ASSESSING THE POTENTIAL OF LOW-SMOKE FUELS IN ADDRESSING AIR POLLUTION AND HUMAN HEALTH IMPACTS DUE TO HOUSEHOLD COAL BURNING EMISSIONS

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1. INTRODUCTION

Low-smoke fuel is currently being investigated by the Department of Minerals and Energy (DME) as a means of reducing air pollution caused by household coal combustion. Phase I of the investigation aims to evaluate the potential of low-smoke fuels and characterise the household coal market. Phase II involves strategisation for and implementation of the low-smoke fuel programme.

The Macro-Scale Experiment (MSE), undertaken during July 1997 as part of Phase I, comprised the *in situ* testing of low smoke fuels in the isolated township of Qalabotjha in Villiers, Free State Province. The experiment aimed to determine the social acceptability and technical performance of selected low-smoke fuels in the field. Indoor and outdoor air pollution concentrations were measured before, during and after the low-smoke fuel placement, social surveys were undertaken and marketing strategies reviewed as part of the experiment. Reductions in ambient particulate concentrations were noted to occur by some researchers during the LSF burning period of the experiment. This was taken as an indication of the potential success of the fuels implemented.

SASOL Synthetic Fuels (SSF) initiated the eMbalenhle Air Quality Project (EAQ) during 1997, instructing the NOVA Institute to propose a strategy to supply low smoke coal to this heavily polluted township near Secunda. 'Energy solutions' tested and compared included low smoke coal, new stoves, repaired stoves, repaired chimneys, liquid petroleum gas and insulation. Indoor levels of pollution were measured before and after the implementation of the various 'energy solutions' and the desirability of solutions to household members determined. Results from the eMbalenhle Experiment indicated that there may be solutions that are more effective, desirable and affordable than low-smoke coal.

In developing strategies within Phase II, the DME will need to identify least-cost, most-desirable and most-effective energy options. Several discrepancies exist in results drawn from the Qalabotjha and eMbalenhle experiments. Given the DME's need to place a value on low-smoke fuels, a synthesis project was initiated to re-appraise and consolidate all research efforts undertaken to date with emphasis on work completed as part of the Qalabotjha and eMbalenhle experiments. The aim of this project was to provide a comprehensive and sound basis for evaluating low-smoke fuels based on their technical feasibility, environmental and health benefits, social desirability and economic and planning implications. The main findings of the synthesis project, comprehensively documented in Scorgie *et al.* (2001) are outlined in this paper and conclusions reached regarding the local need for and potential of low-smoke fuels (LSFs) presented.

2. THE CASE FOR CONSIDERING LOW-SMOKE FUEL INTERVENTIONS

Prior to evaluating specific low-smoke fuels it is beneficial to summarize the key impacts associated with bituminous coal combustion and to present the rationale for the current emphasis on low-smoke fuel interventions.

2.1 Air Pollution Impacts due to Domestic Bituminous Coal Combustion

Coal burning emits a large amount of gaseous and particulate pollutants including sulphur dioxide (SO_2), heavy metals, particulates including heavy metals and inorganic ash, carbon monoxide (CO), polycyclic aromatic hydrocarbons, oxides of nitrogen (NO_x) and benzo(a)pyrene. Particulates released include inhalable particulates (or PM10, particulate matter with an aerodynamic diameter of <10 μm) and respirable particulates (or PM2.5, particles with a diameter of <2.5 μm). In various coal-burning areas, such as Soweto, ambient particulate concentrations have historically been observed to exceed local air quality guidelines for 20% to 30% of the year by large margins (up to 300%), mainly during the winter season (Sithole *et al.*, 1994; Annegarn and Sithole, 1999). The average indoor exposure to inhalable particulates in coal-burning townships in South Africa is estimated to be 396 $\mu g/m^3$, well in excess of health guidelines (Terblanche *et al.*, 1993).

Indoor air pollution from coal burning has been established as one of the risk factors for the development of acute respiratory illnesses (ARI). Recent epidemiological data have indicated that acute respiratory illnesses (ARI) are one of the leading causes of death in black South African children. The mortality rate of ARI in South Africa is reported to be 270 times greater than for children in Western Europe (Terblanche *et al.*, 1993). When controlled for socio-economic status, age and gender, the risk of URI in the rural winter population exposed to coal and/or wood cooking and heating fires was found to be four times higher than the risk among electricity users (Terblanche *et al.*, 1992).

The conclusion of health assessment studies is unambiguous. The health benefits of removing air pollution are so obvious that health experts have urged that no time be wasted in implementing intervention strategies (Terblanche, 1996). Significant economic and educational benefits are also to be gained by introducing energy interventions at the household level. Such benefits include reduced school and work absenteeism, improved concentration levels and better performances amongst adults and children residing in coal- and wood-burning communities.

