STUDY TO MINIMISE THE EFFECTS OF SAND AND MINERAL CONTENT

STUDY TO MINIMISE ABRASION CAUSED BY SAND AND MINERALS FROM HARVESTED ENCROACHER BUSH BIOMASS WITH POSSIBLE ALTERNATIVE TECHNOLOGIES AND IMPROVEMENTS FOR MANUFACTURING A SELECTION OF COMPRESSED WOOD PRODUCTS IN NAMIBIA

MILESTONE V: FINAL REPORT

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MILESTONE V: FINAL REPORT

(ii) DISCLAIMER

Unless otherwise stated, the views and opinions expressed in this Report, is the views of the three authors: Matthys de Wet, Dr Louis de Lange and Dirk du Toit. The views are therefore not necessarily the views of GIZ, who sponsored this assignment.

- **Matthys de Wet Pr. Eng.,** an agri-industrial and mechanical engineer of NRGen Advisors (Pty) Ltd, is an independent consultant working in association with WML Consulting Engineers (Pty) Ltd in Windhoek, also an independent consultancy.
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- **Dirk du Toit Pr. Eng.,** an electrical engineer of DSV Consulting Electrical and Mechanical Engineers, was responsible for the energy measuring conducted at the *CCF Bushblok* factory and assisted De Wet in compiling the main report with specific reference to the proposed mechanical solutions for the challenges experienced by the wood compacting and compression equipment users.

None of the above authors or their companies or associate companies or institutions has any commercial or other interest or linkages with any of the suppliers or producers or participants mentioned in this report.

Matthys J de Wet
Project Leader

24 June 2016

(iii) GLOSSARY

The following abbreviations, definitions and explanations are applicable to the Report:

- **CCF:** Cheetah Conservation Fund, Namibia.
- **Chippers:** General term used for disc- (vertical rotary disc with blades); drum- (drum with blade cutters spinning horizontally and equipped with drum screen) chippers. Used to cut soft wet wood into flakes or chips. Some drum chippers can be strengthened to chip dry hard woods like some of the Namibian encroacher bush species. [Also see "Grinders", defined below].
- **CO_2:** Carbon dioxide gas (emission).
- **GCV:** Gross Calorific Value, normally measured in kcal/kg or in the SI system referred to as *Higher Heating Value [HHV]* measured in kJ/kg. Both GCV or HHV refers to the amount of thermal energy available in a dry combustible material [*1 calorie = 4.187 Joules*; *1 Joule is equal to the amount of energy required to raise the temperature of 1 cm^3 of pure water from 14.5°C to 15.5°C].*
- **GIZ:** Deutsche Gesellschaft für Internationale Zusammenarbeit/German Development Cooperation.
- **GJ/m^3:** Giga Joules per cubic meter; the term generally used to refer to Volumetric Energy Density of a combustible material [The bulk density of hard wood chips are approximately 4.5 GJ/m^3 versus power station (lignite) coal of 21 GJ/m^3].
- **Grinders:** Term generally used for larger chipping equipment. The preferred grinder type for Namibian's abrasive dry bush would be a horizontal infeed drum type grinder/chipper with adjustable anvil (or walking floor anvil) and drumscreen. In the majority of cases, grinders are also called chippers.
- **Janka Hardness:** The Janka Hardness is a measure of the hardness of wood. The test used is a variation on the Brinell Hardness test. The Janka Hardness test measures the force required to push a steel ball with a diameter of 11.28 millimetres (0.444 inches) into the wood to a depth of half the ball's diameter (the diameter was chosen to produce a circle with an area of 100 square millimetres). The results are stated in various ways in different countries, which can lead to confusion, especially since the name of the actual unit employed is often not attached. In the United States, the measurement is in pounds-force [lbf]. In Sweden it is in kilogram-force [kgf], and in Australia, as well as South Africa, Janka hardness ratings are either in Newtons [N] or KiloNewtons [kN]. Sometimes the results are treated as units, e.g., "360 Janka."

  The hardness of wood usually varies with the direction of the grain. If testing is done on the surface of a plank, with the force exerted perpendicular to the grain, the test is said to be of "side hardness." Side hardness of a block of wood measured in the direction of the tree's centre (radially), and on a tangent to the tree's rings (tangentially), are typically very similar. End testing is also sometimes done (that is, testing the cut surface of a stump would be a test of end hardness). The side hardness of teak, for example, is in the range 3 730 to 3 800 N, while the end hardness is in the range 4 150 to 4 500 N.
- **ha:** hectare; 100 m x 100 m = 10 000 m^2
- **Heating value:** The heating value [or energy value or calorific value] of a substance such as wood, is the amount of heat released during the combustion of a measured amount of the substance. The heating value is typical for each substance. It is measured in units of energy per unit, such as mass, of the substance, using parameters such as kJ/kg, MJ/kg, GJ/t or even kJ/mol, kcal/kg or Btu/lb.

- **Higher heating value [HHV]:** HHV is determined by returning all of the products of combustion back to the original pre-combustion temperature, specifically condensing any vapour produced. HHV is calculated with the product of water being in liquid form. In determining HHV it is assumed that all the water escaping from a combustion process is in a liquid state at the end of combustion; it has yielded its latent heat of vapourization i.e. it has been recovered.
- **Lower heating value [LHV]:** LHV is determined by subtracting the heat of vapourization of the water vapour from the higher heating value [HHV]. It means that the energy required to vapourize the water in the substance is not released as heat. In determining LHV it is assumed that the water escaping from a combustion process is in a vapour state at the end of combustion i.e. that the latent heat of vapourization of the water in the fuel [e.g. wood] and the reaction products is not recoverable. LHV is calculated with the product of water being in vapour form.

  HHV relates to LHV as follows:

$$HHV = LHV + H_v \left(\frac{\eta_{H20,out}}{\eta_{fuel,in}}\right)$$

H_v is the heat of vapourization of water
$\eta_{H20,out}$ is the moles of water vapourized
$n_{fuel,in}$ is the moles of fuel combusted

- **hp:** horsepower [1 hp = 0.746 kW] referring to *power* in the Imperial System.
- **ISO:** International Standards Organisation.
- **kWh:** The unit of energy consumption; one kW energy consumed for one hour.
- **LSU:** Large stock unit or large animal unit [LAU]
- **m^3:** cubic meter.
- **MC:** Moisture content, generally expressed as a percentage water content of a material.
- **N-BiG:** Namibia Biomass Industry Group.
- **NCA:** Namibia Charcoal Association.
- **N$/GJ:** Cost of Thermal Energy available in a combustible material measured in NAD per Giga Joule. [The cost of thermal energy available in dry Acacia mellifera is approximately N$ 50.00/GJ versus power station (lignite) coal @ N$ 58.00/GJ, delivered to Windhoek.
- **RH:** Relative humidity.
- **t = Tonne:** Metric ton or 1 000 kgf (vs Ton, referred to as a short ton or 2000 lbf)
- **Tub Grinder:** Vertical infeed grinders with a cylindrical tub equipped with cutters rotating around its vertical axis. Generally used to grind larger root systems and can take a reasonable amount of rocks, stones and sand.

