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DEPARTMENT OF MINERAL & ENERGY AFFAIRS

LOW-SMOKE FUELS AS A SOLUTION TO HOUSEHOLD PROBLEMS

A SYNTHESIS OF CURRENT RESEARCH

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FINAL PROJECT REPORT

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LOW SMOKE FUELS AS A SOLUTION TO HOUSEHOLD AIR POLLUTION PROBLEMS

A SYNTHESIS OF CURRENT RESEARCH

EXECUTIVE SUMMARY

Recent air pollutant monitoring in the homes of bituminous coal users in South Africa has shown that human exposure levels far exceed government health standards. Given that there are approximately one million coal using households and that low smoke fuels have the potential to reduce these high exposure levels, the Department of Mineral and Energy Affairs, in its role as facilitator and co-ordinator of research around low smoke fuels, commissioned a workshop in June 1994 to solicit the perceptions and aspirations of interested and affected parties. One of the outcomes of the workshop was a decision to commission a synthesis of current research and activities relating to low smoke fuels, with a view to identifying key issues that should be considered in future research and intervention strategies.

In the light of the above, this document was commissioned by the DMEA and:
- provides a general overview of the reasons for pursuing low smoke fuels as a potential solution to the high exposures to air pollutants,
- describes the present distribution and household use of bituminous coal and the consequent health problems,
- examines the practicalities of introducing low smoke fuels and the potential benefits of its widespread adoption, and finally
- identifies the key issues that should be considered in the formulation of low smoke fuel policy.

A summary of the key issues arising from the synthesis is presented overleaf. The issues have been grouped in three sections:
- production of low smoke fuels,
- distribution of low smoke fuels, and
- their impact on exposure levels to air pollutants.

Where it is felt that specific actions would be of benefit in response to these issues, they are listed in the shaded areas.

KEY ISSUES RELATING TO LOW SMOKE FUELS

1. PRODUCTION OF LOW SMOKE FUELS

1.1 Emissions from low smoke fuels.

- Crucial that low smoke fuels have a proven ability to emit substantially lower quantities of pollutants than bituminous coal.
- One set of laboratory tests undertaken to date, shows lower emissions from low smoke fuels than from bituminous coal.
- Emissions can vary as a function of a number of factors. To date there has been no formal testing of the influence these factors may have on emissions.
- It is presently difficult for developers to design their fuels in the absence of a specification.

- *Establishment of an emission specification for low smoke fuels*
- *Specification of test procedure - not only for minimum smoke stoves*

1.2 Cost of production

- Little public information available on the cost of production. The estimates that are available are not well developed.
- There are a number of possible sources of feedstock.
- Capital intensive production plant results in lower operational costs (excluding the cost of capital).
- Small scale approach requires less capital but has higher operational costs, mainly due to cost of labour.
- It is not clear from information presently available whether a capital intensive or a small scale approach will result in an overall lower cost of production.
- Costs of low smoke fuels to coal merchants/local distributors could be at least double the cost of bituminous coal. If a tar distilling process is used, this could produce a fuel at a lower premium.

- *Solicit proposals from potential manufacturers, setting out capital requirements for production plant with details of output capacity.*
- *Undertake detailed costing study.*

1.3 Market acceptability

- There is market resistance to fuels priced higher than bituminous coal.
- Low smoke emissions are desirable, although not at the expense of the performance of fuels.
- High reactivity is desirable although a balance should be achieved between ease of lighting and the length of burn.
- Cleanliness would be an advantage, but not a critical aspect to fuels.
- The size and shape of fuels should allow easy use in standard coal stoves as well as braziers.
- Home delivery of fuels, although costly, is an important component of the distribution chain.

- *Undertake further field trials with larger selection of low smoke fuels.*

1.4 Feedstock supply

- More than sufficient lump coal supply. This is an expensive feedstock.
- Sufficient supply of lump discards. There is a cost attached to processing discards, especially if the pre-washed material is to be transported from its source to the processing plant.
- Significant quantities of duff and fine discards are available. Discards from different mines have different qualities and therefore not all the available material is suitable for low smoke fuel briquettes..
- Available quantities of paper and biomass wastes are unknown.

1.5 Production capacity

- No production capacity exists at present.
- Large, centralised production can be relatively easily planned.
- Small scale localised production capacity will be more difficult to establish and to predict.

1.6 Quality control

- It will be easier to control quality through large scale centralised production.
- There are potential problems with quality control of a large number of small localised briquette producers.

1.7 Contributions to the RDP

- Small scale localised production will create a large number of jobs.
- Capital requirements for small scale production is very much lower than for large scale production.

2. DISTRIBUTION OF LOW SMOKE FUELS.

- Potential low smoke fuel market poorly quantified and geographically defined.
- Local distribution costs presently account for more than half the price of household bituminous coal.
- Given present information on the cost of production of low smoke fuels and assuming distribution costs equivalent to bituminous coal, low smoke fuels will be at best 1.4 to 1.5 times more expensive than bituminous coal.

- *Quantification of the present household bituminous coal market.*
- *Predictions of the future coal market. Will it grow will it decline. What influence will an increase in coal price have on user habits. Would it cause a more rapid shift to electricity.*
- *Description of coal distribution system and an assessment of how low smoke coal could be incorporated. Will the cost of distributing low smoke coal be different to the cost of distributing bituminous coal.*

3. IMPACT OF LOW SMOKE FUELS ON EXPOSURE LEVELS TO AIR POLLUTANTS

- Although low smoke fuels were shown to produce lower emissions in laboratory tests, field tests have not yet proved that low smoke fuels are effective in significantly reducing exposure levels to air pollutants.
- Although families that utilise braziers are exposed to some of the highest health risks, there is no information on how low smoke fuels perform in braziers.
- It is assumed that high background pollution levels caused high TSP measurements but no specific measurements have been made to ascertain the actual contribution.

- *Undertake large scale field trials which includes an entire township over a season. Results to be compared to a control which includes both bituminous coal using households and non- coal using households.*

LOW SMOKE FUELS AS A SOLUTION TO HOUSEHOLD AIR POLLUTION PROBLEMS

A SYNTHESIS OF CURRENT RESEARCH

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Chapter One

INTRODUCTION

Recent air pollutant monitoring in the homes of bituminous coal users in South Africa has shown that human exposure levels far exceed government health standards. Given that there are approximately one million coal using households and that low smoke fuels have the potential to reduce these high exposure levels, the Department of Mineral and Energy Affairs, in its role of facilitating and co-ordinating research around low smoke fuels, commissioned a workshop in June 1994 to solicit the perceptions and aspirations of interested and affected parties. One of the outcomes of the workshop was a decision to commission a synthesis of current research and activities relating to low smoke fuels, with a view to identifying the key issues that should be considered in future research and intervention strategies.

In the light of the above, the document that follows is divided into four Parts and aims:
- to provide a general overview of the reasons for pursuing low smoke fuels as a potential solution to the high exposures to air pollutants,
- to describe the present distribution and household use of bituminous coal and the consequent health problems,
- to examine the practicalities of introducing low smoke fuels and the potential benefits of its widespread adoption, and finally
- to identify the key issues that should be considered in the formulation of low smoke fuel policy.

1.1 GENERAL BACKGROUND

The Gauteng and Eastern Transvaal Highveld (ETH) regions of South Africa are characterised by a high density of industrial and mining activity. Also the ETH is the main coal producing area of South Africa and as a result contains a high percentage of the country's electricity generation plants, the SASOL oil-from-coal plants and many other large scale industries such as steelworks, ferro-alloy smelters and saw mills (Tyson et al 1988:2). The combined result of these activities is that large quantities of pollutants are emitted into the atmosphere on an on-going basis. In addition to the industrial and electricity producing sectors, there are a number of other significant contributors to the overall air pollution load in the area. These include vehicle engine emissions, dust from both surfaced and unsurfaced roads and farming activities and, the fact that a high proportion of households in the area utilise bituminous coal for their home energy needs. An added problem is that climatological conditions in the region are extremely unfavourable for the dispersion of air pollutants emitted close to ground level, and in fact, were rated in a study by Tyson et al, as 'among the most unfavourable anywhere in the world' (1988: 1). These unfavourable conditions include high atmospheric stability, clear skies and low wind speeds, with surface inversions occurring almost every night in winter, and elevated inversions with high frequency throughout the year (ibid). The combined effect of the large quantity of emissions and climatological conditions, result in high risks of adverse environmental impacts as well as having serious impacts on the health of inhabitants in the region.

In assessing the extent and consequences of air pollution, it is useful to distinguish between pollution *emissions*, and pollution *concentrations*. The latter, in turn, can be considered in terms of both ***high level*** concentrations, which can increase the acidity of wet and dry deposition processes, and ***low level*** concentrations (close to ground level). While the high level concentrations are a major issue on their own, this document is concerned with ground level concentrations and, in particular, the consequences they have for human health. In spite of the high emissions and the adverse climatological conditions, monitoring in the ETH has shown that ambient concentrations near ground level are usually within health guidelines (Snyman et al 1990: 9; Tosen and Turner 1990: 82).

When attempting to identify the source of pollutants an estimate of the total quantities of various pollutants emitted in the ETH in 1987 has been made, with source apportionments (refer to Table 1-1). This assessment revealed that power stations are the most significant source of primary air pollutants, although the contributions from domestic and transport sources are also important, particularly as these are closer to ground level. The use of tall chimney stacks by Eskom, allows pollutants to penetrate the lower inversion layer where dispersal conditions are least favourable and hence have lower impact at ground level.

TABLE 1-1: ESTIMATES OF POLLUTION EMISSIONS IN THE EASTERN TRANSVAAL HIGHVELD IN 1987 [Thousands of tons] (Source: Els 1990)

Source	*Particulates*	*SO_2*	*NO_X*	*HC*	*CO*	*CO_2*
Power stations %	356 83%	1111 91%	372 91%	-	44 12%	135400 95%
Ferro-alloy works %	28 7%	2 0%	-	-	-	463 1%
Petrochem plants %	-	7 1%	x	246 78%	-	x
Domestic sources %	19 4%	37 3%	3 1%	19 6%	88 24%	4863 3%
Coal dumps %	-	54 4%	x	x	x	x
Motor vehicles %	4 1%	-	28 7%	47 15%	213 57%	x
Other sources %	20 5%	7 1%	4 1%	2 1%	27 7%	1277 1%
TOTAL	427	1218	407	314	372	142000

Notes: '-' indicates that the estimated emissions are zero or close to zero.
'x' indicates that no measurements or estimates have been made.

More recently von Nierop (1994) estimated the total annual quantity of particulates emitted in the Vaal Triangle during 1992 and this showed major contributors to be industry and dust from roads (see Chapter 3, Section 3.7 of this document for more details).

What is of interest in the estimates by both Els and van Nierop is that the contribution by household coal combustion to overall pollution emissions (measured as tons of pollutants per year) is low. However pollutant concentrations are not uniform, regionally nor temporally, and the results of monitoring are very dependent on the location of monitoring stations. Thus notwithstanding measurements indicating that pollution levels in the ETH are within acceptable limits, measurements in coal burning residential areas have shown that local concentration of gaseous pollutants and TSPs, particularly inside peoples' homes and in cooking shelters where confined pollutants lead to high exposure levels, far exceed government health standards. Proof of this has been presented by the Vaal Triangle Air Pollution Health Study (VAPS) and is also shown in the results of air pollution monitoring in Soweto and other areas. Although there are a number of contributors to pollution concentrations in and around the homes of the urban poor in Gauteng and adjacent areas (these include dust from vehicles on unpaved roads, burning of rubbish, and adjacent industrial activity) all indications are that household bituminous coal use is a major contributor. These high pollution concentrations and the resulting human exposure are the focus of this document.

1.2 CONSEQUENCES OF HUMAN EXPOSURE TO HIGH LEVELS OF AIR POLLUTION

Approximately 1 million households, or 5 million people, with a high proportion of these being located in Gauteng, utilise coal for a large proportion of their household energy requirement. High household coal consumption in Gauteng is a function of numerous factors with the most important being; the low cost of South African coal coupled with the proximity of the coal mines to users, the poverty status of a large proportion of users who can only afford the cheapest energy options, and the fact that only recently has grid electricity begun to be provided to the black population of South Africa. Multiple pollutants, both gaseous and particulate, are emitted when coal is burned and for a number of reasons these can be trapped or confined within user's homes, leading to high human exposure. Concentrations can be particularly severe where braziers are used as these devices have no natural draught characteristics and when coal is used, the low temperatures in the combustion zone result in incomplete combustion and high smoke emission.

The major problem with air pollution is that it is harmful to human health. Air borne pollutants are complex and it is difficult to say which type of pollutants are the most dangerous, gaseous or particulate (Terblanche 1994). Although particulates in themselves are not a major problem they become a problem when the constituents of the particulates react with gasses in the air and act as vehicles for carrying these combinations into the respiratory canals and further into the lungs. The impact on human health of air pollution can be measured in terms of both increased morbidity (respiratory illnesses) and increased mortality as a result of cancer, carbon monoxide poisoning and acute respiratory infection. High human exposure over long periods results in a number of illnesses that result in costs to individuals, their families and South Africa as a whole. Apart from the direct cost to the family for the purchase of medicines and health services, and the possible loss of income, there are also costs borne by employers through the loss of production and hence to the national economy, and to the state which must provide medical services to deal with the health problems.

Over the last decade research undertaken in South Africa on the link between human exposure to air pollution and health problems has provided sound justification for the need to pursue intervention strategies. This becomes particularly evident when mortality rates due to respiratory illnesses for South African children are compared with children from Western Europe: white South African children have a mortality rate about 7 times higher, while the rate for black children is higher by a factor of 270 times (Von Schirnding 1991: 79). In South Africa, acute respiratory illnesses (such as pneumonia) are the second highest cause of infant mortality after diarrhoea-related diseases. Moreover, the use of coal has been implicated directly in the high incidence of respiratory problems in children (Terblanche et al 1992, 1993).

1.3 OPTIONS FOR REDUCING HUMAN EXPOSURE TO AIR POLLUTANTS

The aim of any of the potential solutions to the problem of high exposure to air pollutants is to reduce concentrations of air pollutants to a level where they constitute no threat to human health. With this in mind, there is presently no doubt that air in the coal using residential areas is polluted and that many people fall ill as a result of exposure to these pollutants. However in considering options available for reducing human exposure, a major problem that arises is that there is little clarity on the relative quantities of air pollutants being produced by the various sources. Although there is much evidence that household bituminous coal is one of the major contributors, there are other sources that cannot simply be ignored if lasting solutions are to be found. In spite of this uncertainty the premise of this entire synthesis is that household bituminous coal is a significant culprit in the production of localised hazardous pollutant concentrations and hence, the options that will be considered focus solely on reducing polluting emissions from the combustion of household bituminous coal. Given this focus there are three possible approaches to reducing the overall quantity of pollutants:

- reducing the household energy requirement (and hence the quantity of bituminous coal consumed),
- improving combustion efficiency of coal, and
- switching to "non polluting" fuels.

These three approaches which are discussed briefly below, are not mutually exclusive, nor are they only applicable to bituminous coal. Although not an end in itself, education of coal users on the dangers of air pollutants and the dissemination of information on how to reduce or avoid exposure, is an important tool for the facilitation of any of the three above approaches.

REDUCING FUEL CONSUMPTION

Because a high proportion of household energy is utilised for space heating, fuel consumption can be significantly reduced by improving the thermal performance of houses. This can be achieved retro-actively by fitting ceilings and insulation below existing roofs. Retro-insulating walls is not a practical option but better insulated walls can be introduced in the construction of new housing through innovative design. The principle of improved thermal performance will have equivalent advantages, irrespective of the energy carrier used and hence is important in any energy consumption reduction equations.

Improved house design could greatly enhance solar energy capture and storage characteristics of low cost housing and, as a result, significantly reduce the energy requirement for space heating. This option is particularly relevant in Gauteng which experiences long sunshine hours during the cold winter months. The major limitation to this approach is that without great expense, it is virtually impossible to "convert" existing houses to effectively utilise solar energy and thus only new houses have the potential to take advantage of the benefits of solar energy. Despite much research and available knowledge on this subject in South Africa, there are few indications, if any, that large scale, low cost housing developments are taking the possibility of utilising solar energy seriously.

Thus, certainly in the short term and most likely in the medium term, there is little chance that improved house construction and/or design will impact on overall quantities of energy consumed. The nature of construction in large numbers of informally built houses, where thermally inappropriate material such as sheet steel and plastic are being used, makes it even less likely that improved buildings will assist in reducing energy consumption on a regionally significant scale.

IMPROVED EFFICIENCY OF COMBUSTION

Minimum smoke stoves

A decade ago "minimum smoke stoves" with redesigned fuel boxes that resulted in more efficient (complete) combustion of coal were seen as a way to significantly impact on the air pollution problem caused by household coal use. However there were a number of problems with minimum smoke stoves that led to the realisation by the late 1980's, that the improved stoves were not having the required impact. One of the major problems was the fact that there were already a large number of non-smokeless stoves in use and it was not possible to force people to convert to the new improved stoves. However a more serious problem was that, even for those who did purchase improved stoves, the design of the firebox incorporated a baffle plate which was invariably removed by users, rendering the stove as smoky as the older types. A further problem is that many families are not able to afford a stove at all and instead use home made braziers that result in extremely poor combustion efficiencies and high smoke emissions. This use of coal burning braziers has increased over the last number of years with the development of large informal settlements with many unemployed and extremely poor families.

Top lighting method for coal fires

Very recent research in Evaton has indicated that there may be a link between a "top ignition method" of lighting a coal fire and the incidence of respiratory illnesses (LSC Working Group 1994). The top lighting method reduces the smoke emission during the start-up phase of the fire and results in more efficient combustion of the coal. At this stage there are no conclusive results as to whether this approach does reduce exposure or to what extent. It is however an approach that is being researched further at present.

SWITCHING TO NON-POLLUTING FUELS

Anthracite

If anthracite were to be used instead of bituminous coal it would greatly reduce the quantity of pollutants emitted. However, it is only a theoretical option given that South African anthracite reserves are small and located mainly in KwaZulu/Natal, remote from the major points of consumption. The high cost of anthracite in Gauteng relative to bituminous coal reflects the higher cost of extraction, greater distance to the market and competition with international buyers.

Electricity

The use of electricity is generally regarded as the long term solution to air pollution resulting from household solid fuel use. There is much evidence that the utilisation of electricity in the home does reduce the risks of contracting respiratory illnesses associated with air pollution (Terblanche & Pols 1994b). However it is widely accepted that, for a number of reasons, electricity will not counter the problem in the short or even the medium term. Research in several townships where homes are connected to the electricity grid, shows that people continue to use other fuels (coal in particular) in addition to electricity. In Soweto, for example, electrification of formal houses commenced in 1981 and was essentially completed by 1983 (Turner et al 1984: 3), yet a large percentage of these houses continue to use coal stoves for cooking and heating. As a result, air pollution levels remain very high. For instance, the annual mean concentration of fine particulate matter (FPM) in Soweto during the period August 1990 to July 1991 was 112 μgm^{-3} compared to the US standard of 50 μgm^{-3} (Turner & Lynch 1992: 2). Concentrations of FPM in winter were about 8 times worse than in summer months, and this was attributed to the use of coal stoves for heating purposes in winter, over and above their use for cooking throughout the year (ibid: 3).

In another instance CSIR/Medical Research Council research reported high pollution exposures in parts of Sebokeng and Lekoa which were partially electrified. One of the interesting findings of the study, was that there were relatively small differences in personal exposures to particulates within unelectrified, partially electrified and fully electrified households (Terblanche et al 1992a). This was attributed to the close proximity of these areas to one another and the high background levels of pollution from low-level coal combustion emissions. It was concluded that partial electrification will not solve the air pollution problem of such townships.

Thus although eletrification has the highest potential in the long term to reduce human exposure levels to air pollutants, there are numerous reasons why it will not have the necessary impact in the short to medium term (see Chapter 2, Section 2.5 for further details). Given the large number of households that rely on coal, its multiple utility as a space heating, cooking and water heating fuel and the high cost of electrical appliances to perform these tasks, there will be a long lead in period before a full substitution takes place (if this ever occurs). As a result policy interventions, in addition to electricity provision, are necessary to alleviate the air pollution problem.

Low smoke fuels

The widespread utilisation of a low smoke fuel would, in principle, have the same impact as the utilisation of anthracite in that its polluting characteristics are, to a large extent, independent of the appliance in which it is combusted. Within the South African context there are two processes by which low smoke fuels can be produced. The first of these is via the devolatilisation of coal while the second is through a briquetting of duff coal or other waste product such as paper or wood to produce a reconstituted fuel with low smoke forming characteristics.

Indications are that low smoke fuels provide the best available option for dealing with household pollution levels in the short to medium term. However there remain a multitude of unanswered questions pertaining to low smoke fuels and whether their use will indeed lead to improved air quality and health. Answers to these questions are the subject of this document, and hence will not be attempted here. Rather the object of the above discussion has been to locate low smoke coal within the overall list of options available and to attempt to provide justification for further investigation.

SUMMARY OF POSSIBLE INTERVENTION STRATEGIES

In conclusion Table 1-2 provides a brief summary of the possible intervention strategies.

TABLE 1-2: SUMMARY OF OPTIONS FOR REDUCING OVERALL QUANTITY OF POLLUTANTS EMITTED BY COAL USING HOUSEHOLDS

Aim of any strategy should be to reduce concentrations to below health standards

Approach		*Implementation tool*	*Advantages to the approach*	*Problems with the approach*
Education on the dangers of high pollutant exposure	Reducing the consumption of polluting fuels.	Improving the thermal performance of houses	Reduce consumption and hence energy expenditure. Ceilings and insulation can be retro-fitted at relatively low cost	Higher cost of housing in the face of a massive housing backlog. (Few indications of any action to date).
		Improved house design to take advantage of solar energy	Reduce consumption and hence energy expenditure.	Huge number of existing houses which are impossible to alter. Cost constraints to building improved designs
	Improved combustion efficiency of bituminous coal	Minimum smoke stoves	In theory can reduce emissions from coal fires. Marginal reduction in consumption due to higher efficiency.	Has already been tried with little impact.
		Top lighting method for coal fires	Reduced smoke emission at start-up. Still to be investigated.	Still to be investigated
	Switching to non polluting fuels.	Anthracite	Reduced emissions	Insufficient resource. Too expensive No impact
		Electricity.	Eliminate local emissions (although there will be increased emissions by generating plant)	Expensive for space heating. Coal still burned for the generation of electricity. Less efficient conversion and distribution system
		Low smoke fuels	Subject of this document	Subject of this document

1.4 LOW SMOKE FUELS AS AN OPTION FOR REDUCING HUMAN EXPOSURE TO AIR POLLUTANTS - Description of the synthesis

Having decided that low smoke fuels have potential to reduce human exposure to air pollutants, and are therefore worth further investigation, it is necessary to consider the questions that should be asked and answered before a measure of their contribution to solving the problem can be made. This first part (Chapter 1) provides a general overview of the reasons for pursuing low smoke fuels as a potential solution to the high exposure to air pollution and a number of questions are set out below to provide the basis for the structure of the document.

What is the present situation with regard to the household use of bituminous coal?

- To what extent does domestic coal use contribute to total air pollution concentrations to which humans are exposed?
- How much household coal is presently being consumed - where is this coal being consumed?
- What are the consequences of air pollution from household bituminous coal use?
- What are the costs resulting from air pollution related health problems?

In response to these questions Part II of the document provides a description of present bituminous coal use and the consequent health problems. Because present distribution networks are an obvious channel for the distribution of any newly introduced low smoke product, the present distribution and pricing structure of bituminous coal is described. Also it is important to understand the present market in order to assess to what extent low smoke products can compete in the market. The final section of Chapter 2 provides reasons for the present and predicted continued use of coal by households in the face of expanding electricity distribution. Chapter 3 reports results of research that highlights the health consequences of continued bituminous coal use. Chapter 3 also cautions against believing that the elimination of household pollution sources will provide a full solution to wider air pollution problems. The final section of Chapter 3 provides some indications of the financial costs relating to continued high levels of human exposure to air pollutants.

What are the practical aspects to the introduction of low smoke fuels?

- What low smoke products are presently available or are in the process of being developed?
- What is the cost of production of these low smoke fuels and how does their retail price compare with that of household bituminous coal?
- What are the emission levels of low smoke prototype fuels and to what extent are they an improvement on household bituminous coal?
- To what extent can low smoke fuels reduce exposure levels in the real household environment?
- What characteristics do the low smoke fuels require to be acceptable to potential users?

The third part of the synthesis examines the practicalities of introducing low smoke fuels and the potential benefits of widespread adoption. Firstly, developments and experience from other areas of the world are described before the various initiatives and products that have been developed in South Africa are reported (Chapter 4). Chapter 5 takes a look at the performance of the low smoke fuels from an emission point of view (both in the laboratory and in the field) and also assesses their market acceptability. A final section in Chapter 5 considers a framework for a cost benefit analysis for the introduction of low smoke fuels.

What are the policy considerations for a low smoke fuel programme?

- What are the major considerations with regard to developing a successful implementation strategy?
- What information is still required?

The final part of the report (Chapter 6) summarises the findings of the previous two Parts of the document so as to identify the major considerations in developing a successful implementation strategy. It assesses to what extent there is a firm foundation on which to base the formulation of longer term policy and flags areas where insufficient information exists.

1.5 PAST RESEARCH ON LOW SMOKE FUELS

In looking for answers to these questions this synthesis has drawn from available research information and hence it is useful to provide some information on the structure of two important research programmes that have informed this synthesis. It is also useful to provide a brief description of the process that led to the commissioning of this document by the Department of Mineral and Energy Affairs and hence to place it in the context of previous, present and future research work on the subject of low smoke fuels.

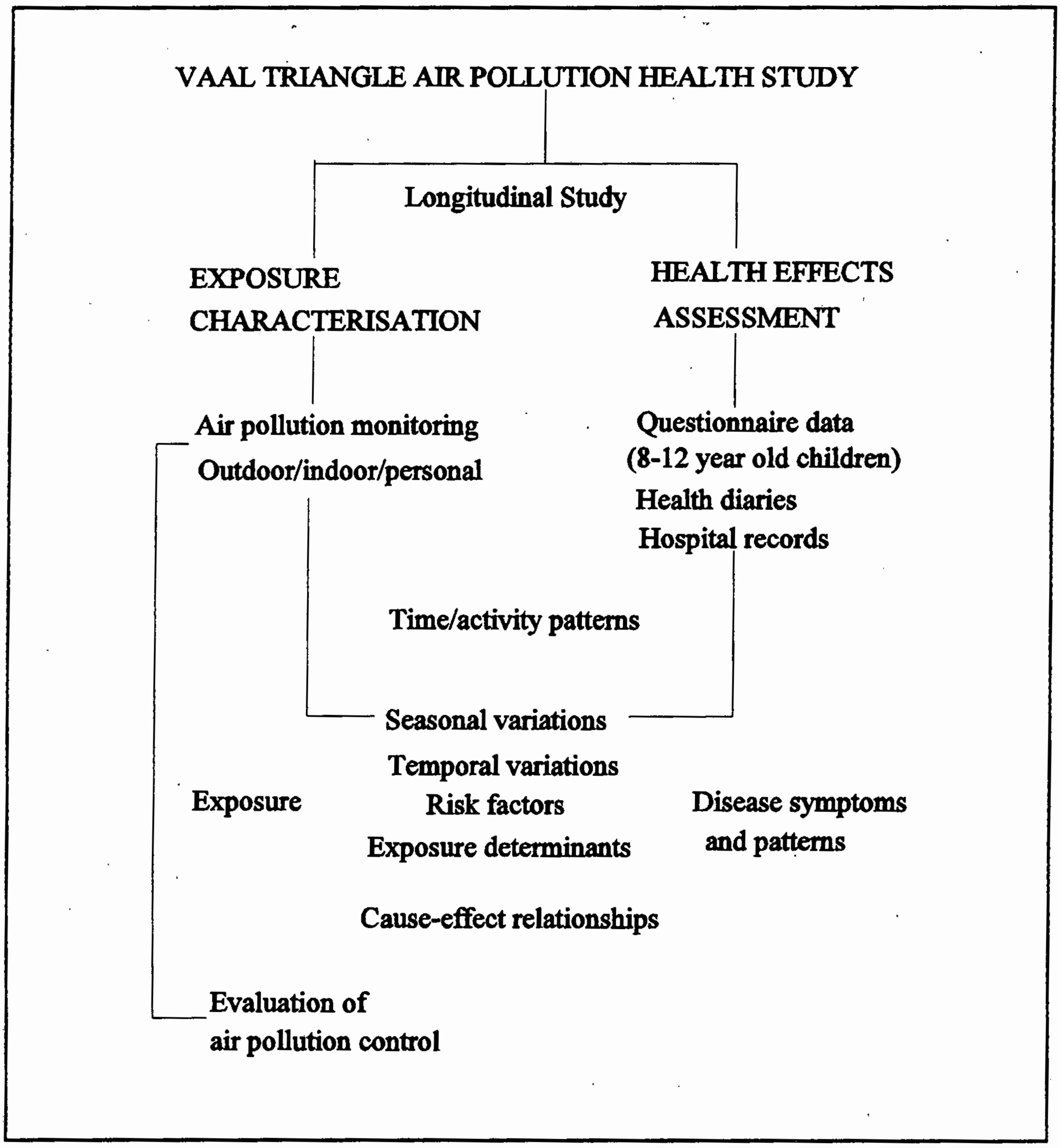
Pertinent low smoke fuels research programmes

Identification of the need for intervention

With regard to identifying the problem in the first instance, the effects of air pollution from household energy sources on the health of developing communities in South Africa have only been studied in any detail over the past decade (Terblanche, Von Schirnding, cited in Terblanche et al 1994a: 9). Two studies investigated the prevalence of respiratory tract symptoms and lung function in children living in highly industrialised areas; Sasolburg and the Eastern Transvaal highveld. Both the studies proved inconclusive and did not collect appropriate exposure data in the respective study areas(Terblanche et al 1992b).

The Vaal Triangle Air Pollution Health Study (VAPS) which was launched in 1990 by the South African Medical Research Council, has provided the most important source of justification for intervention action. The aim was to study the exposure and effects of indoor and outdoor air pollution on the health of children living in the Vaal Triangle and to assess the adequacy of South Africa's air pollution control programme to protect human health. The structure of the VAPS study is shown in Figure 1-1 and results of aspects of this study are reported in Chapter 3.

FIGURE 1-1: SCHEMATIC DRAWING OF THE VAPS STUDY COMPONENTS. Source Terblanche et al 1992b



Research on possible interventions

The second important research project was aimed at testing low smoke fuels as an intervention tactic. Given that the availability of electricity does not necessarily guarantee its exclusive use the Department of Mineral and Energy Affairs launched the "Transitional Fuels Programme" in order to address problems related to the use of paraffin, coal and gas and to obtain further data to assist in policy formulation regarding these fuels. The core of the transitional fuels programme comprised six projects which dealt with the development, distribution, social acceptability and health impact of two types of low smoke fuels. The projects relating to low smoke fuels that were undertaken included:

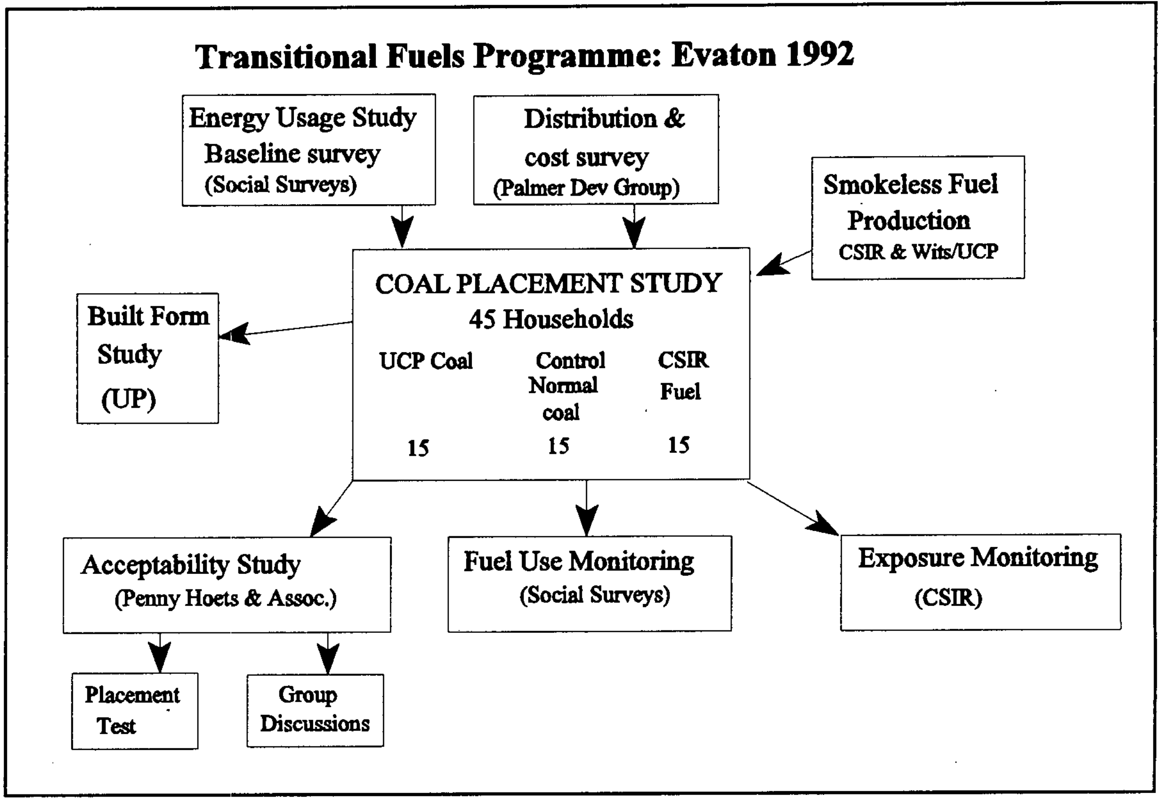
- two projects on the development of low smoke coals (Wits/UCP and Enertek at the CSIR)
- health and safety aspects of transitional fuels
- the cost and distribution of transitional fuels, and
- the social acceptability of low smoke fuels.

The core of the low smoke fuels programme was two sets of field trials undertaken in Evaton during the winters of 1992 and 1993.
The structure of the 1992 research project showing the various components is given in Figure 1-2.

The 1993 cycle of the project was basically a rerun of the 1992 field trials but with an additional fuel and a larger sample (90 homes instead of 45 homes) but also included additional work as follows:

- Characterisation of human exposures to air pollution from household low smoke fuels and bituminous coal,
- Laboratory analysis of three low smoke prototype fuels and bituminous coal, and
- Characterisation of risk factors associated with household fuel usage in South Africa.

