a direct bearing on fuel consumption in this sector. Of direct consequence is the reduction of greenhouse gas emissions for this sector. In this case, CO_2 emissions are related directly to fuel consumption (although for certain fuels, such as natural gas, the ratios of energy to CO_2 differ). There are several instruments available to the government for the implementation of integrated planning for the transport system. These include: [21]

- physical controls such as short-term supply rationing
- investment policies
- education policies
- taxes or subsidies
- market controls such as road tolling
- establishing energy efficiency agencies

Careful consideration must be given in such regulation implementation to ensure that the externality costs are borne by the responsible parties, and that controls do not restrict free-market activity.

Much of the future shape of the transport system and therefore energy demand will depend on government policy, such as the building of infrastructure for future public transport, the introduction of ‘freebates’ (discussed earlier), and enforcing the introduction of catalytic converters or three-way catalysts. From this perspective it is difficult to predict future trends resulting from government-sponsored alternative fuels programmes. For the scenario planning that follows in this work (with consideration to alternative fuels), estimates for the penetration of public and alternative fuels are speculative at best.

4.10 Efficiency improvements

In the following discussion, efficiency will mean fuel consumed either by the entire transport system to meet the demand for transport, in terms of either fuel per passenger-kilometre or fuel consumed per ton-km for freight. While not falling into the definition given, where the demand for transport energy is deliberately decreased (apart from the main drivers such as economic growth or population growth), this will also be discussed in this section. Given demand for transport in society, in order to estimate future fuel consumption trends, it is important to take cognisance of these future fuel ‘efficiency’ improvements. Transport fuel efficiencies may be improved by:

- changing the mix of existing transport technologies, either within a mode or by changing modes,
- management of the existing system, and
- the introduction of new technologies.

(The potential for new fuels is discussed in the following chapter)

When considering efficiency improvements, it is important to make the distinction between what is technically feasible and what is economically probable. The further in the future these projections are made the greater the probability for error, either by overrating the price reduction of technologies or non-uniform breakthroughs. The following table summarises probable efficiency changes used in other studies.

Table 8. Expected efficiency improvements

Transport mode	**Current efficiency (MJ/pass-km or ton-km)[11]**	**Economically feasible projected change by 2020 IEA[1][(11)]**	**Economically feasible projected change by 2020 WEC[2][(1)]**	**Economically feasible projected change by 2025 Dargay & Gately[3][(22)]**
Motorcars	1.2 - 2.0	0 to –30%	-28%	-16%
Buses	0.5 - 1.3	+10 to –10%		
Heavy trucks	0.6 - 1	-10 to –20%	-10 to –20%	
Passenger trains	0.9 - 2.8	+10 to –10%		
Freight trains	0.4 - 1	+10 to –10%		
Air travel	1.5 - 2.5	-20 to -30%	Unclear	
Marine freight	0.1 - 0.4	+10 to –10%		

The above table is based on expert judgement in each case after a consideration of various new and existing technologies, costs of implementation and decrease of these costs over time. The current study is not a technical review. However, the most promising technologies for this time frame are[1,14]:[4]

- For motorcars[5]: hybrid-electric vehicles, variable valve control (20%), lean-burn engines (10%), variable compression ratio (30%), engine pre-heating (12-16%) and advanced transmissions (11.5%).
- For buses: regenerative braking (30%), aerodynamic drag reduction and adiabatic ceramic engines.
- For heavy trucks: gross weight reduction (3%), aerodynamic drag reduction (20%) and adiabatic ceramic engines.
- For (diesel) freight trains: various engine technical (5-10%) and overall non-engine design (weight reduction, rolling resistance reduction and drag reduction) (25-30%).
- For (electric) passenger trains: regenerative braking (30% for metro systems, 15% for suburban) and overall (suburban) non-engine design (weight reduction, rolling resistance reduction and drag reduction) (45-50%).
- Air travel: ‘propfan’ propulsion (10-20%), advanced exhaust gas heat exchange (20-25%).
- Marine freight: engine cooling and exhaust recovery (5-10%), wind assistance (10-20%), propeller design (5-16%), hull design (8-15%) and reduced skin friction (0-14%).

Non-technical measures to reduce fuel demand for transport involve policy decisions. It was estimated by a Dutch[11] study that using a mix of transport management instruments, Holland’s total CO_2 emissions, and thus in this case fuel demand, could be decreased by about 17%. These included measures such as fuel price increases, road pricing (tolling), parking fees, plus improved public transport.

Other efficiency improvement measures result from good maintenance practices. Due to the socio-economic conditions described earlier, many motorcars are poorly maintained. Australian[23] studies show that the efficiency benefits from tuning the worst 10% of their fleet (in terms of pollution emitters) resulted in an overall 5% improvement in efficiency.

[1] This study was made from an OECD perspective and fleet efficiency changes of these countries.

[2] The WEC study projected world fleet averages.

[3] The OPEC study concerned itself with a selection of developing countries.

[4] Potential energy efficiency improvements are in brackets.

[5] Fuel cell vehicles were considered to be economic be just outside the scenario period.

4.11 Alternative fuels

Alternative fuels for transport could prove useful for strategic and economic reasons. At a national level, the greater the spread of fuel sources, the greater the opportunity for fuel switching. Thus with SASOL oil-from-coal, a buffer exists if crude prices were to rise sharply, slowing inflation. In addition, South Africa's electricity load profile is very peaky, thus there is interest in selling large quantities of off-peak power. Alternative fuels such as gas hold potential for greenhouse gas reduction, which may be an important policy consideration in the future.

In terms of basic criteria that must be met, any alternative transport fuel must be available for the task (i.e. fuel station network potential), in sufficient supply and economically competitive with existing service providers. The modes using these fuels must also satisfy criteria such as functionality in terms of trip lengths.

The fuels currently being considered globally include:
- Compressed natural gas (CNG)
- Electricity
- Liquid petroleum gas (LPG)
- Methanol
- Ethanol
- Rape-seed oil methyl ester (RME)
- Hydrogen

It is suggested[1] that due to current costs and rates of progress, in terms of vehicles and necessary infrastructure for private transport, only natural gas holds the potential for wide-scale use and will occur only after 2020. In South Africa, there is potential for, according to ESKOM[4], significant use of electric road vehicles.

Currently ESKOM believes that the cost of travelling by electric vehicle with inexpensive South African tariffs is significantly cheaper than using gasoline or diesel. The IEA points out that market capture will depend on successful demonstration. Electric vehicles are currently hindered by inadequate battery design[11].

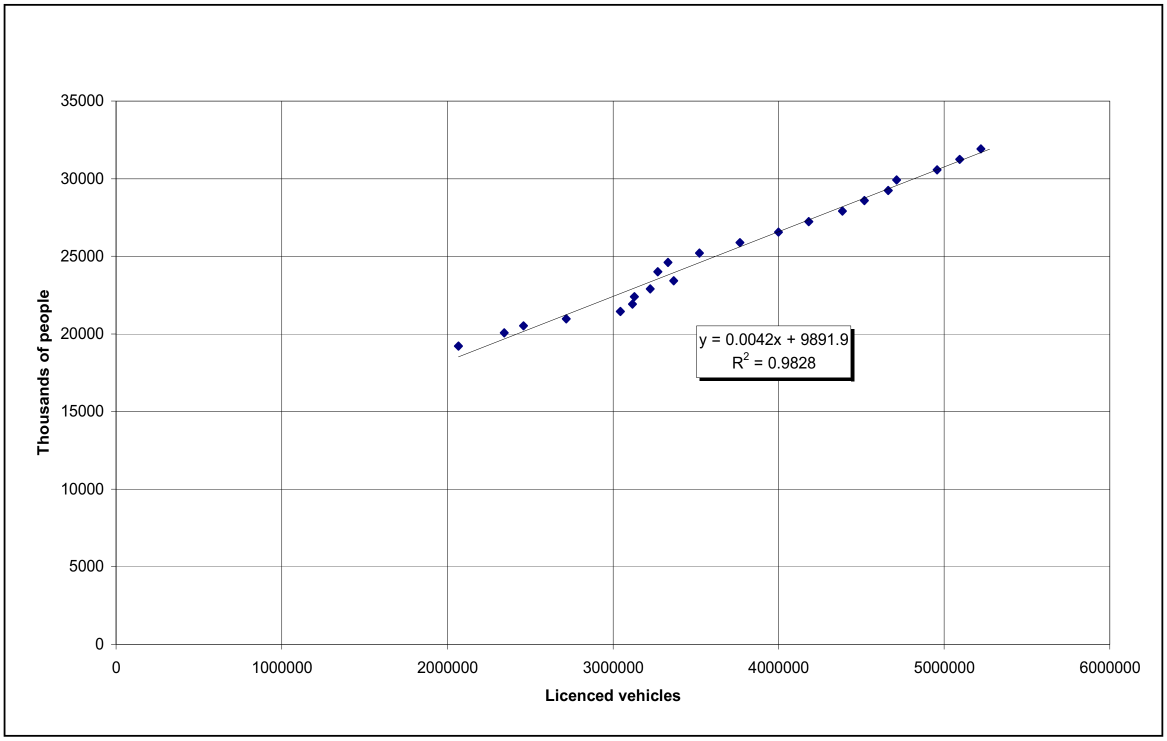
Other fuels are unlikely to make significant inroads due to shortage of reserves, expected increased industrial demand, and infrastructure requirements for longer trip lengths. However, from SASOL upgrades to incorporate Pande and perhaps Waterburg gas, it is likely that some petroleum will be produced from natural gas for transport purposes.

5. CONSIDERATIONS FOR FUTURE TRANSPORT ENERGY

Private vehicle (including minibus taxis and private motor vehicles) fuel demand, synonymous with gasoline demand, has shown consistent trends over the last twenty years. Due to lack of reliable data concerning the split in gasoline consumption between minibus taxis and passenger cars, taxis have been included in this term, representing a mode between private and public bus transport. The inclusion of taxis in the term skews the uniformity of the equation due to differences in efficiencies and average trip lengths. However, when using this framework with aggregate figures, results are consistent, as taxis are far closer in terms of fuel and trip length characteristics to private motorcars than all other forms of passenger transport. It was found that clear links were established between motor vehicle population, population growth and fuel consumption. Given that average efficiencies for the data interval did not change significantly[10], this implies that the average trip length has remained constant.