EXECUTIVE SUMMARY

STUDY TO MINIMISE THE EFFECTS OF SAND AND MINERAL CONTENT

ES.1 OVERALL OBJECTIVES

The overall objectives of the assignment are to determine:

(i) How to reduce sand and or mineral content of harvested Namibian bush raw material in order to reduce abrasive wear in the related downstream mechanical value adding process plant and equipment.

(ii) How to provide possible solutions to the above in order to improve the productivity of compressed wood processes.

(iii) Whether the sand/mineral content is a natural or a man-made phenomenon.

ES.2 PRIORITY BIOMASS PRODUCT FOCUS

The study prioritised the following biomass products and how the negative impact of sand/mineral abrasiveness on its sustainable production could be addressed:

(i) Wood pellets

(ii) Bush logs

(iii) Animal feed products from bush

(iv) Wood chips

(v) Charcoal briquette production

ES.3 METHODOLOGY USED

The team of Consultants undertook site visits to leading operators and manufacturers of the above biomass wood products, took samples at a range of points along the value chain of most of the product lines and conducted interviews with operators and manufacturers of the equipment. Overseas manufacturers were contacted telephonically and per e-mail. Drawings, workshop manuals and proposals to reduce wear were discussed at length. Applicable wood meal samples were screened into various sizing fractions, weighed on-site and checked against operating instructions of the equipment suppliers.

The main on-site and physical tests, with energy recordings of various infeed samples, were carried out during the last week in April 2016 at the Otjiwarongo *Bushblok Factory* of the *Cheetah Conservation Fund [CCF].* Smaller on-site investigations were carried out at EC Biomass Pelletising Plant, Port Elizabeth; the chipping test site of Africa Biomass Company, Robertson; the animal feed plants of Tambuti Wilderness and Green Gold Animal Feed, Moorreesburg.

For the analysis of wood samples, the certified laboratories of Stellenbosch University (Forestry Department) and BemLab, Somerset West, were used. All of the above activities, complete with photographic displays, trial data, laboratory results, etc., are included in this Final Report as Annexures A to G.

It must be noted that the Consultants focussed on those mixed bush samples used at CCF where the wear trials were conducted. The trial results could then be used as a benchmark for the *comparison analysis* between four types of compressed wood technologies (See Chapter 10).

ES.4 EXTENT OF LOSE SAND (SOIL CONTAMINATION) IN THE BIOMASS RAW MATERIALS

The extent of lose sand in the main biomass value addition groups, is reported on as below:

- **Felling**
  Small scale bush felling operations showed a high rate of soil contamination, while felling of bush using hydraulic grab and blade cutter tools and making use of windrow stacking above the ground, had relative low levels of soil contamination.
- **Charcoal lumpy**
  Lumpy charcoal production using the traditional infield kilns generated more than acceptable levels (> 1.5% by mass) of lose sand and soil contamination, mainly because of the open bottom kilns currently in use.
- **Charcoal briquette feed**
  Unacceptable high levels of lose sand and wood ash (from over-burned charcoal) were found in some of the charcoal briquettes analysed and frequently exceeded 4% by mass.
- **Animal feed raw material**
  Little sand and soil dust contamination was observed at the small animal feed plant of Tambuti Wilderness. Young growth was used after some rain and a hand fed wet chipping operation supplied chips to the hammer mill and mixing station. Little (if any) wear was identified by visual inspection on the downstream pelletising die of this operation.
- **Bushblok meal**
  Low levels of lose sand (< 0.5% by mass) was measured at CCF's Bushblok factory when screening the biomass chips after its 40 km trip from point of harvesting and chipping to the factory. The biomass chips are then passed through a hammer mill to produce the 1 - 4 mm wood meal infeed for the extruding machines to produce the compressed wood log. The hammer mill is equipped with a dust extraction cyclone system and dust collector. Samples taken from the dust collector had a laboratory analysis of 4.20% ash and 680 gram/tonne of silica.

ES.5 THE MAIN CAUSE OF HIGH ABRASIVE WEAR IN DOWNSTREAM COMPRESSED CHARCOAL AND WOOD APPLICATIONS

Two possible areas of wear were identified and investigated:

- **Charcoal briquette manufacturing:**
  Little mechanical wear could be detected on the compacting wheels of the charcoal briquette making machines, despite relatively high (> 1% by mass) levels of man-made sand contamination in the charcoal fines infeed. This is because of the clever design of the two compacting briquetting rollers compressing the charcoal fines and its starch binder into a cake without any sliding action. (See Photograph 8 in the main report).
- **Bushblok manufacturing:**
  High levels of wear were detected and witnessed on the high pressure wear parts of the Shimada Extruder at CCF during the trial period of testing 12 samples of wood meal infeed passing through the machine. During all of the trials over a period of four days, hardly any measurable amounts of lose sand could be found in the wood meal infeed to the extruder. Measurable and visible wear however still took place. The Consultants equipped the test

machine with a calibrated kWh, Volt, Amp and Power Factor meter/recorder and could accurately measure real time energy consumption per kilogram of *Bushblok* produced.

It was concluded that the main cause of the wear on the extruder machine was the hardness and high inherent silica (S_iO_2) content of the wood. This finding corresponds with trials conducted by the Shimada manufacturers on high inherent silica content rice husks.

ES.6 TRIALS CONDUCTED AT THE BUSHBLOK FACTORY

It should be noted that the wood meal samples available to the Consultant for the abrasion trials, were of the species mostly used by the CCF and mostly in mixed format.

- **Background**

  As there is a direct correlation between pressure created inside the extruder and the power consumption of the machine, several different wood meal infeeds were prepared for the trials. Twelve bush samples were fed through the extruder over a period of several shifts while energy consumption was being recorded.

  One of the infeed samples (Sample No 4, Table 9) was made up of debarked Sickle bush. This would represent a zero external sand or soil contaminated influence on the wear surfaces of the machine. The total energy consumed to extrude the debarked Sickle bush sample into a log measured 60.39 kWh/t. When compared with the energy required for the normal *Sickle Bushblok* manufacturing process @ 59.66 kWh/t (Sample 3, Table 9), no significant difference could be detected, indicating that the main cause of abrasive and thus sliding wear in these types of compacting machines is the high inherent hardness and high natural silica content of the Namibian encroacher bush.

  Samples, using high flash point cooking oil (Grape seed oil with a flash point of 240°C) as lubricant to better protect the wear surfaces of the machine, were also carried out, with moderately better results. It was discovered during the trials that low flash point lubricants like industrial waxes can also be considered as lubricant provided that care against possible fires during the production process is taken. Tests conducted with an off the shelf low cost, low flash point cooking oil gave good results with no flaming or increased smoking or machine fires.

  The internal lubrications option (See Figure 4) was workshopped in detail with the manufacturer, but was eventually put on a lower priority than the top three possible areas of improvement.