Figure 1-2: STRUCTURE OF THE EVATON LOW SMOKE FUEL RESEARCH PROGRAMME (Source: Hoets 1992)



1.6 CURRENT RESEARCH AND INSTITUTIONAL ARRANGEMENTS FOR IMPLEMENTING A LOW SMOKE FUEL PROGRAMME

The Department of Mineral and Energy Affairs, in its role of facilitating and co-ordinating research around low smoke fuels commissioned a workshop in June 1994 to solicit the perceptions and aspirations of interested and affected parties. The outcome of the workshop was a plan of action with the following components:

Short -term

i. The initiation of a national programme on low smoke fuels,
ii. the undertaking of a synthesis study (this document),
iii. explore energy conservation measures,
iv. monitoring to ensure that standards are met,
v. economic, social and technical research and development,
vi. education on fuel use,
vii. insulation of houses, and the
viii. establishment of a steering committee.

Medium-term

i. establish a pilot project to test the effectiveness and acceptability of low smoke fuels

Long-term

i. replacement of bituminous coal with low smoke fuels
ii. intervention methods and, if necessary, legislation.

Following the workshop, a Low Smoke Fuel Advisory Committee was formed, with a small working sub-group which has the task of generating proposals for consideration by the larger Advisory Committee. Short term projects have already been initiated to meet the short term requirements and are listed in Table 1-3 along with the institutions responsible. These are expected to be completed by the end of the first quarter of 1995.

TABLE 1-3: CURRENT RESEARCH INTO ASPECTS OF LOW SMOKE FUEL

#	Subject of Research	Organisation	Project Leader
1	Characteristics and requirements for low smoke fuels	CSIR	Dr C Eleftheriades
2	Source apportionment of township air pollution	AER	Prof H J Annegarn
3	Market characteristics for low smoke fuels	Palmer Dev Group	Mr R Palmer
4	Impacts of removing air pollution: Physical aspects	AER	Prof H J Annegarn
5	Impacts of removing air pollution: Health aspects	CSIR	Dr P Terblanche
6	Impacts on environment of differing energy mixes	EMScc	Dr L W Burger
7	Possible market interventions to promote low smoke fuels	EDRC	Dr A A Eberhard
8	Education programme proposals	NACA Soweto	Mr J Sithole
9	Programme to prove efficacy of low smoke fuels	Penny Hoets	Ms P Hoets
10	Evaluation of the use of coal in Evaton	CSIR	Dr P Terblanche

A diagrammatic representation of these short-term projects is given in Figure 1-3 while the programme for the medium and long term components is given in Figure 1-4. The medium-term programme is expected to last from 1995 to 1997, while the aim of the long term programme is to eliminate all household bituminous coal use by the year 2000.

FIGURE 1-3: SHORT-TERM LOW SMOKE FUEL RESEARCH PROJECTS (Source: LSC Working Group 1994)

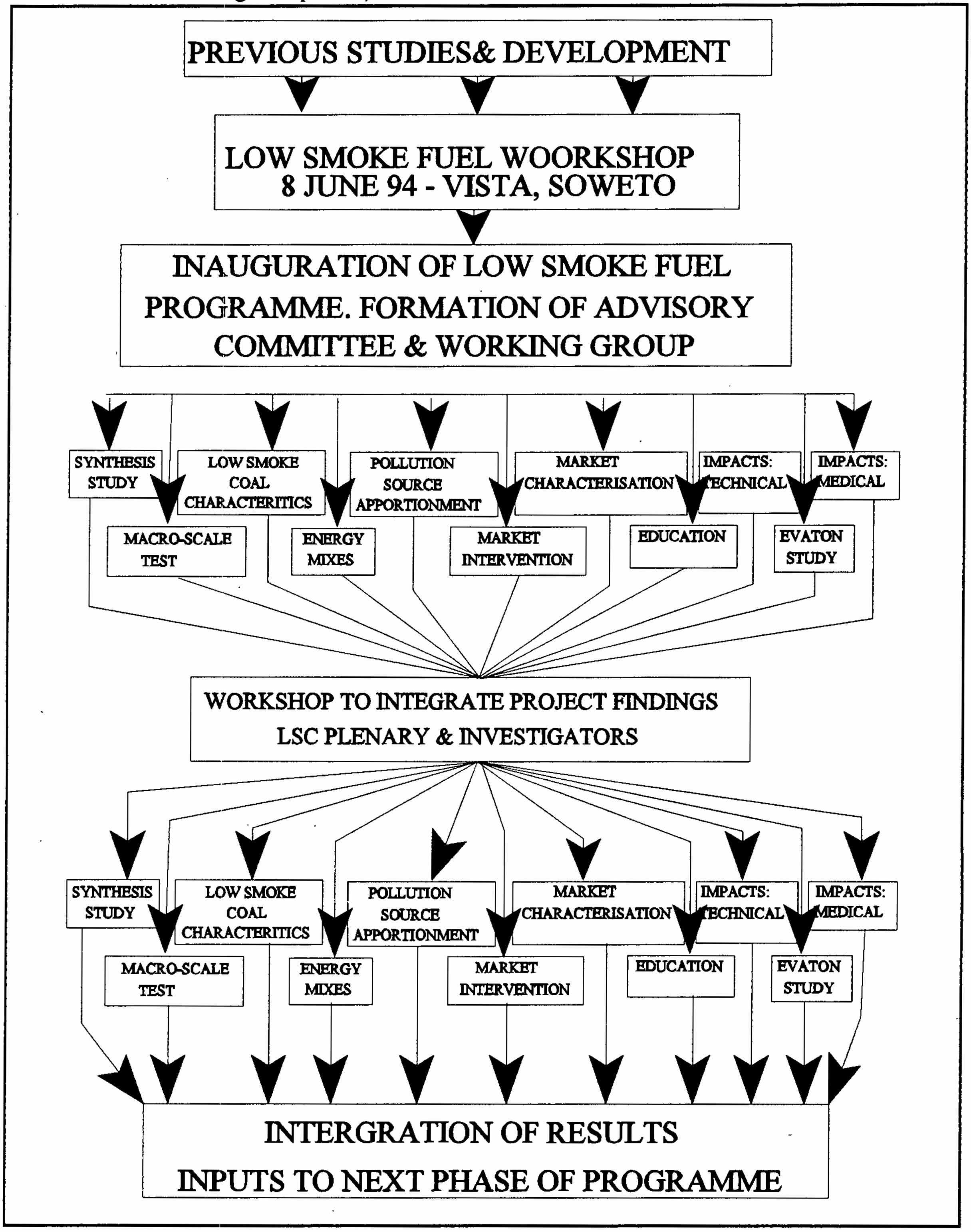
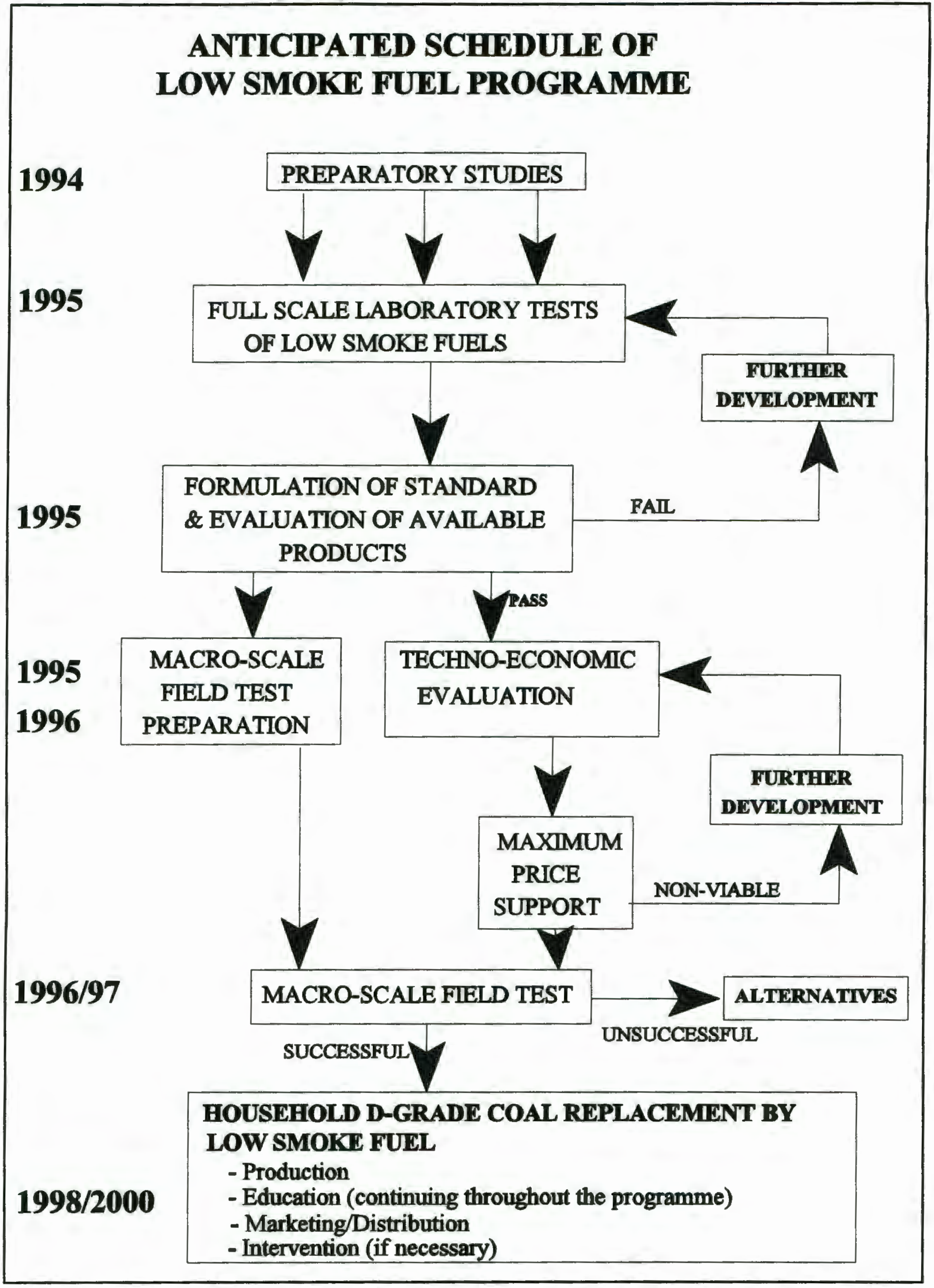


FIGURE 1-4: MEDIUM AND LONG TERM LOW SMOKE FUEL PROGRAMME (Source: LSC Working Group 1994



Chapter Two

PRESENT DISTRIBUTION AND USE OF HOUSEHOLD COAL

2.1 INTRODUCTION

For low smoke fuels to impact on the air pollution problems described in Chapter One, they will not only have to emit lower quantities of pollutants but, in addition, they will have to significantly penetrate the present household bituminous coal market, and ideally completely replace coal as the favoured fuel. Assuming that low smoke fuels do have the characteristics to reduce hazardous emissions, it is thus necessary to consider how the products will find their way from the point of production to the end users. One of the problems with this exercise is that it is not presently clear where low smoke fuels may be manufactured, however an obvious first option for distribution is via the existing bituminous coal distribution network which presently supplies millions of bituminous coal users.

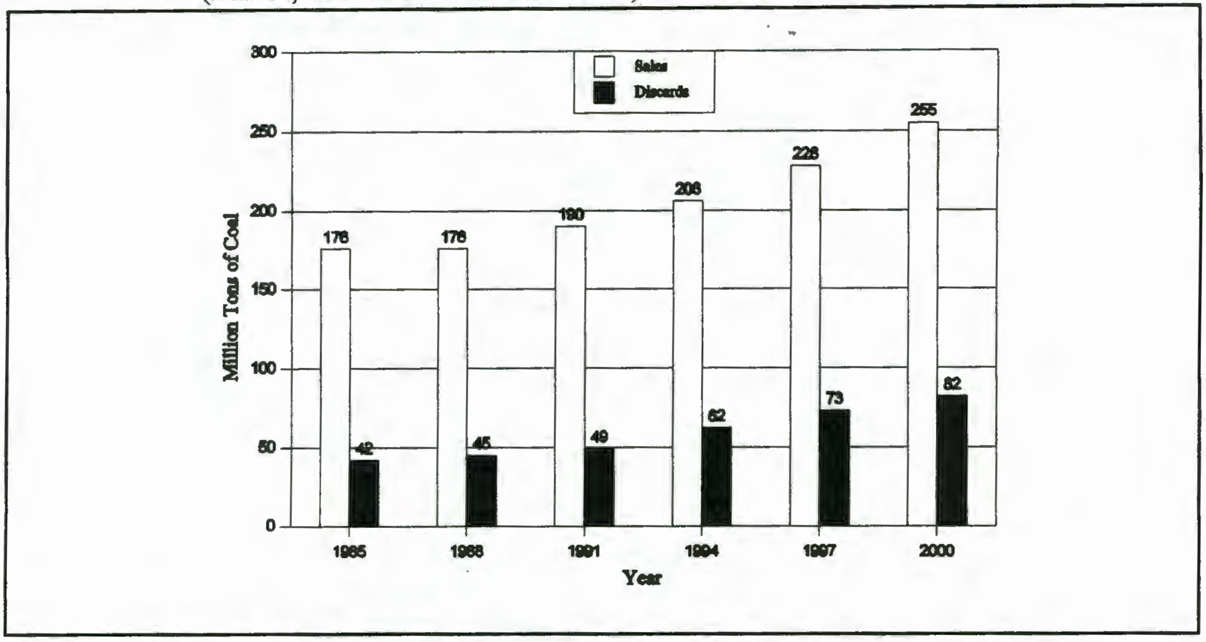
The current coal distribution system is, of course, not the only avenue open for the distribution of a low smoke fuels. However, by understanding who is involved in the business of distributing coal and what profits are made by these various participants, it will be possible to more accurately estimate the likely retail price of low smoke fuels marketed through the same channels. The seasonal variation in the consumption of coal is also an aspect that needs to be considered as this will affect the cash flow, and hence viability, of organisations or individuals that may be involved in low smoke fuel production and distribution.

Thus the aim of this chapter is to provide a description of the current market and distribution system for household coal in the Gauteng/ETH region. The chapter will also provide a brief description of how coal is burned by household users and suggest reasons for the continued use of household coal in the face of growing electrification. In addition, due to the fact that coal discards provide a possible feedstock for the production of low smoke fuels, their availability is also discussed in this chapter. Finally, because anthracite is technically a low smoke fuel, some information on its production is presented.

2.2 PRESENT DOMESTIC (SOUTH AFRICAN) COAL PRODUCTION AND CONSUMPTION

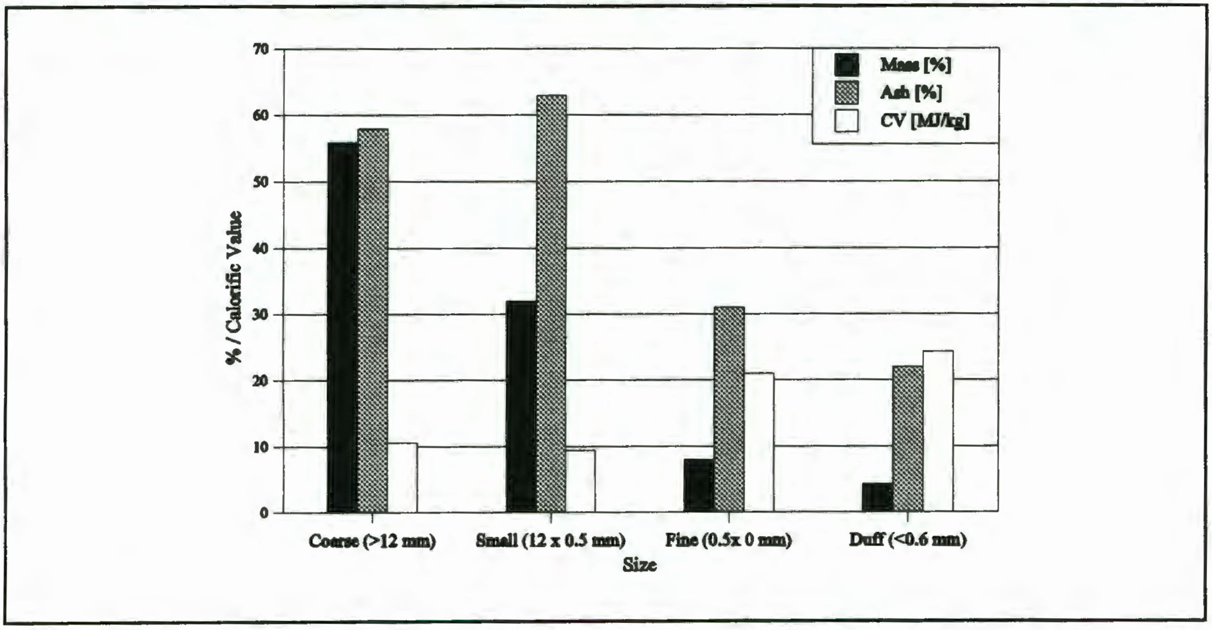
Coal is the major primary source of energy for both industry and household use in South Africa. Apart from providing virtually all the energy used to generate electrical power it is also a feedstock for liquid fuel production and a host of other products produced by Sasol. Figure 2-1 shows both past and predicted future South African coal production and it is evident that in 1994 the coal industry will have produced over 200 million tons of saleable coal (Grobbelaar & Horsfall, 1994). South Africa is ranked as the fifth largest coal producer in the world and actively participates in the international steam coal trade where it is the second largest supplier. Most South African coal is of bituminous thermal grade with only 2% anthracite, and less than 2% metallurgical quality (von Glehn, 1993). Most of South Africa's coal is mined in the Witbank and Highveld coalfields, and collieries range in size from small operations, with an output of a few thousand tons per annum, to the mammoth Secunda colliery which has an annual output of more than 30 million tons from its five mine complex. Nearly 80% of the total saleable production comes from four large mining groups which include Amcoal (25%), Sasol (21%), Randcoal (17%) and Trans-Natal (15%) (von Glehn, 1993). Excluding the unbeneficiated coal used for electricity generation and liquid fuel production, about 35% of the run-of-mine coal is discarded annually. These discards are mainly generated by the preparation plants for export coal (Grobbelaar & Horsfall, 1994). The quantity of discard coal generated in the beneficiation process is also given in Figure 2-1.

FIGURE 2-1: SOUTH AFRICAN SALEABLE AND DISCARD COAL PRODUCTION (Source; Grobbelaar & Horsfall 1994)



A breakdown of the size and quality of discards from four major mines supplying the export market is given in Figure 2-2. It is evident from the figure that the major quantities are in the larger sizes, but the quality of the coarse and small discards is poor with low calorific values and high ash content. On the other hand, the quality of the fine and duff discards is significantly better and, although the percentage yield is low, the tonnages generated are significant relative to the household coal market.

FIGURE 2-2: DISCARD PRODUCTION DURING 1991 (Source: Grobbelaar & Horsfall 1994)



Given that anthracite is a "low smoke coal" it is also of interest to report its availability; South African anthracite reserves are small and mainly located in KwaZulu/Natal. During 1992 only 696 000 tons were sold into the domestic market (see Table 2-1).

TABLE 2-1: ANTHRACITE SALES [Thousand tons] (Source: von Glehn, 1993)							
Year	1986	1987	1988	1989	1990	1991	1992
Domestic sales [Thousand tons]	652	630	750	563	555	439	696
Domestic price (f.o.r) [Rands/ton]	44.12	52.54	59.15	76.75	100.20	110.09	110.32
Export sales [Thousand tons]	4406	3429	2939	3186	3334	3294	2224
Export price (f.o.b) [Rands/ton]	68.21	59.90	78.90	105.19	89.35	98.80	115.88
Domestic price of steam coal (f.o.r) [Rand/ton]	*17.21*	*19.09*	*21.63*	*26.63*	*30.41*	*33.47*	*37.44*

The last row in Table 2-1, showing the pithead price of steam coal is included to demonstrate the large discrepancy between the price of anthracite and steam coal and indicates the main reason why anthracite is not currently utilised to any degree by the household market.

Until April 1987 the pithead price of coal to the inland market was controlled by the State. Price controls were divided into four categories, based on calorific values. Prices of Natal coals were generally double those of the Transvaal and OFS coals and this reflected the higher cost of production and higher quality of coal mined in Natal. The prices of anthracite, metallurgical coal (with a CV higher than 28.5 MJ/kg) and coal used in chemical processes were not controlled. Now that price control has been abolished the only restriction remaining is on the sale of Transvaal coal in KwaZulu/Natal (M^{c}Gregor, 1994).

Focusing again on steam coal sales, the market for the total 1992 production of 181 million tons is shown in Table 2-2.

TABLE 2-2: TOTAL SOUTH AFRICAN STEAM COAL SALES (Source: von Glehn, 1993)		
	Quantity of coal [million tons/annum]	*Proportion of total [%]*
Exports	50	28
Electricity	74	40
Synfuel	39	20
Industry	7	4
Household	4	3
Metallurgical	4	3
Other	3	2
TOTAL	181	100

Table 2-2 also shows that, of the 181 million tons produced, 72% was sold locally, and it is notable that a very small percentage of the total, only 4 million tons, went to the household market as opposed to 74 million tons (or 18 times as much) being used in the generation of electricity. However there is considerable uncertainty on the quantity of coal that is actually consumed by the household sector. This is evident from Table 2-3 which gives figures presented by various authors for the quantity of coal utilised directly by the household sector.

TABLE 2-3: ANNUAL HOUSEHOLD COAL CONSUMPTION

Quantity [million tons/annum]	*Reference*
1.7 (consumption in PWV region only)	LHA, 1987
2.0 (1.1% of total South African production.)	Borchers& Eberhard, 1991
4.0	von Glehn, 1993
1.5 (estimate for the PWV area only)	Horsfall,1994, p12
1 to 5	DMEA, 1994
3.0	Horsfall, 1994b
1.5 to 7.4	McGregor, 1994.
6.5	Chadwick, 1994

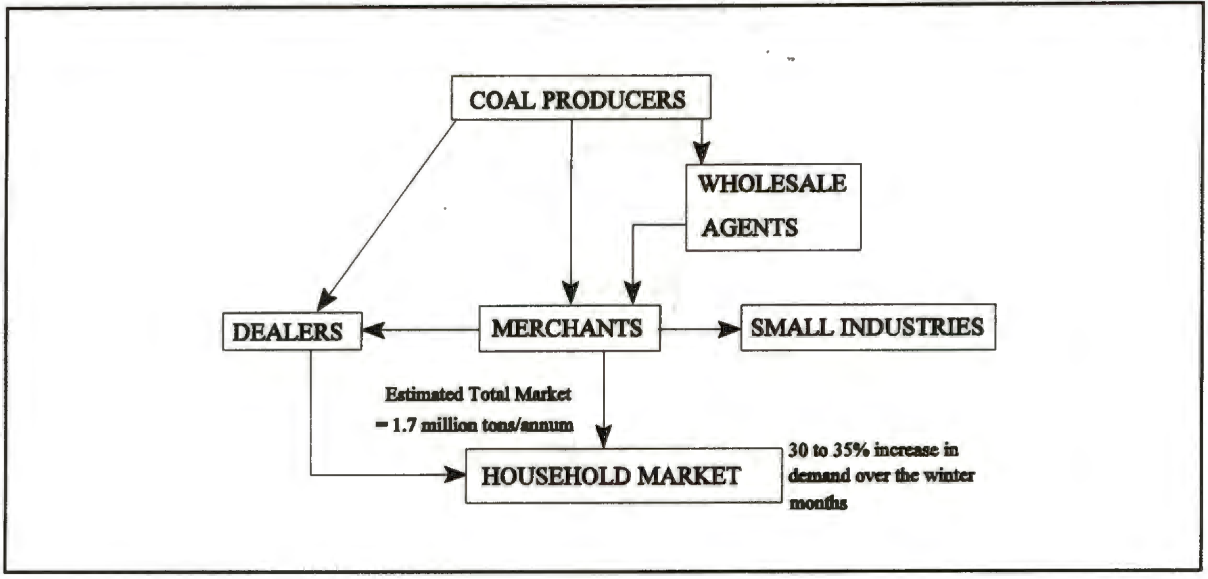
Several grades of bituminous coal are marketed and these range from grade A (highest energy content) to grade D (lowest energy content)(see Appendix B for a list of the various grades of coal available in South Africa). The coal that is generally burned as a household fuel is "grade C nuts", where "grade C" refers to coal with an energy content of over 26 MJ/kg and "nuts" refer to the size range of 22 to 40 mm (Palmer Development Group, 1993).

2.3 HOUSEHOLD COAL DISTRIBUTION

During the initial stages of investigation into the possibility of introducing a low smoke fuel product into the South African market, Louis Heyl & Associates (LHA) undertook an investigation into the supply and distribution system for household coal. Figure 2-3 gives a representation of the coal distribution system as reported by LHA (1987b).

According to LHA there were an estimated 300 coal merchants operating in the PWV region with 200 of these serving Greater Soweto. These merchants operate coal yards which distribute directly to consumers and also to the less sophisticated dealers who distribute coal house to house. The report does not provide any details of the relative sales volumes via the various distribution channels shown in the diagram. LHA reported that the dealers are responsible for applying "high mark-ups" but did not provide any figures on the magnitude of the mark-ups. In addition LHA reported that coal merchants also sell wood (which is required for starting fires) and that anthracite is seldom used by households due to its high price. However, the information provided by LHA is extremely scanty and is certainly not sufficient for the prediction of retail prices for a large scale low smoke fuel distribution strategy.

FIGURE 2-3: HOUSEHOLD COAL DISTRIBUTION SYSTEM (Source: LHA 1987b)



Later, as part of the "Transitional Fuels Programme" (see overview of low smoke fuel research in Chapter One), the Palmer Development Group (PDG) undertook a study for the Department of Mineral and Energy Affairs into the cost and distribution of transitional fuels in the former Transvaal. One of the objectives of the study was to describe the domestic coal distribution chain and to ascertain what price increases are applied by the various elements. The information was gathered at the end of 1991 and during 1992 in five towns, Alexandra, Mamelodi, Orange Farm, Sebokeng (all in Gauteng) and Tumahole (located near Parys in the Free State). The report concentrated on the price of coal and provided few details on transport systems used, number of people employed or other aspects such as the marketing approaches used by coal merchants. As a result, the description presented below is based on information gleaned from the PDG report (1993) and personal communications with Richard Palmer.

All of the coal used by PWV households reaches end users via the local coal merchants that operate in every town in the region. In general the distribution process can be divided into two step. The first step involves the purchase of bulk coal by merchants from suppliers(mining houses and smaller coal mines), while the second step is the distribution of bagged coal by the local merchants to householders. The overall process is presented diagrammatically in Figure 2-4.

If one considers the first step in the process there are a number of possible routes whereby a merchant can obtain a coal supply:

- If merchants have their own trucks (that are in good repair) they can purchase coal at the pithead and transport it to their coal yards. There is a price advantage in collecting the coal from the pithead which must be offset against the cost of transportation.
- If the merchant does not have access to suitable transport, coal can be ordered through one of the large wholesalers that operate in the region. If there is a railway siding close to the merchant's yard, the wholesalers will arrange for a railway truck load (or multiples thereof) to be delivered to the closest siding. It is then the responsibility of the merchant to collect the coal from the siding and to transport it to his yard. If there is no siding in the vicinity, the wholesaler will deliver the order by road. When operating through the large wholesalers only large orders will be entertained (20 tons minimum for railway transport and 22 tons for road transport), and in addition no deliveries will be executed without prepayment by the coal merchants.

There is a considerable range in the size and sophistication of the coal merchants and the method used by the merchants for acquiring their supplies is dependent on the distance of the merchant's yard from a railway siding, the distance of the merchant from a coal mine, and whether the merchant owns a truck (or trucks) capable of hauling coal over relatively long distances. Another factor that influences the method of acquisition chosen by merchants is the availability of sufficient capital for the purchase of a full 20 or 22 ton load. There is no information available on the relative quantities of coal that are distributed to coal merchants via the various routes shown in Figure 2-4. Palmer Development Group (1993, p19) found that the amount paid for coal by the coal merchants does not vary significantly given the large differences in distance between producers and the merchant's yards (see Figure 2-4 for an indication of the prices paid).

In many cases coal merchants would be unable to obtain supplies if they did not own their own transport for the collection of coal at railway sidings or the pithead. Once the merchant has transported the coal to his yard it is bagged and reloaded onto vehicles which are used for distribution to houses in the area. Coal is bulky, dusty and requires large areas for handling. Generally the bagging and loading is undertaken during the morning and distribution and sales are undertaken in the afternoon and early evening when customers are more likely to be at home. A large variety of vehicles are utilised for the household deliveries ranging from animal drawn carts, through bakkies to larger trucks. In many cases these vehicles are old and in poor condition. Coal merchants tend to be "specialists" as they do not operate other lines of business from their coalyard. They do however generally have mechanical skills and are able to maintain and keep their vehicles operational for the delivery of coal to customers. Generally vehicle maintenance work is undertaken during the slacker summer months.

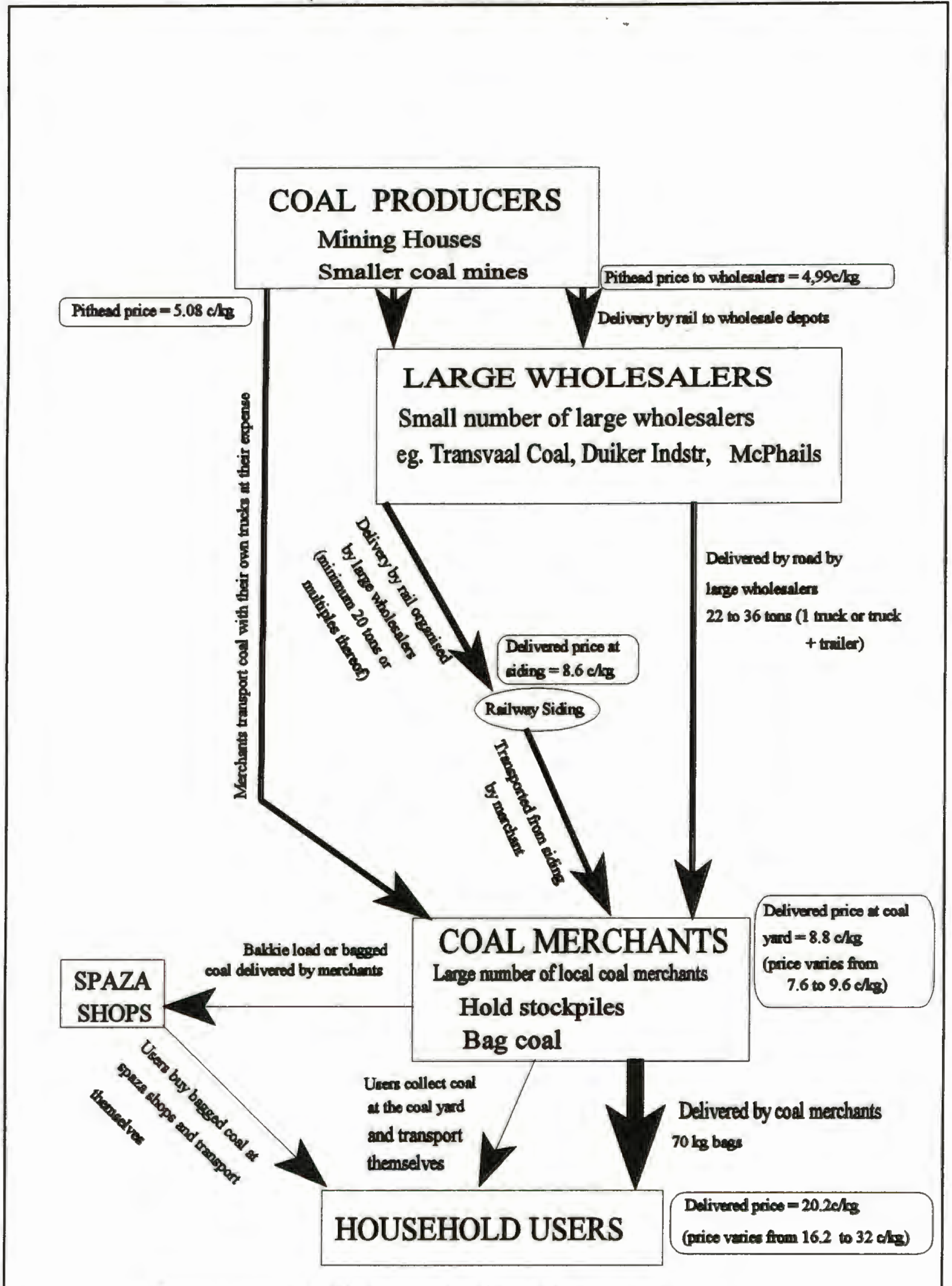
Although Figure 2-4 shows some coal being sold through spaza shops and people collecting their supplies from merchants yards, the vast majority of coal is delivered door to door by the merchants themselves. Coal is virtually always sold in 70 kg bags and the frequency of people using tins, wheelbarrows and hubcaps to sell and/or purchase coal is very low (Palmer, 1994). In general coal is very easily accessible and people who are away, working during the day leave their money and order with neighbours and friends. The extent to which competition exists in the retailing of coal is not clear from the PDG report. However anecdotal evidence indicates that prices are "agreed" within areas (Palmer 1994) and that merchants are concerned about the potential dangers of not keeping prices on a par with other merchants in their area (PDG, 1993a).

Table 2-4 shows the actual and percentage price increases through one of the coal distribution routes. The mark-ups applied by the wholesalers cover the cost of transport and their personnel and administrative costs while those applied by the coal merchants must cover a range of expenses which include transporting the coal from the railway siding to their coal yard, bagging the coal, distributing the coal to customers, and a range of other general overheads. In addition to covering these expenses the mark-up also include the profit earned by the coal yard owners.

TABLE 2-4: COAL PRICES AND THEIR INCREASE THROUGH THE DISTRIBUTION CHAIN (1992 prices). (Source: Palmer Development Group 1993)

Wholesaler			Coal Merchant			Total
Purchase price [c/kg]	Mark-up [%]	Retail Price [c/kg]	Purchase price [c/kg]	Mark-up [%]	Retail Price [c/kg]	Mark-up [%]
4.99	73	8.64	8.8	130	20.24	306

FIGURE 2-4: HOUSEHOLD COAL DISTRIBUTION SYSTEM
(after Palmer Development Group, 1993)



Seasonal variation in sales:2.64 times as much coal is sold during winter than in summer

2.4 HOUSEHOLD USE OF BITUMINOUS COAL

Figure 2-4 shows that households pay between 16.2 and 32 c/kg (R11.50 to R22.40 for a 70 kg. bag) for their coal with the average price paid being 20. 2 c/kg (1992 prices). Results from a survey in Evaton show that most people (85%) buy their coal from coal trucks with the remainder mostly buying directly from coal yards (11%) (Hoets, 1994). The average price paid for a 70 kg. bag was R14-00 (20 c/kg) and on average households used 1.4 bags of coal per week which amounts to an expenditure of R20 per week. Hoets also reports that 92% of households that use coal have a special box or drum at their homes in which coal is stored.