2.2 Rationale for the Consideration of Low-Smoke Fuels as an Interim Measure

Low-smoke fuels comprise only one of several possible energy interventions. Other interventions include electrification, energy efficient housing measures (e.g. insulation, house orientation) and alternatine energy sources (e.g. solar energy). It has been noted that people are increasingly becoming concerned about coal smoke, with a growing number of people possibly prepared to give up *coal* but not necessarily their *coal stove* to get rid of smoke (Hoets, 1994; 1996; 1998a; 1998b). This provides one of the key factors for the consideration of low-smoke fuels as an interim measure. The multi-functional and relative cost-effectiveness of the coal stove, the important role fire is perceived to play in the home, the existing investment of households in having purchased coal stoves, and the cost of buying new appliances represent the main reasons for households wanting to retain their stoves. The current unwillingness of households to give up their coal stoves, despite their willingness to consider alternative fuel types, indicates that low-smoke fuels are likely to be more successful as an interim measure compared to other energy alternatives.

3. EMISSION REDUCTION POTENTIAL OF LOW-SMOKE FUELS

The emission reduction potential of low-smoke fuels represents one of the most crucial considerations in evaluating the usefulness of such fuels. In assessing changes in emissions of particulates, CO, NO_x, SO_2, VOCs and SVOCs due to the replacement of bituminous coal with low-smoke fuels, the following studies were evaluated: Rogers and Pieters (1994), Tait and Lekalakala (1994), Graham (1997) and Britton (1998). Emphasis was placed on the study conducted by the Atomic Energy Corporation of South Africa Limited (AEC) during period 1995 - 1998, as documented by Britton (1998). This study represents the most comprehensive local investigation aimed at establishing the physical and chemical properties and pollutant emission factors of various low-smoke fuels. Ten LSFs and 'normal coal' were tested by the AEC.

3.1 Consolidation of Relevant Findings regarding LSF related Emissions

The significant variations in the physical and chemical properties and performance of low-smoke fuels made it impossible to make generalisations about the emission reduction potential of such fuels. It was therefore necessary to assess whether a significant proportion of the low-smoke fuels tested were associated with emission reductions of specific pollutants, particularly particulates, and whether such fuels could realize emission reductions across all pollutant types. An environmentally successful low-smoke fuel may be defined within the South African context as a fuel which sufficiently reduces particulate emissions whilst not increasing health or environmental risks due to increases in the emissions of other pollutants. Findings pertaining to the emission reduction of low-smoke fuels are outlined in the following subsections.

3.1.1 Particulate Emissions

The synthesis study concluded that *significant reductions in particulate emissions may be achieved by certain low-smoke fuels.* This was noted to be true for Chrome Corp, Flame Africa, Pyro Barbecubes, Wunda fuel, Wits/UCP fuel, CSIR 1993 fuel, CSIR-AEC tested fuel, and Envirofuel comprising 'large' and 'medium' blocks. Total, inhalable and respirable particulate emission reductions for these fuels were estimated to range from ~40% to ~90% within coal stoves, and ~45% and ~99% within braziers.

Various low-smoke fuels, however, failed to reduce particulate emissions. Such fuels included Fire Brick, USA fuel, Genesis Biofuel, Pine Coal and Envirofuel comprising 'medium' blocks. Total particulate emissions were estimated during coal stove combustion tests to be increased by a factor of up to 7, and inhalable particulate emissions by a factor of up to 15 when compared with emissions for bituminous coal. Although the USA fuel was shown to reduce total particulate emissions, this fuel was associated with increased inhalable and respirable particulate emissions and therefore with increased health risk potentials.

3.1.2 SO_2 Emissions

During the synthesis study maximum possible SO_2 emission rates were calculated in mg/MJ for various low-smoke fuels based on the sulphur contents and calorific values of such fuels. Most of the low-smoke fuels investigated had sulphur contents which were lower than that of D-grade coal which is given as ranging from 0.6 to 2.7. The sulphur contents of eight of the low-smoke fuels tested by the AEC had sulphur contents between 0.01% and 0.32% (i.e. 17% to 53% that of the lowest sulphur content for D-grade coal).

Only two of the AEC-tested fuels, viz. the CSIR and USA fuels, were noted to have the *potential* to increase SO_2 emissions due to their having sulphur contents higher than that of low-sulphur D-grade coal. Although the additives within both of these products are speculated to reduce emissions through enhancing the trapping of the sulphur in the ash, the percentage emission reduction achievable has not been quantified. All ten AEC-tested LSFs were expected to perform better than coal in terms of SO_2 emissions when compared to high sulphur D-grade coal combustion (i.e. 2.7% sulphur content), with emission reductions of 30% to 100% possible.

3.1.3 NO_x Emissions and CO Emissions

Low-smoke fuels are generally associated with reduced NO_x and increased CO emissions when compared to normal coal combustion within a coal stove. This is anticipated to be due to the weaker combustion efficiencies of these fuels within the coal stove. Higher NO_x emissions are expected for combustion within a brazier, with certain of the AEC-tested LSFs such as Genesis Biofuel and Pine Coal resulting in NO_x emissions of greater that that of normal coal combustion. CO emissions from low-smoke fuel combustion within a brazier were found to be comparable to or lower than that of normal coal indicating combustion efficiencies comparable to that of coal within this device.