An important point of departure for many existing models used for transport projections is the decoupling (during this data interval) of fuel costs as an important primary driver for fuel consumption. Fuel prices showed some variation over the period[24]. One would expect that, with a growing 'low-cost motorcar market', poorer communities who now own more motorcars would spend less expendable income on fuel for leisure purposes and thus average trip lengths would decrease. This has not occurred. A possible explanation is that such communities live further from the cities. Commuting lengths for these people are thus increased and fuel demand kept high. Other influences over this time include the percentage of 'urban' versus 'rural' vehicles, the effects of company fuel allowances, and company motorcars.

The clearest trends from national historical[3,25] data show that fuel consumption is directly proportional to motorcar population, and that there is a direct increase in motorcar demand with population. This data spans the interval 1970-1993. It was felt that earlier data would not be appropriate for analysis due to restrictions on vehicle use such as prohibitive costs and infrastructure constraints.



Trend of Number Licensed Vehicles against Number of People

It is not clear why population growth and passenger car ownership should grow proportionally. The most probable explanation is that the percentage of people who can afford to buy a vehicle has remained constant over the time period for which the data was gathered. This is dynamic, as the income bracket required will have also changed over time with the cost of motorcars. Interestingly South Africa's motor vehicle ownership was not negatively affected by the first oil crisis in 1973. Instead, vehicle growth per 1000 people rose from 84 to 91 during 1973-74. This is consistent with European trends[11]. During the periods 1970-79 and 1980-91 vehicle growth outstripped population growth, and from the data series examined the ownership to population ratio has steadied.

For the analysis, it was impossible to calculate an average fuel economy of South African motorcars based on ownership numbers and then predict future fuel economy, assuming the rate of and economy of new models and percentage of minibuses entering the transport system with time. It has been found that newer vehicles are driven[4] further than older models. Weighting motorcar population age with distance travelled and economy was, therefore, impossible due to data shortages. In addition, no accurate data for taxi gasoline consumption with time could be found.

Diesel engines have quite recently become much more efficient and convenient to use (starting easily and quickly). This is thanks to new technology, especially in the fuel injection. In Europe diesel cars are becoming increasingly popular because of their improved performance and good fuel economy. The same is expected to happen in South Africa. The recapitalisation of the minibus taxi fleet, replacing petrol vehicles with diesel, would give s step change to this trend.

Electric private vehicles hold significant potential for the reduction of South Africa's peaky electricity load profile.

It was difficult to predict electricity intensity changes over the period in terms of MJ/passenger-km as it is likely that initially vehicles would be larger minibus-type shuttles. With demonstration, growth may move towards smaller less efficient personal motorcars.

Public transport's share of total transport energy is small. In most industrialised and economically growing countries its share is declining further with increased private motorcar ownership and use(1). The reasons for this are many and will have to be overcome for effective penetration of public transport. Fuel consumption, emissions and congestion potential are dramatically reduced compared to current trends of high-density, low-occupancy private motorcars.

There have been encouraging statements recently about large projects to improve public transport in Cape Town and Johannesburg. In Cape Town a fast train service is proposed between the city centre, the northern suburbs and the airport. In Gauteng one is proposed between Pretoria, Johannesburg and the airport.

Small-scale coal consumption takes place for tourist rail movements, 1471 TJ in 1995. This figure is likely to remain constant due to the nature of the service and environmental constraints(30).

Air travel to and from South African airports is dominated by tourist and commercial passenger travel. It is reasonable to assume that, with the increase in commercial activity and hence GDP, there will be an increase in demand for commercial passenger travel. As little fuel consumption is associated with the use of privately owned planes, it is unlikely that tourist air travel is closely linked to disposable income and thus indirectly to GDP for domestic movements. Foreign tourist movements toward SA is a factor that increases GDP. Air traffic should grow more quickly than GDP with a corresponding increase in demand for jet fuel. However, aviation gas, which is used for piston-engined aeroplanes, should decline in demand as there are fewer and fewer aeroplanes, even quite small ones, now using piston engines.

Surface freight transport within South Africa is carried out primarily by means of rail and road. Deregulation in 1989 resulted in the growth of the number heavy motor vehicles. Other commercial goods transportation that is associated with significant fuel demand is 'ocean going' exports.

The South African economy is not yet dominated by the 'commercial' or 'services' sector. Past growth, while including increases in services, has resulted in an increase in material production, and with this an accompanying increase in the demand for freight transport. According to national data, a close correlation exists between GDP and freight, or diesel fuel consumption. This trend may be influenced by changes in overall transport fuel efficiency. It is implied, however, by the straight line in the figure that such changes have yet to take place. Freight transport is an important component of South Africa's large industrial, mining and agricultural sectors.

It is assumed that rail volumes will be dependent mainly on bulk movements of minerals and coal exports. These influence national GDP and are a function of international markets. It is reasonable therefore to include rail diesel with road freight. Rail has a niche in such bulk loads due to the ability to stockpile, while 'just-in-time production' trends favour more convenient road modes. Much freight is increasingly being transported by lighter (more inefficient in terms of MJ/ton-km) vehicles.

Electricity used for rail transport forms approximately 3% of the energy consumed by transport. In 1982 long distance passenger rail 45 million passengers travelled by long distance rail. In 2000, only 4.2 million did. There is 7.4 million capacity today.

Under certain circumstances, gasoline production may exceed diesel demand. Due to political encouragement and a demand for smaller, more flexible hauling, gasoline freight will become viable and important. From an average range(4) for freight transport intensities, the smaller, lower volume gasoline fleet intensity was taken to be at the higher end, 4.2 $MJ/ton_{1995\ GDP}$. This figure decreased by 10% for the green scenarios. Diesel surface transport is predicted to take up more bulky and less intensive freight with the introduction of smaller gasoline fleets, and therefore average diesel intensities decrease below the freight average over these scenarios. The average for the total fleet remained at 3.4 $MJ/ton_{1995\ GDP}$ changing only with time-related efficiency improvements in the green scenarios.

Marine transport consumes large quantities of marine bunker fuel, generally petroleum residual oil. In 1993 106 PJ was consumed. This fuel is a low-grade petroleum fuel with a high sulphur content, and consumption is directly linked to import and export volumes. While it is unclear whether or not exports will rise directly with GDP in the longer term, with an expected shift in the economy towards services, a large percentage of current economic activity is directly associated with GDP. These include bulk exports such as iron and steel, aluminium and coal. It is therefore assumed that for the next 30 years exports and therefore marine bunker fuel will grow directly with GDP.

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ENERGY TRANSFORMATION

1. INTRODUCTION

Of the final energy consumed in South Africa every year, only a small portion is consumed directly. The rest goes through processes of energy transformation which change it into other forms of energy. In 2000, total South African primary energy was 4230 PJ of which only 3055 was used as final energy. The rest was lost in energy transformation.

Coal is burnt in power stations to produce electricity. Electricity is also made from nuclear reactors and hydro-power. Crude oil is refined into petrol, diesel, paraffin and heavy furnace oil. Coking coal is converted into coke and coke oven gas for steel-making. Coal is converted into liquid fuels and gas in the Sasol plants.

There are considerable imports and exports of energy. In 2000 South Africa imported crude oil, liquid fuels, coking coal, nuclear fuels and electricity, and exported coal, crude oil, liquid fuels and electricity.

The three major energy transformations, coal mining, electricity generation and liquid fuel production are considered separately below. The transformation of coking coal into coke and coke oven gas for steel-making will depend on the nature of the steel industry in future, which is considered under the demand section.

2. COAL MINING

Coal mining is considered an energy transformation in that coal in the ground is converted into a form where it may be used by other transformations, such as power stations, or by final users, such as steel-makers or households.

South Africa mines about 270 million tons of coal a year of which about 70 million is exported, 150 million used locally and 50 million is discarded. (The discard figure is an estimate.) 44.5% of the coal is mined by opencast methods. The rest is mined underground, 44.0% by bord and pillar (mostly mechanised), 10.6% by pillar recovery and 0.9% by longwalling.(1)

In 2000, South Africa produced 222.5 million tons of bituminous coal and 1.6 million tons of anthracite. The anthracite is found in the east of the country in Kwazulu-Natal.(2) (X M Prevost. Minerals Bureau. Department of Minerals and Energy. Email to Mark Howells.)

Table 1. below shows the sales of South African coal in mass and value for 1998.

Table 1. Sales of South African coal in 1998.[1]

	Mass (Mt)	%	Value Rmillion	%	Rand/ton
Exports					
Anthracite	1.38	0.6	267	1.5	194
Bituminous	65.9	29.5	9623	52.9	146
Local Sales					
Anthracite	0.64	0.3	143	0.8	225
Bituminous					
Electricity	93.05	41.7	3748	20.6	41.3
Synthetic Fuels	43.54	19.5	2484	13.7	54.6
Industry	6.33	2.8	512	2.8	81
Metallurgical	5.97	2.7	933	5.1	156.4
Merchant & Domestic	4.75	2.1	381	2.1	77.7
Mining	1.52	0.7	86	0.5	57.1
Total (export & local)	**223.08**	**100.0**	**18177**	**100.0**	

3. ELECTRICITY GENERATION

South Africa has three groups of electricity generators: the national public electricity utility, Eskom; municipal generators; and autogenerators. The autogenerators are industries which generate electricity for their own use. These include the pulp mills, sugar refineries, Sasol, Mossgas and metallurgical industries. In 1995 the figures for the percentage of South African generating capacity and actual production were as follows (production in brackets). Eskom: 91.1% (93.5%). Municipalities: 5.6% (2.0%). Autogenerators: 3.1% (4.5%).

Eskom's share of South Africa electricity sent out increased from 74.8% in 1956 to 97.4% in 1995. Eskom is now the only national public electricity generator but with the strong possibility of deregulation of generation it is unlikely that it will be the only one in future.