Coal is generally burned in the traditional coal stoves which have four to six plates and an oven, and a chimney that leads fire emissions out the house. Also a small proportion of the stoves are fitted with water heating tanks (Hoets 1992: 23, Golding & Hoets cited in Williams 1993: 31). The factory built stoves are manufactured from cast iron components and baked enamel sheet steel. These stoves are legally supposed to comply with SABS standards which, amongst other items, specify the format of the firebox in order to reduce smoke emissions. In principle the firebox is divided into a fuel hopper and a combustion chamber by a baffle plate that prevents the combusted gasses from passing through the unburned fuel. However many families own stoves that were purchased prior to the introduction of the regulations and also many of those that do own newer stoves have removed the baffle plates so as to provide a larger fuel loading capacity. The result of this is that coal fires do not burn as efficiently as they could and unburned volatiles are given off in the form of smoke.

Notwithstanding smoke emission problems these coal stoves, although expensive to purchase, are robust and durable and provide users with many years of trouble free use. In addition these coal stoves are versatile devices and are used by owners for multiple functions. The most important of these is for space heating of generally poorly insulated homes during the cold winter months. In addition to being used for daily cooking (including baking) stoves are also used for heating irons and providing a consistent hot water supply.

The study in Evaton revealed that 61% of households lit their coal stoves twice a day, while 36% lit them only once per day. Cooking fires were generally made about 25 minutes before the start of cooking and respondents estimated that it took them about half an hour to cook breakfast and an hour and a half to cook dinner in the evenings (Hoets, 1994). Also it was found that 63% of households allowed their stoves to burn all day but 86% said that they did not leave them to burn all night.

Although many families own the factory manufactured coal stoves there are large numbers of homes, especially in the informal settlements, that do not have stoves. These families use braziers which are usually made from 25 litre tins with holes punched in the side to allow air to enter the combustion zone. Because braziers are portable they are often lit outdoors and only brought indoors after the initial smokey start-up period has passed. These "stoves" do not have chimneys and therefore pose a very high risk with regard to exposure to coal combustion emissions(Terblanche et al, 1994b). These risks are discussed in more detail in Chapter Three.

2.5 REASONS FOR CONTINUED HOUSEHOLD COAL USE

As described in Chapter One, it is presently generally accepted that coal will be used by a large number of households in the PWV region in the medium to long term. Observations in many newly electrified townships show that households do not make a complete switch from hydrocarbon fuels to electricity, either immediately, or over time. Many possible reasons have been postulated, the most important of which are the following:

- Possibly the most important reason relates to the ability of coal stoves to perform multi-functions *simultaneously: space heating, cooking, water heating and heating of irons*. Apart from the convenience factor, the relatively high efficiency of a coal stove being used for a number of functions simultaneously, makes coal a very cost effective fuel. This is particularly so during winter, when space heating is necessary. An important function of coal stoves is their ability to provide a source of *hot water* in dwellings without geyser systems. The use of a large pot or urn of water, which is placed on the side of the stove when it is in operation, provides a steady supply of hot water. The implication is that electric geysers or urns may be a necessary prerequisite for abandonment of coal.

- In coal-using areas of the PWV, Eskom has suggested that coal is preferred because it is cheaper than electricity (Turner & Lynch 1992: 1). Even though a coal price of around R12 per 70 kg. bag of coal is 7 times more expensive than the R23.91 per ton paid by Eskom in 1990, electricity prices include transmission, reticulation, distribution and administrative costs, causing the electricity price to be considerably higher than the coal price in useful energy terms. Table 2-5 demonstrates the cost advantage of coal when compared with other household fuels.

Table 2-5: Cost of Household Fuel (for Space Heating) (Adapted from Horsfall 1994, based on 1992 figures)

	Coal	Electricity	Gas	Paraffin*
Price	20 c/kg	12 c/kWh	R2/kg	140 c/litre
Calorific value	27 MJ/kg	3.6 MJ/kWh	49 MJ/kg	38 MJ/litre
Price/energy unit [c/MJ]	0.74	3.33	4.1	3.7
Relative cost. (Coal = 1)	1	4.5	5.5	5
Appliance efficiency**	60%	100%	90%	90%
Relative cost/useful heat unit	1	2.7	3.7	3.3

* *The price of paraffin given by Horsfall was 93 c/litre. This has been increased to R1.40 as reported by Palmer Development Group (1993).*

** *These comparisons of cost are very sensitive to the appliance efficiency chosen. If for instance the same comparison was performed for cooking rather than space heating coal would be significantly less competitive*

- The cost advantage of coal over electricity is increased where households supplement purchased coal, with low quality discard coal. Even though the energy content of the latter is obviously lower, expenditure levels will probably still be reduced by the use of free or cheap discard coal.

- An economic constraint on electricity replacing coal use, is the high capital cost of *electrical appliances*. The outlays required for large appliances such as stoves and geysers make their acquisition prohibitive, especially for poor households. Poor access to credit is a related constraint. The availability of hire purchase (HP) credit for appliance acquisition may overcome this problem, as was suggested by the high level of expenditure on HP repayments by many households in the Western Cape Electrification Project (Theron 1992: 136). While this argument is valid in many cases, it is also contradicted by the fact that currently about 40 000 *new* coal stoves are sold annually (not to mention the second-hand trade) (Williams 1993).

- Coal stoves perform *social functions* beyond the simple tasks of heating and cooking. In particular, they provide a focal point for members of a household, especially at night when their warmth is far more pleasant than that of an electric, gas or paraffin heater. In addition, tradition and social habits play a role in the reluctance of many people to discard coal stoves. Hoets (19940 reports that coal has a nostalgic value for people as they grew up with it and associate it with a warm home.

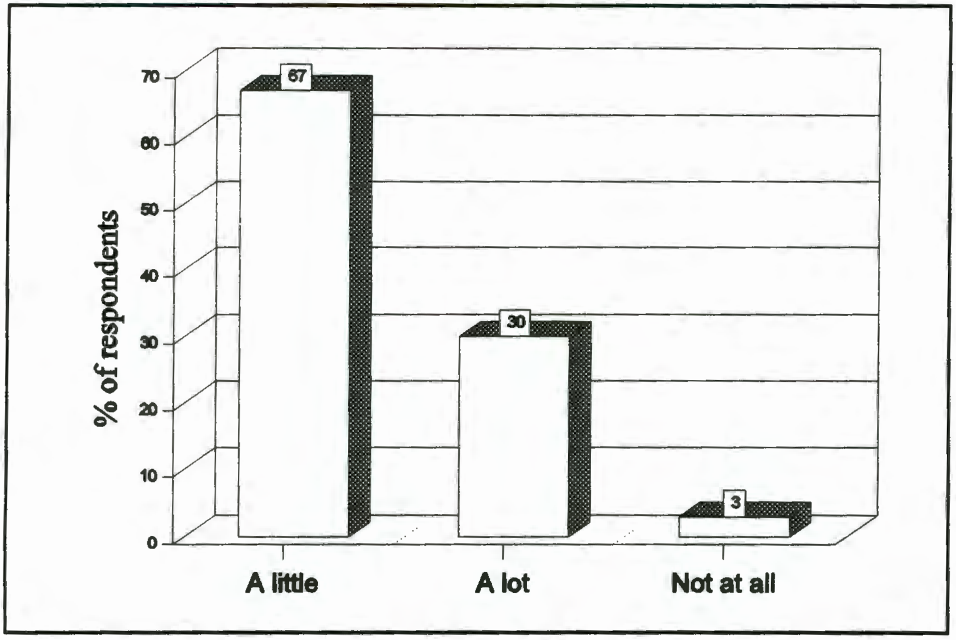
- Where electricity services have been ***unreliable***, households have retained their coal, paraffin and gas appliances in case of power failure.

- The ***length of time*** for which households have been electrified also influences the extent to which reliance is placed on electricity. This decision is informed, in turn, by several of the factors mentioned above, such as perceptions of the reliability of the electricity service, and the affordability of electrical appliances.

Choices on fuel usage in already electrified households, will be based upon a combination of these factors, rather than just one or the other. Moreover, the specific circumstances of each case are likely to differ in practice, depending upon season, climate, proximity to coalfields, costs of appliances, access to savings or credit, and other factors. Thus, while from an environmental perspective, electricity is the preferred source of energy because it is clean and safe in the home, the above factors show that electrification cannot provide the complete solution to household energy-related air pollution problems. Another consideration is that although electricity is a clean fuel in its final form, it requires a long complicated process to convert energy contained in coal to useful energy in peoples homes, with inefficiencies and wastes at each step. On the other hand domestic coal has a much less complex supply route. "Burning coal in the simplest type of closed domestic appliance leads to useful capture of heat to the extent of about 69% of the calorific value of the coal. With a well designed and maintained appliance the figure can rise to 80%. Supplying heat via the electrical chain results in little more that 30% of the coals energy finally heating the user's premises" (Horsfall, 1994).

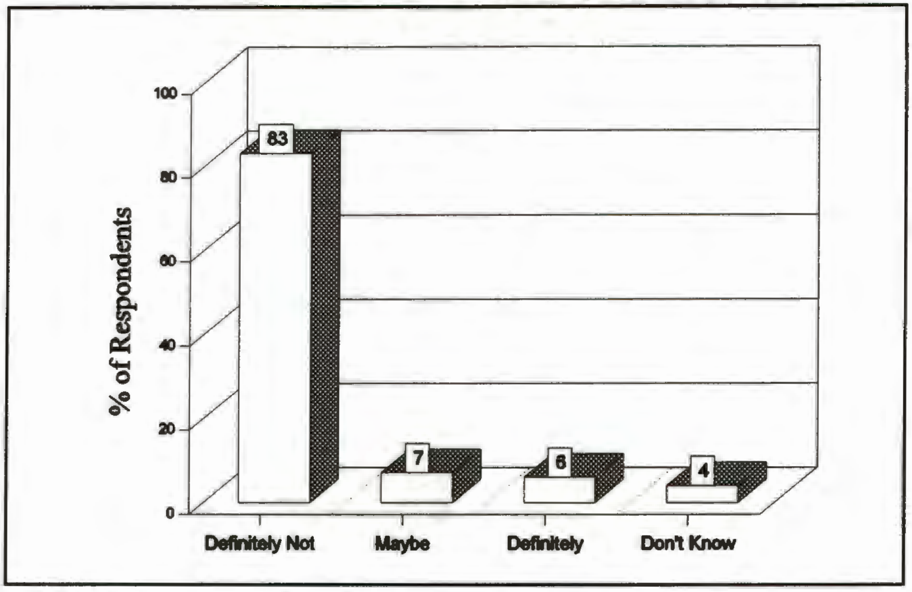
During the 1992 study in Evaton, prior to electricity being available, residents rated electricity above coal and other energy carriers such as paraffin, gas, car batteries and candles. However a year later, when a follow-up survey was conducted, residents rated coal above electricity and all the other fuels (Hoets 1994:v). With regard to the polluting characteristic of coal, two thirds of respondents said that coal smoke worries them "a little" while only a 30% said that coal smoke worries them a lot. Only 3% said that coal smoke does not worry them at all (Figure 2-5).

FIGURE 2-5: EXTENT TO WHICH RESPONDENTS ARE WORRIED BY COAL SMOKE (Hoets 1994:vii)



However the extent of the worry was not high enough to cause people to stop using their coal stoves. 83% of respondents said that they would definitely not be prepared to stop using coal stoves in order to eliminate coal smoke from the area. 81% of people living in electrified households said that they were definitely not prepared to give up their coal stoves in the interest of clean air (See Figure 2-6).

FIGURE 2-6: PREPAREDNESS TO STOP USING COAL STOVE TO ELIMINATE COAL SMOKE (Hoets 1994:viii)



2.6 REASONS FOR PEOPLE DISLIKING COAL

However, despite these reasons for continued coal use and the fact that people are attached to their coal stoves, there are a number of aspects to coal that people dislike. Hoets (1992) reports that " smoke related factors were the main reason for people disliking coal. Smoke was seen as unhealthy and dangerous (killing sleeping people if braziers are not taken out at night) and as causing sickness (gets into the eyes, affecting the chest). Coal smoke dirtied walls, pots, clothing and furnishings inside homes and was also considered to be a problem outside as well as dirtying peoples washing." LHA (1987c) also reports that the dirty aspect of coal and the smoke/health hazard were the main disadvantages to using coal. Other complaints by some coal users were that coal was expensive and poor in quality (Hoets,1992).

Chapter Three

HEALTH IMPACTS OF HOUSEHOLD BITUMINOUS COAL USE

3.1 INTRODUCTION

Global energy use patterns are highly asymmetrical across the divide between 'developing' and 'developed' countries. Industrialised countries, with less than a quarter of the world's population, account for about 70% of total annual fossil fuel consumption. On a per capita basis, commercial energy consumption of fossil fuels in developed countries exceeds the average consumption in developing countries by a factor of between 7 and 18 (WHO 1992a: 16). Not only are there *quantitative* differences between the energy consumption of rich and poor countries, but the nature of energy consumption in poorer countries is also *qualitatively* worse. Poor people in poor countries are usually faced with fewer options in meeting their basic energy needs for cooking, heating and lighting, and therefore have to rely upon readily accessible and affordable fuels, such as wood, animal dung and crop residues. These biomass fuels are the major source of energy for some 2.5 billion people, almost half of the world's population (ibid: 71).

Unfortunately, the fuels used by the world's poorest people are frequently also the dirtiest and least safe. International studies have recently identified major health risks associated with domestic combustion of such fuels as wood and coal. In South Africa a large portion of the total population are reliant on wood and coal for their energy needs and, up until the early 1990's there was little conclusive evidence of an association between the prevalence of respiratory tract symptoms and lung function disorders in children and the use of household coal. However with the launch of the Vaal Triangle Air Pollution Health Study (VAPS) in August 1990 an increasing body of research has been developed on the effects of household coal use on respiratory illnesses. In addition, more consistent monitoring of outdoor air quality in black urban residential areas has begun. Because the focus of this report is the risk associated with emissions from coal combustion , aspects of these studies, both international and local, that deal with coal are of direct interest.

However, before presenting some of the findings of the above research, this chapter provides some basic background technical information on coal combustion emissions and the possible consequent health effects of human exposure to these emissions. Then, after describing the findings of research undertaken in China and other parts of the world, the major section of the chapter presents information gathered in South Africa on levels of pollutants which occur indoors, outdoor particulate concentrations, and the effects of exposure to both indoor and outdoor air pollution on people's health. The chapter also presents results of preliminary research on the source apportionment of air pollutants occurring in the Vaal Triangle which indicates that, in addition to air pollution resulting from household bituminous coal combustion, there are other major contributors to the broader air pollution problem. Finally the chapter provides a brief indication of some of the costs incurred as a result of human exposure to air pollution.

3.2. POLLUTANTS EMITTED DURING COMBUSTION OF COAL

Combustion of coal results in the emission of a number of air pollutants, as well as the creation of an ash waste which requires disposal. The air pollutants are both gaseous and particulate in nature. The most serious gaseous pollutants and indications of their possible health effects are as follows (van Nierop, 1994):

- particulates which consist of liquid and/or solid particles which can vary considerably in size (0.005 to 500 μm), geometry, chemical composition and physical properties. Natural defence mechanisms remove most of the particles larger than 10 μm before they can enter the respiratory system. However PM-10 particles can enter and are deposited in the respiratory system (inhalable particles) while particles smaller than 2.5 μm (PM-2.5) can enter and be deposited on the pulmonary (lung) tissue (respirable particles). Particulate matter may contribute to the development of chronic bronchitis and may be a predisposing factor to acute bacterial and viral bronchitis. Also it may aggravate bronchial asthma and the late stages of chronic bronchitis and pulmonary emphysema. Health effects may depend on synergistic effects with pollutants such as SO_2. (The U.S. EPA air quality standard for total suspended particulates (TSP) was changed in 1987 to a PM-10 (particulates with an aerodynamic diameter of less than 10 μm) after it was realised that particulates with a diameter greater than 10 μm have no apparent health significance).
- the synergistic effects known to exist between SO_2 and particulate matter (Terblanche & Pols, 1994)
- sulphur dioxide (SO_2), which can alter the mechanical function of the upper airway.
- nitrogen oxides (NO_x), Nitrogen dioxide can penetrate deep into the lungs where tissue damage occurs.
- carbon monoxide (CO) which chemically binds with blood haemoglobin, impairing oxygen transport in the blood and causes asphyxiation of body cells.
- other pollutants include organic compounds and trace metals (El-Hinnawi 1981: 17). Although not a pollutant, carbon dioxide emissions are also of concern in view of their contribution to the greenhouse effect.

The type and quantity of pollutants emitted when coal is burnt depend upon its composition; in particular, its sulphur and ash contents. In addition, combustion conditions, such as temperature, ventilation and the design of the stove or other `appliances' (like braziers), influence the quantity of pollutants produced. When coal is ignited, the volatile matter that is distilled off (gases, oils, tars, etc.) constitutes a supply of easily ignitable fuels which enables the combustion of coal to be rapidly and securely established. If the distilled-off volatile matter is not properly ignited, possibly due to lack of air, poor mixing or low temperature, the unburned fuel is emitted as smoke, which represents a high pollutant load (Clark 1990).

Industrial scale coal-burning installations operate at elevated temperatures and hence emit very small quantities of smoke which contain very fine pyrolysed particulate carbon (ibid). In domestic appliances coal burns at much lower temperatures and as a result the volatile matter emitted consists of unpyrolysed or partially pyrolysed liquid tar and oil droplets. It is this difference that makes the domestic smoke (on an equal emission basis) the most damaging of the two types. The adhesive properties of domestic coal smoke means that it tends not to be washed off crops and buildings by rain and also, if inhaled, much of it is deposited in the bronchial passages and lungs (ibid).

3.3 INTERNATIONAL STUDIES OF EXPOSURE LEVELS FROM HOUSEHOLD COAL COMBUSTION

Coal is an important source of fuel for many urban and rural households in China, and a number of studies have attempted to identify the health impacts of its use. Some of these studies have also measured the concentrations of such pollutants as sulphur dioxide, particulates and fluoride (Hong 1992). Many households respond to the high levels of pollution from coal combustion, by moving their coal stoves outdoors, whenever weather permits (ibid: 60). This practice is also found in some Chinese cities, where residents are often forced to use coal while waiting to be connected to the city's piped gas supply. In high rise buildings, even though apartments have kitchens, many residents use their stoves in public corridors and stairwells, thereby lessening indoor air pollution, but creating a massive flue in corridors and stairwells. A study of pollution levels in one such six storey building revealed severe pollution levels, both in the corridors, and outside the building. In general, pollution levels increased from one storey to the next, with SO_2 levels peaking at 2 790 μgm^{-3} on the sixth floor (ibid: 61). By comparison, the WHO guidelines for SO_2 suggest annual levels of 40 – 60 μgm^{-3}, with peak concentrations (in the 98th percentile) not to exceed 100 – 150 μgm^{-3} (McGranahan 1991: 18).

Another study in a small Chinese town called Bisi, measured indoor SO_2 and carbon monoxide (CO) concentrations in kitchens and bedrooms in 4 types of dwelling: single storey houses, two storey houses, low income apartments and traditional single storey houses (Cai 1987 in Hong 1992: 61). As would be expected, pollution was worse in winter than in summer, and in kitchens than in bedrooms. The mean winter indoor concentrations of SO_2 and CO are shown in Table 3-1. From the data, it was apparent that low income apartments experienced the worst pollution levels, and that even in the bedrooms, the WHO's health guidelines were far exceeded for both pollutants.

TABLE 3-1: INDOOR SO_2 AND CO CONCENTRATIONS (MGM^{-3}) DUE TO COAL COMBUSTION IN VARIOUS DWELLINGS IN BISI, CHINA.
Source: Cai 1987, in Hong (1992)

	Single storey houses	*Two storey houses*	*Low income apartments*	*Traditional single storey houses*
SO_2 Kitchen	950	810	2 550	620
SO_2 Bedroom	140	40	700	90
WHO Guideline annual 98th %tile	 40-60 100-150			
CO Kitchen	11 700	14 300	66 800	10 800
CO Bedroom	3 600	1 700	37 900	3 800
WHO Guideline 1 hour 8 hours	 30 000 10 000			

Other studies of Chinese households which use coal for cooking and space heating, have recorded extremely high pollution levels. SO_2 concentrations of up to 5 050 μgm^{-3} have been reported (33 times higher than China's hygienic standard), with the highest indoor particulate measurement being 2 450 μgm^{-3} (16 times the standard) (Hong 1992: 62). The fact that concentrations are far higher in kitchens than in bedrooms, again suggests that women and infants who spend the most time in the kitchen, have the highest exposure to air pollution and are therefore at greatest risk of suffering ill effects.

Health effects of coal combustion

One of the most dramatic incidences of health-endangering air pollution occurred during the 'killer smog' episodes in London during 1952. Thousands of deaths were attributed largely to the high levels of smoke and sulphur dioxide which were emitted from domestic coal stoves (WHO 1992a: 36, 47). The London smogs of the 1950s featured high levels of 'particulate acidity', measurable in the form of sulphuric acid. The acid formed in the atmosphere, in the presence of fog, giving rise to sulphuric acid concentrations of about 680 μgm^{-3}.

Associations between air pollution (SO_2, smoke and other pollutants) and increased morbidity and mortality have also been reported in Athens. Although its pollution derives from oil-burning boilers, poorly controlled diesel vehicles, and other industrial and vehicle emissions, the pollutants produced are similar to those emitted in coal combustion. Studies of daily deaths in Athens have indicated small changes when 24 hour mean SO_2 concentrations are 150 μgm^{-3} and upwards (with individual site concentrations reaching 1 000 μgm^{-3}) (ibid: 46). Other epidemiological studies have indicated that increases in morbidity, as measured by the prevalence of respiratory symptoms in adults or children and the frequency of respiratory illness in children, become detectable with mean annual concentrations of sulphur dioxide in excess of 100 μgm^{-3}, together with particulate concentrations at the same level (ibid: 47).

Epidemiological studies of coal-using households in China, have identified numerous adverse health effects. In one study, 213 women aged 50-70 years were studied for lung function impairment, and it was found that, after adjusting for confounding factors such as smoking, a statistically significant difference was detected between those women exposed to emissions from coal, and another group exposed to gas emissions (in Terblanche et al 1992a: 25). Similarly, a study conducted in Shanghai, China, involving 1316 persons using coal stoves and 721 using gas stoves, found a 79% prevalence of respiratory illness amongst the coal users, compared to a 44% prevalence in gas users (ibid). The same study concluded that the (women) cooks had almost double the risk of developing respiratory diseases than gas users. In another study involving 12 037 people in Shanghai, it was found that illnesses such as chronic bronchitis, emphysema, cough, expectoration and shortness of breath, were 1.8 to 4.5 times more common among those exposed to coal smoke than among gas users (ibid: 26). Hong (1992: 64) also reported that in a study among 5 668 subjects in coal-using houses, a logistic regression analysis found that, aside from smoking, domestic use of coal for cooking was the most important single risk factor for chronic obstructive pulmonary diseases (COPD).

Several Chinese studies have found strong links between lung cancer and exposure to air pollution from coal stoves. In a case-control study in Haerbin, north-eastern China, 55 women aged 30 – 69 years, who had lung cancer, were matched with women of the same age, but free from the disease. The study found that annual coal consumption per square metre of living quarters floor space (mg/m^2/yr) was the most important contributive environmental factor to the form of lung cancer suffered by the women. The role of biomass fuels, such as firewood, straw and tree bark, was found to be much smaller (Wong et al 1989 in Hong 1992: 69).

In northern China, which experiences very cold winters, many houses use heated beds, called `kongs'. A kong is a brick bed under which heated smoke from coal, firewood, crop residue or other kind of fuel is passed through pipes before venting to the outside. When the fuel is burned directly under the bed, then this is termed a `directly fired kong' (Hong 1992: 70). A study during 1985 – 1987 of all newly diagnosed cases of primary lung cancer among residents of Shenyang in northern China, involved 1 249 patients with lung cancer and 1 345 controls (Xu et al 1989, in Hong 1992: 69-70). Though tobacco smoking was the dominant cause of lung cancer in Shenyang, significant associations were found between lung cancer and measures of indoor air pollution. Risks were 50 – 70% higher among those who spent most of their lives in houses heated by coal and who used coal for domestic cooking. Persons who slept on directly fired kongs, and those who cooked in their sleeping quarters had higher risks of lung cancer than those who did not.

Another striking case of female lung cancer was found in Xuanwei county, a mountainous plateau in south-western China, where less than 1% of women smoke (He 1988, in Hong 1992: 72-73). The ratio of male to female lung cancer mortality in China as a whole, is 2: 1 (probably linked to the higher smoking rates for men). In Xuanwei county, however, this ratio is much smaller, and even inverted in some areas; moreover, the incidence of lung cancer is far higher than the national average (see Table 3-2).

TABLE 3-2: ANNUAL LUNG CANCER MORTALITY RATES (PER 100 000) AGE ADJUSTED TO 1964 CHINESE POPULATION CENSUS DATA.
Source: Hong (1992)

	Males	*Females*
China (1973 - 1975)	6.8	3.2
Yunnan Province (1973 - 1975)	4.3	1.5
Xuanwei county (1973 - 1979)	27.7	25.3
Three high lung cancer mortality townships in Xuanwei (1973 - 1979)	118.0	125.6

The high rates of lung cancer in Xuanwei county were related to the fuel usage of households: either bituminous coal, anthracite or firewood. The cooking device used in Xuanwei is called a 'fire pit'. This comprises a shallow pit dug in the centre of the living quarters, with a few bricks laid out in the centre of the pit to form some kind of makeshift stove in which fuel is burnt. Daily coal consumption is around 20 kg per stove. As the 'stove' is unvented and combustion incomplete, indoor air pollution conditions were reported to be 'staggering'.

Combustion of coal contributes to several other ill effects on people's health, such as skeletal and dental fluorosis, birth defects and reduced immunological defences (Hong 1992; Terblanche et al 1992a). The findings of the health studies referred to in this section, suggest that domestic coal users are exposed to very high risks of serious illnesses. Taking into account the costs of coal usage in terms of ill health and the suffering that accompanies it, loss of productivity due to illness, and higher mortality, it is clear that coal use carries with it enormous social and health costs. These costs are generally borne by those exposed to the effects of coal use: in the first instance, women cooks and their infants, and secondly, other members of their households or families. In the South African context, as will be discussed below, coal users fall into the poorer sections of society; the costs of energy-related ill health therefore fall most heavily on the poor.

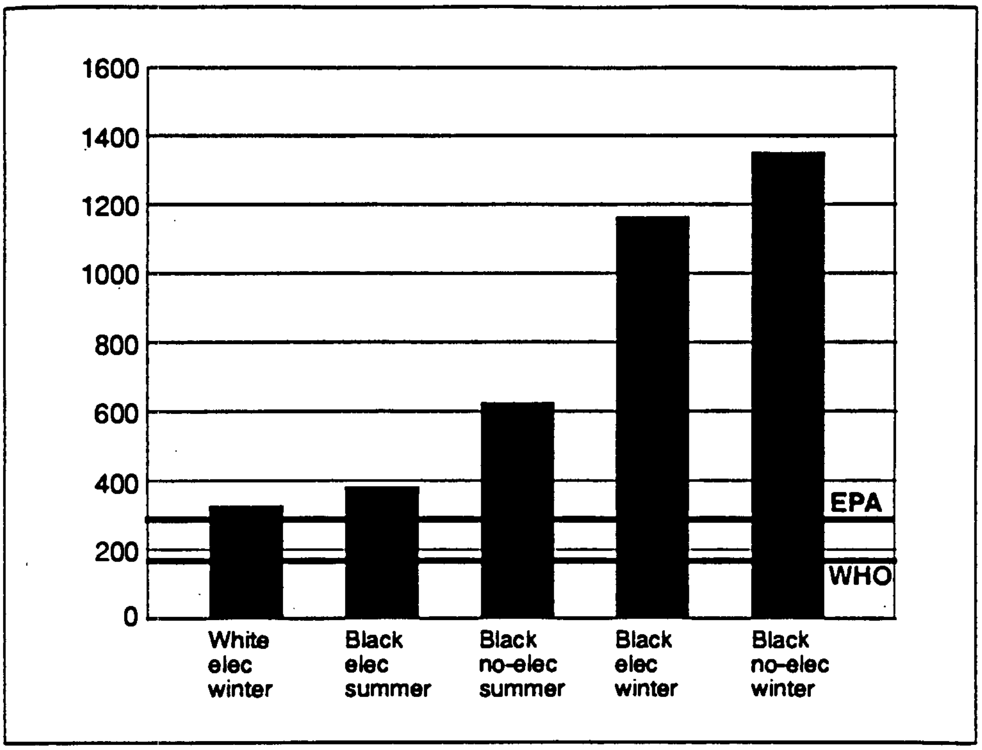
3.4 INDOOR AIR QUALITY IN URBAN COAL BURNING HOUSEHOLDS IN SOUTH AFRICA

The mixture of fuels used by poor households produces a range of impacts on their indoor air environment. The most serious of these in the South African urban context, results from the combustion of household bituminous coal - the fuel used by the majority of poor households in Gauteng. The average sulphur content of local coal (about 1%), is fairly low by world standards, but its ash content is especially high, ranging from 15-50% and averaging around 25% (Lawrence 1990: 32). Although the combustion of coal emits a number of pollutants which have serious impacts on indoor air quality, particularly as many have no chimneys or are poorly ventilated, the most serious of these pollutants is particulate matter, in terms of both the extent of its emission, and the ambient levels which occur in homes.

Pollution studies in South Africa have historically measured ambient levels of pollutants at fixed monitoring stations (Turner et al 1984; Kemeny et al 1988). Only recently have some pollution and health studies utilised the total exposure assessment (TEA) approach, which recognises that the health effects suffered by people are a function of both the concentration of pollutants in the air, and the duration of exposure (Smith 1988: 17). The response therefore is to measure the personal exposures of study participants to the pollutants under examination, and simultaneously to gather information regarding their movement patterns. Inevitably, the data derived includes not only indoor exposure levels, but also exposures during outdoor activities. A recent study of school children aged 8 to 12 years in the Vaal Triangle, south of Johannesburg, indicated that the median time spent indoors was about 75%, which is less than the 80 to 90% spent indoors by boys in the USA (Terblanche et al 1992b: 553).

The first personal exposure studies in South Africa were conducted in 1991 by the Council for Scientific and Industrial Research (CSIR) and the Medical Research Council (MRC). In one component of the project, a group of 45 black children, aged 8 to 12 living in and near Sebokeng, carried personal exposure monitors which collected data on their exposures to air pollution (Terblanche et al 1992a: 41-3). The results indicated extremely high levels of exposure to total suspended particulates (TSPs), with 12 hour levels exceeding the USA Environmental Protection Agency (EPA) 24 hour standard of 260 μgm^{-3} in 99% of cases. Every single case exceeded the World Health Organisation (WHO) 'lowest-observed-effect' level of 180 μgm^{-3} (this is the lowest level at which health effects have been observed). Average concentrations on a summer weekend day were 387 μgm^{-3} and 620 μgm^{-3} for electrified and non-electrified areas respectively. As expected, increased coal consumption in winter was reflected in higher exposure levels. Average concentrations on a winter weekday were 1 168 μgm^{-3} in electrified areas and 1 363 μgm^{-3} in non-electrified areas. This relatively small difference between electrified and non-electrified areas was an important finding and was attributed to the close spatial proximity of electrified, partially electrified and non-electrified areas, and to the high background pollution levels caused by low-level coal burning in areas where dispersal conditions are unfavourable. These findings suggest that only widespread electrification, which is accompanied by changes in appliance-fuel combinations, will have the effect of reducing people's particulate exposures to acceptable levels.

FIGURE 3-1: AVERAGE 12 HOUR EXPOSURES TO TOTAL SUSPENDED PARTICULATE (TSP) CONCENTRATIONS IN GAUTENG RESIDENTIAL AREAS.



Interesting comparisons can be made with a similar study, the Vaal Triangle Air Pollution Health Study (VAPS), which aims to assess whether South Africa's air pollution control programme adequately protects human health (Terblanche et al 1992b: 550). As part of VAPS, the exposure levels of white children in primary schools in Gauteng were recorded (refer to Figure 3.1). These revealed levels of TSPs well below those experienced by black school children. Nonetheless, 63% of exposures exceeded the EPA 24 hour standard, with the median level on a winter school day being 310 μgm^{-3} (Terblanche et al 1992b: 553). These children came from homes which were fully electrified, which again suggests that background pollution levels are very high.

The research results described above have concentrated on only one aspect of the indoor air environment: exposures of children in Gauteng to particulate matter. This probably represents the most serious energy-related hazard to urban poor in South Africa. Nonetheless, a range of other pollutants are also produced by coal combustion, such as sulphur dioxide, carbon monoxide, nitrogen dioxide, polycyclic aromatic hydrocarbons and benzo(a)pyrene (Terblanche et al 1992a: 17). Some of the consequences of exposure to these emissions has been described in section 3.2 and 3.3 of this chapter.

As part of its "Transitional Fuels Programme" the DMEA commissioned the CSIR and the Medical Research Council to undertake work on "health and safety aspects of transitional fuel use". One section of this research was a study of black children in Sebokeng and Lekoa which provided an indication of the indoor pollution levels associated with domestic coal usage (Terblanche, Nel & Danford, 1993a). Results of the stationary indoor monitoring programme are given in Tables 3-3 and 3-4.