3.1.4 VOC and SVOC Emissions

Low-smoke fuels, under poor combustion conditions as was associated with the burning of the AEC-tested fuels in a coal stove, were generally associated with an increase of either VOC and/or SVOC emissions. The majority of low-smoke fuels tested by the AEC were able to result in VOC emission reductions and in SVOC emissions equivalent to or lower than that of normal coal when burned in a brazier.

Combustion efficiency was found to be a greater determinant of the extent of VOC emissions than the volatile matter content of fuels. Fuels with volatile matter contents lower than that of normal coal were, however, noted during the synthesis study as being unlikely to result in higher VOC emissions even given poor combustion conditions.

3.1.5 Overall Emission Reduction Potentials

On average, low-smoke fuels tested by the AEC performed better, in terms of emissions, in braziers than in the Dover 88 coal stove given as being typical of township coal stoves (Britton, 1998). This is likely to have been due to these fuels exhibiting poorer combustion efficiencies within the coal stove when compared with normal coal.

Only one low-smoke fuel was identified during the synthesis study as having emissions either lower than or equivalent to that of normal coal across all pollutant types and various devices, viz. the Chrome Corp fuel. This fuels is comprised of charred coal, has a high energy potential (27.33 MJ/kg), an exceptionally low volatile matter content (4.9%), a low total sulphur content (0.32%) and an average ash content (17.5%).

Given combustion efficiencies similar to or better than that of 'normal coal', the majority of the AEC-tested LSFs were able to result in emissions equivalent to or lower than that for D-grade coal. This was evident for the brazier combustion tests during which 60% of the low-smoke fuels tested realized overall emission reductions. A further 20% only resulted in higher NO_x, probably due to their having experienced more complete combustion than the normal coal burned in the brazier. The two remaining fuels, Wunda fuel and Fire Brick, were associated with higher SVOC and PM2.5 emissions, respectively, with emission reductions realized for all other pollutants.

Fuel size and physical strength were observed to be important determinants of combustion efficiency, and hence of the extent of CO, VOC and NO emissions. This was clearly demonstrated by tests on the 1993 CSIR fuel (Rogers and Pieters, 1994) and on various size categories of Envirofuel (Britton, 1998).

4. ENVIRONMENTAL IMPACTS OF LOW-SMOKE FUELS

In order to assess the potential of low-smoke fuels in reducing environmental impacts, changes in outdoor and indoor air pollutant concentrations due to fuel switching were evaluated and the implications of such changes in terms of human health risks investigated.

4.1 Changes in Outdoor and Indoor Air Pollutant Concentration Levels

Results from the following field studies were considered during the synthesis study in order to determine likely changes in ambient air pollutant concentrations due to fuel switching:

- 1992-3 Evaton Study - In 1992 three fuels were investigated (conventional bituminous coal, CSIR 1992 briquettes, Wits/UCP fuel). In 1993 three low-smoke fuels were tested, viz. CSIR 1993 briquettes, Wits/UCP fuel and Ecofuel. Studies included measurements of indoor concentrations of CO, NO_2, SO_2, VOCs and particulates (Terblanche et al., 1995).
- 1997 Macro-Scale Experiment (MSE) conducted in Qalabotjha - Three low-smoke fuels, Chartech, Fire Africa and African Fine Carbon (AFC) were tested. Outdoor concentrations of PM10, PM2.5, SO_2, VOCs and SVOCs were measured and indoor concentrations of SO_2, NO_x, CO, total suspended particulates (TSP) and VOC recorded.
- 1998 Sasol Synthetic Fuels eMbalenhle Air Quality (EAQ) Project - One devolatilized lump coal, prepared by Sastech R&D in Sasolburg, was tested. Indoor TSP concentrations were measured.

A synopsis of the findings regarding changes in indoor and outdoor air quality related to the substitution of normal coal burning with low-smoke fuel combustion is given in Table 1.

Discrepancies in the findings of the various field studies regarding the direction and extent of changes in air pollutant concentrations due to fuel switching are evident. Although the results from all studies were considered in the synthesis study, a higher level of confidence was assigned to the findings of the Qalabotjha experiment. One reason for this is that Qalabotjha was found to have been a much more suitable location for assessing the impact of low-smoke fuel implementation than either eMbalenhle or Evaton due to its relative isolation from other major sources. The experiment at Qalabotjha also comprised the switching of most households to LSF burning, whereas the Evaton and eMbalenhle studies recorded indoor improvements due to fuel switching within a small number of households.

Prior to consolidating the findings of the Qalabotjha experiment and comparing such findings with those of other investigations it was necessary to address discrepancies in the results reported by various studies undertaken as part of the MSE.