There was a high growth in electricity demand during the 1960s and 1970s, where it was above 8% in some years, followed by a drop in growth of demand to about 2% in the 1990s. It takes about eight years from the decision to build a power station to its coming into service and, because of the expectation of high electricity demand from the past, Eskom committed itself to an ambitious programme of building big coal stations. The result is that Eskom now has surplus capacity, which however will run out in about 2008.

In 1999 Eskom had a peak demand of 27 813 MWe. Its licensed capacity was 39 870 MWe. The total amount of electricity sent out by Eskom in 1999 was 178 561 GWh, which gives an average demand of 20 384 MWe.[3]

The "generation load factor" gives a measure of the difference between peak demand and average demand. It is defined as (Net MWh generated) / (peak demand x hours in year). With uniform demand and no peaks at all the generation load factor would be 1.00. For 1999, from the figures above, it was 0.74 The peaks in electrical demand happen typically at 08h00 and 19h00 and are caused mainly by residential demand. With increased electrification of households, these peaks are expected to get worse, and the load factor expected to decline.

To ensure reliable electrical supply, there should be a reserve margin of electrical generating capacity. This allows for unexpectedly high demand or unexpected outages on power stations. A reserve of 15% is usually considered adequate. However, some electrical consumers have interruptible contracts. They pay less for their electricity and concede to the electricity utility the right to stop their supply during periods of high demand. Typically the proportion of such interruptible electricity demand is 7% of total possible maximum demand. This effectively reduces the required reserve margin to 8%.

To maintain the reserve margin there are two approaches: increasing supply or decreasing demand. Total demand may be decreased by improved efficiency in electrical usage and by energy conservation. Peak demand may be reduced by differential electrical tariffs or by electrical storage such as in pumped water storage. Electrical supply may be increased by running stations for longer than their expected life, by bringing mothballed stations back into production, by building new stations or by importing electricity.

The average sales price of electricity in South Africa in 1999 is given by Table 2 below.

The existing electrical generation capacity is discussed below.

Table 2. Electricity Prices in 1999. [3]

	Sector	Average Sales Price 1999 (c/kWh)
	Agriculture	22.87
	Commercial	23.47
	Domestic	24.59
	General	14.36
	Manufacturing	12.83
	Mining	12.32
	Transport	14.49
	Total	**16.29**

3.1.1 Coal: Existing Generation

Over 92% of the electricity now generated in South Africa is from conventional coal power stations. In 1998 Eskom coal stations produced 165 TWh of electricity.

In the first half of this century, the coal power stations were each less than 200 MWe in capacity, used a chain grate to transfer lumps of coal to the furnace and were often located away from the coal mines and had coal transported by rail. Since then the chain grates have been replaced with mills which crush the coal to pulverised fuel (PF) and inject it into the furnace with blowers. This gives more complete and efficient combustion. The size of coal stations has increased radically and from 1980 on Eskom has only built power stations of capacity greater than 3000 MWe comprising of six units each. Because of their huge coal requirements, typically of about ten million tons a year, it is too costly to transport the coal over long distances and so the power stations have been built on the coal fields and the coal transported from the mines by conveyor belts. This means that all the large coal power stations are concentrated around the coalfields in Mpumalanga, Gauteng and the Northern Province.

Eskom's systematic programme of building large, modern stations each with six identical units have driven down capital costs per installed kilowatt. The combination of cheap coal and big, standardised coal stations without flue gas desulphurisation has allowed South Africa to produce the cheapest electricity in the world.

These stations have some disadvantages. They are polluting. Because they must be located at the coal fields, they are concentrated in the northern interior of South Africa and power has to be transmitted long distances to coastal centres such as Richards Bay, Durban and East London. This leads to problems with the quality of electricity in these places. The problem is made much worse during the cane-burning season in Natal, where power lines pass through sugarcane fields and there are electrical disturbances, perhaps caused by air being ionised because of the fires and causing short circuiting between the overhead conductors.

South African coal has high ash, low sulphur and low calorific value. Typically coal from the mines is sorted into three categories of descending quality: export, steam coal and discard. The steam coal typically has a sulphur content of 1%, an ash content of 20% or more and a calorific value of 20 MJ / kg.

Table 3. shows some characteristics the Eskom coal stations now operating, mothballed or being built.

Table 3. List of Eskom's current coal power stations. [4]

	Nominal capacity (Mwe)	First unit commissioned	Thermal efficiency	MJ / kg for coal	Cooling	Operating Status
Arnot	2100	1971	33.3	22.35	Wet	partly operating
Camden	1600	1966			Wet	Mothballed
Duhva	3600	1980	34.5	21.25	Wet	Operating
Grootvlei	1200	1969			Wet	Mothballed
Hendrina	2000	1970	32.34	21.57	Wet	Operating
Kendal	4116	1988	34.31	19.96	Dry	operating
Komati	1000	1961			Wet	mothballed
Kriel	3000	1976	35.02	20.04	Wet	operating
Lethabo	3708	1985	34.89	15.27	Wet	operating
Matimba	3990	1987	33.52	20.77	Dry	operating
Majuba	4100	1996			wet/dry	being built
Matla	3600	1979	35.47	20.58	Wet	operating
Tutuka	3654	1985	35.32	21.09	Wet	operating

As well as the Eskom coal power stations above, the municipalities of Cape Town, Bloemfontein, Johannesburg and Pretoria each have small coal stations. In 1995 they generated in total 3.7 TWh.[5]

Most of the coal stations dump their heat from the condensers in conventional cooling towers, which use between 1.8 and 2.0 litres of water for every kilowatt-hour of electricity generated. However, two stations, Kendal and Matimba, have dry cooling, and use only 0.1 litres of water for ever kilowatt-hour. [4] As can been seen from Table 3.10 above, the costs in lost efficiency for dry cooling are small.

With water being South Africa's most critical resource, dry cooling is a great benefit for the country. In 1995 South African coal stations consumed 214 gigalitres of water. [4] This compares with the annual 1995 water consumption of Bloemfontein at 129 gigalitres, Pretoria at 375 gigalitres and Durban at 404 gigalitres.[6] A coal station with the capacity of Matimba (3990 MWe) but using wet cooling would consume about 43 gigalitres a year. Because of its dry cooling Matimba actually consumes about 2.4 gigalitres a year. This saving is equivalent to the annual water consumption of a large sized town.

Coal stations produce large amounts of waste, both solid and gaseous. Coal consists of carbon, hydrogen, nitrogen, oxygen, sulphur and ash. The ash is made up of a variety of elements including silicon, aluminium, iron, calcium, potassium, iron, lead, arsenic, cadmium, chromium, uranium and radium. All of these elements end up either in the atmosphere or on ash tips. In South African coal power stations, the only pollutant that is removed from the flue gas are particles (smoke), which are removed with electrostatic precipitators or, as will happen with Majuba, filter bags. There is no flue gas desulphurisation on any station in South Africa. The other pollutants in the flue gas, including sulphur dioxide, nitrous oxide, heavy metals, organic compounds and radioactive nuclides, pass straight into the atmosphere.

Coal stations also release two major greenhouse gases, water vapour and carbon dioxide. The hydrogen fraction of coal is small, typically about 3%, and so the water vapour coming from combustion is relatively low. The carbon fraction is large, typically 65%, and so the carbon dioxide from the combustion is high. Typically every kilogram of coal burnt in a power station releases 1.54 kilograms of carbon dioxide. Every kilowatt-hour of electricity produced from a coal station releases about one kilogram of carbon dioxide.

In 1995, Eskom coal station released into the atmosphere 600 millions tons of carbon dioxide, 1.3 million tons of SO_X (sulphur dioxide and other sulphur compounds) and 150 thousand tons of NO_X [4]

3.1.2. Coal: Future Generation

There are various technologies now being developed that will make coal power stations cleaner and more efficient. However, all of them will add to capital costs.

South Africa could simply build more conventional coal stations such as already exist. However, most of the growth in coal generated electricity is expected to come from new technologies with greater efficiencies and fewer emissions. Simply improving efficiency necessarily reduces pollution because for each unit of power generated you burn less coal and therefore have fewer emissions. The technologies for improving efficiency use the following methods: (i) increasing the pressure and temperature of the steam (ii) making use of more pre-heating and re-heating of the steam (iii) recovering energy from the waste heat of a combustion process and using it for perform more work.

There are various technologies used now or being developed which purely reduce pollution. These include flue gas desulphurisation, in which the flue gas from the boiler goes through a scrubber containing lime. The sulphur from the flue gas combines with the calcium in the lime to form calcium sulphate. This method adds about 30% to the costs of coal power stations.

Altering furnace conditions and dropping combustion temperatures reduces the amount of NOx produced in combustion but also reduces thermal efficiency.

A summary of the most likely new technologies follows below.

Supercritical Coal Power Station

The thermal efficiency of all power stations increases with the highest temperature in the heat cycle. This is limited by material restraints. However, the thermal efficiency can also be increased by increasing the steam pressure. Above a certain critical pressure, 22.09 MPa, water when heated does not boil but goes directly to dry steam. Building power stations using steam at these elevated pressures presents less technical difficulty than building them at elevated temperatures. Stations using steam at greater than 22.09 MPa are called “supercritical”. Such stations have already been built. They have achieved efficiencies of 43% or more.

For example, the Nordjyllandsvaerket supercritical coal station in Denmark, which produces combined heat and power, was due to begin commercial operation in Oct 1998. If producing electricity only, its nominal capacity is 411 MWe and its expected thermal efficiency is 47%. It produces steam at 285 bar and 585°C. It uses double reheat. It removes particles in the flue gas through an electrostatic precipitator and sulphur through flue gas desulphurisation. Research is being done in Europe on new nickel alloys that will be able to handle steam at 700°C. Such temperatures could raise the thermal efficiency of a power station to 55%. (Ecoal, 1999).

Such stations would have about 20% higher capital costs than conventional coal stations but would have lower running costs because of their higher efficiency. However, their higher capital costs could rule them out in the period being considered.

Integrated Gasification Combined Cycle (IGCC) Coal Power Station

In the IGCC, coal is first gasified, the gas is fired in a gas turbine and then the exhaust gases are sent to a boiler to raise steam for a steam turbine. The combined cycle raises the thermal efficiency of the plant, which can go over 45%.