TABLE 3-3: MAXIMUM HOURLY AVERAGES FOR SPECIFIC POLLUTANTS MEASURED INDOORS IN COAL USING HOUSEHOLDS DURING THE WINTER OF 1992 (Source: Terblanche, Nel & Danford, 1993a:21)

*Pollutant**	*Concentration [Parts/million]*	*Sample*
SO_2	3.28	15
NO_2	0.46	15
CO	145.00	15

* *The hourly health standards for these three pollutants are: SO_2 0.40 ppm, NO_2 0.60 ppm and CO 35 ppm.*

TABLE 3-4: 12 HOUR AVERAGE CONCENTRATIONS OF TSP MEASURED INSIDE COAL BURNING HOUSEHOLDS DURING WINTER OF 1992 (Source: Terblanche, Nel & Danford, 1993a: 22)

*μg/m³ **	*Sample*
750 (161 - 1568)	27

* *The 24-hour USA health standard is 260 μg/m3, based on high volume sampling methods. Recommended exposure limits based on personal exposure monitoring is 50 times below the occupational exposure limit of 10 mg/m³ (thus 200 μg/m³)*

What is clear from the work which has been done on indoor air quality in South Africa, is that the poor, who rely most heavily on dirtier and less efficient fuels, are exposed to extremely high levels of indoor air pollution. While only information on pollution levels in coal burning households has been presented in this synthesis, there is increasing evidence that even higher concentrations of TSP matter occur in wood-burning rural households of South Africa. The exposures which have been documented thus far in coal burning households, are well above the health guidelines of the WHO and EPA; the impact of these on people's health and safety are discussed later in this chapter (see section 3.6)

3.5 OUTDOOR AIR QUALITY IN BLACK URBAN AREAS IN GAUTENG

The earliest monitoring of air quality in South Africa commenced in 1955, but the concentration of financial resources in wealthier white local authorities, and the ignored needs of disenfranchised township dwellers, meant that this monitoring was based mostly in city centres. Some surveys were undertaken in Soweto township in the 1970s, but a recent review of the available air quality data in black urban residential areas of South Africa showed it to be limited in scope and intermittent (Sithole et al 1994a). A more comprehensive picture of township air pollution emerged in the 1980s when various monitoring programmes were established in Soweto (Turner et al 1984; Kemeny 1988). The scope of these programmes has since widened to include not only sulphur dioxide and particulates, but also nitrogen oxides, carbon monoxide, ozone, and other pollutants (Tosen et al 1991). Recently, similar studies have been carried out in other coal-burning areas in the PWV region, such as Sharpeville. The results of all of these studies present a bleak view of air quality in townships.

Soweto's air quality has been studied more widely than that of any other township in South Africa, partly because its air is so heavily polluted, and partly because electrification was expected to bring about substantial improvements. For various reasons which have been explored in Chapter 2 (Section 2.4) of this report, coal continues to be used on a large scale in Soweto and, consequently, air pollution problems remain serious.

Eskom commenced its monitoring programme in Soweto in June 1983. Results from the first few months of operation showed that concentrations of TSPs frequently exceeded the EPA's primary and secondary 24 hour standards (Turner et al 1984). Long term sulphur dioxide (SO_2) levels approached the EPA standards, while nitrogen dioxide (NO_2) levels were well within the limits. Measurements carried out from August 1990 to July 1991 by Eskom again revealed that concentrations of particulates were unacceptably high. The mean annual concentration of fine particulate matter (FPM) over this period was 112 μgm^{-3}, more than double the US standard of 50 μgm^{-3} (Turner & Lynch 1992: 2). In addition, there were 84 days during the year under examination in which the 24 hour EPA standard was exceeded (Sithole et al 1991: 7). Strong seasonal and diurnal fluctuations in concentrations confirm that particulate pollution is closely related to household coal usage patterns (Figures 3.2 and 3.3), as well as to the dust created by vehicles travelling on unpaved roads.

Levels of gaseous pollutants were also monitored, and it was found that SO_2 levels followed similar cyclical profiles — winter levels far higher than those in summer, and strong morning and evening peaks. The measurements recorded were mostly within the health guidelines, although these were occasionally exceeded during winter. While NO_x levels were higher than those of SO_2, they were well within the government's health guidelines. The diurnal and seasonal distribution of NO_x suggested that the bulk of this pollutant is derived from the extensive vehicular traffic in the township.

FIGURE 3.2 MONTHLY MEAN FINE PARTICULATE MATTER (FPM) CONCENTRATIONS, SOWETO AUGUST 1990 TO JULY 1991. Source: *Turner & Lynch (1992)*

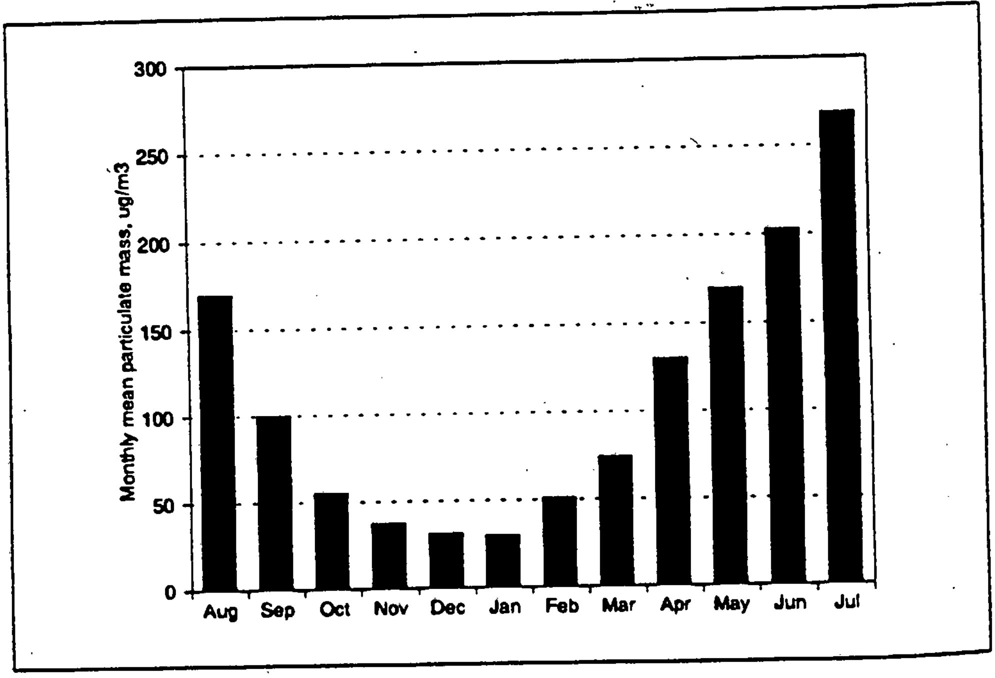
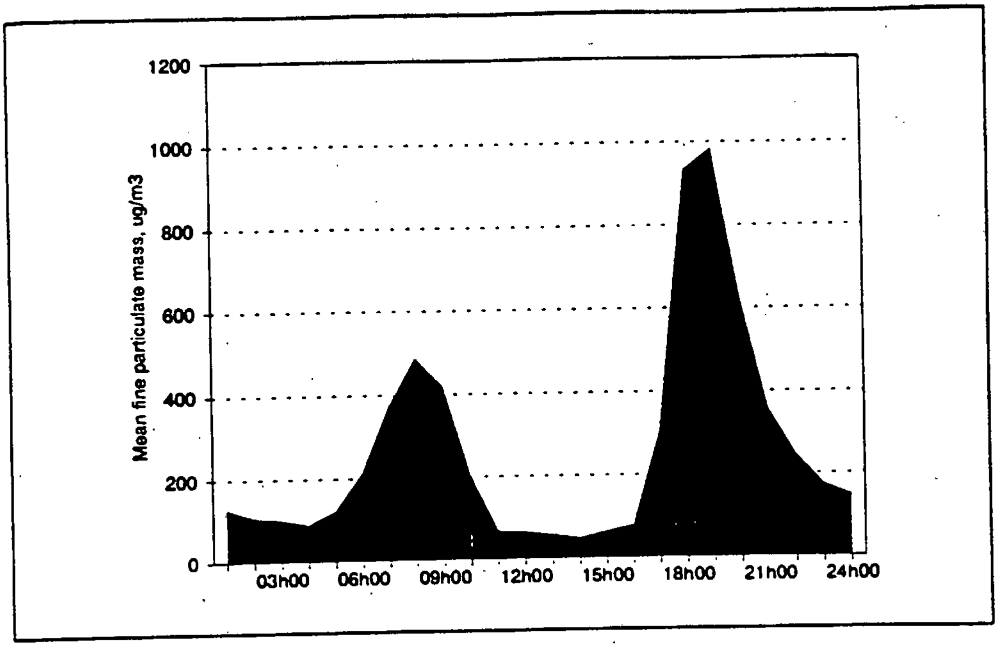


FIGURE 3.3 DIURNAL DISTRIBUTION OF FINE PARTICULATE MATTER CONCENTRATIONS *Source: Turner & Lynch (1992)*



The Soweto Air Monitoring Project (Project SAM), initiated in 1991 under the auspices of the Soweto branch of the National Association of Clean Air (NACA), was devised to establish an air pollution monitoring network which would provide a particulate air quality data base extending over multiple years and several sites, which could be used as input to health related studies and environmental policy decisions. The fields of study covered indoor air, gaseous pollution, environmental particulate levels, asbestos and health (Sithole 1994a). Of interest to this synthesis are the results of the *airborne particulate* monitoring show that:

- Monthly average concentrations of *fine particle mass* (aero-dynamic diameter < 2.5 μm) for the period Dec 1991 to March 1994 showed no seasonal variation and did not vary by more than a factor of 2. Hence the generation of fine particles by industry and conversion sulphate aerosol from coal fired power generation is fairly uniform with time and independent of season. Fine particles also have a longer atmospheric residence time and may reflect contributions of regional sources rather than local Sowetan sources.
- In contrast, monthly average *coarse particle concentrations* showed distinct seasonal variations with maxima during the cold winter months. With the onset of spring, coarse particle pollutant levels decreased sharply with the decrease appearing to be dependent on the onset of the spring rains.
- Pollution levels measured over the two years show that Department of National Health and Population Development guide-line values for suspended particulate matter were exceeded for 20 % of the year, mainly during winter. A comparison of maximum 24-hour concentrations against the US EPA standard for PM-10 concentrations (250 $\mu g/m^3$) showed that exceedences occurred on 109 days (30%) during 1992 and 97 days (27%) during 1993).

Project SAM also undertook analysis of selected samples for elemental composition which showed that some of the sources may be beyond the borders of Soweto. The following source types were identified (ibid):

• Coal burning	Domestic heating and cooking.
• Heavy metals: Ni, Cu, Zn, Pb	Indiscriminate garbage burning.
• Soil dust	Resuspended by wind and by traffic on paved and unpaved roads
• Automobile exhaust	Leaded fuel combustion.
• Biomass burning	Wood fires and veld fires.
• Conversion sulphur	SO_4 aerosol from SO2 gas emissions.
• Iron, excess	Source process unknown.
• Calcium, excess	Source process unknown.

Inorganic components, converted to oxides accounted for from 25% to 50% of particulate mass. The remainder of the gravimetric mass is assumed to be made up of elemental carbon and organic compounds, with a minor component of water. Coal burning is assumed to be the main source of these unanalysed carbonaceous components (ibid).

In summary Sithole et al (1994a) state that the "evaluation of particle concentrations in the atmosphere of greater Soweto have established quantitatively that the air quality guidelines for the protection of human health are exceeded for 70 to 100 days per year. The US Environmental Protection Agency standards permit no more than one exceedence per year." Consequently they "conclude that the particulate air quality in greater Soweto constitutes an unacceptable environmental health risk and requires urgent attention to preserve the health and economic prosperity of the entire region"

The Vaal Triangle Air Pollution Study described earlier also has an outdoor component, with two continuous monitoring stations, one in Sharpeville, a coal-burning township, and the other at Makalu, situated downwind of major industrial sources of pollution (Terblanche et al 1992b: 553). The preliminary results from these stations revealed high levels of particulates in Sharpeville, with a very strong daily cyclical pattern which reflects the living habits and energy requirements of residents. Climatological conditions are extremely unfavourable for the dispersal of pollutants emitted close to ground level because of the presence of stable inversions, which are especially strong in winter. The site at Makalu, by contrast, is affected by high-level emissions which are transported over greater distances, and shows much smaller diurnal variation due to better mixing of pollutants in the atmosphere (Figures 3.4 and 3.5).

FIGURE 3.4 DIURNAL DISTRIBUTION OF FINE PARTICULATE MATTER CONCENTRATIONS, SHARPEVILLE, MARCH TO JULY 1991

Source: Terblanche et al (1992b)

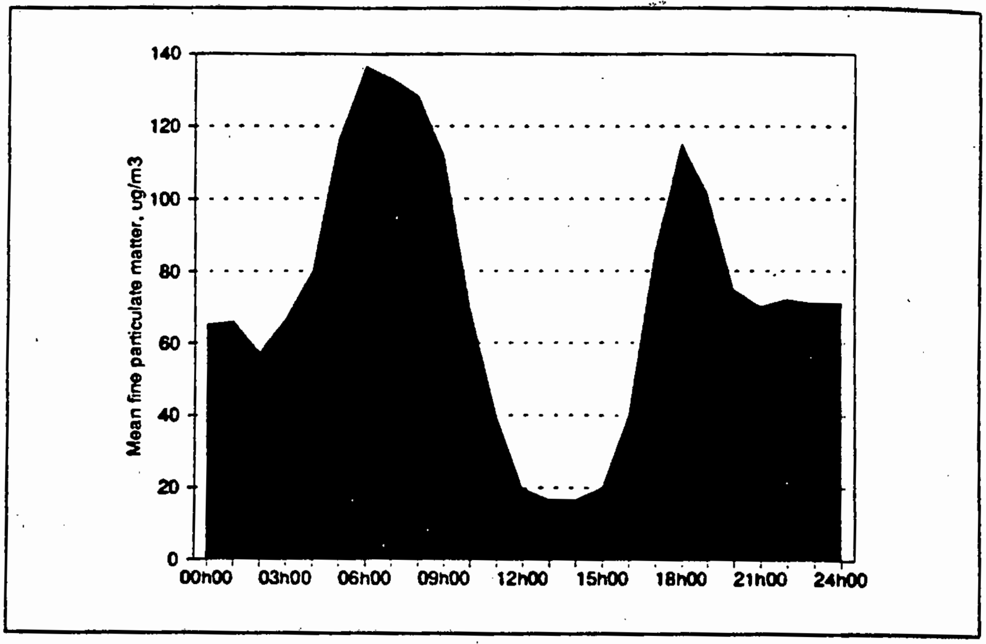
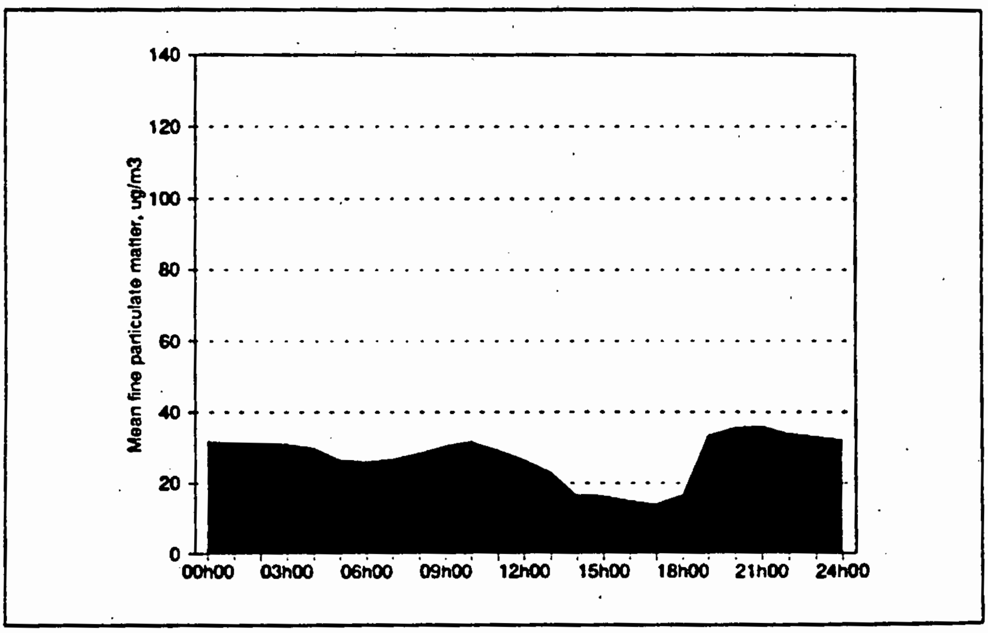


FIGURE 3.5 DIURNAL DISTRIBUTION OF FINE PARTICULATE MATTER CONCENTRATIONS, MAKALU, MARCH TO JULY 1991

Source: Terblanche et al (1992b)



The levels of gaseous pollutants (SO_2, NO_x) monitored at both sites were within the government's health guidelines, but their diurnal profiles followed similar patterns to those for particulates (ibid). These findings confirmed that emissions in Gauteng townships such as Sharpeville come from low level sources, and are closely related to people's daily living patterns. The results from Makalu indicate high background pollution levels.

3.6 HEALTH IMPACTS OF HOUSEHOLD BITUMINOUS COAL USE

Medical research indicates that acute respiratory infections (ARI) constitute the second most important cause of death in South African children, after gastro-related illnesses (Von Schirnding et al 1991: 81). In Cape Town, ARI (specifically, pneumonia) is the leading cause of infant mortality. Both international and local experience has found strong links between air pollution and the incidence of respiratory illnesses. Significant difficulties exist, however, in attempting to establish definitive cause-effect relationships between air pollution and human health. Some of the problematic factors include spatial and temporal variability in pollution levels, subjective symptom reporting, long latency periods of health outcomes, and confounding factors such as parental smoking (Terblanche et al 1992b: 552). Nonetheless, several epidemiological studies conducted in South Africa have demonstrated harmful health effects associated with pollution exposures.

A case-control study of children in the Eastern Transvaal highveld (ETH) attempted to determine whether exposure to ambient pollution resulted in any detectable effects on their respiratory status (Zwi et al 1990: 647). The study compared 1 031 white children from schools in the ETH with a control group of 978 children from less polluted towns in the former Transvaal. The exposed children experienced higher incidences of respiratory symptoms than the control group, and after correcting for age, the exposed children were found to be slightly (0.83 cm) shorter on average. While this could be attributable to other factors such as parental smoking and genetic make-up, this finding confirmed a similar observation in an earlier study by Coetzee et al (1986: 339).

In the latter study, a group of white children from schools in the heavily industrialised Sasolburg area, were compared with a control group of children from nearby rural towns where pollution was negligible (ibid: 339-343). Questionnaires were administered to 674 children in Sasolburg and 332 from the control group, and found no important differences in the reported incidence of respiratory illness. There was however, a significant difference between boys in the two groups, in the most important measure of lung function: forced expiratory volume in 1 second (FEV_1). Other measures of lung function were also found to be slightly worse in the study area. Children in the control area were bigger (height and mass) than those from the study area, and in the case of boys, this difference was significant. The results of the study indicated that the trends were unlikely to be affected by smoking habits of the families, but that social class from which the children originated may have been a contributory factor (ibid: 339).

Some of the uncertainty inherent in such case-control epidemiological studies can be accounted for in longitudinal or follow-up studies, which hold a better chance of identifying true relationships between pollution exposures and observed health effects. Two such projects have been undertaken in South Africa: the VAPS project referred to earlier, and the Birth to Ten project. The latter is a multi-faceted study which is monitoring the health status of approximately 4 000 children born in Johannesburg and Soweto between 23 April and 10 June 1990 (Yach et al 1991: 212). Amongst other objectives, it aims to study the environmental factors that are associated with the survival and health of children, with major interception points occurring at 6 months, 1, 2, 6 and 10 years (Von Schirnding & Mokoetle 1991: 4). This study is expected to provide important insights into the effects of South Africa's historically racially segregated health and social services on the physical and psychological health of this generation.

The CSIR/MRC study (commissioned by the DMEA) of black children in Sebokeng and Lekoa referred to in section 3.4 (and provided measurements of indoor pollution levels) has also provided an indication of the adverse health effects associated with domestic coal usage. A health survey was conducted with mothers of 1 563 children aged 8 to 12 years, living in townships in Gauteng. Coal was found to be the main fuel for cooking and heating, and was used by over 50% of households (Terblanche et al 1992a: 52-53). The study examined the prevalence of respiratory illness of participants living in three areas: those without electricity (using mainly coal), partially electrified areas (mixed fuel use), and fully electrified areas (electricity only).

Respiratory symptoms were classified as either lower respiratory illness (LRI, defined as presence of bronchitis, pneumonia, asthma, phlegm, coughing and chest wheezing during the past two months), or upper respiratory illness (URI, defined as presence of a running nose, earache and sinusitis during the past two months) (ibid: 58-9). The results of the health survey indicated that children from homes which used coal for cooking had a 120% higher prevalence of URI than those which used paraffin (ibid: 60). The general trend in the data pointed towards higher prevalence of URI in groups using coal, than those using electricity or paraffin. The prevalence of LRI indicated the same pattern as for URI: that is, coal users had higher risks. Significantly, ***the health survey was carried out in summer*** which represents the most favourable possible outcome, as pollution exposure levels are at their lowest.

Where coal was the primary domestic fuel, it was found to be the most significant predictor of respiratory illnesses when compared to crowding, socio-economic status and parental smoking. This corresponded with the perceptions of the participants, the majority of whom perceived that domestic coal burning was the primary source of air pollution, followed by motor vehicle emissions (ibid: 55). On the whole, therefore, the study found that a higher prevalence of upper and lower respiratory illness was associated with use of coal, compared to electricity, paraffin and gas.

A second phase of the CSIR/MRC project described above, undertook a similar survey during the winter months of 1992 . Results showed that, overall winter exposures were higher than summer exposures for all pollutants monitored and the prevalence of LRI and URI increased during winter (Terblanche, Nel & Danford, 1993:98 & 99). The urban winter population was selected from three different areas, unelectrified, partially electrified and a completely electrified area. Despite the availability of electricity in the partially electrified areas, up to 45% of households still use coal for coking and heating (ibid:99). Results from the above study were used to provide a "characterisation of risk factors associated with coal usage" showed that:

- children living in homes utilising electricity instead of coal, have up to 9.3 times lower risk of developing URI,
- electricity use is associated with lower risk than coal, wood or paraffin, and
- electricity and gas used together have a 4.2 times lower risk than coal (Terblanche & Pols, 1994:3).

A more recent study reported by Nel et. al. (1994) and undertaken as a collaborative effort between the MRC, the CSIR and Pretoria Technicon, in the coal burning community of Sebokeng in August 1993, aimed to investigate some of the variables affecting the respiratory health of 8-12 year old children in coal-burning households. The variables investigated included:

- the condition of the coal stoves,
- exposure to wood and/or coal smoke,
- quality of coal (the coal used varied in size only, but there is a perception amongst users that the size of the lump coal used has an influence on the quantity of smoke emitted),
- type of cooking facility, and
- ventilation in the kitchen.

Results showed the following:

- children living in a home where the coal stove was in a poor condition (as opposed to a stove in good condition) had a 1.16 times higher risk of developing lower respiratory symptoms and illness.
- children who were exposed daily to wood and /or coal smoke (as opposed to those who were not exposed) had a 1.8 times higher risk of developing upper respiratory symptoms and illnesses(URI).
- children living in homes where braziers were used (as opposed to a coal stove) had a 3.33 times higher risk of developing URI.
- the "quality" of the coal used and the ventilation characteristics of the structure had minor influence.

An important message from these results is that it is not "simply the burning of coal" that causes the most serious health impacts but rather sub-groups of coal burning households that are predisposed to the highest risk of developing respiratory illnesses. The fact that the use of braziers rather than coal stoves with chimneys results in a 3.33 times higher risk of children developing URI indicates that there are options in addition to the use of low smoke coals for improving the health status of children in coal burning homes. This discussion is taken up further in chapter 6 of this report when policy issues with regard to the implementation of a low smoke coal policy are considered.

3.7 THE CONTRIBUTION OF HOUSEHOLD BITUMINOUS COAL COMBUSTION TO TOTAL SUSPENDED PARTICULATES

Potential atmospheric pollution can be traced and studied with considerable accuracy at the point of emission from say a coal burning power station, a household coal fire or a motor car engine, but after the pollutants have emerged into the open air, their individuality begins to be lost and they rapidly become unidentifiable among the host of other pollution elements. Thus it is extremely difficult to ascertain the source of pollutants that are captured in monitoring exercises, especially in situations where there are multiple possible sources in the surrounding area. Thus although the results of the air quality monitoring in Soweto (which have been described in section 3.5 of this chapter) show that emissions from the combustion of household coal are "assumed" to be a major contributor to overall TSP measured, the contribution has not been quantified.

An approach to dealing with this problem is to develop an inventory of all the identifiable pollution sources in a given area and over a given time. If it is known what pollutants are being emitted at each source and in what quantities, it is then possible to theoretically calculate the relative contributions of each of the source to the overall concentration. Van Nierop (1994) has developed "an inventory of particulate air pollution in the Vaal Triangle" which includes a large number of coal burning residential areas in addition to a high density of industries. There are, as can be imagined, immense problems in quantifying emissions from many of the sources and this is particularly so for the calculation of emissions from household coal combustion. To estimate the emissions it is necessary to know how many households there are in the area, how many use coal, the quantity of coal burned by each home and then to multiply the total coal usage by an emission factor (grams of particulates per kilogram of coal burned). Apart from the problem of having no accurate house counts for the area, nor an accurate statistic for the quantity of coal consumed per home, there were also no emission factors for South African coal stoves. Notwithstanding these many problems the results of the study are indicative of the contribution of household coal use to the overall air pollution problem in the Vaal Triangle. Table 3-5 shows total Vaal Triangle emissions for 1992.

TABLE 3- 5: VAAL TRIANGLE TOTAL PARTICULATE EMISSIONS (van Nierop 1994)

SOURCE DESCRIPTION	*TSP*			*PM-10*		
	Annual Emissions [tons]	*% of Total*	*Fractional Uncertainty*	*Annual Emissions [tons]*	*% of Total*	*Fractional Uncertainty*
POINT SOURCES						
Primary iron and steel	21870	16	-	7178	13	-
Open cast coal mining	14239	10	-	4968	9	-
Secondary iron and steel	10343	8	-	5078	9	-
Power generation	8753	6	-	5781	10	-
Fertilizer manufacture	7491	5	-	3654	7	-
Chemicals manufacture	5591	4	-	2207	4	-
Brick and tile manufacture	5016	4	-	1904	3	-
Other industries	6121	4	-	3104	6	-
POINT SOURCES TOTAL	**79424**	**58**	-	**33875**	**61**	-
AREA SOURCES						
Household coal combustion	2128	2	0.31	872	2	0.36
Household combustion- other fuels	394	0	0.33	387	1	0.36
Industrial coal combustion	4444	3	0.23	1801	3	0.23
Industrial combustion - other fuels	430	0	0.21	165	0	0.20
Veld fires	759	1	0.82	759	1	0.82
Agricultural activities	2886	2	0.41	683	1	0.38
Heavy construction	278	0	0.60	97	0	0.68
Paved roads fugitive dust	27583	20	0.55	9908	18	0.55
Unpaved roads fugitive dust	17964	13	1.01	6467	12	1.02
Mobile (exhaust, brake & tyre wear)	891	1	0.43	837	1	0.43
AREA SOURCE TOTALS	**57757**	**42**	**0.41**	**21977**	**39**	**0.39**
TOTAL INVENTORY	**137180**	**100**		**55852**	**100**	

The immediate most striking feature of the above table is that household coal combustion only contributes 2% of both TSP and PM-10 particulates. It is obviously possible to point to all the errors in the exercise that led to the above table and it is evident from the table that an inventory undertaken in an area with lower industrial activity would cause household coal combustion to be more prominent. Also the results are an annual average and give no indication of temporal and seasonal peaks in pollutant as are known to occur indoors in coal burning homes. Nevertheless the results should be borne in mind if there is any expectation that low smoke coal can provide more than a short term solution to a localised problem.

3.8 COST OF AIR POLLUTION FROM HOUSEHOLD COAL USE

The environmental problems encountered by the urban and rural poor result in huge costs to the country and to the poor themselves, both in terms of direct costs incurred, for example on health care, and in foregone opportunities, such as early death, low productivity and time wasted in domestic tasks. These costs are especially significant because of the large number of people involved: essentially all coal using households, containing about 5 million people, are exposed to one or other of these risks, to a greater or lesser extent. Estimating the economic costs of these effects, however, is a highly complex and potentially controversial issue to which justice cannot be done here. Nonetheless, an indication of the order of magnitude of the direct costs of these problems can highlight their potential scale.

Approximately 1 million households, or 5 million people depend on coal for cooking and heating. Clearly, it would be fallacious to assume that *all* of these people are exposed to the same levels of pollution as those reported; however, it is probable, based on the results of the health surveys reported earlier, that many of these people will suffer higher incidences of respiratory ailments as a consequence of their high pollution exposures.

Von Schirnding et al (1991: 79) reported that an average of 2 882 deaths from pneumonia occurred per year from 1980 to 1985 in South Africa, but that the percentage of deaths-to-hospitalised cases of pneumonia is unknown in South Africa. By applying the equivalent Chinese factor to South African deaths, they derived a conservative estimate of 13 000 infants requiring hospitalisation each year. Using an average daily in-patient hospitalisation cost of R250 and an average period of hospitalisation of seven days per case (Deas 1993), this amounts to about R23 million per annum on direct hospitalisation expenditure. This figure, however, probably represents only the tip of the iceberg, as it excludes the larger social costs of ill health:

- the bulk of illness remains unreported in official statistics;
- the costs (however measured) of early death are excluded from this figure;
- the lost productivity due to illness is not quantified even though it results in huge economic losses;
- indirect costs associated with poor health, such as absence from work, less chance of obtaining formal employment, and reduced quality of life, are largely unrecorded.

At the other end of the scale, Viljoen (1992: 12) has estimated that the *direct costs* attributable to poor health from coal-using households in Gauteng could be in the region of R280 million per annum based on, firstly, the direct costs of health care services, and secondly, foregone production by employees . Whilst these figures were derived from simplistic calculations, they are so significant as to indicate that a more thorough analysis is warranted. This becomes particularly evident when mortality rates due to respiratory illnesses for South African children are compared with children from Western Europe: white South African children have a mortality rate about 7 times higher, while the rate for black children is higher by a factor of 270 times (Von Schirnding 1991: 79). In South Africa, acute respiratory illnesses (such as pneumonia) are the second highest cause of infant mortality after diarrhoea-related diseases. Moreover, the use of coal has been implicated directly in the high incidence of respiratory problems in children (Terblanche et al 1992, 1993).

Chapter Four

THE PRODUCTION OF LOW SMOKE COAL

4.1 INTRODUCTION

In the recent past considerable research and development work has been conducted in South Africa by commercial organisations, government institutions and universities in an effort to produce a low smoke fuel appropriate for the South African market. The concept and technology required to produce low smoke fuels is not new and has been utilised successfully on a large scale in a number of other countries. The challenge in South African has been, and still is, to develop a specific fuel (or fuels) that utilises locally available feedstocks and at the same time competes, on a price basis, with the presently used household bituminous coal.

As a background, the first section of this chapter will provide a brief description of experience with low smoke fuels in a few other countries. Of particular interest in examining international experience, are cases where low smoke coal products have developed to a point where they have actually been introduced into the market.

We will then present a description of early low smoke coal initiatives in South Africa before focusing on the main objective of the chapter; a description of products presently being developed in South Africa. The final section of the chapter summarises the present South African approach to low smoke fuel production and notes important characteristics for the technical comparison of the various fuels.

4.2 INTERNATIONAL LOW SMOKE FUEL EXPERIENCE

Although the devolatilisation of coal is a relatively standard process, there is not just one, nor even a small assortment of well-defined technologies for coal briquetting. Rather, a set of parameters - temperature, pressure, pressing time, binder, type of coal, type of press, and pretreatment - can be varied to produce unique briquetting processes. Nevertheless a general description of the steps in briquetting and carbonization processes can be given. These are as follows (Stevenson and Perlack 1989):

- Crushing of the feedstock is performed to obtain a fairly uniform particle size for later pressing.
- Screening to remove particles too large or too small for optimal briquetting.
- The coal may be dried, depending on the binder used.
- If a binder is used, it is added to the coal particles in either solid or liquid form.
- The temperature of the mixture is then adjusted to within a certain range, prior to pressing.
- The material is then pressed by two main types of briquetting machinery, extrusion presses and mould presses. Pressures from under 70 to 5600 kg/cm^2 can be applied.
- After pressing, the briquettes can go through some type of post treatment, such as curing at about 200°C, drying, and/or cooling.
- Carbonization of the fuel then takes place whereby the coal is converted by pyrolysis to a "soft coke" or char. The process is accomplished by heating coal in a controlled atmosphere to a temperature at which it decomposes chemically and/or physically to simpler compounds. When coal is heated to temperatures between 120 and 150°C, moisture is driven off. Between 480 and 600°C, most of the volatiles are driven

off. Between 800 and 1100°C, essentially all the volatiles are driven off and a residue that is highly carbonaceous and difficult to ignite is left (hard coke). The byproducts driven off during carbonization have value in their own right. The off-gasses contain a number of combustible constituents and can be used for fuel or chemical production. Indeed the off-gasses can be used to fuel the carbonization process. The tars and liquors also can be used for fuel or chemical production.

Coal carbonization and briquetting has been researched worldwide since the beginning of this century, and more particularly during the 1950's and early 1960's, in such widely dispersed locations as the United Kingdom, Europe, USSR, Australia, New Zealand, Korea, Japan, India and the USA (Mao 1994, Stevenson and Perlack 1989, LHA 1987). There are several reasons for this wide extent of research. First, all coals are not alike, and often research has been aimed at developing an improved process for a particular coal. In the case of briquetted fuels, they can be produced with or without a binder to achieve the necessary cohesive strength and the method used is largely influenced by the particular feedstock coal. Also, some research has been directed at improving the properties of briquettes, such as maintaining reactivity while keeping volatile matter low, or reducing smoke and sulphur emissions during combustion. However, due to the impact of large scale electrification over the last 25 years the rate of research and development has slowed or stopped in many of these countries (LHA 1987).

Yao (1994) states that coal briquetting has developed into a mature technology, especially in some technically advanced countries with limited natural resources, such as Japan, before these countries became rich enough to switch to high-quality fuels (oil, gas and electricity). Presently briquetting is receiving great attention in developing countries where oil and gas are scarce and the fuelwood supply is diminishing. Output of coal briquettes has increased briskly in India, Pakistan and South Korea and, in China, the output almost tripled during the 1980's. Yoa (1994) also states that research has focused on four main areas; easy ignition, smokeless combustion, reduction of cost and research on stoves for utilising the briquetted fuels.

One of the briefs for the completion of this synthesis is that it should include a review of international technology and provide pertinent case studies where this information is available in South Africa. However, after an on line computerised literature search through three data bases, Energyline, Engineering Information and the American Chemical Society Abstracts, it became evident that there is apparently very little information available in the generally accessible literature. Nevertheless the information that has come to hand is reported below for a selection of countries, and provides some insight into international low smoke coal activities. Also one aspect that came to light from the available literature, with regard to the production of low smoke coals, is that research and development of low smoke fuels in developing countries focuses on briquetting technologies rather than the more capital intensive devolatilisation of lump coal.

The United Kingdom

Given the United Kingdom's former problems with air pollution, significant low smoke coal research and development has been undertaken in the past. The major organisation involved is the Coal Research Establishment (CRE), a section of the British Coal Board, which has accumulated extensive experience in briquetting of coal and also has extensive laboratory and pilot scale equipment for experimentation and testing of briquetted fuels. In recent years the CRE has conducted work for clients with projects in Ireland, Australia, South Africa, Russia, Ukraine and China. Clark (1990) lists a large number of fuels with various compositions that have been, at one time or another, investigated by the Coal Research Establishment (these are listed in Appendix C).