- **The effect of fine particles on energy consumption when extruding**

  By removing the very fine wood dust (and dust caused by soil or gravel road transportation) the energy required to compact wood meal can be reduced. See Figure 8 of the main report to note that energy required increases rapidly to compact particles < 1.0 mm.

  Although most of this fraction would consists of wood dust, it would also contain soil dust and the removal thereof would further reduce mechanical wear.

- **Main findings to improve economic viability**
  The main findings of the CCF trials were:

  - The cost of wear parts can be reduced considerably by doing hardfacing of the wear surfaces at an earlier stage, long before the spigot of the screw breaks off and thus rendering this expensive part useless.
  - Mechanically remove the under and oversize fractions to ensure that the infeed particle sizes are between > 1.0 mm and < 4.0 mm. This will not only reduce the energy required (See Figure 8) of the machine, it will also lower the wear rate on the machine.
  - A batching type production approach will reduce the large electricity demand of the hammer milling and extruding processes, which do not have to operate simultaneously.
  - The poor power factor of the large induction motors can be corrected to further save on electricity supply costs.

ES.7 SAND REMOVING TECHNOLOGIES

The following simple mechanical sand and dust removing devices are reviewed in the main report, Chapter 8:

- Vibratory screens
- Washing plant (not recommended)
- Cyclones
- Air knives
- Air classifiers
- Debarking (not practical for encroacher bush)

It was found that all of the above mechanical means of removing lose sand and dust can, when used in its optimum particle size band, be highly effective to reduce unwanted particles. Figure 8 (Chapter 13) gives a good indication on what particle size fraction the most suited sand and dust removal systems can be applied to.

ES.8 ANIMAL FEED PRODUCTION FROM BUSH

Two methods of compressing animal feed from bush were investigated:

- **Pelletised animal feed**
  The pelletising of green and young bush growth to produce shelf-stable animal feed can be done successfully with a small pelletiser when the following key factors are observed:

  - The infeed should be mixed with other (softer) components like maize bran, brewers' grain, straw, seed pods, etc.
  - The moisture content should be between 18 - 22% (Not scientifically confirmed, only reported).
  - The die temperature (controlled by throughput) should be between 80 and 90°C for sterilizing of the product.
  - The final infeed mix should have a particle size of between 0.5 - 3.0 mm.

- The infeed should consist mainly of the young green fraction of the bush. (Only the hemicellulose and cellulose fractions of the bush are digestible. The lignin fraction is not).

- **Cuber animal feed from bush**
  A more robust compacting machine is proposed for producing animal feed in Namibia. It is called the Cuber. See § 6.3 of the main report. Cubes of say 25 x 25 x 25 mm can be produced at tempos of up to 5 tph with this machine which can be overhauled in a basic farm workshop.

  Although animal feed, cubes are softer (less dense) than animal feed pellets, a cuber can produce at a much higher volumetric tempo at less kWh/t.

  A further advantage of the cuber is that it can cube wet chipped young growth directly and would not need to hammer mill the chips for further size reduction.

  For good quality animal feed, however, the same digestive principles would apply and feed cubes should not consist of more than say 30% bush.

ES.9 WOOD PELLETS FOR THE THERMAL MARKET

The manufacturing of wood pellets for the boiler thermal market from encroacher bush infeed is not recommended for Namibia. The main reasons are:

- The Namibian bush is simply too abrasive (too hard and with a too high an inherent silica content) and would cause unsustainably high wear on pelletising equipment.
- The energy required to produce an acceptable pellet from the high density bush meal of Namibia would be too costly.
- The final product would have a high ash content and would therefore have limited access to regulated high volume export markets.

ES.10 COMPARISON ANALYSIS OF WOOD COMPACTING TECHNOLOGIES FOR THE THERMAL MARKET

Chapter 10 of the Final Report compares four wood compacting technologies. The comparison analysis is conducted based on actual data obtained for the Shimada (Bushblok) extruder. However, for the other technologies, brochures and operating manuals were used. The following four similar kW-rated machines were compared:

(i) Screw type extruders for manufacturing logs.
(ii) Piston or cam type extruders for logs.
(iii) Cubers for boiler fuel.
(iv) Pelletisers for boiler fuel.

It was found that (both) the extruders for log production could work reasonably well in Namibia with a few adjustments and modifications with specific reference to:

- A diligent and scheduled hardfacing preventative maintenance programme on the critical (three or four) wear components.

- Reducing energy costs by removing the unwanted size fractions from the infeed, improve maximum demand and consider power factor correction.
- Right-sizing of the electricity supply to the factory and the introduction of power factor correction.

As far as high volume thermal markets are concerned, the Cuber machine appears to have better potential to successfully produce compacted cubes from hard woods than the pelletiser.

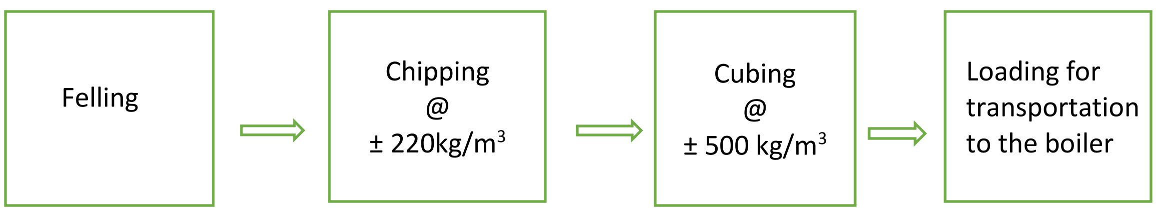
ES.11 INTRODUCING THE CUBER MACHINE TO PRODUCE BIOFUELS FOR THE THERMAL MARKETS

The cuber machine can double the bulk density of small wood chips from ± 220 kg/m^3 to ± 500 kg/m^3 (See Table 10), at a higher production rate and lower energy and wear cost than any of the other machines investigated.

It should be noted, however, that the cubes produced will be at a lower structural integrity than for pellets and would therefore have more breakages and thus create more fines when handled.

Compacted wood fibre cubes appear to be ideal for step grate furnaces and other wood fired boiler applications, and are earmarked by the Consultant as perhaps the best biofuel option yet analysed for the Namibian encroacher bush feed stock. No intermediate hammer milling stage is needed for the cuber when the chipping operation is set up to produce smaller wood fibre.

All of the following actions can take place at the biomass harvesting site since the cuber plant could be made mobile:



ES.12 ADDRESSING EXPORT MARKET REQUIREMENTS

The three major stumbling blocks identified for Namibian biomass to penetrate the export thermal markets are:

(i) High ash content (where markets are regulated).
(ii) Energy density (impacting negatively on transport costs).
(iii) Consistency of supply.

- *The high ash content* can be addressed by finding export markets and market segments (e.g. some retailers in the domestic barbeque market for extruded logs and charcoal products) that are less sensitive to ash content.