Table 1. Synopsis of findings regarding changes in ambient air pollution concentrations during low-smoke fuel combustion

Study / Reference	Fuels / Fuel Combinations	Changes in Ambient Air Quality Concentrations during Low-smoke Fuel Combustion (compared with Normal Coal Burning)								
		TSP	PM10	PM2.5	NO_x	CO	SO_2	Hydrocarbons	VOC	P-VOC
1992-3 Evaton Study:										
Terblanche *et al.*, 1995	CSIR 1993 fuel	↑			↓	↓	↑			
	Wits/UCP fuel	↑			↓	↓	↑			
	Ecofuel	≈			↓	↓	↓			
1997 Macro-scale Experiment (Qalabotjha):										
Taljaard *et al.*, 1998 - initial assessment	AFC, Chartech, Flame Africa	↓			≈	↑	↓	↑		
Taljaard *et al.*, 1998 - taking met into account		?			?	?	?	?		
Engelbrecht, 1998 - initial assessment			↓	↓						
Engelbrecht, 1998 - taking meteorology into account			↓	↓						
Sowden, 1998 - taking met. into account									↓	
Taljaard, 1998 - based on indoor measurements	AFC	↓			↓	↑	≈		↑	↑
	Chartech	↓			↓	↑	↓		↑	↓
	Flame Africa	↑			↓	↓	↑		↑	↓
1998 eMbalenhle Air Quality Project:										
van Niekerk and Swanepoel, 1999	Devolatilized lump coal produced by Sastech R&D	≈ ↑								

↓ - reduction in pollutant concentration levels

↑ - increase in pollutant concentration levels

≈ - no significant change in pollutant concentrations

4.1.1 Addressing Discrepancies within MSE F indings

Two main discrepancies within the MSE findings were identified and addressed during the synthesis study, viz.: (i) disparities regarding the extent of ambient particulate concentration reductions achieved by low-smoke fuel burning when variations in meteorology between baseline and LSF burning phases are accounted for, and (ii) conflicting findings regarding changes in ambient VOC concentrations which occurred as a result of the combustion of the low-smoke fuels during the MSE.

Engelbrecht (1998) attempted to correct for meteorological variations between coal burning (baseline) and LSF burning phases by calculating 'zero-wind' pollutant concentrations. Taljaard *et al.* (1998) compared pollutant concentrations observed during worst-case meteorological periods (i.e. periods of atmospheric stagnation) in order to account for such variations. Whereas Engelbrecht concluded that a significant reduction in PM10 and PM2.5 concentrations occurred based on comparison of 'zero-wind' concentrations, Taljaard indicated that pollutant concentrations, including TSP, remained unchanged.

Atmospheric dispersion modelling was undertaken during the synthesis study to independently assess whether meteorological variations could have been responsible for the reduction in TSP, PM10 and PM2.5 noted by Engelbrecht (1998) and within the initial assessment of Taljaard *et al.* (1998). The well-known US-EPA Industrial Source Complex Short Term model (ISCST3) was applied for this purpose using hourly meteorological data from Qalabotjha as input. The Qalabotjha residential area was divided into several area sources. Emission rates from these sources were given as varying every hour based on the diurnal emission trends noted to be associated with domestic fuel burning within local townships.

Dispersion simulations proved that variations in meteorology could not have accounted for the total reductions in PM10 and PM2.5 levels measured during the LSF burning phase. Between 20% and 50% of the concentration reductions measured for stations within Qalabotjha could not be accounted for by meteorological variations. This finding supports the conclusion reached by Engelbrecht (1998) that significant particulate concentration reductions, in the order of 36%, were achieved through LSF burning.

The AEC reported a 40% reduction in total ambient VOC and SVOC concentrations at the Clinic during the MSE's LSF burning phase (Sowden, 1998). Each of the three LSFs were, however, reported by the CSIR to result in increases in indoor VOC concentrations making outdoor reductions in VOCs unlikely (Taljaard, 1998). A possible reasons is that the AEC monitored for a larger number of compounds (~42) compared to that of the CSIR (~30 compounds), with only 12 compounds being monitored in common by both studies. Due to discrepancies in the potential of LSFs to reduce total VOC concentrations emphasis was placed on changes in the concentrations of individual compounds during the health risk assessment undertaken as part of the synthesis study.

4.1.2 Synopsis of Findings regarding Changes in Pollutant Concentrations

Based on the detailed assessment of published findings from the MSE and additional work undertaken to address discrepancies within such findings, the following conclusions were drawn:

- Ambient PM10 and PM2.5 concentrations were significantly *reduced* due to LSF burning during the Qalabotjha experiment, with reductions of at least 20% to 30% having occurred.
- Ambient CO concentrations *increased* significantly as a result of the low-smoke fuel burning by at least 10% to 30%.
- Although NO emissions due to low-smoke fuel burning are anticipated to have been reduced, the reduction was insufficient to realize significant changes in ambient NO_x levels.
- No distinct upward or downward trend in ambient SO_2 concentrations occurred during the LSF burning phase of the Qalabotjha experiment.
- Hydrocarbon concentrations are likely to have *increased* during the LSF burning period.
- The direction of change of ambient concentrations of total VOCs remains uncertain.

Findings from the eMbalenhle and Evaton studies, when compared to the conclusions drawn with regard to the Qalabotjha experiment, served to confirm the following:

- Changes in CO, SO_2 and total particulate emissions, and hence indoor and outdoor concentrations, are specific to low-smoke fuel types and combustion device types.
- Not all fuels labeled as being 'low-smoke fuels' can perform effectively as such. Care must therefore be taken in selecting suitable fuels.
- Fuel switching by isolated households is unlikely to be successful in achieving significant concentration reductions.
- Reductions in NO_x levels are likely to be associated with various low-smoke fuel types.
- User education on appropriate lighting practices for fuels is essential.