India

A wide range of coal carbonization and briquetting technologies has been employed in India using bituminous, subbituminous and lignite coals, and as a result it has considerable experience in the field.

Technologies range from one-person, 'village coal piles' to advanced carbonization plants (Stevenson and Perlack 1989).

The advanced technology coal carbonization plants are either government pilot plants or commercial plants, modelled on government projects and in addition to producing carbonised coal, they carry out full by-product recovery. The sizes of the advanced technology plants run from pilot scale of 20 to 25 tonnes/day coal input up to full scale plants with designed input capacity of 1500 to 2700 tonnes/day. These large plants, however, have generally not been running to full capacity (ibid).

Intermediate technology plants, where crushed or briquetted coal travels through retorts or on chain grates through a kiln, have an input capacity of between 25 and 100 tonnes/day. The intermediate technology plants, however, practice limited or no by-product recovery and as a result are heavy polluters. Often, the off-gasses are passed through a scrubber, but are then vented to the atmosphere.

The "village coal pile" is the simplest technology of all, and the heaviest polluter. A pile of coal and coal fines is ignited and when the smoking stops, it is water quenched. By removing outer ash, an inner char is found that can be used as a smokeless fuel.

With regard to briquetting, coal fines are used with molasses, bentonite (clay), or an inorganic binder. With the lignite coals, briquetting is performed without a binder and prior to carbonization.

Profitability of the village coal pile and intermediate technology producers is reported as being positive, although at times it is marginal. Costs are reduced by avoiding capital investment to recover by-products. On the other hand the high technology producers must often operate unprofitably for seven, eight or ten years before reaching break even point. The difficulties that plague the larger operations, in addition to the high capital costs, are irregular coal supplies, transportation difficulties, power supply breaks, labour problems and the inability to sell products (ibid).

Researchers at the Central Fuel Research Institute at Dhanbad in India have been involved in the development and refinement of appropriate coal briquetting technologies and in one instance have proposed a process for the production of solid smokeless fuel from high ash washery rejects and middlings, and low grade caking coals and fines, by adopting a low pressure briquetting technology (Sengupta et. al. 1991). The combustion properties and crushing strength of the briquettes compare favourably with conventional smokeless fuels. A feedstock ash content of up to 40% is acceptable and the fuel utilises volcanic clay and starch as a binder. The essential steps for its production include, crushing the feedstock to an optimum fineness, moistening the solid ingredients, mixing with volcanic clay and cooked starch and then compacting the material in a twin roll press at 200 to 240 kg/cm^2. Thereafter the briquettes are left to air dry until they reach an optimum moisture content. The binder holds the shape of the briquettes after discharge from the press, and because the binder is highly hydrophilic, it absorbs moisture from the crushed coal fines. This moisture in the binder, while being driven off in the devolatilisation process, gives the fuel a porous structure leading to complete combustion of all fixed carbon constituents. The fuel is devolatilised in a simply designed and inexpensive retort which utilises the volatiles as fuel for the process. The shape and size (55x45x30mm) of the briquette was found to be critical in providing the necessary porosity and hence the combustion characteristics of the fuel.

Korea

The Koreans have used raw anthracite coal briquettes extensively for cooking and heating for many years. After starting coal briquetting in 1930 there are now approximately 20 large briquetting plants in the country (Stevenson and Perlack 1989). Typical Korean briquettes are comprised of 90% Korean anthracite and 10% Chinese coking coal. The briquettes are very large, weighing 3.6 to 7.5kg. each. The briquettes are pressed at only 12 to 17 kg/cm^2 and do not meet normal briquette compression strength criteria. Also the briquettes fracture when dropped and are in fact only a well compacted coal that is convenient for handling. Because the briquettes have anthracite as a feedstock they do not require carbonization but this also means that this experience cannot be transferred to many other countries.

China

Given China's large population, abundant coal resources and the fact that household bituminous coal is utilised by a large proportion of Chinese families, it is not surprising that there has been a significant amount of research into the consequences of human exposure to pollutants from coal combustion (see Section 3.3 for results from some of this research). A result of this situation has been considerable development on low smoke coals, accessories such as briquette burning stoves, and institutions that support the overall industry. Unfortunately, for the purposes of this synthesis it was not possible to obtain any of the Chinese literature, however, it is evident from a list of English abstracts of Chinese literature on the subject that there is a wealth of information available on subjects as diverse as technical details of briquetting machinery, through the optimum composition of coal briquettes, the design and performance of briquette burning stoves (including stoves with electric power ignition), information on low smoke coal manufacturing associations, the establishment of production networks and a host of other related subjects.

4.3 PAST SOUTH AFRICAN LOW SMOKE COAL DEVELOPMENTS

Low smoke fuels can be classified into two categories: natural and manufactured (LHA 1987). The natural fuels include anthracite, semi-anthracite and lean bituminous coal with a volatile content of less than 16%. Manufactured fuels include products from coal or anthracite such as:

- carbonised lump bituminous coal,
- briquetted anthracite fines or a mixture of anthracite and bituminous coal fines, and
- briquetted and carbonised bituminous coal fines or a mixture of bituminous and anthracite fines.

As mentioned in Chapter 2, anthracite reserves in South Africa are limited and command relatively high prices and hence anthracite is not used by the vast majority of household coal users. Anthracite duff is also becoming increasingly valuable and hence difficult to obtain especially at highly discounted prices (Jabrenski, 1994). Thus lump anthracite or briquetted anthracite discards do not have any potential to replace household bituminous coal in the market.

The following is a chronicle of past research conducted in South Africa.

1. During the 1960's the Fuel Research Institute (FRI) of South Africa carried out research into the production of smokeless solid domestic fuel and formed coke for blast furnace use. This work was prompted primarily by South Africa's shortage of coking coals. Subsequently carbonising and briquetting equipment was installed at the FRI and a number of further research projects were undertaken (LHA, 1987).
2. In 1967 one of these FRI projects investigated the possibility of producing a solid smokeless fuel by briquetting anthracite and bituminous coal fines with pitch as a binder. Unfortunately the reactivity and smoke emission of the briquettes were not tested.
3. At the end of the 1960's, due to the availability of large quantities of discard coal, a general assessment of coal briquetting technologies was undertaken by the FRI. This included high pressure and elevated temperature, binderless techniques which had been developed in England, Germany and Russia (Sander, 1970).
4. Further FRI work focused specifically on hot briquetting, where coal is heated under controlled conditions to a temperature of about 400^{0}C, when it softens and the resulting plastic mass can be briquetted at

relatively low pressure. Again, English, West German, American, Japanese, Russian and Indian processes were reviewed and the report recommended that the "hot briquetting of South African coals be investigated" (Sander, 1973:19).

5. In 1981 the FRI further investigated the possibility of high pressure binderless briquetting of South African coals. Using only a small-scale laboratory briquetting press the work showed that:
   - many South African coals form strong briquettes without the addition of a binder.
   - low volatile lean bituminous coals and anthracite do not produce strong briquettes due to their elastic recovery.
   - rank, maceral composition, moisture content, ash component and the chemical composition of the ash, bulk density and granulometry are all important parameters affecting the ability of a given coal to form strong compacts (LHA 1987).
6. Further work by the Coal Research Institute compared the combustion of Phoenix coal with that of binderless briquettes made from the same coal in a "minimum smoke" stove. Temperature profiles and smoke emissions were analysed and results showed that smoke emissions from the briquettes were only marginally less than that of the lump coal. The briquettes did however have some other advantages. One being that they were more reactive than lump coal, resulting in higher stove plate temperatures. A further advantage was that more complete combustion resulted in fuel savings. The work was of a preliminary nature and it was recommended that further work should be carried out to investigate the effect of utilising briquettes of different sizes, to undertake a more thorough investigation into smoke emissions when burning briquettes as compared to sized coal, and that this work should be limited to the possible use of duff coal for briquette production (Desterkte & Tasker, 1984).

It was not until the latter part of the 1980's, when it became evident that both minimum smoke coals and electrification were not going to effectively deal with the air pollution problem, that low smoke coal was considered as a serious option for reducing air pollution levels. In 1987 the Foundation for Research Development (FRD) of the CSIR, commissioned Louis Heyl and Associates (LHA) to conduct a literature survey of possible suitable low smoke fuels for domestic use. The report provided an assessment of past work on the development of smokeless or low smoke fuels, technology for production of a suitable fuel and a preliminary economic analysis of the production of potential fuels. Some of the past work reported by LHA has been described above. They made first order estimates of the cost of production of low smoke fuels by LHA and compared with the cost of normal coal. These were very rudimentary but are nevertheless given in Table 4-1 and illustrate the large discrepancy between bituminous coal and manufactured alternatives.

TABLE 4-1: LHA ESTIMATES OF THE COST OF PRODUCTION OF LOW SMOKE COAL. (Source: LHA, 1987)

Type of fuel	*Production cost (excludes profit) [R/ton] 1987*
Coal	18.00
Carbonised lump coal	58.20
Carbonised and briquetted fine coal	66.80
Briquetted coal fines	46.25

At the time, 1987, LHA identified three companies involved in the development of low smoke solid fuels. These included Bowco (Utrecht), Industrial Furnace Fuels (Johannesburg), and Brick-A-Crete (Heidelberg). Virtually no information on the three products was reported by LHA and no formal smoke emission tests had been carried out on any of the fuels at the time of the report. There is no subsequent record of these fuels.

In 1990 Clark undertook a study for the National Energy Council (now part of the Department of Mineral and Energy Affairs) which aimed to "identify the most viable smokeless fuel" for South Africa. Clark started with the premise that "the most viable smokeless fuel" should have the following characteristics:

- The maximum volatile contact should be a maximum of 10%. This will guarantee a smokeless fuel. Also it would be desirable for the fuel to have as high a reactivity to oxygen as possible.
- Fuel production costs should be as low as possible.
- Production units should be sited so as to minimise transport costs.
- It would be desirable for the fuels to be manufactured from coals that do not find a ready market in South Africa.

Clark's report describes tests performed on behalf of Gencor, as part of their now defunct torbanite project, which compared a number of coals with two anthracites, pitch bound anthracite briquettes and torbanite char (a low smoke fuel). Conclusions from the tests were that the anthracites and low smoke coals took an unreasonable amount of time to produce sufficient usable heat. These slow ignition problems resulted in the focus being shifted to the development of a cheap and easily installed modification for existing stoves that would provide rapid and effective ignition of low smoke coals. An essential aspect of the device was that the stove would not perform well with low smoke coal unless the modification was installed (Clark, 1990). There is however no further record of this development.

Clark's report also considers a wide range of options for the production of low smoke coals and also discusses the advantages and disadvantages of each within an overall approach. For instance the question of direct or indirect carbonisation processes, which are either suitable for the manufacture of low smoke coal or could be adapted for the purpose is discussed in detail. Another aspect dealt with is which coals should be used for the manufacture of smokeless coals, duff coal, discard coal, anthracite duff or fines. Transport costs and plant location are also considered.

Conclusions made by Clark for the most viable smokeless fuel include the following:

- Anthracite appears to be the main ingredient of manufactured smokeless fuels in the UK and Europe. Also, despite the number of redundant retorts for carbonisation available at closed gas works, none appear to be used.
- South African anthracite discards could make a worthwhile contribution to a national smokeless coal supply, but at best this could only be a partial solution due to the limited occurrence of anthracite in South Africa. For the Gauteng region the raw material would have to be coal, preferably duff coal. The economical price of duff coal as the feedstock would offset the cost of processing.
- If duff coal is used, the cheapest binder available in suitable quantities should be used. The duff coal would have to be processed to extract the components with suitable characteristics. It is also recommended that carbonisation is carried out after briquetting.
- Ideally an indirect carbonisation process should be used. However in the absence of suitable indirect carbonisation facilities, direct carbonisation will perform adequately. Carbonisation should be done at low temperatures to produce a more reactive fuel.

It was intended, as part of the investigation into the most viable low smoke fuel, for Clark to investigate work carried out by the Coal Research Establishment (CRE), with the aim of identifying approaches that could be applicable to the South African situation. However a proposed visit to the United Kingdom by Clark was never made and hence the full investigation was not completed (information that he was able to obtain regarding work performed by the CRE has been described in Section 4.2).

However, more recently Enertek at the CSIR in South Africa employed the CRE to investigate the briquetting of South African duff coal for the production of a low smoke fuel. Although it was evident from the start that a process could quite readily be developed for producing such a fuel, a major question that would have to be addressed was its economic feasibility. Discussions with CSIR indicated that, in order to produce an acceptable low smoke fuel from the South African feedstock volatile content would have to be reduced down to about 15%. The approach adopted was to apply thermal analysis techniques to the coal and to plot weight loss against temperature. This would indicate the treatment temperature required to achieve the necessary volatile content. This char was then briquetted in a laboratory using a range of common binder systems. The best composition was found to be 86% char, 13% molasses and 1% phosphoric acid and the resulting briquettes were cured in a low oxygen atmosphere at 250°C for 2 hours. The briquettes were then tested for crushing strength and water resistance. A gravimetric smoke determination gave a figure of 2.2 grams/hour, compared to the UK regulation limit for smoke emission of 5 grams/hour (CRE:nd).

In an attempt to produce a low cost briquette a similar exercise was conducted, except that the volatile reduction process was excluded. In this case the crushing strengths were low as a result of the friable nature of coals with a high volatile content, and also the gravimetric smoke determination gave a figure of 8.9 grams/hour.

Thus overall, the work by CRE showed that there were no technical difficulties with producing an acceptable low smoke fuel, as long as the feedstock was subjected to heat treatment. Briquettes produced with untreated feedstock were unacceptable from both a strength and smoke emission point of view. The work by CRE did not include any assessment of the cost of production of fuels and hence there was no indication of how the technically acceptable fuels would fare in the South African market.

About three years ago Suprachem, a company wholely owned by Iscor and involved in coal tar distillation, undertook investigatory work into the production of reconstituted fuels for use in Iscor ovens and also for the household solid fuel market. The motivation for the research was the large stockpile of waste coke duff which had accumulated at Iscor's plants. Points of investigation included binders, formulation, briquetting pressure and drying of the briquettes. The coke fines had less than 3% volatiles, about 20 % ash content and about 0.8% sulphur content. The binders investigated included starch and molasses which proved to be scarce and expensive while other binders tested were not available commercially. Also the binders created problems in the briquetting process as they quickly fouled the briquetting press. A further problem encountered was the poor reactivity of the briquettes. However the most serious problem was the estimated high cost of production which meant that the fuel had no chance of competing with household bituminous coal. As a result of the high cost of the briquetted fuel the investigational project was terminated and no further developments have taken place at Suprachem (Brits, 1994).

Summary of past South African low smoke coal development

A brief summary of the state of the art of low smoke coal development in South Africa at the start of the 1990's shows that:

- Low smoke production technology is well developed and available from a number of countries around the world.
- Some basic desk top research and a limited amount of laboratory research had been carried out by the Fuel Research Institute and a number of commercial companies.
- Much of the research was motivated, more by the desire to find an economic use for the large discard coal supplies than by the need to find a solution to pollution problems created by household bituminous coal use.
- It was only in the late 1980's that smokeless fuel was seriously investigated in the light of pollution caused by household coal use.
- Briquetted anthracite discards could provide a partial solution but there are insufficient discards available to drive a national low smoke coal initiative.
- No formal smoke emission tests had been carried out on any of the fuels and thus there was no indication of the capacity of the various approaches to confront air pollution problems.

4.4 CURRENT SOUTH AFRICAN LOW SMOKE COAL DEVELOPMENTS.

Having described some selected international experiences and earlier activities in South Africa around the development of low smoke fuels, the main aim of this chapter is to describe the various low smoke fuel products presently in the process of development. An attempt is made to compare their various characteristics with regard to suitability for application in a large-scale low smoke fuel programme. Two of the fuels that will be described, CSIR briquettes and the University of Witwatersrand/United Carbon Producers devolatilised coal, have been developed within the enabling environment of the DMEA's Transitional Fuels Programme, described in Chapter 1. The remainder of the fuels have been developed, or are in the process of being developed, by independent commercial organisations. As a result, for the CSIR and Wits/UCP fuels, public reports have been compiled while for the remainder significantly less information is presented. This is partly because the fuels have not yet been well developed and comprehensive testing and costing has not been completed by developers, but also because the product developers are reluctant to fully expose their techniques and ingredients.

A further reason for incomplete reporting has been the fact that a number of companies involved in developing low smoke coals have only come to the attention of the Department of Mineral and Energy Affairs and the author in the very recent past and it is likely that there are other low smoke fuel developments that are not described in this report. Notwithstanding these shortcomings it is the intention to report on all low smoke fuels that are being developed, irrespective of the stage of development reached. The fuels described in this chapter are given in Table 4-2. (This list is repeated, along with addresses and contact persons in the various organisations, in the Appendix).

TABLE 4-2: LIST OF LOW SMOKE FUELS DESCRIBED IN THIS REPORT.

Ref	*Fuel*	*Concept of Fuel*	***Organisation undertaking development***
4.4.1	CSIR briquettes	Discard coal and cement mixture - cast in a slab and then broken into blocks	Council for Scientific and Industrial Research
4.4.2	Wits/UCP low smoke coal	Sized discard lump coal, devolatilised using waste heat	Univ. of Wits and United Carbon Producers
4.4.3	Coal Tar Products low smoke coal	Devolatilised lump coal. The char is one of a number of products from the process.	Coal Tar Products (Pty) Limited
4.4.4	Wundafuel	Cylindrical ring briquette manufactured from waste material (wood shavings, coal duff), wax and unspecified binder	Ecofuel (Pty) Ltd
4.4.5	Duffco fuel	Briquetted duff coal and a high carbon content waste with calciumlignosulphanate binder	Duffco, in association with Anglovaal
4.4.6	Sastech fuel	Devolatilised lump coal or briquetted precharred fine coal .	Sastech - a division of Sasol
4.4.7	Firebrick	Brick-shaped briquette manufactured from waste paper, wax and other unspecified chemicals	Alan Rodkin Organisation

4.4.1 CSIR RECONSTITUTED COAL BRIQUETTES

In 1991 Enertek of the CSIR (previously the Fuel Research Institute) experimented with a "coal-cement" mixture for the manufacture of low smoke briquettes. Results showed that smoke emissions were much lower than for normal coal and the smoke was of a "better" quality than that emitted by bituminous coal (Tait & Lekalakala, 1994). The CSIR briquette is produced by binding coal discards with cement, in the ratio of 100 kg of coal to 15 kg of cement and 21 kg of water (Tait 1993). The process is extremely simple, and can be done either making use of manual labour or a concrete mixer. The cement acts as a binding agent and reduces the quantity of particulates emitted upon combustion.

Following this development Enertek was commissioned by the DMEA in 1992 to produce 20 tons of low-cost, low-smoke fuel for use in the Transitional Fuels Programme's pollution and social acceptability study in Evaton. The raw materials used for the production of the 20 tons of test fuel were representative of what would be available for full-scale production of the product. The duff coal was a discard from Pretoria Coal while the cement is ordinary Portland cement.

Samples of the briquettes used in the 1992 Evaton field trials were tested to some extent in a laboratory when smoke emissions were compared with bituminous lump coal while burning simultaneously in braziers. Far less smoke was emitted by the briquettes and the smoke that was emitted was much whiter, "suggesting lower sulphur emissions" (Tait, 1993:2). Table 4-3 gives the specifications of the briquettes and lump coal used in the comparative tests.

TABLE 4-3: LABORATORY COMPARISON OF LUMP COAL AND CSIR BRIQUETTES. (Source: Tait 1993)

	CSIR briquettes (used in 1992 Evaton field trials)	*Lump Coal*
Calorific Value [MJ/kg]	24.0	26.7
Ash Content [%]	24.9	17.1
Volatile Content [%]	18.0	28.4
Carbon content [%]	54.1	53.5
Smoke sulphur [%]	0.7	2.8

Authors' Notes: The sulphur emissions from the briquettes is far lower than that of the lump coal. Tait (1993) gives two reasons for this: firstly the briquettes are made from a higher quality coal *that contains less sulphur, and secondly the cement helps to trap the sulphur in the ash because of its lime content. However Tait does not make it clear to what extent the reduced sulphur emission is due to the better quality duff or the interaction of the cement.*

The calorific value of the briquettes is be directly related to that of the feedstock but no information is provided on the feedstock characteristics. Thus it is impossible to predict the characteristics of briquettes manufactured from other duff supplies.

Although results from the first field study showed that the slab-casted fuel was reasonably well accepted and it compared favourably with lump coal with regard to smoke emission, it was felt there was room for improvement and the DMEA supported a further project which aimed to optimise the fuel (Tait & Lekalakala, 1994). The main aim was to minimise the fuel's pollution propensity and to optimise its cost in terms of raw materials. A second aim was to ensure the use of duff coal as a feedstock while a third objective was to investigate the cost of production.

For the optimisation of the fuel, a statistical design approach was employed and sixteen different formulations involving combinations of five variables (type of coal, cement content, lime content, surface area and pressure) were tested. During the tests emissions, which included SO_2, CO, CO_2, total suspended particulates and volatile organic compounds, were measured. Tests were undertaken using a brazier and also a smokeless coal stove and were conducted according to SABS 1111. After completing the tests the best fuel was chosen in terms of its emissions, combustion characteristics, location of coal source and amount of coal available, and the cost of producing the fuel. Analysis showed that some of the variables were contradictory, for instance, low surface area favours low concentrations of $C0_2$ and SO_2 but higher emissions of CO and smoke. However, the best overall formulation was 1% lime, 13% cement, in a briquette with a ***high surface area*** and produced under *low pressure*. In this particular case Skeat coal (one of the two types tested) was chosen as the better coal type due to its lower sulphur content. The particle size analysis of the Skeat coal (a high-ash coal from the Middelburg area, provided by M P Skeat of Skeat Mining) is given in Tables 4-4 and the proximate analysis of the duff and the resulting briquettes is given in Table 4-5.

TABLE 4-4: PARTICLE SIZE OF THE SKEAT DUFF COAL (Source: Tait & Lekalakala, 1994)

Particle size [mm]	*Proportion [%]*
+6	19.6
-6 +3	23.7
-3 +1	27.4
-1 +0.5	9.7
-0.5	19.6

TABLE 4-5: PROXIMATE ANALYSIS OF SKEAT DUFF AND THE RESULTING BRIQUETTES [%] (Source: Tait & Lekalakala, 1994)

	Skeat Duff	*Briquettes*
Calorific value [MJ/kg]	21.0	16.3
H_2O	5	7.1
Ash	25.3	35.6
Volatile Matter	20.9	20.8
Fixed Carbon	48.8	36.5
Sulphur	0.65	0.76

A comparison of the smoke emissions of the best formulation briquettes with those of normal coal and the 1992 briquettes is given in Table 4-6.

TABLE 4-6: SMOKE EMISSION MEASUREMENTS CONDUCTED ON A "SMOKELESS" STOVE (Source: Tait & Lekalakala, 1994)

Fuel	*Average smoke density recorded for initial 2 minute period [%]*	*Average smoke density recorded for the initial 26 minute period [%]*
Normal coal	35.5	42.5
1992 briquettes	11.5	7.3
Best formulation fuel	16.3	8.2

Having undertaken the optimization tests and chosen the best formulation, the CSIR was commissioned by the Department of Mineral and Energy Affairs to deliver another twenty tons of briquetted fuel for further testing in Evaton during the winter of 1993. This time round, for practical reasons, the CSIR completely changed their method of producing the briquettes and instead of using the slab casting method, a brick making machine (purchased from New Dawn Engineering in Swaziland) was used to produce solid 150x150x209 mm blocks[1].

The water content of the mix was reduced to 15% (from 21%), so that the blocks did not slump on extraction from the block-making machine and also 1% slaked lime was added. After fourteen days curing the blocks were broken into smaller pieces, suitable for bagging. This approach of using a block-making machine was not at all successful as the briquettes crumbled very easily and in addition the block making process was very slow, mainly a function of the design of the block-making machine with its cumbersome system of levers. Nevertheless the briquettes produced via this method were put into the field and were poorly received (see Chapter 5 for further details). The result of this failure is that the CSIR consider the manufacturing approach used for the first batch in 1992, the slab casting method, as the most feasible and practical and the costs presented below are based on this method of manufacture (Tait, 1994).

The cost of production of CSIR briquettes

The components in the cost of production of the CSIR's briquettes, using the slab are coal discards, cement, labour and depreciation on equipment. In determining the retail price, distribution costs must also be considered, and will depend to some extent on the distance from the point of production to the point of sale. Of the cost components, cement prices are essentially fixed. While the quantity of cement used could be reduced, this would decrease the product's technical performance and therefore its acceptability. The other cost components are the discard feedstock and labour which are potentially much more variable.

In order to estimate the cost of producing the fuel, a theoretical case study was undertaken by Tait and Lekalakala (1994). It was assumed that a typical merchant retails 96 tons/month as calculated by the Palmer Development Group (1993), and hence the estimate is based on a coal merchant manufacturing his own briquettes using an estimated 7% (of the 96 tons/month) discards generated in his yard. The results of this case study are shown in Table 4-7.

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[1] It is not clear why the brick making machine was used as it produced briquettes under high pressure, while the optimisation process had indicated that holed slab production process was optimal.

TABLE 4-7: CASE STUDY FOR A COAL YARD RETAILING 96 TONS OF COAL PER MONTH - Monthly financial statement with and without briquette production. (Tait & Lekalakala, 1994)

	Coal only	Coal and briquettes
Expenses		
Pithead price of coal (R76/ton)	7334	7334
Transport to coal yard (R28/ton)	2688	2688
Packaging costs (2 x R35/day)	1400	1400
Briquetting wages (1 x R35/day)	-	700
Variable costs (including binder) R45/ton	-	288
Sub-total	**11422**	**12410**
Income		
Product sales	19909	21408
Profit margin	8486	8998
Improvement in margin	-	511

Authors notes: No amount has been allowed for packaging of the briquettes. If packaging costs are increased by 7%, the packing costs for the "coal and briquettes" will increase to R1505, bringing the total improvement in margin down to R407.

Many merchants sell their "discard" coal at a discounted rate. 7% x 96 tons = 6720 kg and if this is sold at 5 c/kg (25% of the average normal price) R336 would be earned and this means that potential improvement in margin will again be less.

Enertek considered a further three scenarios to estimate the cost of their low smoke briquettes relative to the cost of normal bituminous coal. The three scenarios are as follows:

A: Coal merchant converts coal yard fines into briquettes.
The advantages in this scenario are that no-value fines are converted into a saleable product, jobs are created, there are no transport costs as the fines are available in the coal yards in the township. As a result it will be easy to test this approach in practice. However production on this basis can only be small scale as it is based on sales of bituminous coal being far greater than that of the reconstituted fuel. This is also only an interim measure, which will continue for as long as bituminous coal is still being sold.

B: Coal merchants purchase duff coal from mine sources nearby and convert it into briquettes.
The advantages of this approach are that a large number of employment opportunities will be created and also there will be a major environmental impact. Assuming that the product is used and also emits less smoke than bituminous coal. However the limitations to this approach are that the cost of the duff coal and transport will make the product significantly more expensive than normal coal.

C: Integration of briquette production with the rehabilitation of duff coal dumps.
Similar to B a large number of employment opportunities will be created and also there will be major environmental impact. Also the duff coal dumps will be reduced in size. Again the disadvantages are the higher cost relative to normal coal.

TABLE 4-8: ESTIMATES OF COST OF PRODUCTION OF CSIR LOW SMOKE BRIQUETTES (APRIL 1994) [RAND/TON] (Matek, 1994a)

	Normal coal	*Duff coal briquettes*		
		A	*B*	*C*
Pithead price	77	-	15	No cost
Transport	28	-	28	28
Binder (15% cement @ R285/ton)	-	43	43	43
Labour (1.5 mandays/ton)	-	53	53	53
Total cost (before delivery)	**105**	**96**	**139**	**124**
Retail price (delivered)	223	223	223	223

Authors notes:

1. *If the 7% of the normal coal is wasted as fines, the total cost of normal coal will in fact be R77/0.93 = R83 (Alternatively the cost of duff in scenario A should be R77/ton).*
2. *No amount has been allowed for packaging for any of the four cases.*
3. *No amount has been allowed for equipment depreciation.*
4. *Scenario C assumes that the briquette manufacturer makes no profits.*

Thus a revised set of estimates could be as follows:

TABLE 4-9: REVISED ESTIMATES OF COST OF PRODUCTION OF CSIR LOW SMOKE BRIQUETTES (APRIL 1994) [RAND/TON]

	Normal coal	*Duff coal briquettes*		
		A	*B*	*C*
Pithead price	83	-	15	No cost
Transport	28	-	28	28
Binder (15% cement @ R285/ton)	-	43	43	43
Labour (1.5 mandays/ton) @ R35/day	-	53	53	53
Packaging costs	15	15	15	15
Equipment depreciation (3 years)	-	1	1	1
Total cost	**126**	**112**	**155**	**140**
Retail price	223	223	223	223
Gross profit	97	111	68	83

As noted previously, the low cost of production in Scenario A is based on the premise that normal bituminous coal sales will form 93% of the total coal yard sales. Thus this approach will have little impact on the overall bituminous coal consumption.

Conclusions and recommendations by Tait & Lakalakala (1994):

- The present configuration of the CSIR low smoke fuel can be used effectively in existing appliances and has significantly lower combustion emissions than normal coal.
- The system has the potential to create numerous work opportunities.
- There are millions of tons of duff coal presently going to waste.
- Further research is required into the economics of production and the environmental consequences of observed CO_2, SO, C0 and smoke levels for the various reconstituted fuels
- Feasibility of introducing a South African version of the Yanle/Yantan briquette product range should be seriously considered.

4.4.2 WITS/UCP DEVOLATILISED COAL

Research at the University of the Witwatersrand, in association with United Carbon Producers has resulted in the development of a prototype low-smoke fuel (Wits/UCP fuel), which, it is argued, can be almost cost competitive with normal coal (Horsfall 1992a: 1). There are two reasons for this: in the first instance, the feedstock is discard coal, which is essentially a waste product from coal mining and processing. Secondly, the process uses waste heat from industrial processes. Heating processes which are dedicated solely to the production of a smokeless coal, tend to be expensive, which therefore makes such fuel very expensive (ibid: 4). The process, in brief, entails the washing of discard coal in order that the combustible fraction may be separated from excess ash and stone, after which the combustible portion is heated under controlled conditions causing the volatile components to be driven off.

Basic concept of the Wits/UCP fuel

Smokeless coal is produced by heating bituminous coal under controlled conditions to a point, about 600°C for 3 hours, where it is divested of most of the smoke forming tars. It is important not to apply excessive heat so that enough of the gaseous components in the coal particles are retained to allow easy ignition (Horsfall, 1994). South African coal deposits are characterised by seams containing variable materials with some portions having a low inorganic content, while others have a high inorganic content and hence the different components possess varying calorific values.

The major smoke forming component of coal is contained in the "vitrinite" and because of the mode of formation of coal deposits in South Africa, the vitrinite tends to be concentrated in particles of lower density. As a result the discards have the potential for producing less smoke even if not heat treated. Standards demanded by the export market mean that coals with a relative density above about 1.6 (ash content greater than 25%) is rejected. Thus seam components with a relative density greater than 1.6 (but less than 1.9, where the calorific value becomes too low) is available as a potential feedstock for low smoke coal.

Availability of Discards

Extensive studies have been carried out on reject coal (Horsfall 1994) and a committee, constituted by the DMEA, directed investigations which, firstly determined the quality and quantity of discards, and secondly, their suitability for beneficiation. At present it is estimated that South Africa produces 40-45 million tons/annum of plant discards, with a calorific value ranging from 5 - 20 MJ/kg. This is at least ten times the annual domestic coal consumption in the PWV area. A number of mines in the Witbank area, notably those supplying the export market, reject large amounts of reasonable quality coal (ash 25-30%, CV$\leq$ 20MJ/kg). For example, the average calorific value in the Witbank area (a major source of discards) is about 14 MJ/kg (Horsfall, 1994). The quality and availability of discards are discussed in Section 2.2.

Washability studies on discards were completed in 1991 by Enertek. These studies simulated a variety of coal preparation units and revealed that it would probably be better to use a dense medium system to rewash the discards. For the Wits/UCP project, tests at one particular mine showed that at a washing density of 1.9, a product with 25% ash content, 20% volatile matter, 1.0-1.1% sulphur content and in the 10 to 15 mm size range could be produced with some consistency. Rewashed discards may be sized into any range required for processing because, as mentioned above, the quantity of coal discarded each year far exceeds the present household coal market and more than sufficient (about 10 million tons) discards in the quality range are produced (ibid).

Sources of low cost heat

The second major requirement for the manufacture of the Wits/UCP fuel is heat. The route taken by UCP for the application of heat, was to use existing stokers that utilise waste heat for the production of coke. However the production of coke requires higher quantities of heat than the process of producing low smoke coal. Hence stokers would require modifications before low smoke coal can be produced, but due to the cost of modification (estimated to be R150 000, (ibid)) and no clear indication that low smoke coal will be a viable product, modifications were not carried out. As a result the fuel used for trials, both in the field and in the laboratory, was produced in a standard unmodified stoker and was hence not according to design specifications. Thermal degradation caused the fuel size to be smaller than anticipated and also the fuel's outer skin reactivity to be lower than the core of the fuel. The lower reactivity of the skin is caused by temperature gradients across the coal particles and hence less volatiles being driven from the core of the coal particles, thus influencing the ease with which the low smoke coal can be lit. In spite of problems associated with using unmodified equipment, several trial quantities totalling about 100 tons were produced in 1992 and a similar tonnage in 1993 (ibid).

A comparison of grade D coal with the, the rewashed discards and the resulting low smoke coal are given in Table 4-10.

TABLE 4-10: COMPARISON OF SMOKELESS FUEL WITH GRADE D COAL AND REWASHED DISCARDS (Source : Horsfall 1994:16)

	D Grade coal	*Rewashed Discards*	*Low smoke fuel*
Ash [%]	23	30	35
Volatiles [%]	24	20	13
Calorific Value [MJ/kg]	25	20	22

Combustion tests of the Wits/UCP fuel at the University of the Witwatersrand

Tests on the initial batch of fuel produced in 1992 showed that there were a number of problems with the fuel. Firstly it was slow to ignite and slow to heat the stove to a point where it was usable for cooking. Also there was too much undersized fuel in the batch. However the fuel showed smoke emissions considerably lower than those of normal bituminous coal, and because the fuel burned at a lower power, fires could burn for long periods and also result in more efficient use of the heat generated (ie. less heat is lost up the chimney with a slower burning fire). During 1993 Wits carried out further tests using the second batch of fuel produced by UCP (still using the unmodified stoker), and compared smoke emissions and other characteristics of three low smoke fuels; the CSIR briquette, the Wits/UCP fuel, and Ecofuel (described later in this chapter).