  As far as the high volume boiler fuel markets are concerned, Namibian wood fuel producers must first become high volume players on the local front and with a sustainable compression technology. This technology will for reasons explained before, most likely not be pelletising. It is therefore important that other technologies, including the proposed cuber technology, be investigated in more detail.

- The *energy density* (mostly measured in MJ/m^3) of the Namibian charcoal products and Bushbloks are already better than required and these export markets have been identified, partially penetrated and should be further exploited.

  The achievable energy density of the proposed cuber technology still has to be investigated further.

- The *consistency in supply* for Namibian compressed wood products is not good – hence the reason for this study. This study has, however, identified a number of new items, and if addressed diligently, could lead to establishing a renewable biofuel supply base of international standard.

ES.13 PRACTICAL RECOMMENDATIONS TO BE IMPLEMENTED

The implementation of the following practical recommendations per compressed wood feed and product roleplayer should lead to growth in this important Namibian agri-business:

(i) The charcoal industry

Start by implementing stricter measures to reduce sand contamination and the creation of unwanted ash during the charcoal making process.

It is recommended that a new generation kiln be implemented with, amongst all the planned less polluting features, should also be designed it in such a way that less sand is shoveled with the charcoal into the bulk bags.

(ii) The animal feed industry

It is recommended that trials on the cuber type animal feed machine be implemented to reduce the energy required to produce shelf-stable feed for large animal units, while at the same time achieving a higher throughput and lower maintenance cost.

(iii) The extruded log industry

The biomass log producing industry can be made more sustainable should the following recommendations are implemented:

- The powder coating/hardfacing of critical wear parts must be carried out sooner and on a much more proactive and scheduled maintenance basis.
- Mechanically remove the < 1.0 mm and > 4.0 mm fraction from the infeed, not only to save energy, but also to reduce critical high wear fractions from the infeed stock.
- Do not underestimate the impact of high maximum demand power supply charges and power factor correction due to the large induction motors driving the hammer mill and the extruders, in right-sizing the electricity supply to a factory premises.

(iv) The high volume boiler and industrial heating markets

For the hard and highly abrasive encroacher bush woods (a mainly natural and not manmade phenomenon) of Namibia, the *pelletiser technology* of compacting wood meal would not be economically viable. It is recommended that a different type of technology be investigated, namely *cubing*. Cubing of wood chips and fiber is done with a Cuber machine. Cubes as small as 25 x 25 x 25 mm can be produced at bulk densities of approximately double that of wood chips.

It is further recommended that the above (prototype) cubes be subjected to further trials at a test steam boiler plant (e.g. John Thompson Africa, Parow, South Africa) to investigate and report on the structural integrity of the cubes during handling, the ash and emissions produced and its impact on the boiler both mechanically and metallurgically. Only then can the market penetration strategy for this new *Namibian Cubed Bush* technology be developed further.

ES.14 CONCLUDING REMARK

Due to the complexity and wide range of topics covered in this report, it is proposed that a workshop with key role-players of the industry; N-BiG, NCA and others, be arranged so that the Consultant can present this report and its findings. Further debate on the priorities for the way forward, with specific reference to Cubing Technology, is necessary.

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STUDY TO MINIMISE ABRASION CAUSED BY SAND AND MINERALS FROM HARVESTED ENCROACHER BUSH BIOMASS WITH POSSIBLE ALTERNATIVE TECHNOLOGIES AND IMPROVEMENTS FOR MANUFACTURING A SELECTION OF COMPRESSED WOOD PRODUCTS IN NAMIBIA

1. THE TERMS OF REFERENCE

1.1 Background to the assignment

Approximately 30 million hectares of Namibian farmland are affected by bush encroachment. Evidence exists that this phenomenon severely degrades rangelands and hampers agricultural productivity. At the same time bush encroachment creates unique opportunities for the Namibian economy, if biomass is considered as a resource to use for energy production and value chain development in other sectors.

A separate study initiated by GIZ on *Biomass End-Use Opportunities* confirmed that there is considerable demand on international and national markets for defined biomass products in general and for compressed wood products in particular. The latter include products such as ‘white wood pellets’ and wood logs. An opportunity is also present in pelletised “boskos” i.e. animal feeds for which there is a growing demand from livestock farmers. The study also confirmed that the above market opportunities are currently not effectively exploited, mainly because the Namibian bush/biomass material as harvested is often not suitable to be processed into compressed wood products. In particular, it is believed that the high sand/mineral content of the material is prohibitive to extrusion/compression technologies as it causes unsustainable wear to plant and equipment.

So far, it has not been established beyond reasonable doubt whether the high mineral content in Namibian encroacher biomass is a genuine natural phenomenon or a result of harvesting/handling processes, or a combination of both. No real solution has yet been found to substantially reduce sand/mineral content of harvested encroacher bush in Namibia, hence the reason for this research study.

1.2 Primary focus

1.2.1 Overall Objectives

The overall objectives of the assignment are to determine:

(i) How to substantially reduce the sand and or mineral content of the harvested Namibian bush raw material in order to reduce abrasive wear in the related downstream mechanical value adding plant and equipment.

(ii) The levels to which sand/mineral content can be practically reduced (against reasonable standards and benchmarks).

(iii) How to provide possible solutions to the above in order to improve the productivity levels at downstream compressed wood processors.

1.2.2 Aim

The assignment will aim to determine whether the sand/mineral content is a natural phenomenon or a man-made one [or both]. The study will also endeavour to extract the extent of sand/minerals in the virgin bush material and in harvested material due to harvesting and handling processes to the extent that it impacts on the manufacturing of the end-products.

1.2.3 Further aims of the study

The study will further investigate and list:

- Technical processes available to separate residual sand from the raw material.
- Improved harvesting and materials handling practises to minimise sand contamination.
- Equipment/processes to minimize the abrasive impact of sand where possible.

1.2.4 Priority biomass products

The study should prioritize the following biomass products and how the negative impact of sand/ mineral abrasiveness on its sustainable production could be addressed:

(i) Wood pellets
(ii) Bush logs/blocks
(iii) Animal feed pellets from bush
(iv) Wood chip production
(v) Charcoal briquette production

Each of the above end-products and its manufacturing process will be studied and possible solutions to the wear problems will be discussed, and where possible, addressed.

1.2.5 Analysis of related industries

A desktop analysis of research done by others in the field will also be conducted, since the abrasiveness of wood in its downstream processing is an international problem. Research into the curtailing of the abrasive components in wood has been done for many decades in various countries across the globe and is a well researched topic.

Various experts in the field will be consulted and permission will be obtained to report on these valuable contributions as part of the proposed Literature Survey.

1.2.6 Laboratory tests

The professional team will conduct field visits of Namibian and South African biomass processors and where possible, samples and wear results will be obtained. The results of the above will be discussed in this report.

1.2.7 Concise reporting on the above

The Consultant will aim to unravel the true cause of the high wear phenomenon of the downstream compressed wood operations in Namibia, compare it with available laboratory and test results and measure its findings against similar experiences of international role players in the field.

The Final Report will endeavour to produce workable solutions and best practice recommendations for the Namibian role players by end of June 2016.