The coal is converted to synthetic gas (syngas), a combination of hydrogen and carbon monoxide, by interaction with steam and oxygen. The syngas is cooled and sulphur and particles are removed from it. It is heated before it enters the gas turbine. If the syngas could be cleaned while it is hot, you could increase the cycle efficiency by about 1%.

By 1996 there were seven commercial IGCC plants being operated or developed worldwide. An example is the Buggenum plant in the Netherlands. This unit has run at a capacity of 476 MWe and with a thermal efficiency of 48.3%. The estimated capital costs of IGCC plants are about 40% more than conventional PF plants. [(7)]

Eskom has much experience of running coal power stations and SASOL has much experience of coal gasification, so it might seem that South Africa is suited for IGCC plants. However, the ash content of South African coal is high and the melting point of the ash is high, both of which count against IGCC. Moreover the technology of IGCC is still in early stages and the plant is quite complicated to build and to operate. For these reasons it is unlikely that South Africa will have IGCC by 2020.

Fluidised Bed Coal Power Station

By mixing fuel particles with particles of limestone, blowing air through it and burning it in a moving bed of particles, a "fluidised bed", you can get long residence times in the combustion zone and so burn fuels of low CV and poor consistency. This makes it suitable to burn South Africa's high ash coals and, even more promising, her discard coal. The limestone reacts with sulphur in the combustion gases forming calcium sulphate (gypsum). If this is removed and replaced with fresh limestone you can remove sulphur from the exhaust gases. Combustion temperature in the fluidised bed are lower than in a PF furnace and this causes less NO_x to be released.

Fluidised beds may be "bubbling" or "circulating", and at atmospheric pressure or at a higher pressure. The pressurised circulating bed holds out the prospect of a combined cycle where the combustion gases are cleaned, go into a gas turbine and then into a steam boiler to raise steam for a steam turbine. This is because the temperatures of combustion in the fluidised bed are low, 750°C to 950°C, and therefore the volatization of the alkali metals is low and the ash is unlikely to be sintered, so reducing the chances of corrosion or erosion of the turbine blades. With such a combined cycle, higher thermal efficiencies can be reached.

Several fluidised bed boilers have been built and operated in countries like Sweden and Japan. However, these have been of small capacity, in the range to 60 to 80 MWe. One of the difficulties of FBC is slow start-up time. For this reason it is not suitable for peaking power.

The huge benefit of fluidised bed combustion is that it can usefully burn discard coal. Every year South Africa produces about 40 million tons of discard coal from the beneficiation of coal for export and local consumption. By 2020 the amount of discard coal that will have accumulated is estimated to be 2300 million tons. [(8)]. Assuming the discard coal to have a CV of 12 MJ / kg, this gives a total energy reserve in our discard coal then of 27 600 PJ, which is three times the combined reserves of the Kudu, Pande and Mossgas gasfields put together. Fluidised bed combustion offers a way of using this to make electricity.

Eskom is already in advanced stages of investigating a project to convert Unit 6 of the mothballed station at Komati to fluidised bed combustion. The unit would be 110 MWe in capacity with a natural circulation boiler with circulating or high-expansion bed combustion at atmospheric pressure. It would run off discard coal from the Koornfontein mine which has a CV of 13.93 MJ / kg, an ash content of 45.4% and a sulphur content of 3.5%. An Eskom study finds that the levelised costs over 25 years for such a plant will be lower than those for a conventional PF plant at that site and with the same output.[(9)]). This FBC unit should be in early stages of operation by 2004.

If lime is used in the fluidised bed to remove sulphur, an important consideration and cost will be the supply and transport of large amounts of lime.

It is likely that South Africa will use some fluidised bed combustion for electricity generation in the near future and certainly before 2020.

Fuel Cells and Magnetohydrodynamics

Fuel cells are devices which combine oxygen and hydrogen to make water with the release of direct electrical energy rather than heat. They could be made to generate electricity from hydrogen gas after coal gasification but this is a new, untested technology and it is highly unlikely to be used for electricity generation in South Africa by the year 2020.

A magnetohydrodynamic (MHD) device is one that uses a moving stream of charged gas or liquid to generate electricity rather than moving mechanical components. Gas raised to temperatures of about 4000°K becomes ionised and would then be suitable for MHD. If an alkali metal is added to the gas stream, this temperature reduces to about 2000°K. However, this is still too high for common engineering materials. MHD is an unproven technology. It is highly unlikely that it will be used to generate electricity in South Africa by the year 2020.

3.2.1 Hydro-Electric Power: Existing Stations in South Africa

Hydro-electricity is perhaps the easiest way of electricity generation. It can take two forms, with a dam (the usual form) or without a dam in "run of river". Hydro-electric power stations have cool, slow moving machinery and long lives. Africa is blessed with large, strongly flowing rivers and has enormous potential for hydro-electricity but South Africa itself, a mostly arid country, has poor rainfall and few rivers of sufficient size. Most of the sites that are suitable have already been used.

South Africa has 9 operating hydro-electricity stations with a combined capacity is 665 MWe. In 1996 they produced a total of 0.42 TWh (Eskom, 1995). There are also two pumped storage station with a combined capacity of 1400 MWe. In 1995 they sent out 1.3 TWh [(4)]

3.2.2 Hydro-Electricity: Future Imports

There is little potential for expanding hydro-electricity in South Africa expect for small schemes in remote locations. However, electricity could be imported from countries to the north. There is already surplus capacity from hydro-electricity in Zambia and Mozambique of about 1300 MWe, which South Africa could import. The Cahora Basa hydro-electric station on the Zambezi in Mozambique has a capacity of 2000 MWe and Mozambique itself uses a small fraction of this.

There is enormous potential for more hydro-electricity in southern Africa. One site on the Congo River at Inga Falls has by itself got the potential for providing 40 GWe to 100 GWe, more than the total needs of the entire African continent. In the Zambezi river basin, closer to South Africa, there is the potential for an additional 6000 MWe. Table 4 shows the potential additional hydropower in southern Africa.

Table 4. Hydropower Potential in southern Africa in addition to existing or planned hydropower [(10)]

Location	Country	Potential (MWe)
Zambezi River Basin		
Kariba North Extension	Zambia	300
Batoka Gorge	Zambian side only	800
Devil's Gorge	Zambia / Zimbabwe	1240 – 1600
Mupata Gorge	Zambia / Zimbabwe	1000 – 1200
Cahora Bassa North Bank Extension	Mozambique	550 – 1240
Mepanda Uncua	Mozambique	1600 – 1700
Total Zambezi		approx 6000
Other Sources excluding Inga		
Angola	including Kunene Basin	16,400
Lesotho		160
Malawi		250
Mozambique	other than Zambezi	1084 – 1308
Namibia	other than Kunene Basin	500
Swaziland		60
Tanzania		3,000
Zambia	other than Zambezi	1084 – 1308
Total Other Sources excl. Inga		
Inga		36,000 – 100,000
Total southern Africa		70,800 – 134,800

The technology is well proven. Hydro-electricity does present environmental problems when a dam is required. This floods areas and displaces people and animals; the rotting vegetation under the water also releases considerable quantities of carbon dioxide; the salinity of the surrounding soil may increase; and there is always the danger of dam breaks. However, these environmental problems are small compared with coal stations. Some potential hydro-electricity schemes do not require dams at all. These operate off "run of river". The outstanding example of this is the Inga Falls, which will therefore have very little environmental effect at all.

The drawbacks of importing hydro-electricity are the costs of building and maintaining very long transmission lines, line loses in transmission and the politics of southern African countries. The last is by far the biggest problem.

For southern Africa to get the full benefits of hydro-electricity, there must be a regional electricity grid transmitting electricity from one country to another. This requires political stability. Unfortunately the region is beset with political problems at the moment, especially in the area of the Democratic Republic of the Congo and the Great Lakes. The political problems must be overcome to build the grid but the grid would almost certainly help regional co-operation.

The benefits to South Africa of importing hydro-electricity are not only the avoidance of the capital costs of building extra capacity but environmental. The imported electricity could be base load and peaking.

It is highly likely that South Africa will import considerable amounts of hydro-electricity in the period being considered.

3.3.1 Gas Turbines: Existing Stations

There are 7 gas turbine power stations in South Africa, 2 owned by Eskom and 5 by municipalities. These stations are small and are not used for base load electricity generation but for meeting load peaks or for stand-by generation for start-ups or in the event of loss of power from the main plant. They consist of simple gas turbines where the exhaust gases from the turbines go to waste. In South Africa they run on liquid fuels such as paraffin or diesel.

The total installed capacity of these plants is just over 606 MWe in 1996. Their production of electricity in 1995 was negligible. Simple gas turbine generators such as these are quick and easy to start, have low capital costs per kW but are inefficient and have high running costs. They have no prospect of providing base load electricity in the future.

3.3.2 Future Gas: Combined Cycle Gas Turbine (CCGT)

The most rapidly growing generation technology in Europe is combined cycle gas turbine (CCGT) running on natural gas. Here gas combustion takes place in a gas turbine and the waste gases go into a boiler to raise steam for a steam turbine. The technology is well-proven. Capital costs are low, typically $500 to $1000 per kilowatt. Construction time is short. Efficiencies are high, typically 55% or above. These high efficiencies come from the fact that a gas turbine can run at higher temperatures than a steam turbine because a smaller mass of metals is exposed to the high temperatures and these can be made from special materials. There are no solid wastes and the waste gases are mainly just the two greenhouse gases, carbon dioxide and water vapour. To release 1 GJ of energy (heat) by burning coal you release 90 to 95 kilograms of carbon dioxide compared with only 65 to 70 kilograms of carbon dioxide by burning gas. This is because gas contains a large proportion of hydrogen which forms water when it is burned. (Water is also a greenhouse gas.)

South Africa has no natural gas apart from the small field at Mossgas, which is being used for making chemicals, but it does have coal bed methane especially at the Waterberg field. There is also natural gas in offshore Kudu gasfield at Namibia and the Pande and Temane fields in Mozambique. These fields are not large. Whether South Africa builds CCGT power stations running on gas piped in from Namibia or Mozambique depends mainly on the price of the gas. The cost of natural gas extraction from Pande is estimated to be $0.78/GJ, from Kudu $1.83 and from Waterberg $1.97. The additional cost of bring the gas to South Africa is estimated to bring the cost of Kudu and Pande gas up to $2.5/GJ.