The results of the tests carried out at Wits are summarised below (Horsfall, 1994):

Heat output measurement

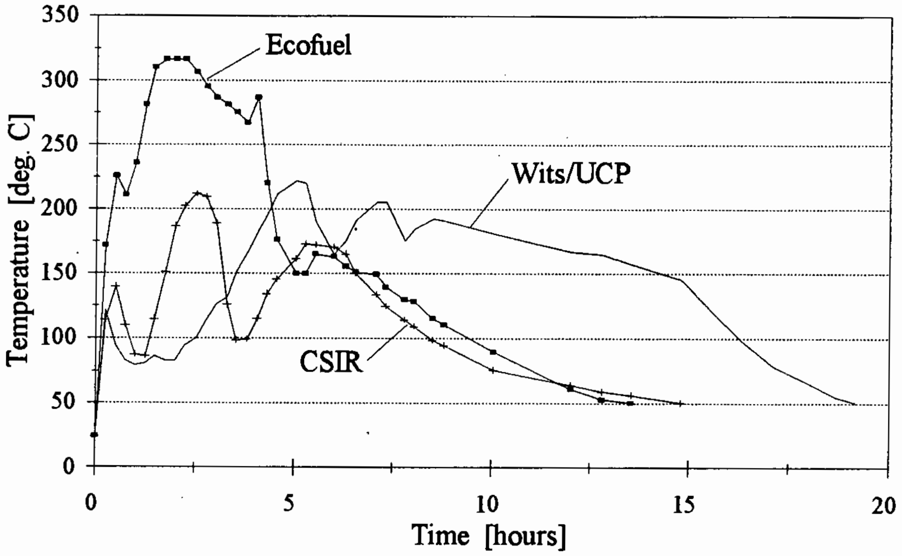
- The plate temperatures produced by the Ecofuel was the highest at 301°C, while those produced by the CSIR briquettes and the Wits/UCP fuel were lower at 231 and 213°C respectively. The temperatures all seemed to be usable for stove top cooking (Horsfall, 1994).
- The Wits tests showed that the "useful cooking times" achieved by the Wits/UCP fuel far exceeded those of the others tested. The useful cooking time was defined as the time the stove plate temperature was above 150°C and is an arbitrary temperature. Further the "space heating time" (defined as the time the stove plate temperature was above 100°C) was also significantly superior to the other two fuels.

  The reason for this is that the Wits/UCP fuel burns at a lower rate, providing more moderate temperatures for cooking and space heating. This slower burn rate has an advantage in that it results in more useful energy being transferred into the cooking pot and into the room through the wall of the stove and less being drawn up the chimney by high draft velocities. Whether this lower power system, with long start up periods, is a desirable feature is open to debate, given the fact that few people operate their stoves continuously but rather start their stoves daily or, in many cases, twice daily (Hoets, 1994).

Time/temperature relationships

- The Ecofuel was quick to ignite and burned at a significantly higher rate than the other two fuels during the first four hours. On the other hand the Wits/UCP fuel took four and a half hours to reach its maximum temperature and only reaching 100° C after two and a half hours. After about four hours the temperatures in the Ecofuel and CSIR tests tailed off much more markedly than during the Wits/UCP test. These results are depicted in Figure 4-1.

FIGURE 4-1: Time Temp. Relationship for three low smoke fuels



Boiling tests

- The water boiling tests measured the temperature rise of one litre of water in a standard time. Due to its quick ignition characteristics the Ecofuel out-performed the other two fuels.

Smoke measurement

- The Ecofuel showed high degrees of obscuration due probably to its wax content. The Wits/UCP and CSIR fuels behaved similarly with generally low levels of emissions (See Figure 5-1).

General conclusions after the Batch 2 Tests (Horsfall, 1994).

1 Ecofuel provided the most rapid heating of the stove, and the highest plate temperatures. As a consequence the Ecofuel was best at heating water, followed by CSIR and then Wits/UCP.
2 The period of useful heat output was greatest by far with the Wits/UCP fuel, followed by Ecofuel and CSIR which were similar. The Wits/UCP fuel has better banking properties[2] as it gave an extended time temperature graph in comparison with the other two fuels.
3 The smoke output of the Ecofuel was significantly higher than that of the other two fuels. Although not tested against Grade D coal, comparison with the initial tests suggests that Ecofuel's smoke emission is higher than that of bituminous coal.
4 The most complete combustion was achieved by the Ecofuel.
5 The CSIR briquettes suffered from serious disadvantages as their size had degraded in the bags and over half the fuel could not be used. There were also questions marks against the Ecofuel's ability to withstand handling in a merchants yard.
6 The Ecofuel produced slightly more "useful energy" than the Wits/UCP fuel and both were significantly better than the CSIR briquettes.

Conclusions and suggested action with regard to the Wits/UCP fuel are given below (Horsfall 1994):

- The supply of suitable rewashed discards is far greater than the potential demand for low smoke coal. In view of the abundance of discards, relative to the domestic market, the discards from any one mine could be screened to give a narrower size range.
- The washing of the discards presents no technical problem as well-established economically-viable technology is available.
- The system of heat treatment has been defined but cannot be achieved due to the required capital investment in the modification of a stoker (estimated cost of modifications is R150 000)
- Market acceptability may be difficult to achieve. It could be improved by pilot introductions.
- Small commercial production should commence as soon as possible using a modified stoker. The quantities produced by a pilot production plant should be sufficient to supply an entire coal burning township so that air pollution can be monitored with the improved fuel.

Cost of Production of the Wits/UCP fuel

Indicative costs of the commercial production of the Wits/UCP fuel from discards have been calculated by Ritchie and Rodgers (1994) and are reported unaltered below.

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[2] The term "banking properties" refers to the ability of the fuel to provide constant heat output over an extended period (Refer to Figure 4-1).

Before calculating the cost, certain assumptions have to be made. These are as follows:

1. The material previously produced for tests during 1992 and 1993 established acceptability on a commercial basis.
2. Tavistock Collieries Ltd (JCI) would make available sufficient material with the following specification:

i.	Product size	-90mm +20mm
ii.	Calorific value	21.5 - 24 MJ/kg
iii.	Ash	< 30%
iv.	Yield	40 - 50%
v.	Possible production ex ATCOM	27 000 tons/month
vi.	Operating costs	R4/ton clean coal
vii.	Capital costs	Approx. R10 million
viii.	Cost per ton f.o.t. mine	R12.50/ton

   Note: Tavistock Collieries would have to develop a middlings plant extension at their ATCOM facility which would entail a new middlings washing system and road truck load out facilities.

3. UCP's plant throughput is anticipated at 102 tons/day/furnace
4. UCP would realise a yield of 55%
5. The method used hitherto for the production of smokeless fuel would be that used in future, i.e. UCP would utilise their current technology.

Based upon the above assumptions and current operating costs (June 1994), the following is indicative of what the price of smokeless fuel would be in an unbagged form, available at the UCP Vaal facility.

Cost Item	*Cost [Rand/ton]*
Cost of coal f.o.t. mine	12.00
Transport to UCP Vaal plant	38.00
Landed cost of coal	50.00
Assumed yield 55%	90.92
Operating and depreciation	42.00
	132.91
Gross margin before tax (22%)	29.24
Total	152.15
(Equivalent price per bag	R 10.65)

NB: No bagging costs included.
No delivery or distribution costs allowed for.

Richie and Rodgers (1994) state however, that as certain key information is not as yet available to UCP, cognisance must be taken of elements that would materially affect the indicative costings. These are:

- *Seasonal demand* - this factor could seriously impact upon the profitability of the scheme, making it marginal.
- *Total demand* - the acceptability and consequent total demand for the product would be governed by the availability of feedstock from Tavistock Collieries and subsequently other collieries, and also UCP's ability to produce the required tonnage. Were UCP to develop their Vaal facility to its full potential, they would be in a position to gear up over a period of time to produce approximately 400 000 bags per month of smokeless fuel (at 70 kg/bag this is equal to 28 000 tons/month or 336 000 tons/year).

4.4.3 COAL TAR PRODUCTS LOW SMOKE COAL

Coal Tar Products (Pty) Ltd is a company associated with General Energy Systems, a company involved in energy management in industrial plant and has expertise in coal technology, coal combustion and gasification of coal, as well as other energy-related experience. Relatively recently Coal Tar Products has undertaken development work on a low smoke coal. A description by Beningfield (1994) of developments undertaken by Coal Tar Products is reproduced unaltered below.

Background

Individual members of Coal Tar Products initiated and developed the production of carbon reductants (char) for the chrome industry in South Africa and successfully installed a number of production plants based on the moving grate technology in South Africa and subsequently in Europe.

Char is produced by the heating of selected high volatile content lump coal in a controlled environment in order to remove the volatile matter to produce carbon at a predetermined volatile content of approximately 2 - 4 % or, in the case of low smoke coal, a higher residual volatile content to promote ignition reactivity.

New Technology Development

The use of the "moving grate" char plant technology has the disadvantage of wasting to atmosphere the volatile content distilled from the coal, and exposing the coal being processed to thermal shock. This results in a degradation of the coal and hence a sizing disadvantage. Coal Tar Products undertook design work to improve on the technology and has built a pilot plant on the reef to demonstrate the process. The objectives of the design are:

a) Recovery of the tars and oils for further processing and sale.
b) Reduce the thermal shock effect on the coal and retaining the size grading of the "char" and eliminating the fine particles as much as possible.
c) Of specific concern is the production of a reactive carbon material which is sufficiently strong for handling and transportation.
d) Improved costs of production due to the recovery of the volatile matter in the form of tar and oil, which are commercially valuable, and the reduction of fines.

The plant design caters for the controlled production of reactive carbon with whatever volatile content is required and has been successfully operated with a variety of coal types. Final construction designs are being produced for the full scale plant and will be complete within the next few months. The design is based on a continuous retort concept which has steam injection to provide the carbon reactivity requirements.

Development programme for low smoke coal

Coal Tar Products has invested a considerable amount of money and time on the development work to date and would need to seek a partner or funding to produce market-related quantities of low smoke coal which would be suitable to replace coal currently being burned in high-density housing areas. The pilot plant can produce sufficient low smoke coal to provide material for burning tests to be conducted by CSIR or others to determine the level of emissions and combustion characteristics. If field test tonnages are required these could be produced over a period of time from a continuous production run of the pilot plant.

4.4.4 ECOFUELS "WUNDAFUEL' SOLID FUEL BRIQUETTES

The company Ecofuel has developed 'Wundafuel', which is a tapered cylindrical, briquette with a hollow core. The briquettes are manufactured under high pressure from recycled material (anthracite or coal duff - 3mm and smaller), with an unspecified binder and are then covered with a wax coating to form a hard briquette that can withstand transport and rough handling.

The fuel was originally intended to compete with wood in areas experiencing fuelwood scarcities, but the marketing orientation has shifted to compete with gas and paraffin as a convenient and quick fuel that requires no special storage containers. The fuel is clean to handle and has a high reactivity, allowing swift ignition and development of a hot fire for quick cooking operations. The shape of the briquettes, with the cylindrical centre hole give it a high surface area to mass ratio allowing good air flow through the fire and hence a high burn rate. Another advantage of the fuel is that it can burn on the ground (like wood) and therefore does not require an appliance to be used.

The DMEA incorporated this product into its research support programme during 1993, which originally included only the CSIR and Wits/UCP fuels. The performance of the fuel, from a thermal and emissions point of view, was tested in the laboratory at the University of the Witwatersrand and the results have been presented in Figures 4-1 and 5-1. It should however be noted that the results of the emission test given in Figure 5-1 would not appear to be backed up by the results of those conducted at the CSIR and reported in Section 5-2. The fuel has also been tested by the SABS (test N^{os} 321/85473/H176 and 813/80081/H064) which assessed its gaseous emissions.

The calorific value of the fuel varies between 25 and 28 MJ/kg and will be on the market at between 45 and 50 c/kg. According to the developer the the aim is to utilise a progressive marketing approach, improved packaging, and to expand into a number of plants around the country. Thus for a fuel with a CV of 25 MJ/kg and a cost of 50c/kg, the energy cost is 2.0 c/MJ. If the CV is 28 MJ/kg and the cost reduced to 45c/kg the energy cost will come down to 1.6 c/MJ (see Tables 4-11 and 4-12 for comparison with other fuels).

4.4.5 DUFFCO LOW SMOKE BRIQUETTES

Very little information about this product was available due to the late stage at which the Duffco product was identified, and the information presented below is based on one telephone conversation with Mr Jabrenski of Duffco. Duffco has been involved in the development of low smoke fuel briquettes for about five years. About two years ago Anglovaal became a major shareholder in the company and this has allowed the accelerated development of a low smoke briquetted fuel product. It is intended that the product will be in production and available on the market by February 1995. The product is aimed at the poorest sector of the household fuel market and market research has shown the product to be acceptable.

The briquettes are 90x90x50 mm in size with perforations to facilitate air supply during combustion and are manufactured from D grade duff coal with calciumlignosulphanate, a waste product from the production of paper, as a binder. According to Jabrenski (1994) about 70% of the mass of the fuel is duff coal with the remainder being made up of a waste product with a high carbon content and the binder. The original intention was to utilise anthracite duff as the high carbon additive, however due to very poor availability, an alternative source is being sought, possibly coke duff ex Iscor, Samancor and/or others. The calorific value of the fuel has not yet been determined.

Some of the advantages of the fuel are as follows:

- The briquettes ignite very easily due to the properties of the binder and also the perforations allowing sufficient oxygen supply for a hot clean burning fire.

- The shape of the briquettes allows compact packaging and hence the energy density of the packaged fuel is very high. This facilitates cost effective transport and handling.
- The technology developed by Duffco is not limited to the use of duff coal as a feedstock, and can be used for the production of briquettes using biomass based waste products such as 'filter cake' from fruit juice production in the Western Cape. Duffco is in the process of investigating these other options.
- The equipment for the production of the briquettes is suitable for localised use by small entrepreneurs and the proposed marketing strategy is to enter into franchise agreements so that the fuel can be produced at many locations. Thus the approach has the potential to stimulate small scale localised industry and to be an employment creator.

It would appear that a major potential shortcoming of the Duffco product is the intended ex-production price of R800/ton with an anticipated retail price of approximately R2000/ton. If the fuel is assumed to have a calorific value of 30 MJ/kg, based on a high anthracite content, the energy cost ex-production will be 2.7 c/MJ.

4.4.6 SASTECH LOW SMOKE FUELS

Sastech has performed "laboratory" work on the development of technology to briquette most South African coals without a binder (Slaghuis, 1994). Sastech points out that the concept and production of low smoke coal is not new and that the technology is well known. However, South African coals are low in vitrinite and therefore, to produce binderless briquettes, different processing conditions to those developed in the northern hemisphere are required. The basic concept of Sastech's approach has been set out by Ooms et. al. (1994):

- South African coal is low in vitrinite and therefore requires different processing conditions to those developed for the northern hemisphere, to produce a binderless briquette. Sastech has developed a suitable technology to briquette most South African coals without a binder.
- These briquettes have shown exceptional strength and resistance to temperature shock during devolatilisation. The briquettes have been shown to be water durable.
- Smoke emission tests on devolatilised briquettes, in comparison to anthracite and commercial briquettes have shown the Sastech product to be superior.
- Capital requirements are relatively high and calculations have shown the production of the briquettes to be marginally economical.
- As a possible more economic alternative, Sastech has developed a technique by which precharred fine coal is moulded into briquettes using a readily available inexpensive binder. These briquettes have a porous structure giving them easy ignitability as well as good burning properties.

At present Sastech does not have a specific low smoke coal that can be marketed in the immediate short term but says that it is not able to proceed with further development until certain enabling steps have been undertaken by the DMEA (Slaghuis, 1994). These are:

- A specification for a low smoke coal should be established. There are many internationally available specifications and these could be adapted to the South African situation. Once a specification has been established it makes it possible for potential developers to design and measure the performance of their products.
- The DMEA should engage an independent party to undertake a techo-economic study from which realistic production costs can be estimated. These results can then be used to determine the appropriate "market intervention" by the government and hence allow private enterprise to proceed within a known set of parameters.

4.4.7 FIREBRICK FUEL

The Alan Rodkin Organisation's "firebrick" is a fuel that has reached prototype stage and consists basically of compressed wastepaper which is impregnated with an unspecified flammable chemical and then coated with wax. The developer has not disclosed the relative proportions of components of the firebrick. Both the wax and the chemical are products of Sasol.

The prototype bricks have been manufactured in a hand operated press and are 230x100x100 mm in size with a weight of between 1.1 and 1.2 kg. A determination of the energy content of the fuel was carried out by Sasol Waxes using the American standard test method (ASTM No D2015/77). For the test a small sample of the brick was cut off and the results could vary depending on where in the brick the sample was taken due to the coating having a different calorific value to the core. Tests were undertaken on two versions of the firebrick, one uncoated and a second with a coating of wax. The calorific values are 30.2 and 31.8 MJ/kg respectively.

The expected ex-factory price for the firebrick is R2.00 per brick, although there is a possibility that this cost could be lower, depending on economies of scale (Rodkin, 1994). Nevertheless, assuming a cost of R2.00 per firebrick, the cost per kilogram will vary between 167 and 182 c/kg (depending on the density). At a CV=31 MJ/kg the ex-production energy cost is thus between 5.4c and 5.9 c/MJ.

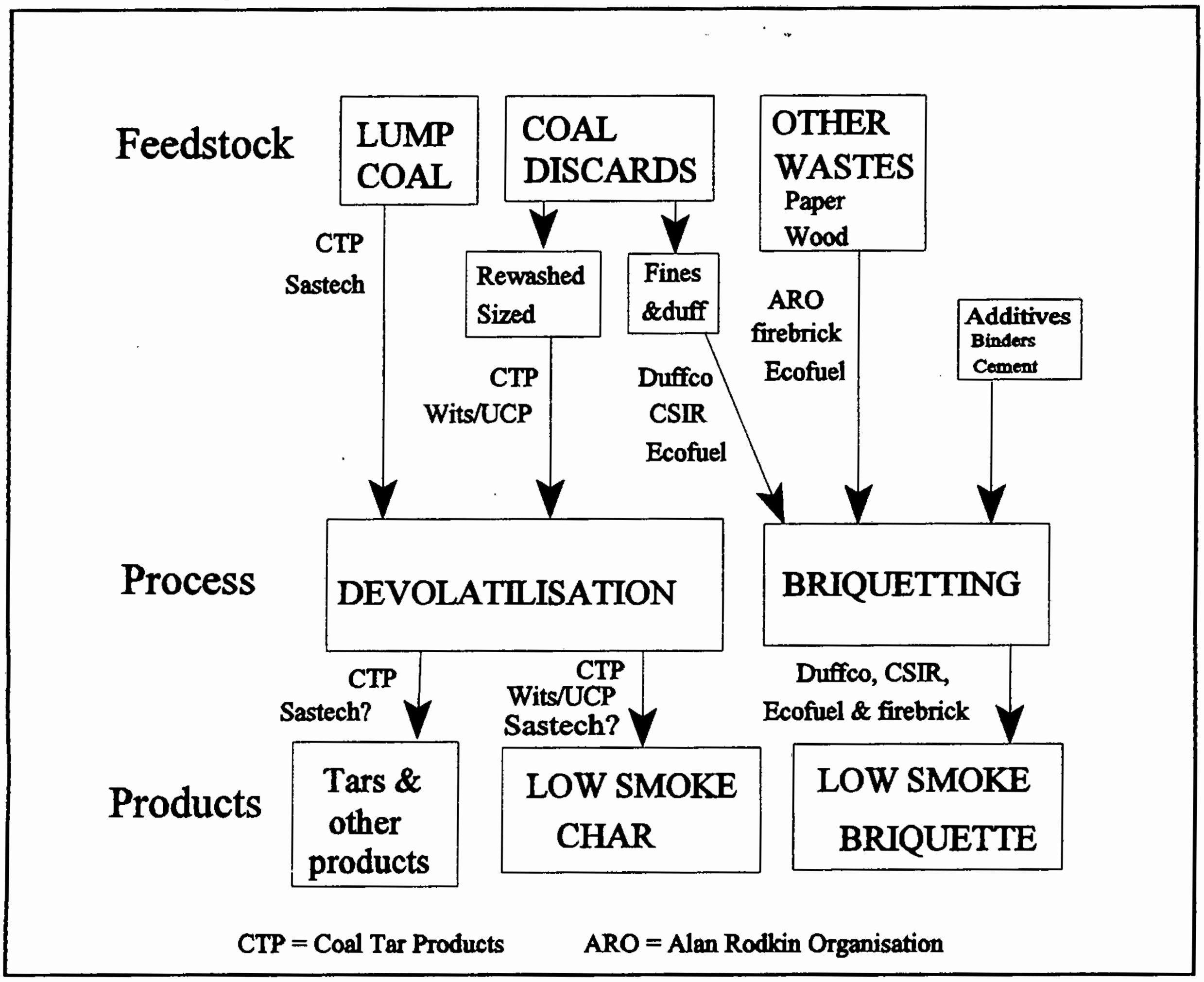
4.5 SUMMARY AND COMPARISON OF TECHNICAL CHARACTERISTICS OF SOUTH AFRICAN LOW SMOKE FUEL PRODUCTS

One of the problems with making comparisons between the various fuels is that the necessary information is not all available. Nevertheless it is useful to compare available information and to note the information that is presently not available. For the sake of making comparisons, important characteristics of the various fuels include:

Emission levels,
Combustion performance,
Reactivity, and
Cost of production and distribution.

However, before assessing the various fuels in terms of the above characteristics, an overall summary of the approaches to the production of the low smoke fuels described in section 4.4 of this chapter is given in Figure 4-2. There are three categories of feedstock for the production of low smoke fuels, lump coal, coal discards and biomass wastes. The Coal Tar Products' approach can use either lump coal or coal discards, although if discards are used, they would need to be of a reasonably high calorific value so that tars can be produced during the devolatilisation process. The approach taken by Sastech can only be speculated as they have not disclosed details of their experiments to date.

FIGURE 4-2: SUMMARY OF PRESENT SOUTH AFRICAN APPROACHES TO LOW SMOKE FUEL PRODUCTION



Emissions
Of the seven fuels described, only three have been tested for combustion emissions; Ecofuel, CSIR briquettes and the Wits/UCP fuel. All three performed considerably better than bituminous coal (see Chapter 5 for results) but it will be necessary to compare all the fuels in one set of tests for meaningful comparisons to be made. The intention is for these tests to occur in the near future (see Chapter 6 for details of anticipated low smoke fuel programme).

Combustion Performance
Similar to the situation with regard to the comparison of emissions, comparative combustion performance tests have been conducted by Wits University with the same three fuels and compared with D grade coal. These results are reported in section 4.4.2. Again it will be necessary for tests to be conducted by an independent body and should include all potential low smoke products. These can be performed at the same time as the emission measurements.

Reactivity
One of the problems encountered with the devolatilisation of coal is that the end product has a low reactivity which makes it less acceptable to users than bituminous coal. Again, the reactivity of the various fuels can be tested during combustion performance and emission tests.

Cost of production and distribution

Of critical importance in the comparison of the fuels is their cost of production and probable retail price. Where developers have provided indicative prices of their fuels these have been at different points in the distribution chain making it difficult to compare them directly. In some instances the prices given have been ex-production (or freight on board) and therefore do not include the cost of transport from the point of manufacture to local merchants/distributors; nor do the prices take account of the cost of local handling and delivery.

Table 4-11 gives an account of all the prices that have been reported or have been provided or estimated by developers of their products.

TABLE 4-11: AVAILABLE PRICES OF LOW SMOKE COAL PRODUCTS [c/kg, 1994]

Fuel	*Ex-production*	*Merchant/ distributor*	*Retail*	*Ref. in this document*
Bituminous coal (C grade)	6.0	9.0	23.0	Chapter 2
CSIR : Scenario B Scenario C		15.5 14.0		4.4.1
Wits/UCP	15.2			4.4.2
Coal Tar Products	No prices indicated			
Ecofuel			50.0 (max) 45.0 (min)	4.4.4
Duffco		80.0	200.0	4.4.5
Sastech	No prices indicated			
ARO Firebrick		200.0		4.4.7

It is evident from Table 4-11 that there is no sure method to compare the prices of the various fuels. If the products were all to be manufactured at the same location and distributed through the same channels it would be possible to accurately predict their prices at the various stages of distribution. However, some fuels will be manufactured close to their markets, while others will be produced at the source mine. Also there are likely to be different distribution systems, and not all the fuels will be marketed through the present coal merchant system. For the sake of initial comparisons one can convert all of the fuel prices to those paid by the merchant/distributor and make a comparison at that point. Thus these prices will have taken account of the transport costs from the point of production to the local merchant/distributor, but not the mark-up applied by the local retailer. For the purposes of these calculations, mark-ups similar to those applied in the distribution of household coal are used.

TABLE 4-12: PRICES OF LOW SMOKE COAL PRODUCTS [1994]

Fuel	*Price at Merchant/ distributor [c/kg]*	*Calorific value [MJ/kg]*	*Energy price [c/MJ]*	*Energy Price Ratio [Low smoke fuel/Bit. coal]*
Bituminous coal (C grade)	9.0	25	0.36	1
CSIR : Scenario B	15.5	20	0.78	2.2
Scenario C	14.0	20	0.70	1.9
Wits/UCP	18.0	22	0.82	2.3
Coal Tar Products	No prices indicated			
Ecofuel	17.6 (lowest) 19.6 (highest)	28 25	0.63 0.78	1.8 2.2
Duffco	80.0	30	2.67	7.4
Sastech	No prices indicated			
ARO Firebrick	200.0	31	6.45	17.9

Table 4-12 indicates that at best low smoke fuels will cost merchants/distributors nearly double what is paid for bituminous coal. In the case of the CSIR Scenario C the cost estimate is based on the optimistic assumption that duff coal will be available at no cost (see Tables 4-8 and 4-9). However it is likely that duff will have a price attached, especially as some processing will be required to separate and stock pile the desired component. Also the scenario C estimate is based on the unlikely assumption that the coal merchant is also the briquette manufacturer. The other fuel with a relatively low price is Ecofuel, however, this price is based on projected large scale production and it remains to be seen whether this can be achieved. These factors mean that it is more likely that the low smoke fuel/bituminous coal price ratio will increase to above 2.

There is the possibility that the approach taken by Coal Tar Products and Sastech can produce a product at a price below those of the CSIR briquette and Ecofuel and hence closer to that of bituminous coal. However there is little chance that the bituminous coal price can be matched by either of these companies.

The fact that the cost of low smoke fuels to the merchant/distributor is double that of bituminous coal does not necessarily mean that the cost to the end user will also be double as the cost of distribution will remain the same, and depending on the distribution sytems employed by product manufacturers, could be slightly lower. Given the present high cost of local delivery and the apparent profits made by merchants there is possibly scope for a reduction in the mark-ups that they apply (see Section 6.2.2 for further discussion).

Chapter Five

INTRODUCTION OF LOW SMOKE FUELS

5.1 INTRODUCTION

Chapters 2 and 3 have provided a detailed look at the household use of bituminous coal, pollutants emitted during its combustion, resulting human exposure and consequent health effects. In addition Chapter 4 has identified a number of low smoke products that have the potential to reduce levels of human exposure to hazardous pollutants. However the question that now arises is, what is the potential of these low smoke fuels to improve air quality and, if introduced across the board, to what extent will human exposure to hazardous pollutants be reduced.

At the outset, an essential point to be made is that low smoke fuels are not "no smoke fuels" and if burned in confined spaces also have emissions that are harmful to human health. Thus, an important tool for evaluating the merits of any one of the low smoke products is a measure of their emissions under specified conditions, thus allowing comparisons to be made with the emissions of bituminous coal. Section 5.2 of this chapter presents results of laboratory emission tests that have been undertaken for some of the low smoke fuels described in Chapter 4. Section 5.3 goes on to describe the influence various low smoke fuels had on exposure levels during two sets of field trials in Evaton.

In addition, this chapter gathers available information on the characteristics of fuels that can make them capable of satisfying users's needs and thereby giving them a chance of competing in the market against the presently used bituminous coal. The acceptability of three of the low smoke fuels was tested during the field trials in Evaton and the results are described in Section 5.4.

The final section of the chapter assumes that low smoke fuels will not be price competitive with normal coal and that some form of intervention is required before widespread acceptance by users is possible. Thus the elements of an effective framework for a cost benefit analysis are listed.

5.2 LABORATORY MEASUREMENTS OF EMISSIONS FROM THE COMBUSTION OF PROTOTYPE LOW SMOKE FUELS

5.2.1 CSIR laboratory measurements of emissions from low smoke fuels

Between August 1993 and March 1994 the Material Science and Technology division of CSIR undertook laboratory measurements of emissions from a number of low smoke fuels (Rogers & Pieters 1994). These tests were requested by the Transitional Fuels Working Group as a result of there being inconclusive evidence of reduced emissions from the low smoke prototype fuels tested during the Phase I field trials in Evaton (see Section 5.3). In these field trials three low smoke fuels (Wits/UCP fuel, CSIR briquettes and Ecofuel briquettes) as well as normal bituminous coal were tested.

Tests were conducted according to SABS-1111 on a Univa 40 low smoke SABS approved stove which was set up at the AEROTEK combustion test facility. A dilution tunnel was erected according to the EPA G5 specifications and the standard EPA test procedures were used to monitor CO, CO_2 and NO_x. SO_2 was monitored using the standard CSIR test procedure which is essentially the same as the EPA procedure. Flow and particle sampling was undertaken in the dilution tunnel with provision for temperature, humidity, pressure (absolute and ambient) and gas density measurements.

Fire lighting procedure could not be standardised due to the relatively poor reactivity of the CSIR and Wits/UCP fuels. The procedure which was followed, if possible, was to place a bed of fuel (2 or 3 kg) on top of 400 grams of wood and 50 grams of paper. This procedure was found to be very successful for the bituminous coal and the Ecofuel. In the case of the CSIR fuel, additional wood was added if required. In the case of the UCP fuel, no satisfactory lighting procedure could be found to cause ignition within meaningful time periods. It was therefore necessary to light the fuel first with an acetylene flame and, when combustion was achieved, to add a charge onto the glowing bed (Rogers & Pieters 1994).

A summary of the essential data for the comparison of the four fuels is given in Table 5-1.

Table 5-1: SUMMARY OF EXPECTED EMISSIONS FROM LOW SMOKE FUELS AND NORMAL BITUMINOUS COAL (Rogers & Pieters 1994)

Fuel	*Emission period*	*Particulate mass per kg fuel burnt [mg/kg]*	*Average gas composition dry basis*					
			SO_2 [ppm vol]	*CO [ppm vol]*	*CO_2 [ppm vol]*	*HC [ppm vol]*	*NO_x [ppm vol]*	*Smoke Bosch [% full scale]*
Bituminous Coal	start-up	13017	78	1490	2.7	40	64	12.00
	refuel	8150	76	1447	2.5	71	58	5.60
Ecofuel	start-up	3310	12	945	3.2	128	68	1.00
	refuel	1339	16	922	2.1	21	30	0.44
CSIR*	start-up	3126	6	1589	2.5	395	57	4.40
	refuel	2400	9	935	1.1	56	13	0.17
Wits/UCP	start-up	**						
	refuel	3570	60	825	2.3	33	35	0.41

* *1993 version of the CSIR fuel*

** *In the case of the Wits/UCP fuel, a meaningful measure of start-up emission was not obtainable.*

Discussion of results

Rogers and Pieters (1994) provide little discussion on the merits or disadvantages of any of the fuels, either from a performance point of view or with regard to emissions. The discussion provided is reproduced below.

1 Ecofuel performs successfully both as a low emission fuel and as a fuel for a low smoke stove due to its high reactivity, which results in high efficiency of combustion of volatiles.
2 The normal coal performs the worst as the result of the high concentrations of volatiles and the slower rate of ignition of the charge.
3 The CSIR fuel has potential to perform well from the emissions point of view, but is limited by the structural strength of the fuel. If moved in the firebox the fuel decomposes and smothers the fire, with a resultant increase in volatiles and CO emissions. From the combustion view point, it was not able to meet the heating requirements of SABS 1111.
4 The Wits/UCP fuel also has the potential to perform well in terms of emissions. However it needs a well established fire to ignite properly. It was also not able to meet the SABS heating requirements.
5 Significantly, the low smoke fuels typically have lower particulate emissions. Emissions were however

high for the least combustible fuels during start-up as the result of smoking and the use of additional starting fuels.

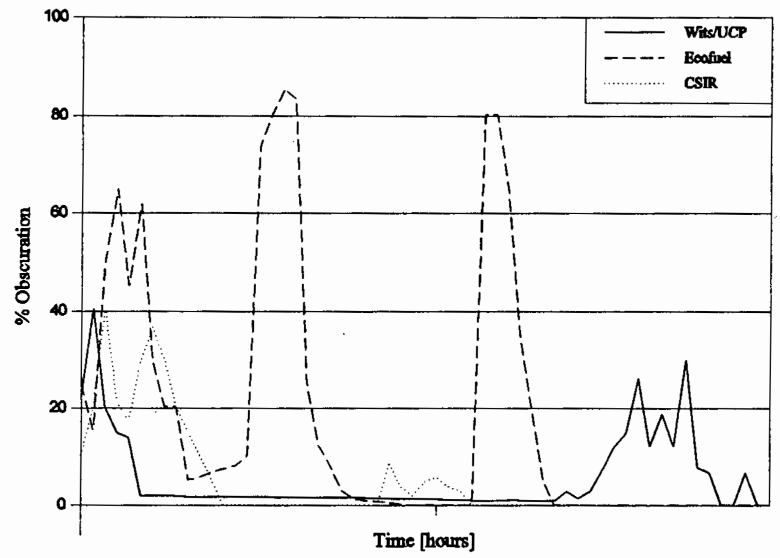
Given the fact that the fuels were tested in a good quality stove with sufficient air flow, these results provide a "best case scenario" for emissions from the combustion of the particular low smoke coals tested. The same is of course true for the bituminous coal as it can easily produce higher emissions than those measured, if burned under different operating conditions or in other appliances such as braziers. Thus Rogers and Pieters (1994) state that, "while an understanding of the burning characteristics of fuels in the SABS low smoke stove gives an insight into the likely contributions to emissions caused by other domestic low draught combustion devices, eg. braziers and other designs of stoves, the results of combustion measurements of a particular fuel in a particular stove cannot be automatically applied to another combustion device".

In addition, it should be borne in mind that the fuels tested were only one of many possible types/formulations of each of the fuels. For instance the test results provided by Rogers and Pieters provide no information on the source, grade or composition of the bituminous coal tested. Similarly, the emissions from the two briquettes fuels will depend directly on their ingredients. The low SO_2 emissions reported for the CSIR briquettes are a result of the low sulphur content of the "Skeat" coal used for the manufacture of the briquettes (see Section 4.3). For the Ecofuel, the ingredients of the briquettes have not been revealed and for the present it is impossible to comment on the effects of varying the feedstock on the emissions.