1.3 Deliverables – A Milestone Approach

Table 1 gives an insight into the key tasks (deliverables) to be performed by the Consultant. The deliverables are grouped into five Milestones:

TABLE 1: MILESTONE APPROACH TO DELIVERABLES

Milestone	Milestone Title	Task Elements and Activities
I.	Inception Report	• Signing of Contract • Project kick-off • Compile Inception Report
II.	Field Survey Report	• Visit existing wood and animal feed pelletizers • Visit extruder/compressed wood plant(s) • Visit key charcoaling plants • Collection of material samples applicable to the study • Interviews with applicable processors • Witness trials and field operations
III.	Literature Survey & Information Review	• Findings of research re sand/minerals in other parts of the world and South Africa – a literature study • Compilation of expert opinions • Evaluations of existing analytical and laboratory test results • Most likely cause of the abrasiveness problems • What are other industries doing (per commodity)?

IV.	Bush log trials and possible solutions to the high wear problem – Draft Report	• Various approaches in handling and processing to reduce wear
		• Understanding the true cause of high wear in the following key processes:
		  ○ Wood pellets
		  ○ Bush logs/blocks
		  ○ Animal feed pellets
		  ○ Wood chips
		  ○ Charcoal briquettes
		• Possible engineering considerations to reduce wear
		• Qualification of and quantification for additional funding to provide systemic solutions, including trials and further developments, to the problems identified during the project
		• Proposed strategy per wood-product/commodity
		• Interim test results from CCF plant on bush blocks

V.	Final Report	• Compilation of (possible) best practices per end-product • Feedback from international research • Results of material testing and bush log trials • Alternative/possible solutions • Findings • Conclusions • Recommendations

1.4 Programme

Table 2 gives the proposed programme for the assignment per milestone.

TABLE 2: PROPOSED PROGRAMME

Milestone	Milestone Title	Proposed Completion Dates
i.	Inception Report	23 February 2016
ii.	Field Survey Report	11 March 2016
iii.	Abbreviated Literature Survey and Laboratory Test Results – Interim Report	31 March 2016
iv.	Possible Solutions and bush log trials – Draft Report and remainder of laboratory test results	20 May 2016
v.	Final Report	27 June 2016

1.5 The Professional Team

The professional team consists of the following key members:

- **Mr Matthys de Wet** Pr. Eng. – Team leader. Agri-industrial and Mechanical Consulting Engineer.
- **Dr Louis de Lange** – Organic chemist and biomass specialist.
- **Mr Leon Boye** – MD of WML Consulting Electrical Engineers. Protected tree species and legislative expert.

Mr Dirk du Toit of DSV Consulting Electrical Engineers will assist the Consultant during the test runs at Otjiwarongo by recording the amperage and kWh/kg of logs made per trial recipe.

Stellenbosch University and BemLab, Somerset West, will conduct most of the laboratory testing for sand, ash, minerals, etc.

2. FIELD VISITS

2.1 Samples taken at ABC Robertson on 18 January 2016

The WML Consulting Engineers and NRGen Advisors team started their field visits by attending trials of chipping sundried Namibian encroacher bush at the test plant facilities of the *African Biomass Company [ABC]* in Robertson, Western Cape, South Africa. Approximately six to seven tonnes of each of the following species were available for tests:

- Purple pot Terminalia (Terminalia prunioides)
- Bush mopane (Colophospermum mopane)
- Sickle bush (Dichrostachys cinerea)

While ABC were concentrating on achieving optimum chipping results, the WML/NRGen team, consisting of Dr Louis de Lange and Matthys de Wet, were taking laboratory samples of each of the pre-chipped as well as chipped biomass to be laboratory tested for residual sand and other abrasive minerals. Samples were also taken of the dust and micro wood particles sucked in by the air filters of the large diesel engine of the Beast Model 2680 (540hp) chipper. This dust was generated during the chipping process of the dry bushes (young trees) going through the machine in a large dusty cloud – See photograph display of the above trials below:

Photograph 1: Sickle bush dried and ready for chipping

Photograph 2: Large chipper in action (Africa Biomass Company, Robertson)

2.2 Northern SA

Several pelletising equipment suppliers and manufacturers are domiciled in the Gauteng and Limpopo Provinces of SA.

Interviews with the Drotsky Hammer Mill an animal feed equipment manufacturer in Alrode, Alberton, Gauteng, revealed that bush pelletisers can only be used on bush when green, soft growth points of bush are chipped, hammer milled and pelletised. When dry hard woods are attempted, the dies would block and great difficulty would be experienced to re-open the holes of the pelletising die.

On 21 January 2016 Matthys de Wet had an interview with Mr Piet Simpson of Bos-tot-Kos [‘Bush-to-Feed’] a manufacturer of integrated wet chipping and pelletising machinery. According to Mr Simpson, no abnormal wear is taking place in his pelletising machines when animal feed is produced from bush in the Dwaalboom area. His machines consist of an integrated wet wood chipper & hammer mill as shown in the photograph below:

Photograph 3: ‘Bos-tot-Kos Machine of Piet Gouws, manufactured by Piet Simpson of Dwaalboom

Mr Piet Gouws of Tarentaal Farm, Outjo-Okaukuejo, has been appointed by Mr Piet Simpson to represent Mr Simpson’s company, Bosvreter [www.bosvreter.co.za] in Namibia.

2.3 Namibia

The Namibian activities started with:

- **Kick-off meeting at GIZ, Windhoek**
  The official start of this assignment took place in Windhoek on 27 January 2016 with GIZ and members of the *Namibian Biomass Industry Group [N-BiG].*
- **The Namibian site visits**
  See **Annexure A** for the itinerary of the tour of Namibian biomass sites which took place between 26 January and 4 February 2016. Dr Louis de Lange accompanied Matthys de Wet to more than 17 interviews and site visits in Windhoek, Okahandja, Otjiwarongo, Outjo, Otavi, Grootfontein, Sargberg and Dordabis over a ten-day period.

Annexure A also contains the trial period programme at the CCF factory in Otjiwarongo between 24 April and 1 May 2016.

2.4 Focus of the field surveys

The focus of the field survey was to familiarise the two key authors (De Wet & De Lange) with the Namibian conditions, with specific reference to the encroacher bush situation. Although it is not possible to get the full picture in 10 days, it must be borne in mind that Matthys de Wet has been studying the Namibian encroacher bush challenge intensively for the past nearly four years. Dr Louis de Lange has extensive knowledge of biomass and biomass projects in general, accumulated over decades.

The trials conducted at the CCF Bushblok factory focussed mainly on determining the main cause(s) of the high wear experienced by the wood compacting machines, See Chapter 11 for further detail.