4.2 Human Health and Welfare Changes due to Low-smoke Fuel Use

Only two quantitative health assessment studies addressing LSF related impacts were available during the synthesis study. The first, undertaken by Terblanche (1996), was based on the indoor air quality changes observed during the 1993 Evaton Study to be due to the substitution of conventional coal with the CSIR, Wits/UCP and Ecofuel 'Wundafuel' fuels. The second study was undertaken by van Niekerk (1998) as part of the DME's low smoke fuel programme, with emissions data for 10 such fuels published by the AEC being used as the basis for a health risk assessment.

The risk assessment study by Terblanche (1996) was restricted to the calculation of health indices for acute exposures to three gaseous pollutants, viz. SO_2, CO and NO_2. Changes in health indices due to changes in TSP exposures was not considered since the three low-smoke fuels had been found during tests to have been associated with equivalent or increased particulate concentrations when compared with normal coal burning. The comprehensive health risk assessment undertaken by van Niekerk (1998) was intended to be comparative analysis with risks due to conventional coal representing the baseline against which increases or decreases in risk due to the alternative fuels could be gauged. AEC emission factors were used in a dispersion study, undertaken by Burger and Coetzee (1997), to predict ambient air pollutant concentrations for input in the health risk assessment. Inconsistencies and inaccuracies in the emission factors for SO_2, CO and several organic compounds resulted in the validity of this health risk assessment being questioned. The emission factors were subsequently revised by the AEC, and the "final" emission factors published in Britton (1998), DME Report No. ES9506.

4.2.1 Health Risk Quantification u ndertaken during the Synthesis Study

Two key issues were identified during the synthesis study as not having been adequately addressed by previous health risk studies, viz.: (i) extent to which the combustion of *individual* low-smoke fuels are able to reduce outdoor concentrations sufficiently to ensure compliance with air quality guidelines, and (ii) potential health benefits and risks of individual low-smoke fuels. Additional work was therefore initiated during the synthesis study in order to address these issues.

Ambient air quality concentrations were predicted based on the 'final' emission rates published by the AEC (Britton, 1998) and the dispersion simulation results generated by Burger and Coetzee (1997) for 'very large' townships. Predicted pollutant concentrations for each fuel-appliance combination were used to assess compliance with guidelines and facilitate the calculation and comparison of health risks. Health risks were also calculated based on: (i) ambient air quality data measured by the AEC during the Qalabotjha macro-scale experiment; and (ii) indoor air quality measurements made by the CSIR during the Qalabotjha experiment. In the prediction of health risks use was made of the health risk engine developed as part of the Integrated Decision Support Model (IEDS). This tool facilitates the prediction of health effects (i.e. systematic, cancer effects and irritation effects), over various exposure periods (i.e. acute, sub-acute, sub-chronic, chronic), and target organs.

4.2.2 Consolidation of Findings regarding Air Quality and Health Risk Impacts of LSFs

The synthesis study concluded that no generalisations could be made regarding the air quality and health risk benefits of low-smoke fuels. The health risk assessment provided sufficient evidence that changes in health risks associated with the substitution of conventional coal with low-smoke fuels are *fuel specific.*

Four of the twelve AEC-tested fuels were identified as being successful in reducing human health risks and visibility impacts, viz. CSIR fuel, Chrome Corp, Envirofuel (large) and the AEC tested version of the Flame Africa fuel. Each of these fuels were associated with reduced pulmonary effects associated with particulate exposures, whilst also providing for reduced or equivalent cancer, irritation, systemic and visibility effects. Despite the reduction in cancer risks, it was noted that the combustion of each of these fuels is still expected to result in "potentially unacceptable" cancer risks, i.e. a risk of greater than 1: 10 000 of developing cancer. The CSIR, Chrome Corp and Envirofuel (large) fuels were also predicted to result in particulate concentrations which are related to "low" health risks (i.e. hazard indices of between 1 and 10).

Five of the fuel types (Envirofuel medium, Fire Brick, Genesis Biofuel, Pine Coal Products, and USA fuel) were found to be unsuccessful in achieving the most important aim of low-smoke fuels, viz. reduction of pulmonary effects due to particulate exposures. The health benefits of three fuels (Envirofuel small, Pyro Barbecubes and Wunda fuel) in reducing pulmonary effects due to particulate exposures, was offset by their being associated with increased cancer risks. Envirofuel (small) and Pyro Barbecubes were also associated with increased irritation and systemic effects due to exposures to organic compounds.

Although the Chartech and AFC fuels showed some promise in terms of their reduction of particulate exposures, the indoor particulate concentrations associated with their combustion were still found to be associated with unacceptably high health risks. Despite resulting in reduced or equivalent systemic effects due to SO_2 exposures, both fuels were associated with increased risks of systemic effects due to CO exposures. The cancer risks associated with these fuels had not been quantified.