In future it might become economically viable to import liquefied natural gas (LNG) from fields such as Angola, Nigeria or further away. The production of LNG from natural gas requires liquefaction by refrigerating to very low temperatures of about –160°C. The sea tankers transporting it require elaborate insulation to maintain these temperatures. This makes the production and transport of LNG expensive [11]. However, from 1969 to 1997, because of improving technology, these costs have halved and there is now a considerable world trade in LNG, for example from Australia to Japan and from north Africa and the Middle East to Europe. If gas power stations were built in South Africa to use Kudu gas, it might be that they could change to LNG when the Kudu field ran out.

Because of their efficiency, low capital costs and cleanliness, it is likely that CCGT stations will be built in South Africa before 2020.

3.4.1 Nuclear Power: Existing Stations

Nuclear power offers the possibility of producing large amounts of electricity from very small amounts of fuel, which can be easily transported so that nuclear stations can be sited anywhere.

There is an extreme difference between the facts of nuclear power and public perceptions about it. In fact nuclear power has the best safety record of any large scale source of electricity generation and is the only one to have procedures for storing its waste safely.

The worst ever nuclear power station accident in the West was at Three Mile island in the USA in 1979. It killed no one, injured no one and had no ill health affects afterwards. By contrast there have been a large number of accidents in oil, coal, gas and hydro killing tens and sometimes hundreds of people [12] . The Chernobyl accident was caused by a bad reactor design that would never have been allowed in the West and even it has had a small health effect on the surrounding population. [13]

The table below gives approximate amounts of waste materials produced in one year from a coal and a nuclear power station of 1000 MWe capacity running for one year.

Table 4. Waste per year from 1000 Mwe coal and nuclear plants [14]

Nuclear	Coal
30 tons of radionuclides	8 tons of radionuclides eg. thorium(half-life: 14 billion years) 42,000 tons of SO2 21,000 tons of NOx 2,000 tons of particulates 2640 tons of heavy metals: lead, arsenic, strontium etc (half-life: infinity) Organic compounds: PAH etc. 5,000,000 tons of CO2

The nuclear waste is small, stable and solid. It stays in one place and can be easily stored above ground or underground presenting no danger to people or the environment. The coal waste is either blown into the air or scattered onto large ash heaps. Because of the radioactive substances in coal, coal stations actually expose the public to more radiation than nuclear ones, although the amounts are trivial in both cases. In operation nuclear power releases no greenhouse gases.

There is little connection between nuclear power and nuclear weapons. Nuclear bombs require 90% or more fissile material whereas nuclear power reactors have less than 10% fissile material, making it impossible for them to explode like bombs. In South Africa during the apartheid era, the enrichment plant at Pelindaba near Pretoria had two plants, one of which enriched uranium to 3% for Koeberg Power Station and the other to over 90% for atomic bombs. The bombs and the high enrichment plant have since been dismantled.

However, despite these facts, the perceptions are that nuclear power is dangerous and has a waste problem. Perceptions matter. This is the first problem with nuclear power. Perceptions have been worsened by the nuclear industry itself, which in the past has been arrogant and secretive, so increasing public suspicion towards it. Under apartheid, the secrecy around nuclear power was extreme.

The second problem is high capital costs. Existing designs have complicated safety systems that increase capital expenses and often have long construction and commissioning periods.

South Africa has only one nuclear power station, Koeberg, just north of Cape Town. Koeberg is a French-built station consisting of two Pressurised Water Reactors (PWR's) with a total nominal capacity of 1930 MWe. The first unit was commissioned in 1984. In 1995 Koeberg produced 11.3 TWh of electricity, just over 6% of the national total. [4].

Pressurised Water Reactors use uranium enriched to 3% or 4% 235 as the fuel, normal water as the coolant and normal water as the moderator. Water being a dense coolant with a high specific heat, the power density of the PWR is high, about 90 kW / litre. Because of the temperature limitation imposed by the need to keep the water in the primary loop liquid, which means it can never go above about 330°C, the thermal efficiency of the station is limited to about 32%.

PWR's are by far the most popular nuclear power reactors in the world. In 1996, of the 431 nuclear power units operating in the world, 249 were PWR's [15] Their safety record has been exceptionally good.

During the apartheid years, there was an attempt to make South Africa self-sufficient with nuclear fuel and the Atomic Energy Corporation developed the technology and equipment for making Koeberg fuel elements. However, the fuel was very expensive and with the opening of South Africa to the outside world, Koeberg now buys cheaper fuel from overseas.

The future prospects for PWR's in South Africa are uncertain. Their advantages are the mature technology and the good safety record. The disadvantages are the high power density, the high capital costs, the low efficiency, the long construction time for a station and the complicated mechanical design. There are potentially simpler and cheaper nuclear technologies that could well be developed in the near future.

3.4.2 Nuclear Power: Future Stations

There are only four large-scale power sources available to South Africa for the long term future: coal, nuclear, imported hydro and imported gas. Nuclear fuel is different from coal in that, containing so much energy in such a small mass, it can easily be transported around the world with negligible extra costs to power generation.

At the moment South Africa imports the fabricated nuclear fuel for Koeberg because it is cheaper than making her own. However, South Africa has 205 kilotons of "reasonably assured" and 56 kilotons of "estimated additional" reserves of uranium.[16] If used in conventional nuclear reactors at 1.3 g of Uranium-235 per megawatt-day of thermal energy, this would give South Africa uranium reserves of 158 thousand PJ, second only to coal reserves. If used in fast breeder reactors this would give energy reserves of 7.9 million PJ, about five times larger than the coal reserves. Most of South African production of uranium is mined as a by-product of gold mining and so is declining. But if uranium were required for itself, these large reserves would be available.

There are a range of possible nuclear reactor designs for the future. These include the fast breeder reactor, which actually produces more fissile fuel than it uses. However, most of these designs are too new and unproven to be considered for power production until 2020. The only two types of designs likely to be used in South Africa in this period are Advanced Pressurised Water Reactors and the Pebble Bed Modular Reactor. The "advanced" reactors are designed to be simpler, more standardised, cheaper and with a higher degree of passive safety than existing PWRs. They are likely to be the next generation of reactors in Europe, Japan and the USA.

However, a more interesting and more likely design for South Africa is the pebble bed reactor discussed below.
The only nuclear power being considered is from nuclear fission. Nuclear fusion is too uncertain and too far into the future to be at all likely for South Africa before 2020.

Pebble Bed Modular Reactor (PBMR)

This is a design now being considered by Eskom. It is based on a German pilot reactor, the AVR, of 15 MWe capacity, which ran successfully from 1967 to 1989. The PBMR uses helium as a coolant and graphite as a moderator. Because the coolant is a gas, the power density is very low (about 6 kW / litre compared with 90 kW / litre for the PWR). This of itself makes a huge improvement in safety. It means that if the reactor should go out of control it would take a long time to reach dangerous temperatures. In fact the PBMR is designed so that it can never reach dangerous temperatures. The safety of the plant is entirely passive.

The fuel for the PBMR is uranium enriched to about 8% in the form of pellets about 1 mm across which are embedded in graphite balls about 60 mm in diameter (the "pebbles"). The pebbles lie in a reactor vessel and are so designed that controlled fission occurs when they rest against each other in sufficient numbers. The reactor is cooled by helium which takes the heat via two turbo-compressors to a turbine which drives a generator. Once a pebble has entered the reactor vessel, it is enclosed in the power plant for its entire life. Pebbles are routinely sampled by automatic devices. If they are spent, they are dropped into a waste storage vessel. If they are not spent, they are returned to the reactor.

The German AVR reactor used the hot helium to raise steam for a steam turbine. The South African design will take the helium directly to a turbo-generator. The maximum temperature of the helium will be 900°C compared with the 320°C of the water in the primary loop of a PWR. This means that the thermal efficiency of the PBMR is much higher, about 48% compared with the 32% of a PWR.

The Germans built a 300 MWe pebble bed unit, the THTR, but it was less successful than the AVR. 300 MWe exceeds the size under which the pebble bed reactor gets the full benefits of its passive safety. The proposed South African design will be about 115 MWe. The modular design would mean that units could be built quickly with a minimum of site construction. The smaller units would fit in with an international trend towards smaller power stations with lower capital costs and quicker construction time. The hope is that if the South Africa prototype PBMR were to prove successful, it could be exported around the world and would be particularly suited to a niche market where the demand is for a small unit with completely flexible siting.

At present an environmental impact assessment is under way for the PBMR. If this is successful, Eskom expects that by 2005 the first PBMR could be designed, licensed in principle and in advanced stage of construction. The expected capital cost for the PBMR is \$1000 - \$1500/ kW. [17], which is comparable with coal.

3.5.1 Solar and Wind Power: Existing Capacity

Solar power and wind power both have the advantage that the "fuel" is free and both have the disadvantage that the fuel is very dilute and intermittent. In both cases, therefore, you need a lot of plant to produce a reasonable amount of useable energy. This means that capital costs are high. In both cases there are no emissions during the operation of the power plant, which makes them environmentally attractive. Both take up a lot of land area which might pose environmental problems.

South Africa is well suited for solar power and parts of it have some of the world's highest levels of solar insolation (solar energy per unit area of land surface). Insolation in South Africa averages about 220 watts / m^2 during the year (including day and night) or about 5 kWh / m^2 / day. It is highest in the Northern Cape because of fairly low latitude and a dry, cloudless climate, where it averages 6 kWh / m^2 / day.

Solar power is used in three ways to make electricity: photovoltaics, solar thermal and solar chimney. Photovoltaic panels convert sunlight directly into electricity and solar thermal systems use the heat of sunlight to raise steam to drive a turbo-generator. South Africa has only used the former, and this has always been for remote sites away from the electricity grid. Photovoltaics are used for remote radio transmitters and receivers, for rural schools and clinics, and for rural houses.

Photovoltaic electricity is expensive per kWh. Because of night time and bad weather, solar installations must have batteries to store the electricity and associated electrical equipment to control and regulate it.