2.5 Namibian tour highlights

The highlights of the authors' site visits and interviews during the Namibian field survey can be summarized as below:

- **EcoLog factory, Okahandja [Interview with Heiko Meyer]**
  Although the factory is mothballed at present, future plans are to restart it. The CFNielsen piston press system is preferred since the high wear costs of the Shimada extruder presses have made the compacting of the EcoLog unsustainable.
- **Jumbo Charcoal factory, Okahandja [Ian Galloway]**
  After a site visit to the factory it was concluded that sand and minerals are not having a significant wear effect on any of Jumbo's packing or waxing components, but charcoal contaminated with sand and ash is bringing down the charcoal yields of some farmers.
  No briquetting of charcoal fines takes place at Jumbo. Previous visits by De Wet to Kilo 40 Charcoal plant had revealed some wear on its briquetting machine. This is about the only place where sand and mineral content in the charcoal industry could have high a wear effect on moving parts.
- **Drotsky Agent (Massey Ferguson), Otjiwarongo [Thorsten Kopp]**
  Little pelletising history is available because very few farmers are pelletising bush for animal feed. Most farmers doing 'boskos' are only chipping and hammer milling the young bush into meal prior to mixing it with other feed components.
- **CCF Bushblok Factory, Otjiwarongo [Dr Bruce Brewer]**
  A thorough visit was conducted at this plant. See photograph display in **Annexure B**. High wear is experienced with the screws, taper bushes and barrel of the Shimada extruders despite dust extraction by means of a cyclone and bag filter system. Samples of the extracted dust were taken by the consultant for analysis.
- **Burgers Equipment, Otjiwarongo [Marius Cronje]**
  Burgers Equipment does not sell wood compacting machines. They concentrate on bush felling and chipping equipment. Marius Cronje accompanied the consultants to Arthur Götz, Willem Groenewald and Larry Bussey.
- **Animal feed producer Arthur Götz, Outjo**
  Successful chipped and hammer milled animal feed mixes of bush, bran and other additives are being made here. No pelletising is being done yet.

- **Ryneveld Farm of Willem Groenewald, Otavi district**
  Several samples of bush were taken by Dr de Lange from this farm for further analysis. Infield surveys to ascertain the effect of termites and dust in general were undertaken.
- **Tambuti Wilderness of Larry Bussey**
  Pelletised animal feed from bush takes place at Tambuti Farm. See **Annexure C** for a photograph display of the pelletising process. Little wear is experienced by Mr Bussey on the pelletiser die. He still operates with the original die, now approaching two seasons in use. See Chapter 10 of this report for further insights into Mr Bussey's pelletising operation.
- **Carbo Charcoal, Grootfontein [Hans Strydom]**
  Carbo Charcoal is one of Namibia's largest charcoal operations and large volumes of briquetting of fines takes place without any abnormal abrasion or wear problems. It is believed that most of the sand is screened out prior to the mechanical pelletising process. The design of the briquetting machines is such that very little or no grinding or sliding action is present during the compacting of the charcoal fines between two synchronized rollers.
- **Visit to the biomass marshalling yard, EFF, Ohorongo Cement [Wimpie van Rensburg]**
  Although the cement plant was undergoing a shutdown, the stockpiles of chipped biomass could be inspected. It is expected of biomass suppliers to deliver encroacher bush with an ash content of less than 7%. The overall ash content contains sand plus minerals. Namibian encroacher bush has a high ash content in comparison with wood used in the cement industry of Germany. See Literature Study (Chapter 7 of this Report) for further detail in this regard.
- **AgriConsult, Okahandja [Dr Axel Rothauge]**
  Care should be taken not to regard wood as animal feed. Only selected soft growth points should be used in <20% mixes with other feed components to produce a balanced ration, according to Dr Rothauge.
- **O & L Energy, Windhoek [Eike Krafft]**
  O & L Energy would use dried brewers grain mixed into bush meal to produce animal feed pellets. Samples have been sent to pelletising companies in Germany. Project still in progress.
- **Omunguidi Ranch, Dordabis [Anton Dresselhaus]**
  Animal feed meal from bush is manufactured on this farm. Silage and feed for pigs are also planned for the near future. Project in progress.
- **Farm of Gys Joubert, Dordabis**
  Experimental planting of Brasseed grass under irrigation is being done. Feed from selected bush is being considered. Project in progress.

2.6 Western Cape of SA

- **Green Gold Animal Feed Cuber, Moorreesburg**
  This visit became the most outstanding discovery of the field surveys and led to the expansion of Chapter 6. The design of the cuber is such that it could change the future of animal feed production from greenwood chips in Namibia for large animal units. The potential also exists for this technology to be used for the production of boiler fuel from wood chips.

- **Seed Oil SA, Somerset Wes**
  Mr Faffa Venter, MD of Seed Oil SA, heads a seed pressing facility and uses a Chinese extruder to compress seed cake into logs for the domestic barbeque market. The first lubricant used by the Consultant at the CCF trials was grape seed oil from the above plant.
- **Rumax BJP Suppliers, Worcester**
  Mr Jaco Pieters, owner of Rumax Pelletisers and Foundry, are a leading animal feed mixer and pelletiser manufacturer in SA. This factory has the ability to manufacture, hardface, case harden and overhaul small pelletiser dies, and are also used by Green Gold Feeds to hardface their Cuber dies.
- **Africa Biomass Company, Worcester**
  Messrs Willem van der Merwe and Johan du Preez are the owners of Africa Biomass Company, are perhaps the leading wood chipping company in SA, with chipping volumes exceeding 60 000 t.p.a. Their testing facilities at Robertson were used by the Consultant to check the wear rates on grinding and chipping tools when four species (Acacia mellifera; Colophospermum mopane; Dichrostachys cinerea; Terminalia prunioides) of dry Namibian encroacher bush were chipped, screened into various fractions and where some of the wood and dust samples were taken.
- **Italcotto, Cape Town**
  Mr Redvers Smith handed over samples of white wood pellets produced by their supplier in Pietermaritzburg, KwaZulu-Natal, where these pellets are manufactured from off cuts of debarked pine trees.

2.7 Eastern Cape of SA

A site visit was conducted by the Consultants to EC Biomass, near Port Elizabeth during the week of 14 March 2016 and the results of their interviews are addressed in the next chapter.

3. LITERATURE SURVEY AND INFORMATION REVIEW (By Dr Louis de Lange)

3.1 Background

This Information Review delves into available information regarding the topic of processing of woody biomass into valuable energy products with a focus on products which place a high demand on the mechanical resilience of equipment and the materials used for their construction. These information resources include:

- Published literature reporting on research done by various organizations and individual researchers; effectively a Literature Review.
- Case Studies reported on in the scientific and more popular literature.
- Interaction, such as interviews, with individuals with experience on the topic.
- Interaction with suppliers of technologies and mechanical systems used for processing of woody biomass into valuable energy products.

The purpose of delving into these sources of information is to determine if there is an existing and adequate information and knowledge base on which an industry for woody biomass energy products could be built and grown and, importantly in the case of the industry in Namibia, if this information and knowledge base has been effectively tapped. The fact that this fledgling industry is experiencing problems of a technical nature suggests that this has not been the case.