The main conclusions drawn by the synthesis study with regard to the human health risks associated with LSF burning were as follows:

- *Low-smoke fuels are available which significantly reduce health risks, including systemic, irritation and cancer risks.* The successful implementation of *suitable* fuels has a significant potential to realize real improvements in the health of coal-burning communities.
- *Even the most successful LSFs in terms of their potential for reducing current health risk levels, are still associated with potentially unacceptable health risks.* Low-smoke fuels should therefore be introduced as an interim measures and not be as long-term solutions.

5. SOCIAL ACCEPTABILITY OF LOW-SMOKE FUELS

In investigating the link between energy use and religious, cultural and social factors reference was made to the LSF social acceptability studies conducted during the 1992-3 Evaton, 1997 Qalabotjha and 1998 eMbalenhle field experiments (Hoets, 1994, 1995a, 1995b, 1998; van Niekerk and Swanepoel, 1999). Results from the social acceptability study conducted in Soweto in 1996 (Hoets, 1997) and information gathered during LSF testing at Kagiso during 1994 (van Niekerk *et al.*, 1994) were also taken into account. During the Soweto study, user acceptability of nine low-smoke fuels were tested including two wax-based fuels (ARO and Flame Africa), two bound char fuels (Dufferco and Ecofuel's Wundafuel), three devolatilized charred coal fuels (Chrome Corp, GES and UCP) and two extruded wood-based products (Pine Coal Products and Envirofuel). Trial runs for three Sasol produced low-smoke fuels were undertaken in Kagiso. Fuels labeled as the "pink fuel" (lump char, 20-35 mm in size), "green fuel" (paper bound fine char, 50 by 75 mm in size) and "red fuel" (smokeless fine coal briquettes) were supplied to various households in Kagiso for use and the response of users recorded.

Findings of the social surveys conducted as part of the Qalabotjha, Soweto, Evaton and eMbalenhle experiments were generally in agreement despite the discrepancies noted in the results of these studies with regard to the environmental and health implications of low-smoke fuels. The main findings of these studies are discussed in the subsequent subsections.

5.1 Social (and Technical) Requirements for Low-smoke Fuels

In order to be acceptable socially, low-smoke fuels must meet various technical prerequisites and be cost-effective/affordable. In addition to such requirements, efforts must also be made for low-smoke fuels to comply with additional criteria given as being socially desirable. Key requirements for low-smoke fuels identified during the various social surveys undertaken were identified as follows: (i) *essential technical criteria:* heat production, heat retention, speed of cooking, ease of ignition, smoke reduction, suitable size and strength (no dusty), and burn fast and well; (ii) *socially desirable criteria:* capacity to 'bring family together', small amount of ash generated, no blue flame, ability to be used without making people and places dirty, and odour reduction potential; and (iii) *cost-related criteria:* requires no new appliances or changes to existing appliances, and is cost-effective and affordable.

The intensity and durability of heat was found to be the most important factor when dealing with energy carriers. Fuels must ignite easily, burn effectively, and produce a sustained heat. In order for this to be achieved, fuels must be of a suitable size and strength so as not to fall through the grid of the stove. Fuels that pass technical tests may prove completely unacceptable to consumers as a result of the appearance, weight, size (etc) of the fuel, the colour of the flame or the smell of the smoke. Ideally, the fuel should not have a blue flame since this is believed to be unhealthy, and should reduce odours or be odourless. Fuels could also evoke positive responses by offering improvement with regard to the negative aspects of coal, e.g. being cleaner to handle and store and generating less or cleaner ash. Warmth, safety and cleanliness are given as being crucial elements in what constitutes a "home" and are therefore classified as being socially desirable.

5.2 Performance of Low-smoke Fuels given Social (and Technical) Requirements

During the synthesis study the performance of each individual low-smoke fuel tested was assessed based on the various social and technical requirements. It was concluded that the optimum low-smoke fuel is one that would offer a compromise between high reactivity and sustained heat production.

The "pink" and "red" fuels tested at Kagiso during 1994 represent the only low-smoke fuels reported to be able to facilitate easy ignition and sustained heat production. (Unfortunately, the chemical compositions of these fuels could not be obtained and their smoke reduction potential has not been established quantitatively.) The low-smoke fuels tested at Evaton, eMbalenhle, Soweto and Qalabotjha were generally unsuccessful in meeting the most essential critical requirements, viz. suitable heat production and retention, speed of cooking and ease of ignition.

The easily ignitable fuels received a largely positive response, with, for example, 74% of users rating Ecofuel as being better than coal and 90% of users stating they would purchase Flame Africa. Such fuels did not, however, burn for sufficiently long periods as required for effective space heating purposes. The manner in which such fuels would be used should they be purchased is therefore of concern. Most of the high reactivity fuels were perceived to be used most effectively *in addition to*, rather than in place of coal. This is evident by indications that such fuels be used as substitutes for paraffin, enabling the preparation of meals and the boiling of water more quickly, or possibly as a starter fuel to speed up the lighting of normal coal.