For applications of less than 100 Wh / day and further than 20 km from the grid, however, the cost of solar photovoltaics is competitive with grid electricity. It is estimated that in 2000 South Africa had a total solar photovoltaic capacity of about 6 MWe.

Wind energy has so far mainly been used for water pumping on farms and game reserves. South Africa has suitable sites for wind power in the coastal regions and at one region near the Drakensberg. Sites at Port Elizabeth, East London, Cape Town and Alexander Bay have wind speeds averaging about 4.3 metres / second, which would give annual outputs of about 24 MWh from a 16kW wind generator. However the costs would typically be more than 12 times the costs of Eskom's existing grid electricity. [8] No significant amount of electricity is now produced from wind.

3.5.2 Solar and Wind Power: Future Capacity

Until now South Africa has only made electricity from the sun by photovoltaic panels. Their use is expected to grow rapidly to provide off-grid electricity for schools, clinics and households in remote areas. Eskom and Royal Dutch Shell are now implementing a programme to provide households in the Eastern Cape with photovoltaic panels for lighting and small electrical appliances, and LPG for cooking and heating.

The other method, which could be used on a larger scale, is solar thermal electricity, where the heat of sunlight is used to drive a mechanical generator. There are various such designs. The parabolic trough, which tracks in one plain, focuses sunlight onto a central pipe containing a fluid which is heated up and pumped to a heat exchanger to raise steam to drive a turbine. Such plants have been built by the Luz International Ltd in California in plants up to 80 MWe (peak) capacity. They used natural gas as an auxiliary fuel source. Electricity costs were reported to be about $0.12 / kWh (USA 1988 dollars). Unfortunately there was a bad accident at one of the plants in 1989 when there were a series of explosions in the oil used as the operating fluid.

Recently there has been work done on solar thermal plants heating water directly as in a conventional rankine cycle thermal plant. The water, under pressure, goes through pipes which are heated by focussed sunlight. It is heated to steam which then drives a turbine, condenses back to water in a condensor and is return by a feedwater pump to the heated pipes.

Another method is to have an array of reflectors, tracking in two plains, focusing sunlight onto a single elevated point on a tower either to raise steam or to drive a Stirling engine.

Reflectors used in solar thermal power stations need to be cleaned with distilled water every day to remove dust. This might be a handicap in the dry areas of the Northern Cape.

Another quite different principle of solar thermal power is the heat pipe, where a large vertical pipe, using the chimney effect, draws air from under a large, horizontal, heating surface and drives the air vertically up it, turning a turbine at its base. This is being seriously considered for the Northern Cape and design work is being undertaken for it at the University of Stellenbosch. The design is for a pipe 1500 metres high, 160 metres in diameter and with a circular collecting surface 4 kilometres in diameter. It would have a peak capacity of 200 MWe. To make it viable, crops would be grown under the heating surface, which would be glass. The plants would respire under the glass releasing water vapour into the air stream. The less dense the air in the pipe, the more efficient the system. Since water vapour is less dense than air, plants would improve the efficiency of the solar pipe.

Wind generation is growing rapidly in northern Europe and the USA, and the size, reliability and efficiency of winds turbines is improving markedly. About 10,000 MWe of wind energy is now installed in the world. However, costs are still high. So far the growth of wind generated electricity has depended on subsidies.

Eskom is planning a wind project under the auspices of South African Bulk Renewable Energy-Generation (SABRE-Gen) in the Western Cape. An Environmental Impact Assessment is under way and if it is successful construction of the wind project will begin in 2002. Six to eight wind turbines would be erected with a total capacity of about 10 MWe.

Another proposed wind project in the Western Cape is the Darling Demonstration Wind Farm, an IPP funded by a private consortium, whose first phase would be to install 5 MWe of windpower and whose second stage would install another 5 MWe.

The usually accepted wind speed for a viable wind generating plant is 8 m/s at a height of 30 m. Unfortunately these speeds are seldom found in South Africa, even at some of the best sites in the Western Cape. It is estimated that the total wind potential in the Western Cape is a few hundred MWe. There is a greater potential offshore but this incurs higher costs.

In the developed countries, some electricity consumers seem prepared to pay more for "green" electricity, that is, electricity that is seen as being environmentally benevolent. Whether consumers would be prepared to pay more in a developing country such as South Africa is uncertain.

3.6 Biomass

Some industries, notably pulp and paper and sugar refining, use biomass to raise steam to generate electricity. In pulp mills, the bark from the logs and the "black liquor" from the digestors is burned in boilers for process heat and electricity. In sugar refineries, bagasse (husks from the sugar cane) is used in the same way. In future, depending on electricity prices and environmental regulations, some of this electricity could be sold into the national grid. It is unlikely that this would ever been a major contribution to the public electricity supply, though, as the potential for expansion of our sugar cane fields and commercial forests is limited.

3.7 Municipal Waste

Municipal waste contains organic matter with a high enough calorific value to produce useful energy. This may done either by burning it directly in a furnace to raise steam or by allowing it to de-compose in a land fill dump and burning the gas released, which is mainly methane. Small amounts of electricity could be generated in this way but because of the low population density in South Africa this seems unlikely in the period being considered.

3.8 Bringing Back Mothballed Stations

Eskom has three stations in working order but mothballed because there was a surplus of capacity and it was more economical to run more modern, more efficient stations. The stations are Camden (capacity 1600 MWe, last unit commissioned 1969), Grootvlei (1200 MWe, 1977) and Komati (1000 MWe, 1966). Their combined capacity is 2800 MWe. It would be cheaper to bring them back into production than it would to build new capacity but their running costs would be higher.

3.9 Autogeneration

The amount of electricity generated by industries for their own use is expected to grow as the industries expand and acquire more efficient technologies for making electricity from their raw materials or by-products. Modern pulp mills in Scandanavia are already completely self-reliant, getting all of their energy from the bark and black liquor of the wood. Future South African mills are likely to follow suit

3.10 Future Storage

To flatten the peaks of electricity demand, and so avoid building new power stations to meet them, energy can be stored during troughs in demand and released during peaks. At the moment South Africa has 1400 MWe of pumped water storage. Energy could also be stored by compressing air, by batteries, by capacitors, by flywheels and other means. It is expected that South Africa will increase both pumped water storage schemes and other methods of energy storage.

4. LIQUID FUELS

Liquid fuels, such as petrol, diesel, paraffin and jet fuel, are made in South Africa by three methods: (i) refining from crude oil (ii) production from coal (iii) production from natural gas. Table 5 below shows the daily production capacity of liquid fuels in 2000. The units of barrels of crude oil equivalent entering the process. (So for Sasol, for a given production of liquid fuels, the figure would give the barrels of crude oil that a normal refinery would use to produce that amount of liquid fuel.)

Table 5. South African liquid fuel capacity. [18]

	Capacity (2000) Barrels /day equivalent	PJ/year
Oil Refineries		
Calref (Cape Town: Caltex)	105 000	223
Sapref (Durban: BP/Shell)	185 000	394
Genref (Durban: Engen)	105 000	223
Natref (Sasolburg: Sasol/Total)	90 000	191
Coal to Liquid Fuels		
Sasol 2 & 3	150 000	319
Natural Gas to Liquid Fuels		
Mossgas	45 000	96

4.1 CRUDE OIL REFINING

The average efficiency of conversion of crude oil to liquid fuels and non-energy products is 91.5% [20] Wright [21] estimates that 7% of the energy in the crude is used in the refinery, with losses of 0.5-2.0%, giving a total efficiency of 92.5-91.0%. Wong and Dutkiewicz [20] give non-fuel refinery production to be about 6% of input energy and Wright (1999) about 5%. Crude oil refinery capacities of South African oil refineries, shown in Table 14, were taken from the South African Petroleum Industry Association (1998). The 1997 oil refinery capacities were used as these represent the culmination of a number of expansion programmes. Refinery capacity factors were assumed to be equal for all refineries. Table 3.14 also shows the estimated long-term capacity limits of crude oil refineries [21].

Table 6 shows the fuel output product mix of crude oil refineries as calculated for 1995 based on consumption (accounting for the output product mixes of Sasol and Mossgas).

Table 6. Crude oil refinery combined product output mix (% energy basis)

Fuel	Calculated for 1995
Petrol	34.4
Diesel	32.1
Fuel oil	19.9
Paraffin	4.4
Jet fuel	6.8
Avgas	0.7
LPG	1.0
Refinery gas	0.8

Electricity use by refineries was based on that used by Natref (Sasol, 1996) which was 150 kWh per barrel.

The price of liquid fuel can be split into (International Energy Agency, 1996):
- Crude oil – 10.8 US c/litre ($17.1/barrel)
- Refining (including wholesale margin) – 9.09 US c/litre ($14.4/barrel)
- Transport and distribution (including retail margin) – 8.3 US c/litre ($13.2/barrel)
- Taxes and levies – 23.6 US c/litre for petrol and 20.2 c/litre for diesel

Future expansion of oil refining capacity will depend on demand for fuel, which in turn will depend of economic growth, growth of the population owning motor vehicles, growth in transport (passenger kilometres and freight kilometres). It will also depend on the costs of finished liquid fuels, which in turn will depend on the costs of crude oil. And it will depend on policy decisions about energy deregulation and fuel imports.

Recent events, namely the fire at the Natref refinery and the strike at Engen (June 2001), have caused fuel shortages and show that South Africa does not have much reserve capacity in oil refining. It is unlikely that any more oil refineries will be built in South Africa and so in future demand above the existing capacity is likely to be met by imports.

4.2 OIL FROM GAS

In 1995 oil was made from gas only at the Mossgas plant. In 1995 the crude oil equivalent capacity of Mossgas was 45 000 barrels per day, and actual output of finished liquid fuels was 30 200 barrels per day (Mossgas, 1999). Using the natural gas consumption given by Cooper (1997), Mossgas was calculated to have a conversion efficiency of 89.0%. Mossgas also produces about 110 000 tons of alcohol per annum which is categorised as a non-energy product, and included under the demand module. The 1995 petrol:diesel split was taken from Wong and Dutkiewicz (1995), with a small amount of paraffin and LPG production being estimated. The output mix is not expected to change significantly. The output mix on an energy basis was:

Petrol	66.6 %
Diesel	31.9 %
Paraffin	1.5 %
LPG	0.5 %

Electricity consumption was based on an assumed average load of 150 MW (120 kWh per barrel) of which 90 MW is autogenerated.