5.2.2 University of the Witwatersrand smoke monitoring tests

The only other attempt to measure emissions from low smoke fuels was a series of smoke monitoring tests carried out at the University of the Witwatersrand in 1993, where three fuels were tested; Wits/UCP low smoke coal, Ecofuel and the CSIR briquettes (1993 version). The three fuels were tested in an identical manner in a closed stove equipped with a photo-electric cell and a light source in the chimney (Horsfall 1994). Figure 5-1 shows the results.

FIGURE 5-1: RESULTS OF SMOKE MONITORING TESTS AT UNIVERSITY OF WITWATERSRAND (Source: Horsfall 1994: 43)



It is evident that the Ecofuel showed high degrees of obscuration at the start and after refuelling, while the other two fuels behaved similarly, with generally low emission levels - the peaks in the curves occurred after refuelling. The initial period of emission of the CSIR fuel was longer than the Wits/UCP fuel, but the refuelling of the latter led to higher degrees of obscuration (ibid).

5.3 IMPACT OF LOW-SMOKE COALS ON HUMAN EXPOSURES TO POLLUTION

5.3.1 1992 field trials in Evaton

The research projects undertaken in Evaton as part of the Transitional Fuels Programme have been outlined in Chapter 1. One of the components of the programme was to evaluate the benefits of low smoke coal, and particularly its ability to reduce indoor air pollution levels. A "comparative evaluation of human exposures to air pollution from low smoke and conventional household coal usage" was therefore undertaken during the winter of 1992 and again in the winter of 1993 (Terblanche et. al., 1994). In 1992 three fuels were investigated; conventional bituminous coal, the CSIR briquettes (1992 version) and the Wits/UCP fuel. The objectives of the comparative evaluation were to:

- measure gaseous emissions, i.e. CO, NO_2, SO_2, volatile organic compounds (VOCs) and particulate matter from low smoke coal and normal coal under real life conditions,
- evaluate the potential health risk of the exposure of people to such emissions, and
- make recommendations based on the above, regarding the possible introduction of low smoke fuels as an alternative household energy source for cooking and space heating (ibid).

Emissions from the three fuels were monitored in 45 homes (15 homes for each fuel type). A series of statistical analyses was conducted using the collected data and results showed that:

- For *TSP exposures,* levels for all three fuels exceeded the 24 hour health standards for most of the time. Although the CSIR fuel showed less exceedences, this could not be statistically proven.
- For *gaseous pollutants*:
  SO_2 levels exceeding health standards were documented for more than 20% of the hourly maximums that were recorded. Ambient concentrations of SO_2 did not differ between the three fuels.
  For NO_2, the Wits/UCP fuel produced lower concentrations than the other two fuels
  For CO, the CSIR fuel produced lower concentrations than the other two fuels. CO was also found to be a problem for conventional coal, with maximum hourly averages of 145 ppm (The health standard is 35 ppm).

Thus in general the results showed that little or no difference existed between the fuel types with respect to exposures. It was, however, noted that failure to establish significant differences did not necessarily prove that differences did not exist (Terblanche et. al. 1994). Nevertheless it was not possible to recommend the use of any of the three fuels as a result of this real life experiment, and it was recommended that emissions from the fuels be monitored in a controlled laboratory environment before any conclusions could be made. In the laboratory it would be possible to control a number of the variables such as the position of monitors in the room, fire lighting procedures and the type of stove used. These tests were carried out as described in Section 5.2.

5.3.2 1993 field trials in Evaton

As a consequence of the inconclusive results of the 1992 field trials, Phase II was undertaken during July 1993, with a larger sample and more control of the variables that had plagued the Phase I test. However for Phase II, conventional coal was not one of the fuels monitored and instead Ecofuel was included, along with the other two low smoke fuels tested in Phase I. It should also be noted that the CSIR fuel used in the 1993 tests was not the same as that used during 1992 (see Section 4.3). The total number of households involved in the tests was 90, with each fuel being tested in 30 homes. The objectives for Phase II were the same as for Phase I, but in addition, the results were to be compared with those for normal coal using Phase I data.

Gaseous pollutants

Gaseous pollutants (CO, NO_2 and SO_2) were measured inside each of the homes using EXOTOX 75 gas monitors (with a low detection limit of 0.1 ppm) during monitoring sessions of 8 hours which included peak cooking and heating periods. Results of the measurements are presented in Table 5-2.

TABLE 5-2: HOURLY AVERAGE EXPOSURES FOR GASEOUS POLLUTANTS DURING 1993 EVATON FIELD TRIALS (Source: Terblanche et. al. 1994: 10)

Fuel type		*Pollutant*		
		SO_2 [ppm]	*NO_2 [ppm]*	*CO [ppm]*
Hourly Health Standard		0.40	0.60	35
Average exposure*		0.31296	0.01655	6.63906
All fuels	Max hourly avg**	3.90917	0.44615	145.217
	Corresp. hour	18	22	20
	Fuel type	UCP	Normal coal	Normal coal
	Time of occurrence	Day	Day	Night
Normal coal	Max hourly avg***	1.8325	0.44615	145.217
	Corresp. hour	18	22	20
	Time of occurrence	Day	Day	Night
CSIR briquettes	Max hourly avg***	3.36417	0.005	55.292
	Corresp. hour	18	16	16
	Time of occurrence	Day	Day	Day
Wits/UCP	Max hourly avg***	3.90917	0.18	83.15
	Corresp. hour	18	22	18
	Time of occurrence	Day	Day	Day
Ecofuel	Max hourly avg***	3.28583	0.19701	15.858
	Corresp. hour	16	0	17
	Time of occurrence	Day	Day	Day

* *One overall average for the 365 hourly averages in the data set was computed for each of the three pollutants*

** *The maximum of the 365 hourly averages, as well as its corresponding information, was selected for each of the three pollutants.*

*** *The 365 hourly averages were divided into the different coal types. From each subset (coal type), the maximum average, as well as its corresponding information, was selected for each pollutant.*

The extent to which concentrations of pollutants from each of the fuel types exceed the USA Health Standard is given in Table 5-3.

TABLE 5-3: PROPORTION OF 1993 EVATON FIELD TRIAL READINGS ABOVE THE HOURLY USA HEALTH STANDARDS [% of observations exceeding]
(Source Terblanche et. al. 1994: 12)

	SO_2 *(USA standard, 0.40 ppm)*	*NO_2* *(USA standard, 0.60 ppm)*	*CO* *(USA standard, 35 ppm)*
Normal coal	29.79	0	5.66
CSIR	13.16	0	3.51
Wits/UCP	28.97	0	6.54
Ecofuel	17.58	0	0

Comparison of gaseous pollutants: One-way analysis of variance

To compare gaseous pollutant emissions from the four different fuels, a one way variance analysis was performed. Results showed that for the early hours of the morning and the first hours of the afternoon (monitoring was not undertaken between 9h00 and 13h00) pollution levels were below detection levels while from 15h00 to 16h00, there was no statistical difference between the four fuels (although measurements were above the detection limit of 0.1 ppm for some of the fuels). For the period 16h00 to 23h00, results showed no significant differences between any of the fuels (ibid).

Comparisons of gaseous pollutants: Two-way analysis of variance

A two way analysis of variance was performed to compare concentrations of the three pollutants (SO_2, NO_2 and CO):

- resulting from the four different fuels over all the monitoring hours, and secondly
- during the day as opposed to during the night, irrespective of fuel type.

The results of the analyses showed the following:

SO_2 Without taking temperature into account, Ecofuel produced the lowest SO_2 concentrations and there was no difference between day and night. However when temperature influences were included as a covariant, there was no difference between the fuel types but there was a significant difference between day and night values, with the higher values occurring during the day.

NO_2 Without taking temperature into account, normal coal produced the highest NO_2 concentrations, and day and night concentrations differed significantly. After adjusting for temperature, normal coal still produced significantly higher concentrations than the low smoke fuels. Also a significant difference between day and night remained, with daytime concentrations being higher than those during the night.

CO Without taking temperature into account, normal coal produced the highest CO concentrations, and day and night concentrations differed significantly with the highest occurring during the night. After adjustment for temperature, normal coal still produced the highest concentrations of CO. The night time concentrations were also higher than during the day after adjustment for temperature.

The results of the concentrations after adjustment for temperature are shown in Table 5-4.

TABLE 5-4: HOURLY AVERAGE EXPOSURES OF GASEOUS POLLUTANTS AFTER ADJUSTING FOR TEMPERATURE (Source: Terblanche et. al 1994:21,22,24)

	N *[N°]*	*SO_2* *[mean ppm]*	*NO_2* *[mean ppm]*	*CO* *[mean ppm]*
Fuel Type				
Normal Coal	47	0.3859	0.0472	22.0791
CSIR	114	0.4455	0.0042	6.6812
Wits/UCP	107	0.4363	0.0058	6.4759
Ecofuel	91	0.2582	0.0090	3.9224
Time Period				
Day	270	0.2300	0.0282	5.1612
Night	89	0.5330	0.0050	14.4181

While the variations in gaseous concentrations resulting from the various fuels is a direct result of the composition of the fuels, Terblanche et. al. (1994) do not give reasons for the differences between the day and nighttime concentrations.

Finally a comparison was made between the three low smoke fuels only, in order to exclude the possible confounding influence of the different years of monitoring, expressed in the analysis as temperature differences. When looking at the differences in gaseous concentrations during the day as opposed to the night for the three separate fuels, the following was apparent (Terblanche et. al. 1994):

- For SO_2, CSIR and Ecofuel performed similarly while UCP fuel showed higher levels during the day.
- For NO_2, Ecofuel and UCP coal were similar with CSIR fuel having lower levels during the day.
- For CO, CSIR and UCP fuels did not differ during the day and have significantly higher CO levels compared with Ecofuel.

However, "the analyses that were performed for SO_2, NO_2 and CO at the different monitoring times did not indicate any differences between the four coal types. In all the cases the standard deviations were greater than the means and the sample sizes relatively small. This is an indication that the underlying variability is too large and the sample size too small to pick up any statistically significant differences" (ibid).

In the overall analysis for the gasses (all hours taken together), the standard deviations were also greater than the means, however, the number of observations was sufficiently large for significant differences to be found. A comparison of the concentrations of the three gasses from the three fuels is given in Table 5-5.

TABLE 5-5: AVERAGE CONCENTRATIONS OF POLLUTANTS - all hours taken together [ppm] (Source: Terblanche et. al. 1994:25)

Fuel	SO_2	NO_2	*CO*
CSIR Wits/UCP Ecofuel	0.205 0.469 0.212	0.0005 0.010 0.011	5.6 8.7 2.5
p-value (95% confidence level)	<0.006	<0.004	<0.003

Particulate Emission measurements during 1993 Evaton field trials

Similar to gaseous pollutants, total suspended particulate (TSP) monitoring was conducted during 12-hour monitoring sessions, to include peak cooking and heating periods. Also similar to the gaseous emissions, a two way variance analysis was used to compare TSP concentrations:

- as a result of the four different fuels, and
- during the day as opposed to the night (irrespective of the fuel type).

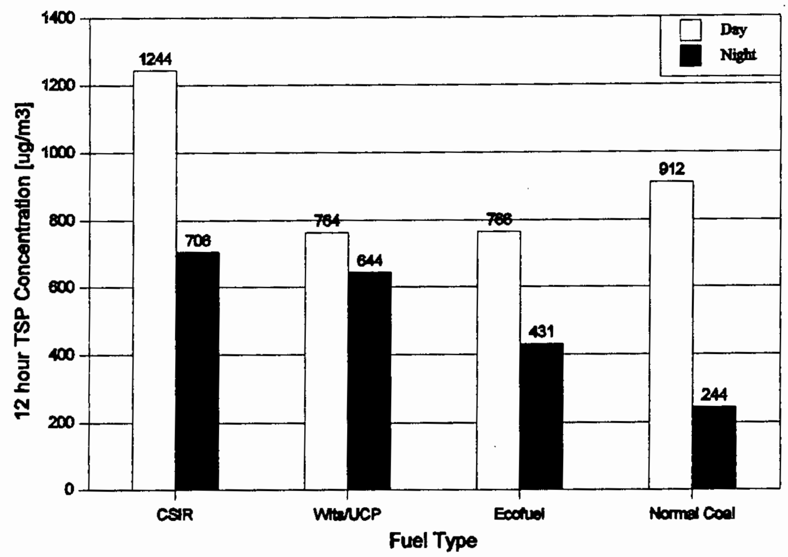
Temperature was not recorded during the TSP measurements and was hence not included in the analysis. The results show that on average for all hours, the fuel type was significant ($P < 0.0004$) and that the CSIR fuel produced the highest levels of TSP while Ecofuel had a tendency towards lower levels. TSP concentrations differed significantly between day and night ($P < 0.001$) with the highest occurring during the day. These results are given in Table 5-6.

TABLE 5-6: AVERAGE TSP CONCENTRATIONS MEASURED DURING 1993 EVATON FIELD TRIALS (Source: Terblanche et. al. 1994:32)

	N *[N°]*	*Mean TSP concentration [μg/m³]*	*STD*
Fuel type			
Normal coal	26	732.2308	448.7607
CSIR briquettes	30	1064.6667	497.8349
Wits/UCP fuel	29	722.7586	286.3801
Ecofuel	30	654.0000	377.6570
Time Period			
Day	78	923.5513	448.2208
Night	37	527.5946	251.7816

Figure 5-2 shows the average concentrations of TSP for the different fuels during the two periods of the day. The higher day-time concentrations can be attributed to fire lighting procedures occurring during the day, coupled with the fact that fire lighting generates more smoke than fire maintenance (Terblanche et. al. 1994: 34). Although Terblanche et. al. indicate that road dust is a contributor to TSP levels they do not comment on the possibility that road dust is a reason for higher day time readings.

FIGURE 5-2: 12 HOUR AVERAGE TSP CONCENTRATIONS MEASURED IN EVATON, 1993 (Source; Terblanche et. al. 1994:35)



The extent to which the TSP levels exceeded the USA 24-hour health standard as well as the World Health Organisation (WHO) no-effect-exposure-limit is shown in Table 5-7.

TABLE 5-7: PROPORTION OF TSP 12-HOUR AVERAGES EXCEEDING HEALTH STANDARDS - regardless of day or night. (Source: Terblanche et. al. 1994: 11)

Fuel Type	*Proportion of readings exceeding health standards [%]*	
	WHO Standard (180 μg/m³)	*USA 24-hour Standard (260 μg/m³)*
CSIR	100	100
Wits/UCP	100	100
Ecofuel	100	100
Normal coal	96.15*	84.62*

* *All the day-time TSP values exceeded both health standards while some of the night-time values did not.*

Composition of Total Suspended Particulates

Further, X-ray fluorescent (XRF) analyses, which is a powerful tool for determining the composition of TSPs and the presence of air toxics such as lead and cadmium, were performed to provide a full profile of elements present on TSP filters. XRF elemental screening was performed for a wide range of element and quantitative data was obtained on each element. Results are given in Table 5-8.

TABLE 5-8: AVERAGE CONCENTRATIONS OF ELEMENTS MEASURED ON TSP FILTERS (Source: Terblanche et. al. 1994: 13)

Element	*Average concentrations [µg/m³]*			
	Normal Coal (Phase I results)	*CSIR*	*Wits/UCP*	*Ecofuel*
Silica	75.7	91.11	66.69	51.23
Iron	60.2	77.40	48.07	34.54
Aluminium	43.7	49.97	38.76	29.57
Sulphur	15.8	7.68	13.74	2.64
Calcium	22.7	35.90	16.10	12.07
Potassium	7.8	9.51	7.52	7.55
Titanium	6.4	7.94	5.02	3.62
Phosphorous	1.2	1.54	1.77	0.98
Lead	1.4	0.49	0.37	0.26
Magnesium	1.6	0.68	0.49	0.54
Sodium	1.7	0.85	1.89	1.44
Chromium	0.4	0.40	0.35	0.04
Manganese	1.8	2.72	1.35	1.15
Arsenic	0.04	0.00	0.00	0.00

5.3.3 Summary of the results of the 1993 Evaton Monitoring

Terblanche et. al. (1994) summarize the results of the Evaton indoor monitoring as follows:

INDOOR GASEOUS CONCENTRATIONS

- Normal coal was associated with the highest hourly average concentrations of NO_2 and CO.
- Wits/UCP coal produced the highest hourly average concentrations of SO_2.
- Ecofuel was associated with the lowest concentrations of SO_2 and CO.
- The SO_2 hourly health standard was exceeded in 13.1% (CSIR), 17.5% (Ecofuel), 28.9% (Wits/UCP) and 29.7% (normal coal) of measurements.
- The NO_2 health standard was not exceeded.
- The CO hourly health standard was exceeded in 3.5%(CSIR), 6.5%(Wits/UCP) and 5.6%(normal coal) of measurements. The Ecofuel did not exceed health standards.
- Ecofuel performed better across the board than the CSIR and Wits/UCP fuels with respect to gaseous pollutants.

INDOOR TSP CONCENTRATIONS

- TSP health standards were exceeded in 100% of the time for the low smoke fuels and 96% of the time for normal coal.
- Elemental analysis of TSP indicated that the major differences between the four fuels are related to sulphur, calcium, chromium, arsenic and lead content (See Table 5-8).
- TSP concentrations were lowest for Ecofuel (654 $\mu g/m^3$) and highest for the CSIR fuel (1064 $\mu g/m^3$) (see Table 5-6).

5.4 OTHER EFFECTS OF THE INTRODUCTION OF LOW SMOKE COAL

Employment creation

With the exception of the CSIR briquettes, it is not clear from the information provided by the various low smoke fuel developers as to what manpower will be required to produce their fuels. However it is clear that the local production of briquetted fuel has a much higher potential to provide employment opportunities than the devolatilised fuels which will require large capital intensive plant for their production. If one uses the CSIR briquette production as an indicator of employment creation potential the following rudimentary calculations can be made:

Fuel requirement:	3 million tons/annum
Production rate:	1.5 tons/manday
No of days production:	240 days/annum
Number of jobs created:	(3 x 1.5)/240 = 18750

It is of course entirely unlikely that a single low smoke fuel would be capable of meeting the market requirements and it would be much more likely that a range of fuels would best suite the demands of the market. However a low-tech, labour intensive approach, with its ability to create employment, is a consideration in a cost benefit analysis.

Reduction in the rate of growth of discard coal dumps

A reduction in the quantity of discard coal that needs to be dumped is a possible small benefit of the introduction of low smoke fuels. This will only occur if the fuels manufactured from discards are more (or at least equally) viable than the devolatilisation of lump coal. The benefits of reduced discard production would include reduced air pollution as a result of a reduction of spontaneous combustion of dumps, reduced ground water contamination under dumps and also a lower land requirement by mines.

However, given the small household coal requirement (approximately 3 to 5 million tons/annum) relative to the total discard production (about 40 million tons/annum) the benefits mentioned above will be marginal. A point worth noting is that it would not be at all viable to use existing discard dumps as the cost of processing would be far higher than that of processing discards into the desired fractions as they are produced.

Increased revenue for mines from the sale of discards

If discards can be used for the manufacture of low smoke coals they will provide added income for the mines. However, this additional income is likely to be limited as the cost of processing and stockpiling usable portions will be higher than simple dumping.

5.5 MARKET ACCEPTABILITY OF LOW SMOKE PRODUCTS

In 1987 research by LHA Management Consultants assessed peoples' attitudes to solid fuel use and concentrated mainly on coal use trends in electrified as opposed to non-electrified homes. With regard to perceptions of smoke generated by the use of coal and the possibility of using "low smoke coal", LHA concentrated on differences between coal and anthracite. The study showed that:

- coal is the prime fuel used by non-electric households for cooking and heating, and
- in electrified households, 64% continue to use coal; primarily for heating. It was only amongst this group that there was any evidence of anthracite use and this was at a very low level (2% of electrified households).

The two reasons given for this low use of "smokeless coal" was the poor accessibility of anthracite (not delivered and only available at a few coal yards) and the high price of anthracite, double that of coal (LHA 1987c). Thus possibly the only lesson to be learned from this research is that high price is a definite deterrent to widespread use.

More recent research into the market acceptability of low smoke fuels was undertaken by Hoets during the low smoke fuel trials in Evaton during 1992 and again in 1993. One of the primary objectives of the study was to determine the acceptability of three low smoke fuels (Wits/UCP, CSIR briquettes and the Ecofuel) to users. As explained in Section 5.3, 90 households were involved in the trials (30 for each fuel) and with each using the test fuel for two weeks, after which they reverted to ordinary bituminous coal. Two recall interviews were conducted with the person responsible for the energy decisions in each household, the first at the end of the low smoke trial period, and the second a week later after respondents had again used standard bituminous coal. Table 5-9 gives responses to various questions after the two week test fuel period.

TABLE 5-9: LIKES AND DISLIKES ABOUT LOW SMOKE FUELS. EVATON FIELD TRIALS, 1993 (Source: Hoets 1994)

CSIR (1993 version)		*Wits/UCP*		*Ecofuel*	
Item	*%*	*Item*	*%*	*Item*	*%*
What do you like about the low smoke fuel (mentioned spontaneously)					
Doesn't produce so much smoke	40	Doesn't produce so much smoke	36	Burns very fast	73
Burns very well	12	Coal lasts longer	24	Does not produce so much smoke	23
Lasts longer	8	Heat lasts longer	24	Produces more heat	19
		Burns very well	20	Easy to light	19
		Produces more heat	12	Doesn't need wood	19
		Heats the whole house	12	Lasts longer	8
		Smells less of chemicals	8	No smog	8
				Use it without getting dirty	4
				Heats the whole house	4
				Smoke is not dangerous	4
What do you dislike about the low smoke fuel (mentioned spontaneously by respondents)					
Coal breaks up easily	40	Too much wood needed to start the fire	28	Doesn't last	23
Size is too big	16	It warms rather than heats	12	Burns too fast	23
Warms rather than heats	12	Makes smoke with a chemical smell	12	Breaks up easily	12
Does not burn well	12	Makes too much ash	8	Heat does not last long	12
Goes out when you add more coal	12				
Lots of coal wasted due to crumbling	8				
Does not burn for long	8				

Table 5-9 shows how the three low smoke fuels were rated by the users in comparison to normal bituminous coal. The numbers refer to the difference between the percentage of participants which rated the low smoke fuel better in the first recall interview and the normal coal as better in the final interview (after they had used normal coal again for a week). Thus for example: on the ease of lighting, Ecofuel was rated better than normal coal by 96% of users, while normal coal was rated better by 4% of Ecofuel users giving a difference of +92% (Hoets 1994: xvi).

TABLE 5-10: COMPARISON OF LOW SMOKE FUELS WITH NORMAL COAL
(Hoets 1994: xvi)

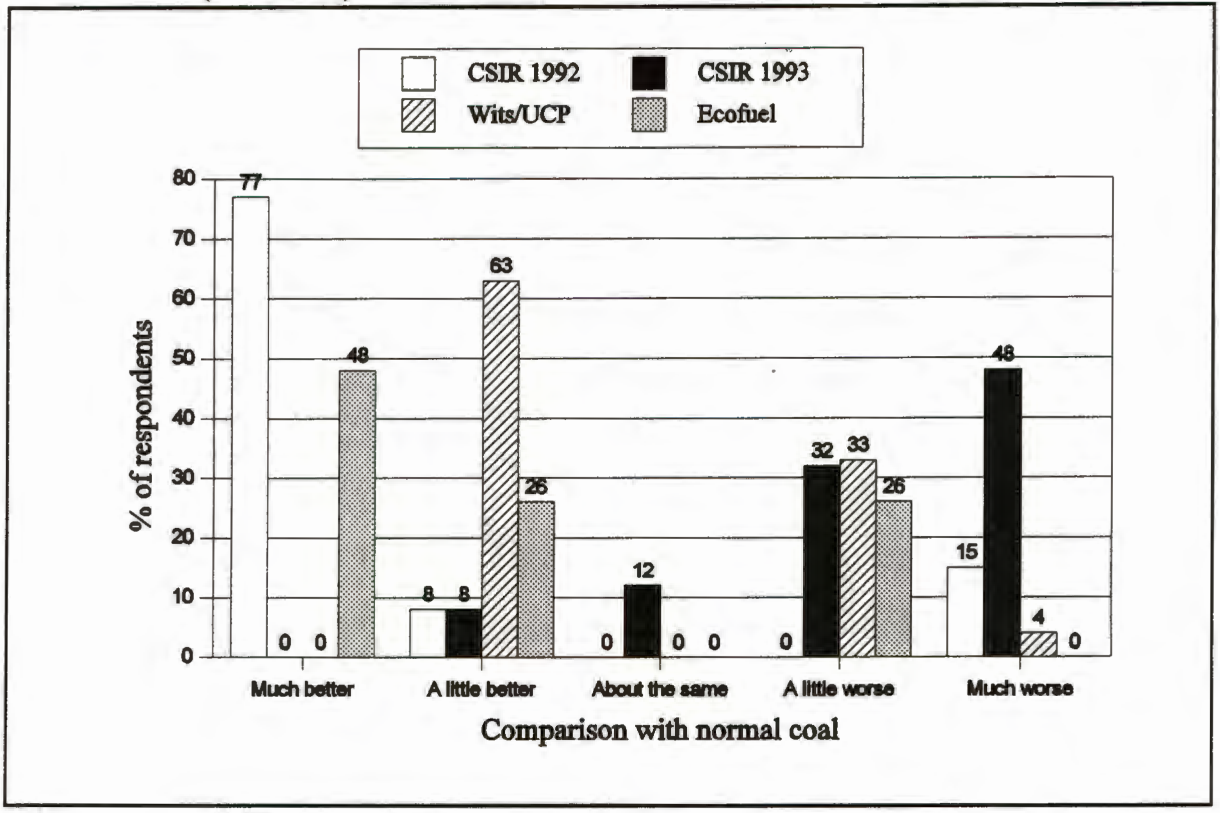
Fuel Attribute	*CSIR*	*Wits/UCP*	*Ecofuel*
Amount of smoke	+76	+ 96	+ 76
Ease of lighting	- 80	- 84	+ 92
Amount of heat	- 76	+51	+ 87
Speed of cooking	- 80	- 68	+ 87
Amount of ash	- 29	+12	+ 37
Heat retention	- 68	+39	- 83

Thus from Table 5-10 it can be seen that Ecofuel rated better than coal on all points except for heat retention. With the exception of smoke emission the CSIR briquettes were rated well below normal coal on all points while the Wits/UCP coal had mixed desirable attributes when compared with normal coal.

Hoets also tested the field trial participants' attitudes to the pricing of the three fuels. Findings indicate that there will be a resistance to any fuel that is priced higher than normal bituminous coal. Ecofuel was the fuel most likely to find a market at the same price as coal but its marketability decreases rapidly when premium prices are proposed. The 1993 version of the CSIR fuel would not find a market, even at prices below the price of normal coal. The Wits/UCP coal would find a market if it was priced R2/bag below the price of normal coal but would encounter resistance at the same price as coal (Hoets 1994: xvii).

Finally Hoets asked respondents to give the test fuel they used a rating in comparison with normal coal. One of the confounding problems with the surveys was that the results for 1992 and 1993 were not comparable for the CSIR fuel. As explained in Chapter 4, Section 4.3, the 1992 version was superior to the one tested in 1993 and the users' opinions on both versions of the fuel are included in Figure 5-3.

FIGURE 5-3: FINAL RATING OF LOW SMOKE FUELS AGAINST NORMAL COAL (Hoets 1994)



5.6 ECONOMIC FRAMEWORK FOR COST BENEFIT ANALYSIS

Given all the evidence presented so far in this synthesis it seems highly unlikely that low smoke fuels will be able to enter the market at a price equal to or lower than that of bituminous coal. The question that then arises is, how much is it worth to South African society to reduce the current pollution levels?.

The major considerations in developing a strategy for the implementation of a workable low smoke programme is whether the cost of implementation will be offset by the resultant benefits. The principle underlying a cost benefit analysis (CBA) is that all the costs and benefits accruing to society as a whole should be identified and valued in monetary terms so that it can be established whether there is a net cost or benefit to the society. Van Horen & Eberhard (1994) point out that, while a CBA can make the decision making process more explicit, it should not be misconstrued as an entirely objective and judgement-free decision making tool. Apart from obvious controversies such as those of quantifying, in monetary terms, impacts such as loss of human life, CBA's also entail value judgements, for example, regarding the relative weightings attached to benefits and costs incurred by different classes or groups. Thus, a CBA may attach a higher priority to benefits accruing to the poor or to the environment.

To date there has been no detailed research on identifying the components of a CBA for the introduction of low smoke fuels and hence for the purposes of this document a preliminary list of costs and benefits is presented.

COSTS

1 Present cost of household bituminous coal to users.
2 Capital cost of plant and equipment required for the production of sufficient low smoke coal to meet future demand.
3 Production costs.
4 Cost of distribution.
5 Cost of marketing, education and information dissemination.

BENEFITS

1 Revenue derived from sale of low smoke fuels.
2 Cost of avoided health care expenditure.
3 Increase in income to employers and employees due to a decrease in absenteeism and time not worked as a result of illness,
4 Effects of reduced mortality rates.
5 Aesthetic impact of reduced air pollution.
6 Avoided disposal costs of discard coal.
7 Increased employment attributable to a low smoke programme.

Chapter Six

KEY ISSUES IN CONSIDERING LOW SMOKE FUEL POLICY

6.1 INTRODUCTION

The objective of this final chapter is to identify the key issues that have arisen in this synthesis and to flag those that should be considered in the development of appropriate low smoke fuels, the planning of future research and formulation of policy for the introduction of low smoke fuels. These are discussed with regard to the *production of low smoke fuels*, their *distribution* and their *impact on the health* of current bituminous coal users. Using these issues as a basis, areas in which further research would be useful are suggested. Finally comment is made on the anticipated schedule for a low smoke fuel programme, as published by the Low Smoke Fuel Advisory Committee, in the light of these suggestions.

6.2 KEY ISSUES IN CONSIDERING LOW SMOKE FUELS AS A SOLUTION TO HEALTH PROBLEMS

6.2.1 PRODUCTION OF LOW SMOKE FUELS

In assessing the potential efficacy of low smoke fuels as an intervention strategy there are a number of technical characteristics of the fuels which are important. These include:

1. *combustion emissions,*
2. *cost of production*,
3. *acceptability of the fuels to the market,*
4. *availability of sufficient quantities of feedstock* to meet demand,
5. *production capacity,*
6. *quality control* in the manufacture of low smoke fuels, and
6. the ability of the various approaches to provide a *contribution to the RDP.*

Each of these aspects is considered below.

COMBUSTION EMISSIONS

From the policy developer's point of view, the entire justification for a low smoke fuel programme is in fuels emitting considerably lower quantities of pollutants than currently used bituminous coal. As a result, it is crucial that any fuels that are to be supported, as part of a low smoke fuels programme, have a proven ability in this regard. To date one set of laboratory performance and emission tests have been undertaken on three prototype low smoke fuels, and when these results are compared with those of normal bituminous coal (see Section 5.2), it is evident that the prototype fuels produced fewer hazardous emissions. However there are a number of problems with accepting these results at face value.

Firstly, the low SO_2 emissions reported for the CSIR briquettes are a result of the low sulphur content of the "Skeat" coal used in their manufacture, and are not necessarily an inherent characteristic of the manufacturing method. Also for the Ecofuel, the ingredients of the briquettes have not been revealed and for the present it is impossible to comment on the influence that varying the ingredients will have on emissions. A further problem is that the test results provide no information on the source, grade or composition of the bituminous coal tested.

Secondly, the pollutants emitted during combustion are not only a function of the fuel itself, but also depend on the appliance in which it is utilised as well as the actions of the appliance operator. For instance, the characteristics of the emissions from the combustion of an amount of coal in a closed stove will be different to those of the emissions resulting when a similar amount of fuel is burned in an open brazier. The results of the CSIR laboratory tests which have been undertaken, provide emissions data for one particular best scenario (i.e. fuel being used in a good condition closed coal stove). At present there is little knowledge on the number of braziers that are in use and how this compares with the number of closed stoves. If the number is high, and a low smoke fuel performs less favourably in a brazier, the overall impact will need to be assessed. Thus, it would be useful to devise and perform standard laboratory tests for a typical brazier in addition to the standard coal stove test.

If it is to be expected that low smoke fuel developers produce products with acceptable emission characteristics, and at the same time retain interest in entering the market, it would be helpful to have an emissions specification that should be met by fuels. This will allow developers of briquettes to finalise their ingredient mix. Also, for those developers using a process where devolatilisation is coupled to tar distilling, an emission specification will allow them to fix the volatile content and hence determine tar yields. Only then, will it be possible to determine revenues from the sale of low smoke char and the tar products and hence, the viability of the process. This approach of establishing a specification as a first step has been suggested by a number of commercial organisations that are involved in the development of low smoke fuels.

Issues with respect to emissions from low smoke fuels.

- **Crucial that low smoke fuels have a proven ability to emit substantially lower quantities of pollutants than bituminous coal.**
- **One set of laboratory tests undertaken to date, shows lower emissions from low smoke fuels.**
- **Emissions can vary as a function of a number of factors. To date there has been no formal testing of the influence these factors may have on emissions.**
- **It is presently difficult for developers to design their fuels in the absence of a specification.**

THE COST OF PRODUCTION

The cost of production of fuels can be divided into two components; the cost of fuel constituents, and the cost of manufacture.

The cost of fuel constituents:

All of the low smoke fuels described in Chapter 4, with the exception of one, which is a briquetted waste paper, have coal as their primary feedstock. For certain of the fuels, lump coal can be used as a feedstock while for others, discard coal provides the major energy component.

Where lump coal is used as feedstock it enters the volatile reduction process at the same price as coal going to the household market, and as a result there is an immediate premium to be paid for the resulting low smoke product. However in certain cases this can be offset by the value of tar products that are rendered from the process and thus it is not necessary for the overall cost of production to be covered solely by the sale of the devolatilised char. This is the approach that has been taken by Coal Tar Products.

The Wits/UCP low smoke coal production process utilises discard lump coal which is washed to extract lump components with higher calorific value. Thus, in addition to the cost of the unwashed discards, there is also the cost of the washing process. Notwithstanding these two cost components the overall price of feedstock is considerably lower than that of ordinary lump coal. This discard lump coal could also be used to reduce the feedstock cost in the process used by Coal Tar Products.

The cost of the constituents of briquetted fuels depends on the source of the constituents and also the binders. All the briquetted fuels described in this document utilise wastes as their major energy component and hence the feedstock cost is low. For the present there is no market for coal discards, however if a market develops due to the manufacture of low smoke coal, the cost of discards will rise, putting pressure on the overall cost of manufacture. In addition, the cost of the binder needs to be considered and for example, in the case of the CSIR briquette where cement is used, the cost can be significant.