3.2 Introduction

There is no question that a large, well established and growing woody biomass to valuable energy products industry, and a related industry of converting biomass into feed for livestock and game, could contribute substantially to national goals to better manage encroacher bush in Namibia. Past experience with the harvesting and marketing of wood and the manufacturing and marketing of charcoal and briquettes has demonstrated the socioeconomic possibilities of woody biomass as energy products. Where these initiatives were undertaken in a coordinated and centralised way, its impact on eradicating encroacher bush were also measureable. The technologies to manufacture the abovementioned energy products are straightforward and well-established; sawing and selective gathering, sawing into logs, packed in bags or delivered in bulk, conversion into charcoal using simple pyrolysis processes, briquetting [where feasible] and then packaging for the various markets. All these processes use only a selection of woody biomass: most of the biomass cannot be used because of their shape and size, being bent logs and thin branches and twigs. This “waste biomass” was recognized as a feedstock for a new range of energy products: manufactured fuel logs and fuel pellets. A number of entrepreneurial enterprises accepted the challenge to turn this alternative biomass resource into new and marketable biomass derived energy products. Unfortunately, by their own admission, they have not closely achieved the potential presented to them by the available markets for these products. So, the problem is not so much market size and accessibility to these markets, but the ability to produce, and specifically the shortcoming in the technologies and processes used to produce wood fuel logs and pellets from encroacher bush.

3.3 Problem statement

The woody biomass resource presented by the encroacher bush in Namibia presents two main inherent factors:

- The inherent hardness of the wood of the [mostly indigenous] encroacher bush types in Namibia. The various genera and species all have hardnesses which are much higher than the "softwood" types used in e.g. Europe for the purpose of fuel logs and pellets.
- The chemical composition of the wood types including cellulose, hemicelluloses and lignin as well as the silica [S_iO_2] content of the wood. It also includes the moisture content of the wood as well as the extractives [volatiles] present in the wood. The sand [mostly silica] imbedded in the bark of the wood should also be included in the overall chemical composition of the wood. The total silica content of the wood will comprise most of the ash content of the wood. The following two factors result from the two major factors mentioned above:
    - The abrasiveness of the wood mainly brought about by its total silica content.
    - The corrosiveness of the wood caused by the decomposition of the chemicals in the wood under certain processing conditions.

The above four factors do not function in isolation, but together when wood is processed mechanically. The problem is that although these factors are present, to a greater or lesser degree, in all wood types, the manufacturing equipment to produce energy logs and pellets are mostly, if not all, tailored for milder European wood types.
Furthermore, in Namibia a range of encroacher bush wood types are harvested simultaneously; it is difficult to separate types should it be desirable.

An overarching problem appears to be that the wood energy log and pelletising manufacturing technologies and processes currently used for manufacturing energy logs in Namibia have not been selected with full consideration to these problem factors and that the available information and knowledge base to do an appropriate selection have also not been properly utilized.

3.4 Searching for solutions

The problem factors above will now be dealt with in greater detail. The available published information and knowledge base will be used. The experiential information and knowledge of operators in the field will also be used.

3.4.1 The inherent hardness of Namibian encroacher bush wood types

The Janka Hardness Test is a recognised method to determine the harness of wood types. It is used for the purposes of comparing various wood types with specific uses of woods in mind and also its machine-ability for those uses [Wiemann and Green 2007]. There is also a relationship between the Specific Gravity of woods and their Janka Hardness; a relationship which makes it easier to compare woods and determine their machine-ability and their uses. Also the hardness of dry wood is greater than that of green wood which means that their machine-ability is more difficult and tougher on the tools used. Therefore, wood moisture content is important, with hardness increasing as wood dries below its fibre saturation point [Panshin and de Zeew 1980]. Janka harness is expressed in Newton [N]. In **Table 3** below a comparison is made between a few soft woods and hard woods, both green and dry woods, and their relationship with their respective Specific Gravities.

TABLE 3: RELATIONSHIP BETWEEN JANKA HARDNESS AND SPECIFIC GRAVITY OF VARIOUS SOFT- AND HARDWOODS

Softwoods (Coniferous species)				**Hardwoods (Angiosperm species)**			
Species	**SG**	**Green [N]**	**Dry [N]**	**Species**	**SG**	**Green [N]**	**Dry [N]**
Pinus radiata	0.42	2130	3330	Swartzia leiocalycina	0.87	11390	18950
Sequoia sempervirens	0.38	1820	2130	Diospyros crassiflora	0.90	n/a	14310
Populus canadensis	0.35	2050	2220	Tabebuia serratifolia	0.92	13570	16270
Quercus alba	0.60	4700	6030	Dalbergia nigra	0.80	10820	12060
Salix alba	0.34	1820	2580	Autranella congolensis	0.76	8270	13400

Although no Janka Hardness data could be found on the specific Namibian encroacher bush species being used to manufacture fuel logs and pellets, possibly indicating that it never has been determined, it can be safely assumed that these encroacher bush woods will be amongst the hard woods ("wood that is hard") for which Janka Hardness becomes even higher when it is dry. This assumption is supported by analytical work done previously by the Department of Wood Chemistry at the Faculty of Forestry of the University of Stellenbosch. The results are tabulated in **Table 4**.

TABLE 4: RESULTS OF ANALYSIS OF THREE NAMIBIAN ENCROACHER BUSH SPECIES

Species	**Moisture Content [%]**	**Density [Specific Gravity] in g/cm^3**	**Ash Content [%]**	**CV or Higher Heating Value in MJ/kg**
Colophospermum mopane	10.00	0.78	2.88	18.18
Terminalia prunioides	9.88	0.90	1.98	18.03
Dichrostachys cinerea	8.50	0.94	1.12	20.33

The high Specific Gravity values are indicative that the Janka Hardness Values for these species will also be high. These analyses are currently being repeated on a much bigger sample of the selected species.

Although Janka Hardness will impact firstly on the harvesting and chipping processes [its impact on the equipment not measured] used to prepare the wood for the fuel log and pellet manufacturing processes, a number of questions can already be raised regarding the re-densification/compression/compaction of wood chips into logs and pellets:

Q1: To what extent will high Janka Hardness values impact on re-densification during the extrusion processes currently used in Namibia to manufacture logs and pellets?

Q2: What shear forces will be required and pressures generated during the processes?

Q3: What are the Janka Hardness's of the various fuel logs and pellets produced especially since these represent mixture of wood types?

Q4: Do the extruder shear forces and pressures required for re-densification of high Janka Hardness woods generate higher temperatures in the extruder than for softer woods?

Q5: What are the actual temperatures in the pressure zones of the extruders?

Q6: If higher than anticipated, what will the impact of these higher pressures and temperatures be on the decomposition of the woods?

Q7: Have these factors been considered during the selection of the processes/plant for the manufacturing of fuel logs and pellets, particularly by the suppliers of the equipment?

Q8: What guarantees (if any) have been provided by the suppliers that their equipment will be able to (sustainably) process the wood from Namibian encroacher bush?