The floor price for Mossgas's import protection subsidy was $21.40/barrel in 1995, which gave Mossgas a 10% profit margin on liquid fuels production. At this price the cost of liquid fuels production at an oil refinery would be $36.3 i.e. the equivalent cost of liquid fuels production at Mossgas. Excluding gas ($10.4/barrel), gives a production cost of $25.9/barrel.

The future of Mossgas will be determined by the amount of gas available in the Mossgas fields. It is possible that gas from elsewhere could be piped or shipped to the Mossgas plant for conversion into liquid fuels.

4.3 OIL FROM COAL

In order to apportion coal usage to Sasol products, it is necessary to consider the integrated Sasol process. Sasol can be divided into the Sasolburg and Secunda complexes, with 6.6 million tons of coal used in Sasolburg and 36.1 million tons used in Secunda in 1995 (Sasol, 1995), giving a total consumption of 893 PJ. 197 PJ of white products (6 million litres) and 8 PJ of fuel oil are produced at Secunda. Wong and Dutkiewicz (1995) and Cooper (1997) estimated that the efficiency of fuel production is 33.3%. It is estimated that the 26 PJ of pipeline gas is produced with an efficiency of 75%. The National Electricity Regulator (1995) gives Sasol electricity production to be 5097 kWh, which required about 23 PJ of coal (80% efficiency). The remaining input coal is attributed to chemical production. Table 7 summarises the apportionment of coal use at Sasol.

Table 7. Summary of the apportionment of coal consumed at Sasol

	Secunda		Sasolburg	
	Coal in (PJ)	Output (PJ)	Coal in (PJ)	Output (PJ)
Liquid fuels	615	205	0	0
Gas	7	5	27	20
Non-energy products	114	?	106	?
Electricity	20	16	4	3
Total	756		137	

In 1995 crude oil equivalent production capacity of Sasol was 165 000 barrels per day and 1995 actual output was 39.3 million barrels. The 1995 output mix was taken from Wong and Dutkiewicz (1995), and by 2020 a significant amount of paraffin production is expected to have been replaced by jetfuel production.

Electricity use at Sasol is based on the average demand of 1 100 MW at Secunda divided into the 8 000 million litres of products i.e. 190 kWh per barrel.

The SAS reactors were fully commissioned by 1999, improving efficiency and output capacity from levels in 1995.

The floor price for Sasol's import protection subsidy was $21.40/barrel in 1995, which gave Sasol a 10% profit margin on liquid fuels production. At this price the cost of liquid fuels production at an oil refinery would be $36.3, which is the equivalent cost of liquid fuels production at Sasol. The production cost at Sasol excluding coal cost ($6.5/barrel) is therefore $29.8/barrel.

The future of coal to liquid fuel plants is uncertain. If the price of crude oil rises in the long term, as seems likely, these plants offer a large savings in foreign exchange by making fuel from indigenous coal, of which we have large reserves. However, the process is polluting and releases huge amounts of greenhouse gases. Using natural gas instead of coal as the feedstock is much cleaner and more efficient, and this might be done in future using gas piped in from the rest of Africa. It seems unlikely that another coal to liquid fuel plant will be built in the period being considered.

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ENERGY RESOURCES AND THE ENVIRONMENT

There is no sector of the modern economy that has a bigger effect on the environment and the natural resources of the world than the energy sector. The huge advances in human welfare brought about by the Industrial Revolution have depended on a plentiful supply of energy. If the human race is to prosper in the coming centuries, it is essential to consider the energy resources of the world and the environmental consequences of using further very large amounts of energy. South Africa is no exception in these considerations. Indeed, because South Africa has a very energy intensive economy, they are particularly important for her.

1. South African Energy Reserves

South Africa has very large reserves of coal and large reserves of uranium. However, she has very little oil and gas. On renewables sources of energy, South Africa is poorly endowed with rivers suitable for hydro-electricity but good conditions for solar power, particularly in the Northern Cape, and some quite good conditions for wind power, mainly in the coastal regions. Biomass is an important source of energy, especially for poor people in the rural areas.

The rest of Africa has large reserves of gas and oil and a huge potential for hydro-electricity.

1.1 Coal

Coal is by far South Africa's largest and most important source of energy. For a long time South African economically recoverable coal reserves have been estimated at 55 billion tons (by, for example, the Minerals Bureau, Department of Minerals and Energy). A major new study of coal reserves is being undertaken by the Department of Minerals and Energy and this should give the most accurate figure available.

Any figure for "economically recoverable reserves" for any energy source must be treated with caution. New technologies might be able to recover reserves previously thought to be uneconomic. Alternative fuels might drop in price to such an extent that the reserves of a more costly fuel become uneconomic. Transport costs might go up or down to such an extent that reserves in remote places either become uneconomic or economic.

The simple calculation of dividing the present coal reserves (55 billion tons) by the present consumption of coal (220 million tons), gives a life for our reserves of 250 years. However, for economic and environmental reasons, this figure should not be taken seriously.

55 billion tons of coal is about 1 612 000 PJ of energy. This should be compared with South Africa's total primary energy consumption in 2000 of 4 230 PJ.

1.2. Uranium

Uranium is the most highly concentrated form of useable energy that we know. Uranium-235 is the only naturally occurring fissile material today. (A fissile material is one that can usefully harness the energy from the nuclear force.) However, fissile materials can be made from thorium, which is roughly twice as abundant as uranium.

South Africa has 205 000 tons of "reasonably assured resources" or uranium and 56 000 further tons of "estimated additional resources". (SA Mineral Industry 1996/7. Minerals Bureau. DME.) For conventional nuclear power reactors, using a figure of 0.6048 PJ per ton of natural uranium, this gives an energy reserve of 157 853 PJ. If the uranium were used in "fast breeder reactors", which make fissile material from non-fissile uranium, the available energy would be increased 50-fold to 7 893 000 PJ.

However, nuclear fuel is unlike fossil fuels in that it is so small per unit of energy that transport costs for it are insignificant and it can be moved around the world at negligible costs.

In South Africa, uranium is usually extracted as a by product of gold mining since gold, uranium and radium are found together.

1.3 Oil and Gas

South Africa's reserves of oil and gas are very limited. There are small oil fields at Oribi, Oryx and Sable offshore, south of Mossel Bay. The largest gas field is in the same region and it feeds the Mossgas operation. The proven reserves are about 600 billion cubic feet (660 PJ) but there are some indications that they might be as large as 3 trillion cubic feet (TCF). A new gas field, the Ibhubesi Field, with reserves of about 1.8 TCF has been found in South African waters south of the Kudu Gas Field.

Our immediate neighbours have larger gas fields. The Kudu Gas Field, offshore from Namibia, has reserves of 3 to 9 TCF (3315 to 9750 PJ). Mozambique has the Pande Field, with reserves of 2.5 TFC and the Temane Field, with reserves of 1.5 TCF.

Further north, Angola has very large gas fields and oil fields and so does Nigeria.

1.4 Hydro-Electricity

South Africa has a licensed hydro-electricity capacity of 667 MWe. Because of the low rainfall and scarcity of large, strongly flowing rivers, the potential for more hydro-electricity within South Africa is small. However, the potential in the rest of Africa is enormous. This is discussed above in the section on Energy Transformation.

1.5 Solar and Wind

The "reserves" of solar power are vast since the sun will continue to shine for billions of years and it falls on almost every square metre of South Africa. However, practical considerations limit the useful energy that can be drawn from the sun. The Northern Cape has some of the best conditions for solar power in the world. Similarly wind energy will last as long as the sun shines, and there are quite good sites for wind power, mainly in the coastal regions. Both are discussed in more detail in the section above on Energy Transformation.

1.6 Biomass

Biomass comprises of wood and other matter from living things that can be used as an energy source. It is used commercially in pulp mills and sugar refineries, and it is used for cooking and heating in households. Biomass is renewable if the trees cut down are replaced. Unfortunately this does not always happen in some parts of South Africa. Biomass contributes an important fraction of South Africa's total energy consumption. South Africa is not a particularly fertile country, and a large part of her is desert or semi-desert, and so biomass must be carefully husbanded.

It is very difficult to get even a good estimate of our total biomass reserves but in 2000 biomass contributed 398 PJ to South Africa's primary energy consumption, and it is reasonable to believe that at least this amount is sustainable into the indefinite future.

2. Energy and the Environment

The use of energy has environmental consequences for land, air and water. Power stations, vehicles, manufacturing, smelting and processing, other industrial activities and cooking and heating in households all release gaseous emissions. The effluent from power stations and industry can enter the water courses. Large areas of land are taken by mines, factories and power stations. The landscape can be disfigured by power lines, smokestacks, wind turbines and waste dumps. Sustainable development depends upon managing the environmental effects of energy.

2.1 Greenhouse Gas Emissions

Gases such as carbon dioxide, water vapour and methane are "greenhouse gases", which trap heat in the atmosphere. In the last hundred years or more, the concentration of carbon dioxide has increased in the atmosphere, leading some people to believe it will cause a warming of the whole world and change the global climate system for the worse. Whether this is actually happening is not known with any scientific certainty but it is a cause for concern and there is international pressure to reduce the emissions of greenhouse gases.

All fossil fuels contain carbon and so release carbon dioxide when they are burned in air. The fossil fuels are coal, oil, natural gas and peat. Carbon dioxide is also released by industrial processes such as steel-making and cement-making. Since South Africa has an energy intensive economy and gets most of its energy from coal, she releases large amounts of carbon dioxide for the size of its economy. This may her vulnerable if in future there are international penalties against emissions of greenhouse gases.

The estimated release of man-made greenhouse gases in 2000 was 356 million tons of carbon dioxide equivalent, and most of this was carbon dioxide. Figure 1.below shows the sectors of the South African economy responsible for greenhouse gas emissions.