Most low-smoke fuels were associated with improved performances (when compared to coal) in terms of ash, smoke and odour reduction and were found to be cleaner to handle and store. Despite low-smoke fuels performing very well in this regard, these fuels were generally rated below coal due to the enormous importance placed on the space heating potential of fuels.

5.3 Prices Households were Willing to Pay for LSFs

All investigations evaluated during the synthesis study indicated that there is a strong resistance to paying a premium for a low-smoke fuel. Considering the low income of many households, and that a large proportion of the income of such households is currently spent on energy, this is to be expected. Prior to being exposed to any low-smoke fuels, 30% to 40% of households indicated that they would pay the same price or a slightly higher price than the retail price of normal coal for such fuels. Having used various of the fuels, the percentage of households willing to pay the same or more varied from 7% to 55% depending on how the various fuels performed. Households generally indicated a willingness to pay prices in the same range as that of normal coal (on average -9% to +7% the price of coal). (It should be noted that LSFs are priced as being in the range of 65% to 900% above that of normal coal.)

5.4 Overall Willingness of Communities to Switch to Low-smoke Fuels

The unwillingness of communities to stop using coal to eliminate smoke was found to be due mainly to the *absence of an affordable alternative.* For example, only 34% of Qalabotjha respondents were reported to be definitely prepared to stop using coal to eliminate smoke. When offered a hypothetical low-smoke fuel (obtainable from coal suppliers but characterised by less smoke), most households stated that they would purchase such a fuel. Positive responses to the purchase of a hypothetical low-smoke fuel were similarly received from over 90% of households in Evaton in 1992 and in Soweto in 1996.

The synthesis study concluded that the hurdle faced in implementing LSFs is not the unwillingness of communities to switch from coal, but rather the need to produce fuels which: (i) are as multi-functional as coal, (ii) can function effectively in existing appliances, and (iii) are affordable.

6. ECONOMIC IMPLICATIONS OF LOW-SMOKE FUELS

Various techno-economic studies were evaluated to determine the market viability of various low-smoke fuels (LHA, 1987; Palmer, 1995; van Horen *et al.*, 1995; Dickson *et al.*, 1995; Lloyd, 1998). The main conclusions reached on the viability of low-smoke fuels, based on the studies undertaken to date, are as follows:

- The cost of producing LSFs is significantly higher than the cost of mining bituminous coal.
- Based on the low-smoke fuels for which data were available, two devolatilised coals (Wits/UCP and Coal Tar Products) and one briquetted fuel (CSIR fuel), were identified as being priced within the same range (i.e. within a factor of 2) as bituminous coal.
- Given the relatively small production capacities reported for various LSFs, production will need to be substantially scaled up if the entire 3.3 Mtpa domestic coal market is to be targeted. At current production rates, it would appear more feasible that smaller crucial markets be identified (e.g. winter market in the Gauteng region).
- Much of the work done to date tends to support the pertinent conclusion reached by previous studies that devolatilised coal represents the most feasible alternative to coal. Devolatilised coal seemingly represents the only LSF with a good prospect of: (i) coming close to being as cheap as coal, (ii) being produced in sufficient quantities to impact significantly on the national household coal market, and (iii) providing the critical heat retention attributes that are essential for space heating (Lloyd, 1998; Hoets, 1996).

(The CSIR briquetted coal was identified during the synthesis study as representing the possible exception. The potential of this fuel, particularly with regard to production rates possible was, however, noted as requiring further substantiation.)

- Although further attempts at improving the performance of the low-smoke fuels available will increase their social acceptability it will only *marginally* increase the price households are willing to pay (by <20%?). Such improvements will therefore not serve to address the significant price differential between low-smoke fuel retail prices and 'community prices'.

The synthesis study concluded that if low-smoke fuels are to penetrate the household coal market, intervention measures would need to be taken to nullify or reduce the retail price differential.

7. CONCLUSIONS AND LSF IMPLEMENTATION RECOMMENDATIONS

7.1 Viability of Low-smoke Fuels as Alternatives to Coal

Significant differences exist in the performance of individual low-smoke fuels with regard to emissions, potential for health impacts/benefits, social acceptability, technical feasibility and economic viability. No generalisations can therefore be made regarding the environmental and health benefits, social acceptability and economic viability of 'low-smoke fuels'. In assessing the potential for low-smokes fuels as an interim measure during the synthesis study the arduous approach was therefore adopted of evaluating each fuel individually based on all available information. The classification of fuels, where possible, based on their performance with regard to emissions, air quality impacts, health risk, social and technical feasibility and economic viability is given in Table 2. The classification criteria is outlined below the table.