Cost of manufacture

The cost of manufacture is an area in which there is presently little information available. In the case of the Wits/UCP fuel and the CSIR briquettes, which have been developed using public funds, estimates of the cost of manufacture have been presented (see Section 4.4.1 and 4.4.2). For the remainder of the fuels, either developers have provided estimates or no information is available (see Table 4-11).

For the manufacture of devolatilised fuels, centralised , capital intensive production will be required. For the Wits/UCP approach it has been estimated that capital requirements will be of the order of R10 million for the production of 336 000 tons/annum (see 4.4.2). Assuming a total national requirement of 3 million tons/annum, the total capital requirement for the establishment of sufficient production plant could therefore be close to R90 million.

The briquetted fuels lend themselves to small scale localised production, although this need not necessarily be the case, with very much lower capital requirements. Using the CSIR briquetting approach as an example, a group of six workers require a work-station costing about R3000 (the cost of a concrete mixer, spades, wheelbarrows, etc), and will be capable of producing 960 tons/annum (see Section 5.4). Thus to produce an annual requirement of 3 million tons, a total of 3125 work-stations will be required at a total capital cost of R9.4 million.

The above examples of capital requirements are first order estimates and a much closer study of the actual requirements and the consequent production capacities will have to be undertaken before accurate figures can be calculated and compared.

With regard to the cost of operation, the large scale capital intensive approach can produce fuels at a lower cost per ton than the CSIR labour intensive method (see Section 4.4.1 and 4.4.2). In general this principle will probably be true, however, the extent of the difference can only be determined if much more detailed financial data is available.

Table 4-12 gives an indication of the production costs of various low smoke fuels and compares them to household bituminous coal. The table indicates that, at best, low smoke fuels will cost merchants/distributors nearly double what they pay for bituminous coal. However if the two lowest cost options (CSIR, Scenario C and Ecofuel) are examined more closely it will be seen that their estimates may be optimistic and hence a energy price ratio of higher than 2 is therefore more realistic. Given the approach taken by Coal Tar

Products, and possibly Sastech, it is possible that they can produce a product at a price below those indicated in the table and hence closer to that of bituminous coal. However there is little chance that the bituminous coal price can be matched by either of these companies.

Issues with regard to the cost of production

- **Little public information available on the cost of production. The estimates that are available are not well developed.**
- **There are a number of possible sources of feedstock.**
- **Capital intensive production plant results in lower operational costs (excluding the cost of capital).**
- **Small scale approach requires less capital but has higher operational costs, mainly due to the cost of labour.**
- **It is not clear from information presently available, whether a capital intensive or a small scale approach will result in an overall lower cost of production.**
- **Costs of low smoke fuels to coal merchants/local distributors could be at least double the cost of bituminous coal. If a tar distilling process is used, this could produce a fuel at a lower premium.**

MARKET ACCEPTABILITY

Given that the objective of a low smoke fuels programme is to cause present bituminous coal users to shift to low smoke products, it will be necessary for newly introduced fuels to compete directly with bituminous coal. In this regard, there are a number of considerations. These are:

Retail price,
Lower smoke emissions,
Reactivity/length of burn,
Cleanliness,
Adaptability to existing appliances, and
Accessibility/delivery.

Retail price

Findings indicate that there will be a resistance to any low smoke fuel that is priced higher than normal bituminous coal. In field trials of three low smoke fuels in 1993, the characteristics of Ecofuel meant that it was likely to find a market at the same price as coal but its marketability decreased rapidly when premium prices were proposed. As a result of various problems with the other two fuels, they were unlikely to compete in the bituminous coal market. In the case of one of the fuels, people said that they would not be prepared to buy the fuel at all, even at prices below the price of normal coal, while in the case of the second, it would find a market if priced lower than normal coal (see Section 5.6).

Lower smoke emissions

Lower smoke emissions is a characteristic that field trial participants liked about the low smoke fuels (see Table 5-9). However, although coal smoke is a concern (see Figure 2-5), people will certainly not stop using coal to eliminate smoke (see Figure 2-6), and this implies that people will not purchase fuels simply because they emit lower quantities of pollutants.

Reactivity/length of burn

Field trials indicated that high reactivity is a desirable feature (see Table 5-9). In general briquetted fuels are more reactive than the devolatilised fuels, although these characteristics can be altered for all the fuels. The Wits/UCP devolatilised coal experienced serious problems with poor reactivity and this was a specific problem mentioned by field trial respondents (see Table 5-9)[1]. The fuel being developed by Coal Tar Products has not been part of any public research, however the developers say there is no problem with reactivity as the fuel is manufactured along the lines of activated carbon.

The corollary to high reactivity is that fuels will not burn for long periods, a feature that a significant number of users desire. Hence the optimum fuel is one that offers a compromise between these two features, possibly with more emphasis on good reactivity.

Cleanliness

Although there are many desirable features of bituminous coal, one aspect that household users dislike is that it is dirty. Not only is it dirty to handle and store, but also the smoke emitted attaches itself to walls, clothes and furniture (see Section 2.5). Low smoke fuels are, in general, cleaner to handle and, with lower volatile content, will emit less tars to dirty users' environments.

Adaptability to various appliances

Apart from the shape of briquettes, their size is also a characteristic that influences their ease of use and hence marketability. A large proportion of potential users will be using low smoke fuels in their coal stoves which have been designed to accommodate high energy density bituminous coal which comes in small size configurations. Some of the briquettes are produced in a large size and at the same time have a low energy density. For example, there would be a definite problem with fitting more than one ARO Firebrick briquette into any of these stoves, and if one does, their long rectangular shape would lead to reduced surface to mass ratio, poorer oxygen supply and hence lower power output from the fire. A further problem with large briquette configuration is that it is not possible to add a small amount of extra fuel to a fire. Large configuration will, however, not prevent use in braziers or without any appliance at all.

The fact that their fuels can be used without an appliance is a claim made by both Ecofuel and Alan Rodkin. Whether this is a feature that will attract the attention of users will remain to be seen but it would seem that there are very few families that make fires with no appliance at all.

Accessibility/delivery

At present the vast majority of coal users have their supplies delivered to their homes by coal merchants. Given the bulky and heavy nature of the fuel this is a critical component of the coal distribution chain. Low smoke fuels, with their higher ash contents and generally lower energy densities will be more bulky and heavier per energy unit than bituminous coal. Thus, strategies that seek to reduce distribution costs by excluding house to house delivery may not be desirable by coal users.

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[1] However the problem was a result of the prototype fuels being manufactured in less than optimum plant and would be solved if modified plant was used.

Issues regarding market acceptability

- **There will be market resistance to fuels priced higher than bituminous coal.**
- **Low smoke emissions are desirable, although not at the expense of the performance of fuels.**
- **High reactivity is desirable although a balance should be achieved between ease of lighting and the length of burn.**
- **Cleanliness would be an advantage, but not a critical aspect to fuels.**
- **The size and shape of fuels should allow easy use in standard coal stoves as well as braziers.**
- **Home delivery of fuels, although costly, is an important component of the distribution chain.**

AVAILABILITY OF FEEDSTOCK

The various feedstocks that can be used in the production of low smoke fuels, as well as comment on their availability are given below.

Lump coal

Given South Africa's coal reserves, there is, in effect, an unlimited supply of lump coal that can be used in devolatilisation and tar distilling processes.

Lump discards

Extensive studies have been carried out on reject coal and at present it is estimated that South Africa produces 62 million tons/annum of discards, with a calorific value ranging from 5 - 20 MJ/kg. This is of the order of ten to twenty times the annual household coal consumption. Not all of these discards are useful for low smoke coal products but a number of mines in the Witbank area, notably those supplying the export market, reject large amounts of reasonable quality coal (ash 25-30%, CV≤ 20MJ/kg). Rewashed discards may be sized into any range required and tests for the Wits/UCP project, at one particular mine, showed that at a washing density of 1.9, a product with 25% ash content, 20% volatile matter, 1.0-1.1% sulphur content and in the 10 to 15 mm size range could be produced with some consistency.

Duff

Total coal duff production in 1991 amounted to 2.2 million tons (see Figures 2-1 and 2-2) and will grow to about 3.6 million tons for the year 2000. In addition discard fines production in 1991 was 4 million tons and will grow to 6.7 million tons for the year 2000. If these two categories of discards are taken together there is a sufficient supply with acceptable calorific values for briquette production, to supply a large proportion of, if not the entire present household bituminous coal market.

Waste paper

At present it is not clear what quantities of paper and biomass wastes are available for use as a fuel feedstock. Unlike coal discards, the supply points are likely to be dispersed around the entire country and this implies a collection and transport cost which may mean that they are no cheaper than coal discards.

Issues regarding feedstock supply

- **More than sufficient lump coal supply. This is an expensive feedstock.**
- **Sufficient supply of lump discards. There is a cost attached to processing discards, especially if the pre-washed material is to be transported from its source to the processing plant.**
- **Significant quantities of duff and fine discards are available. Discards from different mines have different qualities and therefore not all the available material is suitable for low smoke fuel briquettes.**
- **Available quantities of paper and biomass wastes are unknown.**

PRODUCTION CAPACITY

At present there is no installed low smoke fuel production capacity in South Africa. All the fuels that have been used in field tests have been produced on a contract batch basis rather than coming from commercial production. Only one organisation, United Carbon Producers have provided any indication of what production output they could expect to achieve, and after a gearing up period this amounts to 336 000 tons/annum. Coal Tar Products are presently designing a full scale plant for the production of devolatilised fuel and tar products, however the design production capacity is not known. In theory the production capacity of briquetting operations can grow spontaneously in response to demand.

One of the advantages to the establishment of large scale production plant is that it will be possible to develop high production capacity in planned time frames. On the other hand the establishment of localised small scale briquetting operations will be much more difficult to predict and will require a longer lead in period as small entrepreneurs are unlikely to commit themselves unless it is evident, through demonstration by others, that there are financial gains to entering the market.

Issues regarding production capacity

- **No production capacity exists at present**
- **Large centralised production can be relatively easily planned.**
- **Small scale localised production capacity will be more difficult to establish and to predict.**

QUALITY CONTROL

Quality control is a crucial aspect in the production of low smoke fuels and will require careful consideration when contemplating intervention strategies. If devolatilised fuels are produced on a large scale in industrial scale plant, there is little problem with assuring that products stay within emission specifications. Similarly, if briquettes are produced on a macro-scale with large scale plant, it will be relatively easy to assure quality.

On the other hand, in the case where briquetting is undertaken on a localised small scale basis, quality will be much more difficult to control. From the earlier discussion on combustion emissions it is evident that the quality and quantity of emissions from reconstituted fuels is very dependent on the ingredients. Thus for briquetted fuels using duff coal as a feedstock it is necessary for the correct feedstock to be obtained and utilised. Possible problems arise when tens or possibly hundreds of these briquetting manufacturers are operating at a local level: will they all obtain the specified duff or, will they purchase lower priced, poorer quality discards which will result in fuels that produce emissions no better than bituminous coal?

Issues regarding quality control

- **It will be easier to control quality through large scale centralised production.**
- **There are potential problems with quality control of a large number of small localised briquette producers.**

CONTRIBUTION TO RDP

Localised, small scale briquetting plants have a large benefit in the light of the aims of the RDP. Using the CSIR briquetting approach as an example, the production of 3 million tons/annum of low smoke briquettes can create nearly 19 000 permanent jobs (see Section 5.4) and will have the effect of distributing income to a large number of people rather than to a small number of large companies. Another apparent advantage to the localised briquetting approach is that there is a relatively low capital requirement for the establishment of production capacity, a desirable characteristic from the RDP's point of view. Large scale production will obviously also have benefits for the national economy, although the number of jobs created will be very much lower.

Issues regarding contributions to the RDP

- **Small scale localised production will create a large number of jobs.**
- **Capital requirements for small scale production is very much lower than for large scale production.**

6.2.2 DISTRIBUTION OF LOW SMOKE FUELS

An important and very useful aid for any product developer is an accurate quantification and description of the potential market, in this case the present household bituminous coal market. However at present the market is poorly defined and estimates of its size vary from 1.5 through to 7.4 million tons per annum (see Table 2-3). For potential low smoke fuel producers the size of the market, projected over at least the life of production plant, would allow for more informed evaluation of risks associated with investment in production plant and human resources.

From the government's point of view an overall quantification of the market will be required for a possible strategic plan of support to producers. On the one hand it would problematic if a national initiative was established and it was then discovered that there was insufficient production capacity, while on the other hand an over-supply of the product, would most likely lead to prices falling to a point where production operations were not viable, and a resultant waste of public resources.

Cost of distribution:

With regard to the cost of distribution, no public research has been undertaken on distribution strategies specific to low smoke fuels. However an examination of the present bituminous coal distribution system has given a sound indication of expected distribution costs of low smoke fuels (see Section 2.3). If a centralised approach to production is adopted, as would be the case for the production of devolatilised coal, the present distribution arrangements would most likely be the most effective. If, however, briquetted fuels are to be produced at a local level, as has been suggested by a number of the developers, the results provide no suggestions on appropriate entry points for the products into the distribution chain.

What is evident from the research on the bituminous coal distribution system is that a significant portion of the user price is added by the coal merchants. This amounts to 11.4 c/kg (1992 prices) and constitutes more than half the of the price paid by users (see table 2-4). The proportion of this price increase that is a result of actual costs (labour, vehicle running costs etc.) rather than profit for operators is not evident and will remain very difficult to ascertain. However, if low smoke fuel distributors were to compete against bituminous coal in a free market, the cost of distribution is possibly an area where some of the higher cost of production of low smoke fuels could be made up.

Despite this possibility, it can be fairly assumed that the cost of distribution of low smoke fuels will, at worst, be equivalent to that for bituminous coal. Table 6-2 shows that if this distribution cost, from the merchant to the user, is applied equally to all the low smoke fuels, the energy price ratio is more favourable than when considered at the merchant /distributor point in the distribution chain (see Table 6-1 for a comparison).

An aspect of low smoke fuels which could influence the cost of distribution is their energy density. Devolatilised coal has a lower energy density than bituminous coal and therefore will require larger transportation capacity and storage space. If a briquetting process is being used it is possible to adapt the shape and size of the briquette at will. For instance the shape of the Ecofuel briquette has been determined by the need to develop a fuel with a high surface area to mass ratio to promote good air flow through the fire and hence a high power output. However when packaged the fuel is bulky. On the other hand the Duffco briquette has been designed with transportation and packaging in mind and, given its rectangular shape, can be packaged more compactly than bituminous coal and the other briquettes. However for the calculations in Table 6-1 it is assumed that energy density does not influence the cost of distribution.

TABLE 6-1: USER ENERGY PRICE OF LOW SMOKE FUELS [1994]

Fuel	*Energy price at Merchant/ distributor [c/MJ] (see Table 4-12 for source)*	*Local distribution cost * [c/MJ]*	*Energy price to user [c/MJ]*	*Energy Price Ratio [Low smoke fuel/Bit. coal]*
Bituminous coal (C grade)	0.36	0.55	0.9	1
CSIR : Scenario B Scenario C	0.78 0.70	0.55	1.33 1.25	1.48 1.39
Wits/UCP	0.82	0.55	1.37	1.52
Coal Tar Products	No prices indicated			
Ecofuel	**	**	1.60 2.00	1.78 2.22
Duffco	2.67	0.55	3.22	3.58
Sastech	No prices indicated			
ARO Firebrick	6.45	0.55	7.00	7.78

* *1992 local distribution cost of bituminous coal = 11.4c/kg*
1994 local distribution cost of bituminous coal = 11.4 x 1.10 x 1.10 = 13.8 c/kg (10% inflation assumed)
If the CV of bituminous coal = 25 MJ/kg, 1994 local distribution cost = 13.8/25 = 0.55 c/MJ
** *Prices provided by the developer are retail prices (see Table 4-11).*

Issues regarding the distribution of low smoke fuels.

- **Potential low smoke fuel market poorly quantified and geographically defined.**
- **Local distribution costs presently account for more than half the price of household bituminous coal.**
- **Given present information on the cost of production of low smoke fuels and assuming distribution costs equivalent to bituminous coal, low smoke fuels will be at best 1.4 to 1.5 times more expensive than bituminous coal.**

6.2.3 IMPACT OF LOW SMOKE FUELS

It has been shown that three low smoke fuels emitted lower quantities of pollutants than bituminous coal when tested under one set of conditions in the laboratory (see Section 5.2). However exposure monitoring in the field shows that their use in the home does not necessarily lead to reduced exposure levels relative to those produced by bituminous coal nor to levels that are within health standards.

During a first set of field trials in 1992, emissions from two low smoke fuels were monitored in 30 homes (15 homes for each fuel) and, as a control, from bituminous coal in a further 15 homes. In general little or no difference was detected between exposure resulting from the three fuels. For *TSP exposures,* levels for all three fuels exceeded the 24 hour health standards for most of the time. For *gaseous pollutants, SO_2* ambient concentrations did not differ between the three fuels and levels exceeding health standards were documented for more than 20% of the hourly maximums that were recorded.

It was, however, noted that failure to establish significant differences did not necessarily prove that differences did not exist. Nevertheless it was not possible to recommend the use of either of the two low smoke fuels as a result of this real life experiment.

Further field tests were undertaken in 1993 using improved monitoring methodology and a larger sample. With regard to gaseous pollutants, Table 5-4 shows that both NO_2 and CO emissions from the low smoke fuels were very much lower than those from bituminous coal, while SO_2 emissions from only one of the two low smoke fuels was lower than those of bituminous coal. Notwithstanding these improvements Table 5-3 shows that the low smoke fuels did not reduce average hourly concentrations to below the USA health standard.

In addition to gaseous concentrations exceeding health standards, field measurements showed that TSP concentrations resulting from the low smoke fuels exceeded health standards 100% of the time, an inferior result to bituminous coal (see Table 5-7).

The figures for the average TSP concentrations resulting from the four fuels indicate that, while Ecofuel produced the lowest TSP concentrations, the CSIR briquettes produced concentrations far higher than did bituminous coal (see Table 5-6). Thus overall, low smoke fuels have not yet proved to be effective in significantly reducing exposure levels to air pollutants. Indications are that the relatively high levels of TSP monitored for all the low smoke fuels may be influenced by high background pollution levels[2]. This suggests that partial replacement of bituminous coal will not be effective.

A point that relates to the use of braziers, is that all the field testing to date has been undertaken with low smoke fuels being used in closed stoves. More recent research has indicated that the use of braziers greatly increases the risk of developing respiratory illnesses. For this reason it would be useful to monitor the use of low smoke fuels in braziers as part of future field trials.

Issues regarding the impact of low smoke fuels on exposure levels to air pollutants

- **Although low smoke fuels were shown to produce lower emissions in laboratory tests, field tests have not yet proved that low smoke fuels are effective in significantly reducing exposure levels to air pollutants.**
- **Although families that utilise braziers are exposed to some of the highest health risks, there is no information on how low smoke fuels perform in braziers.**
- **It is assumed that high background pollution levels caused high TSP measurements but no specific measurements have been made to ascertain the actual contribution.**

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[2] It would have been useful if the field trials had monitored homes where no solid fuel stoves were in use in order to test this supposition. This is an aspect that could be considered in future field trials.

6.3 SUMMARY OF KEY ISSUES

A summary of the key issues in each of the above sections is presented in Table 6-2. Where it is felt that specific action would be of benefit in response to these issues it is listed in the shaded sections of the table.

TABLE 6-2: SUMMARY OF KEY ISSUES RELATING TO LOW SMOKE FUELS
PRODUCTION OF LOW SMOKE FUELS
Emissions from low smoke fuels.
• Crucial that low smoke fuels have a proven ability to emit substantially lower quantities of pollutants than bituminous coal. • One set of laboratory tests undertaken to date, shows lower emissions from low smoke fuels than from bituminous coal. • Emissions can vary as a function of a number of factors. To date there has been no formal testing of the influence these factors may have on emissions. • It is presently difficult for developers to design their fuels in the absence of a specification.
Cost of production
• Little public information available on the cost of production. The estimates that are available are not well developed. • There are a number of possible sources of feedstock. • Capital intensive production plant results in lower operational costs (excluding the cost of capital). • Small scale approach requires less capital but has higher operational costs, mainly due to cost of labour. • It is not clear from information presently available whether a capital intensive or a small scale approach will result in an overall lower cost of production. • Costs of low smoke fuels to coal merchants/local distributors could be at least double the cost of bituminous coal. If a tar distilling process is used, this could produce a fuel at a lower premium.
Market acceptability
• There is market resistance to fuels priced higher than bituminous coal. • Low smoke emissions are desirable, although not at the expense of the performance of fuels. • High reactivity is desirable although a balance should be achieved between ease of lighting and the length of burn. • Cleanliness would be an advantage, but not a critical aspect to fuels. • The size and shape of fuels should allow easy use in standard coal stoves as well as braziers. • Home delivery of fuels, although costly, is an important component of the distribution chain.

Table 6-2 continued
Feedstock supply
• More than sufficient lump coal supply. This is an expensive feedstock. • Sufficient supply of lump discards. There is a cost attached to processing discards, especially if the pre-washed material is to be transported from its source to the processing plant. • Significant quantities of duff and fine discards are available. Discards from different mines have different qualities and therefore not all the available material is suitable for low smoke fuel briquettes.. • Available quantities of paper and biomass wastes are unknown.
Production capacity
• No production capacity exists at present. • Large, centralised production can be relatively easily planned. • Small scale localised production capacity will be more difficult to establish and to predict.
Quality control
• It will be easier to control quality through large scale centralised production. • There are potential problems with quality control of a large number of small localised briquette producers.
Contributions to the RDP
• Small scale localised production will create a large number of jobs. • Capital requirements for small scale production is very much lower than for large scale production.
DISTRIBUTION OF LOW SMOKE FUELS.
• Potential low smoke fuel market poorly quantified and geographically defined. • Local distribution costs presently account for more than half the price of household bituminous coal. • Given present information on the cost of production of low smoke fuels and assuming distribution costs equivalent to bituminous coal, low smoke fuels will be at best 1.4 to 1.5 times more expensive than bituminous coal.

Table 6-2 continued
IMPACT OF LOW SMOKE FUELS ON EXPOSURE LEVELS TO AIR POLLUTANTS
• Although low smoke fuels were shown to produce lower emissions in laboratory tests, field tests have not yet proved that low smoke fuels are effective in significantly reducing exposure levels to air pollutants. • Although families that utilise braziers are exposed to some of the highest health risks, there is no information on how low smoke fuels perform in braziers. • It is assumed that high background pollution levels caused high TSP measurements but no specific measurements have been made to ascertain the actual contribution.

6.4 WAY FORWARD FOR A NATIONAL LOW SMOKE FUEL INITIATIVE

The main aim of this synthesis is to provide a clear direction of the way forward for a national low smoke fuel programme. In this regard the DMEA has already initiated a further round of research which is currently under way and scheduled for completion within the first quarter of 1995 (see Table 1-3). In addition to this research the Low Smoke Fuel Advisory Committee aims to implement a national low smoke fuel programme with the intention of replacing household bituminous coal by the year 2000. The anticipated schedule to achieve this has been set out in Figure 1-4 and includes the formulation of a low smoke fuel standard, evaluation of low smoke fuels and macro-scale field tests, over the next four to five years.

An assessment of the key issues summarised in Table 6-2 shows that there are a number of areas where action and/or further research would be useful. These areas are set out in Table 6-3.

TABLE 6-3: SUGGESTED AREAS FOR FURTHER ACTION AND/OR RESEARCH
1. PRODUCTION OF LOW SMOKE FUELS
Emissions from low smoke fuels. • Establishment of an emission specification for low smoke fuels • Specification of test procedure - not only for minimum smoke stoves
Cost of production • Solicit proposals from potential manufacturers, setting out capital requirements for production plant with details of output capacity. • Undertake detailed costing study.
Market acceptability • Undertake further field trials
2. DISTRIBUTION OF LOW SMOKE FUELS.
• Quantification of the present household bituminous coal market. • Predictions of the future coal market. Will it grow will it decline. What influence will an increase in coal price have on user habits. Would it cause a more rapid shift to electricity. • Description of coal distribution system and an assessment of how low smoke coal could be incorporated. Will the cost of distributing low smoke coal be different to the cost of distributing bituminous coal.
3. IMPACT OF LOW SMOKE FUELS ON EXPOSURE LEVELS TO AIR POLLUTANTS
• Undertake large scale field trials which includes an entire township over a season. Results to be compared to a control.

It is apparent that many of the areas identified in the above table are covered in the proposed programme however there are a number of comments that can be made regarding the anticipated schedule and its components.

Laboratory Testing

The laboratory test procedures used by the CSIR for the measurement of emissions do not provide all the necessary information for the evaluation of low smoke fuels. These tests only take account of emissions from good quality closed stoves and, while this approach may be appropriate to the American situation, they do not provide any information on the expected emissions from fuels when used in braziers. In addition, all the fuels that are tested should be specified in terms of ingredients and composition.

Establishment of a low smoke fuel specification

By formulating low smoke fuel standards after undertaking full scale laboratory tests, as proposed in the anticipated schedule, there is the danger that testing will be undertaken on fuels that are not optimally developed. A specification that is published prior to laboratory testing will allow developers to determine their volatile contents or ingredient mixes and at the same time take account of other characteristic with regard to marketing, prior to presenting their fuels for testings.

If laboratory tests are conducted prior to the formulation of a standard, will they measure emissions alone, without regard to other characteristics that will affect market acceptability? If they do only measure emissions, manufacturers can adapt their fuels accordingly, and also it will then be necessary to retest the fuels to see if they conform to the standard.

Evaluation of fuels for macro-scale field tests

It is not clear whether the macro-scale field tests aim to simply test the impact that total coverage by low smoke fuels will have on an entire area or whether it aims to use the opportunity to compare various low smoke fuels. Irrespective of the aims of the macro field trials, it will be necessary to decide on a basis for the evaluation of available products to be used in the macro-scale field trials. Will products be judged in the light of technical characteristics identified in this chapter or will they simply be chosen for their low emission qualities? For example, will it be necessary for the estimated cost of production of fuels to be below a certain value for them to be taken into account. If a maximum production cost is a requirement, how will this be determined? If it is not, there is the danger of spending public funds on assessing a fuel that has no realistic chance of penetrating the market.

There are many other questions regarding the basis of evaluation; e.g. will the product's potential contribution to the RDP be a basis, or will potential problems with regard to quality control in the production fuels be considered?

Quantification of the low smoke fuel market

An area that does not seem to be covered within the current research projects or the anticipated programme is a quantification of the present bituminous coal market. Nor are predictions of the future size of the low smoke fuel market. This information will be important for planning by fuel producers and also to the government in determining the cost of price support.

Ability of the various low smoke fuels to penetrate the market

If certain of the low smoke fuels are priced well above others there is the chance that they will not significantly penetrate the market. The result of this is that they will have little impact on the air pollution problem that a low smoke programme is intended to solve. Thus, although these products may find a niche market, consideration should be given to whether public funds should be used to support the production of these fuels.

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APPENDICES

APPENDIX A

LIST OF ORGANISATIONS AND INDIVIDUALS INVOLVED IN THE DEVELOPMENT OF LOW SMOKE FUELS

Section Nº	***Fuel***	*Concept of Fuel*	***Organisation undertaking development***
4.4.1	CSIR briquettes	Discard coal and cement mixture - cast in a slab and then broken into blocks	Council for Scientific and Industrial Research (DMEA funded) Hendrik Tait Tel: 012 841 4520
4.4.2	Wits/UCP low smoke coal	Sized discard lump coal, devolatilised using waste heat	Dept. of Metallurgy and Materials Engineering, Univ. of Wits and United Carbon Producers (DMEA funded) Prof. Horsfall, Tel 011 716 2538
4.4.3	Coal Tar Products low smoke coal	Devolatilised lump coal. The char is one of a number of products from the process.	Coal Tar Products (Pty) Limited Barry Beningfield Tel. 011 884 2100
4.4.4	Ecofuel	Cylindrical ring briquette manufactured from waste material (wood shavings, coal duff), wax and unspecified binder	Ecofuel Frik Roux, Tel. 011 391 1584 Albert Hoekstra, Tel. 011 702 1621
4.4.5	Duffco fuel	Briquetting of duff coal	Duffco, in association with Anglovaal. Kris Jabrenski, Tel. 011 615 6700
4.4.6	Sastech fuel	Devolatilised lump coal or briquetted precharred fine coal	Sastech - a division of Sasol Hans Slaghuis Tel. 016 708 2906
4.4.7	Firebrick	Brick-shaped briquette manufactured from waste paper, wax and other unspecified chemicals	Alan Rodkin Organisation Alan Rodkin Tel. 011 882 6382 or 011 882 0555
	Suprachem	Briquetting of fine coke residues produced by Iscor. Development was suspended in 1992	Suprachem Mary-Anne Brits (016) 889 6043 Hannes Kruger (012) 386 1165

APPENDIX B

QUALITY COMPARISON OF VARIOUS GRADES OF COAL MINED IN TRANSVAAL
(Source: LHA 1987b:9)

Grade	Calorific Value [MJ/kg]	$H_2$0 Content [%]	Ash Content [%]	Volatile Content [%]
D Grade				
Medium	24.0	4.4	21.0	22.0
Average	23.7	3.8	21.8	23.0
Minimum	21.6	2.4	15.9	18.3
Maximum	25.5	7.0	27.2	28.1
C Grade				
Medium	26.2	2.0	-	-
Average	26.2	2.8	17.5	26.9
Minimum	26.1	2.0	15.4	25.1
Maximum	26.2	3.6	19.9	29.7
A Grade				
Medium	28.4	2.1 &3.4	13.0	27.0
Average	28.0	2.9	13.2	27.1
Minimum	27.5	2.1	11.0	23.8
Maximum	29.5	3.7	16.3	31.3

APPENDIX C

LOW SMOKE COAL BRIQUETTE PRODUCTION PROCESSES DEVELOPED BY THE COAL RESEARCH ESTABLISHMENT (Source, Clark 1990: 24)

Phurnacite
Pitch is used to bind a blend of coals (mainly anthracite and steam coal) into briquettes. The product is "desmoked" at 800°C in special coke ovens. The strength of the product is derived from the coke produced by carbonisation of the binder and the coking ingredients in the feedstock.

Ancit
An inert component (coke, anthracite, etc) is heated rapidly to 600°C in a hot gas stream. A coking coal is similarly heated to 350°C. The two fuels are then blended in a proportion of about 7:3 and briquetted in a roll press. The briquettes are then subjected to controlled cooling followed by water quenching.

Multiheat
Anthracite duff is briquetted using a bitumen binder. The briquettes are "desmoked" by oxidation treatment in a fluidised sand bath. (Note: The fuel suffered from poor abrasion resistance and the process is currently not in use.)

MHT
This is a cold briquetting process in which anthracite duff is briquetted using a molasses binder. A hardening stage is required in which the briquettes are cured at 200 to 300°C in a special oven.

In addition to the above there are a host of other low smoke briquetting techniques with which CRE has been involved and other that are known to them. These are listed in Clark (1990: 24).

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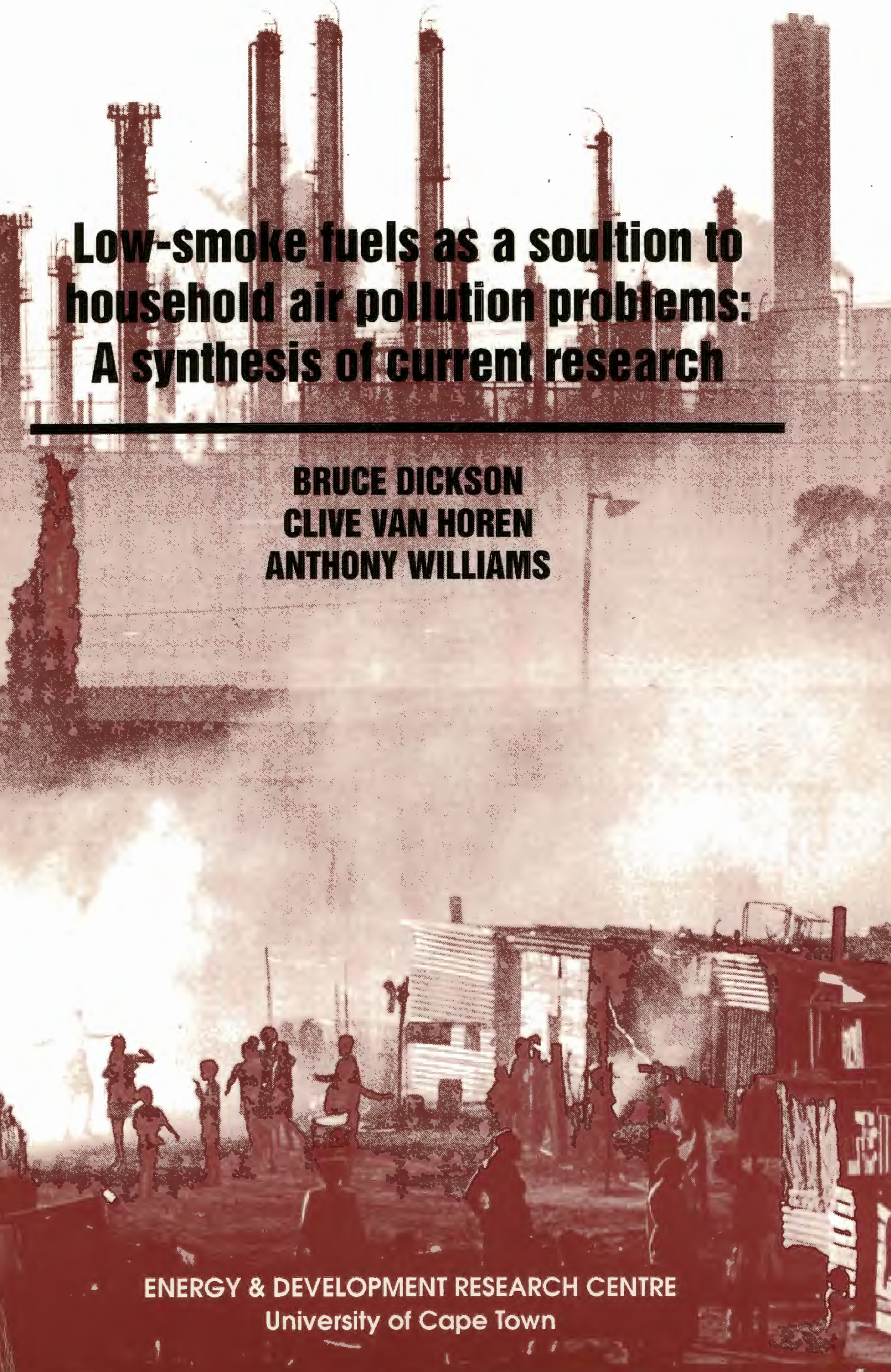

Low-smoke fuels as a soultion to household air pollution problems: A synthesis of current research

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