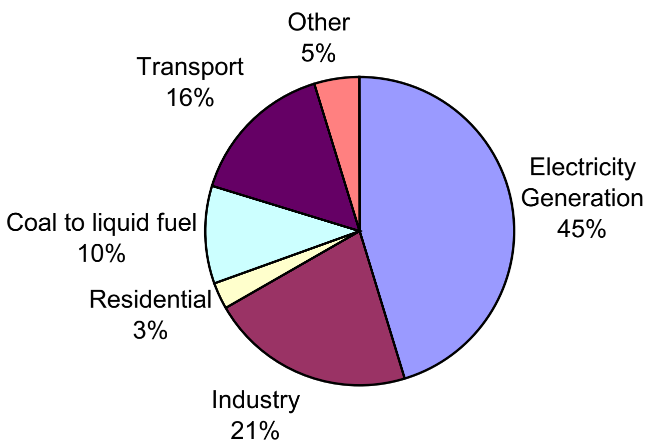

Figure 1. Emissions of Greenhouse Gases in 2000. Total: 359 000 000 tons

“Electricity generation” here is almost entirely coal power stations, and it comprises almost half of the total emissions. Coal stations release roughly twice as much carbon dioxide as gas stations producing the same amount of electricity. However, gas stations also release water vapour, another greenhouse gas, and they run off natural gas, which is mainly methane. Methane is 22 times more potent a greenhouse gas than carbon dioxide, so gas leaks would be a serious cause of greenhouse gas emissions.

There are various ways to reduce the carbon dioxide from our power stations. They could be made more efficient, so using less fuel and releasing less emission for the same amount of electricity. However, this requires large capital expenditure. We could change to other forms of power generation such as hydro-electricity, which releases much less greenhouse gas during operation, or to nuclear, solar and wind power, which releases none during operation - although all release some greenhouse gases during manufacture and construction.

For transport and industry, the best way to reduce greenhouse emissions is energy efficiency, for which there is great scope, often at small cost and indeed often at a profit. South African industry is very inefficient in its energy use and increasing energy efficiency would be profitable.

2.2 Sulphur and Nitrogen Compounds, Particulates and Organic Compounds

If there is much argument about greenhouse gas emissions and global climate change, there is no argument about the effects of SOx (sulphur dioxide and other sulphur gases), NOx (nitrogen dioxide and nitrous oxide), particulates and organic compounds, which are bad. These emissions cause death and disease, increase the acidity of rain and damage crops, forests and materials. The only exception is that a slightly enhanced level of sulphur dioxide can actually increase the yields of certain crops.

In the presence of sunlight, SOx and NOx can form ozone, sulphates and nitrates, leading to “brown haze”, and producing a range of compounds damaging to human health.

In 1998, Eskom’s coal power stations released 1 343 000 tons of sulphur dioxide, 669 000 tons of NOx and 65 210 tons of particulates (Eskom Environmental Report). Eskom’s coal power stations only remove one pollutant in their smokestack, particulates, which is either done by electrostatic precipitators or by bag filters. The most dangerous particles are the smallest ones, PM2.5 (with a diameter of 2.5 microns or less). These are the ones most likely to escape.

However, Eskom’s big coal power stations have high stacks, usually 300 m tall, which widely disperse and dilute the SOx, NOx and particulates. The Sasol plant at Secunda, which also consume large quantities of coal, also have very high stacks. The concentration of any pollutant is all important: the smaller the dose, the smaller the effect. There have been several studies looking at the health effects of air pollution in industrial areas close to power stations, steelworks and Sasol plants in South Africa but none of them have come to any definite conclusion about harmful health effects. This might be because the studies were of limited scope.

It is difficult to find evidence that the benefits of installing flue gas desulphurisation (FGD) on Eskom coal power stations would outweigh the high capital and operational costs.

In the modern parts of the cities, the most serious source of air pollution is motor vehicles, both petrol and diesel. Diesel has a particular problem with particulate emissions, which is perhaps the most harmful pollutant of all. The study of the “Brown Haze in Cape Town” by the Energy Research Institute of the University of Cape Town found that motor vehicles were responsible for two-thirds of the brown haze pollution. Vehicle emissions can be drastically reduced by enforcing existing laws on black smoke, especially on diesel engines. In the longer term vehicle engines can be made cleaner and more efficient. This is dealt with in more detail under the Transport Sector in Energy demand.

However the worst air pollution in South Africa does not come from industry but from the residential sector. The burning of wood, coal and paraffin in poor households poses a very serious hazard for human health, especially for children. This is dealt with in more detail under the Residential Sector in Energy Demand.

2.3 Solid Wastes and Radioactive Wastes

A wide range of solid waste is produced by every modern economy, including domestic rubbish (paper, plastics, tins and food), ground and sludge from mining, slag and metals from metal processing, heavy metals from a range of industrial processes and radioactive substances from medicine, nuclear power and coal power stations.

Every element, unless it is radioactive, lasts forever. So lead, chrome, cadmium, arsenic and other elemental wastes last forever and need to be prevented from entering the human body in dangerous concentrations. In most cases this is easy to do so. The manufacture of all power stations (coal, solar, nuclear, wind and the rest) require the use of some of these metals. So does the manufacture of batteries.

Radioactive elements all have finite lives, and eventually all of them decay away. All living things have been subjected to quite high levels of radiation since the beginning of life on Earth and there are natural radioactive elements everywhere, in all water, in all ground and indeed in all of the tissues of our bodies. These natural radionuclides include thorium (half-life 14 billion years), uranium (half-life 4.5 billion years) and potassium-40 (half-life 1.3 billion years). The shorter the half-life, the more radioactive the substance. Radionuclides with half-lives of minutes are fiercely radioactive; those with half-lives of millions of years are very feebly radioactive.

Coal power stations release radionuclides into the environment, notably thorium, uranium and radium. The public's dose of radiation from a coal station is greater than that from a nuclear station but it is utterly insignificant. The biggest dose of man-made radiation to the public comes from medicine. The nuclear industry contributes a negligible fraction of the radiation dose to the public, typically less than 0.1% of the total radiation dose. (National Radiological Protection Board of the United Kingdom).

Solid wastes from nuclear power are kept on site until the dangerous, highly radioactive, short-lived nuclides have decayed away and then removed in casks to a place of storage. Vaalputs in the Northern Cape is such a place of long term storage, although it still requires to be licensed. In the event of a leak at a nuclear waste facility, the ensuing radiation dose to the nearest members of the public would be trivial. Nuclear waste is not a physical or technical problem but a problem of perception.

Heavy metals, from coal power stations to some extent but from various other industrial processes to a much greater extent are a far bigger problem. However, this can be overcome by sound waste storage procedures and by rigorous inspection.

2.4 Water

Water is South Africa's most critical resource. Various industrial processes are high users of water and power stations use water for cooling, because it is an excellent coolant.

Coal, oil, gas and nuclear power stations all use "heat engines", which require a "heat sink" to get rid of waste heat. The heat sink is usually a river, the sea or a cooling tower which uses evaporating water to dump heat into the air. Cooling towers, can however be air-cooled. Two of South Africa's coal stations, Matimba and Kendall, use dry cooling towers, so saving large amounts of water. There is a small penalty for this in lost efficiency.

Nuclear stations, because the fuel is easy to transport, can be sited anywhere, including at the coast where they can use sea water for cooling. They could also use dry cooling towers if necessary. Hydro, solar and wind power stations do not use heat engines and do not require any cooling.

LIST OF ABBREVIATIONS

CCGT	combined cycle gas turbine
CV	calorific value (amount of energy per unit mass of fuel); an alternate term is “heating value”
DME	Department of Minerals and Energy
DRI	directly reduced iron
FGD	Flue Gas Desulphurisation
GWP	Global warming potential
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
KW	kilowatt, a unit of power: a thousand watts
KWh	kilowatt-hour, a unit of energy
LPG	liquid petroleum gas (usually butane and propane)
MJ	megajoule (10^6 joules), a unit of energy
MPa	Megapascal, a unit of pressure
MW	Megawatt: unit of power: a million watts
MWe	Megawatt of power in the form of electricity
MWh	Megawatt-hours, a unit of energy
NER	National Electricity Regulator
NOx	Gaseous nitrogen compounds such as nitrogen dioxide and nitrous oxide
OECD	Organisation for Economic Cooperation and Development (comprising of the world’s richest countries)
PBMR	pebble bed modular reactor
PF	Pulverised fuel, coal ground to powder, used in most modern coal power stations
PJ	**P**etajoule (10^{15} joules)
PWR	pressurised water reactor
SOx	Gaseous sulphur compounds such as sulphur dioxide
TCF	Trillion cubic feet: a measure of gas quantity
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WEC	World Energy Council

GLOSSARY OF TECHNICAL TERMS

Bagasse. Husks and leaves left over from sugar cane after the sugar-bearing parts have been removed. It has quite a high energy content and is fired in boilers to raise steam for process heat and electricity.
Black liquor. In the processing of wood chips into pulp, the black liquor is what is left when the wood fibres have been extracted in the digestors. It consists of carbohydrates and lignins and is quite high in energy value.
Blast Furnace. A process for making liquid iron which uses coke.
Combined cycle gas turbine. A power cycle where gas is burnt in a gas turbine and the waste gases go to a boiler to raise steam for a steam turbine.
Corex. A process for producing liquid iron using coal.
Flue Gas Sulphurisation. The process of removing sulphur dioxide from the flue gas of a power station.
Global warming potential: This is a measure of a gas's potential to trap heat. Carbon dioxide has a GWP of 1. Methane has a GWP of 22.
Integrated gasification combined cycle. A power cycle where coal is first gasified, the gas then burnt in a gas turbine and the waste gases go to a boiler to raise steam for a steam turbine.
Midrex. A process for producing directly reduced iron using coal or gas.
Pebble bed nuclear reactor. A nuclear reactor where the fuel is in the form of small pellets of uranium embedded in balls ("pebbles") of graphite. It is cooled by helium.
Pressurised water reactor. A nuclear power reactor where water under pressure takes heat from the reactor to the steam generator (a heat exchanger) which raises steam for the turbines.
Recovery boiler. In pulp mills the recovery boiler fires black liquor to raise steam for process heat and electricity.
Syngas. A combination of hydrogen and carbon monoxide. This is the gas produced in the first stage of making liquid fuels or chemicals from coal or natural gas.