Emission and air quality classes:

(1) reduction of all pollutants from all combustion devices (acceptable)

(2) reduction in particulates but increased CO from at least one device (potentially acceptable depending on health risks)

(3) reduction in particulates but increased CO and VOCs from at least one device (potentially acceptable depending on health risks)

(4) increased particulates from at least one device (unacceptable)

Health risk classes:

(1) reduction or equivalent irritation, systemic and cancer risks (acceptable)

(2) reduction in pulmonary effects due to particulate exposures offset by increased cancer risks (unacceptable)

(3) increase in pulmonary effects due to increased particulate exposures (unacceptable)

Social acceptability / technical performance classes:

(1) Only less critical requirements not met (e.g. blue flame, odour) - potential alternative to coal

(2) Problems with ease of ignition and speed of cooking - potential for development as an alternative to coal

(3) Problems with heat retention - potential as a 'convenience fuel', not currently suited as an alternative to coal

(4) Problems with heat retention and speed of cooking - potential for development as a 'convenient' fuel

(5) Problems with heat retention, speed of cooking and ease of ignition - further development required

(6) Problems with east of ignition and strength - further development required

Economic classification:

(1) Estimated retail price < a factor of 2 of the price of bituminous coal - market interventions possible for introduction as a viably priced alternative to normal coal

(2) Estimated retail price a factor of 2 higher than the price of bituminous coal - interventions possible for increasing the market potential of this fuel (as a convenience fuel)

(3) Estimated retail price > a factor of 5 higher than the price of bituminous coal - even given market interventions, these fuels would not be able to be introduced as a viably priced alternative to coal.

The synthesis study concluded that no single fuel was identifiable as comprising all of the attributes necessary to present a viable alternative to the use of bituminous coal within the household energy sector. The reason for this could either be that such a fuel was not yet available or that insufficient information was available for its identification. Various low-smoke fuels were, however, identified which met *one or more* of the following criteria: (i) significantly improve air quality and reduce health risks, (ii) are socially acceptable or are likely to be socially acceptable as an alternative to bituminous coal given minor improvements, (iii) are technically acceptable or are likely to be technically acceptable as an alternative to bituminous coal given minor improvements; and/or (iv) could be economically viable within the household coal market given the implementation of reasonable market-, legislative- and regulatory-interventions.

Several fuels were identified as being marketable as *'convenience fuels'* rather than as alternatives to bituminous coal, including: ARO Firebricks, Flame Africa, Ecofuel (Wundafuel), Pine Coal Products (PCP), Envirofuel and Sasol 'Green' Fuel (for use in koggals and konkas). Such convenience fuels would allow for rapid water heating and cooking when space heating is not required (e.g. morning or during summer) and represent possible alternatives to paraffin (rather than coal). The Dufferco, African Fine Carbon (AFC) and Chartech fuels were similarly anticipated to be successfully marketed at 'convenience fuels' with further development.

Table 2. Classification of fuels based on their environmental, social, economic and technical performances

Fuel	Classification of Fuels based on their Performance with regard to:				
	Emissions	Air Quality Impacts	Health Risk Impact	Social Acceptability / Technical erformance	Economic Viability
Wits/UCP	2	4 (?)	(?)	2	1
CSIR 1993	3	4 (?)	(?)	2	1
CSIR 1992	2	4 (?)		6	1
CSIR (AEC)	3	3	1		(1)
Chrome Corp	1	1	1	5	
Envirofuel (large)	3	3	1	4	
Envirofuel (medium)	4	4	3		
Envirofuel (small)	2	2	2		
Firebrick	4	4	3	4	3
Flame Africa	2	2	1	3	
Genesis Biofuels	4	4	3		
Pine Coal Products	4	4	3	4	
Pyro Barbecubes	3	3	2		
USA Fuel	4	4	3		
Ecofuel's Wundafuel	3	3	2	3	2
Chartech		3		4	
African Fine Carbon		3		4	
Sastech Dev. Lump Coal				5	
Sasol 'Pink'				1	
Sasol 'Green'				5	
Sasol 'Red'				1	3
Dufferco				4	3
General Energy Systems				5	
Coal Tar Products					1

(?) indicates accuracy of results on which classification was based or was to be based is questionable.

Fuels identified during the synthesis study as possibly having the potential for development as *viable alternatives to bituminous coal*, pending additional information requirements or product developments, included: CSIR fuel, United Carbon Products (UCP), Sasol 'Pink' and 'Red' fuels, Coal Tar Products (CTP) and the General Energy Systems (GES) fuel. Of the fuels classified as convenience fuels, Wundafuel and Envirofuel were found to possibly show the most potential of being developed as a competitive alternative to coal should the heat retention abilities of these fuels be improved.

Devolatilised or charred fuels were therefore found to have a greater potential to **replace** coal due to their greater heat retention when compared to other low-smoke fuels. Wood- and wax-based products are more likely to be use **in addition** to coal as 'convenience' fuels due to their ease of ignition and speed of cooking. Such fuels are likely to find a niche market, being used for rapid water heating and cooking at times when space heating is not required, such as in the mornings or in the summer.

7.2 Proposed Intervention Strategy for Low-smoke Fuel Implementation

Given the potential of low-smoke fuels as a suitable interim measure, it is recommended that national government consider the development and implementation of a comprehensive intervention strategy. Such a strategy should typically comprise the following components: (i) development of a national standard for low-smoke fuels, (ii) identification of suitable alternatives to coal, (iii) development of a comprehensive intervention package, (iv) implementation of awareness campaigns and educational programmes, and (v) establishment of key performance indicators and monitoring.

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