Better questions can now be asked after valuable experience gained during extensive field surveys. Answering these questions will provide valuable information for determining the way forward. Factors related to the hardness of wood types now lead to a next set of factors which will influence the selection of the most appropriate technologies for manufacturing wood fuel logs and pellets.

3.4.2 The chemical composition of the wood types

The chemical composition of wood has a direct bearing on its potential to be processes into valuable products [Novaes et al 2010]. Wood is typically composed of about 25% lignin, and 70% cellulosic carbohydrates which are made up roughly of 45% cellulose and 25% hemicelluloses [Sjostrom 1993]. Also present are the extractives [volatiles] and the mineral components including silica [SiO_2] which is the largest part of the ash content of the wood.

Lignin is of particular importance as it provides the mechanical strength which make trees, trees [Fry and White 1938]. Lignin has a higher energy content than cellulose or hemicelluloses. One gram of lignin has on average 2.27 KJ, 30% more than the energy of the cellulosic carbohydrates [Shafizadeh and Chin 1997; White 1987]. The energy content of lignin is similar to that of coal [McLaughlin et al 1996]. So the energy content of wood is largely dependent on its lignin content but, while its value to wood based energy fuels is recognized, it adds to the difficulty to process the wood into these fuels. A further aggravating factor is the presence of extractives and abrasives and its impact on the wearing of tools and machinery.

3.4.3 Abrasiveness and corrosiveness

Wood extractives and silica have a potential adverse effects on tool wear. Rapid chemical wearing due to corrosion and mechanical wearing has been attributed to the presence of extractives and silica in [and on] wood and wood composites [such a fuel logs and pellets] [Darmawan et al 2012]. A corrosion/oxidation mechanism was found to contribute to the wear of SH51 high-speed steel and K10 tungsten carbide when cutting e.g. Tapi-Tapi wood [Darmawan et al 2012]. The range of extractives, which may vary between 1.4% to 13.8%, and ash content from 0.1% to 5%, in wood species [Martawijaya et al 1989] deserve serious consideration when selecting on the materials exposed to wear and the processes to be used when manufacturing wood fuels.

Corrosiveness and abrasiveness go hand-in-hand and are therefore not considered separately in this Review.

It is known that chemical components of wood play an important role in determining tool wear rates. To adequately describe the wear mechanisms, wood and tool interactions must be considered. This is not a simple problem due to the large number of possible interactions, as well as difficulties in characterizing each of these interactions [Darmawan et al 2012]. There is evidence that the extractives in wood act as lubricants and effectively decrease the coefficient of friction during wood cutting [McKenzie and Karpovitch 1968]; however, many studies indicate that the extractives in wood adversely affect wearing of cutting tools. Hillis and McKenzie [1964] postulate a chelation reaction between polyphenolic extractives and the iron in steel cutting tools as a wear mechanism. In 1965 they produced etching on steel knives by exposing them to chemical solutions typical of those found in wood. Their results showed that a measureable amount of tool wear was due to chemical reaction between the cutter and the wood being cut. Kirbach and Chow [1974] emphasized the complexity of tool wear problems inherent in the multicomponent nature of the wood and tool materials. It was noted in their study that the wear of carbide tools was due to chemical attack of the tool material binder and a mechanical failure of the exposed carbide grains.

In the period after 1980, chemical wear due to extractives in the woods, such as gums, fats, resins, sugars, oils, starches, alkaloids, and tannins, has also been reported as an important factor in determining the overall wear of woodworking cutting tools [Fukuda et al 1992; Krilov 1986; Morita et al 1999; Murase 1984; and Darmawan and Tanaka 2006]. Extractives vary in chemical composition, amount and reactivity among tropical wood species, which might affect their degree of chemical impact on cutting tool materials.

On top of all this, rapid mechanical wear of cutting tools have often been attributed to the presence of silica and other abrasive agents in [and on] the woods [Hayashi and Suzuki 1983; Huber 1985; Porankiewicz and Gronlund 1991; Darmawan et al 2011]. It was noted in these studies that woods with high silica content caused high wear rate of high-speed steel cutting tools.

The recent work of Darmawan and co-workers focussed on the impact of abrasives on tool wear in the presence of the known corrosive agents. It is noteworthy that their work was conducted under conditions of relatively low temperatures [about 80^{o}C] and not close to the temperatures which could be expected within the compression zone of an extruder considering the shear and pressure forces at work in the zone.

Once the temperature in the compression zone in an extruder starts exceeding 200^{o}C pyrolysis reactions of the three main wood components start to take place. These reactions are exothermic by nature which means that the temperature in this zone may quickly increase to much higher than 200^{o}C. When lignin thermally decomposes over the broad temperature range which is now possible [200 - 275^{o}C] the main process can soon head towards 400^{o}C [Brebu and Vasile 2010]. A range of chemical reactions may now occur including the release of volatile products and the cleavage of aryl-ether linkages resulting in the formation of highly reactive and unstable free radicals which could result in aggravating the action of abrasives and corrosives on cutting tools. Also, pyrolysis reactions may produce char which could add to the abrasiveness in the compression zone of the extruder.

The fact of the matter is that the information above only confirms the complexity of the chemical and physical processes which take place in an extruder, of whatever description, when wood fuel logs and pellets are manufactured. The extreme nature of Namibian encroacher bush wood makes it even worse. This reality leads to further questions:

Q9: Have the suppliers to the extrusion equipment used to manufacture fuel logs and pellets from Namibian encroacher bush adequately considered the complexity of the process described above?

Q10: Have they conducted the necessary trials to prove that their equipment can deal with the extreme conditions, which result from Namibian encroacher bush as described above?

Q11: Were they prepared to provide guarantees to that effect?

Q12: Can the existing technologies be modified/redesigned and the process be changed to mitigate the extreme condition described above?

Q13: For example, can lubricants e.g. oil or molten wax, be injected into the compression zone without compromising the physical properties of the fuel logs or pellets?

Q14: Have any technologies and processes been considered where the extreme conditions described above will not have the destructive effect on the wear components and its materials of construction?

Q15: Even if those technologies and processes still have to be developed?

The answers to Q14 and Q15 may present the simplest and most sustainable solution(s)

The fact that these very same factors and questions have not been adequately considered by other initiatives in the field of manufacturing wood fuel is illuminating. The example of EC Biomass in Port Elizabeth, funded by the Industrial Development Corporation [IDC] in South Africa needs to be mentioned. This enterprise had an investment value of ZAR 200 million and is currently mothballed with very little prospect of ever being put into operation again. And even worse, there are two other similar ventures, one in Sabie, Mpumalanga Province and the other near Mooiriver, KZN Province, both mothballed and both after having extracted substantial capital investment from the IDC. There are a number of reasons for the demise of these operations [distance from markets, exchange rate fluctuations, etc.] but at the heart of it all was a misjudgement of the technology and processes which were supposed to deliver the energy fuels.

3.5 Case studies

During the information gathering stage of the project a number of Case studies, which have a direct bearing on the encroacher bush project in Namibia, were identified. The most significant is the example of EC Biomass in Port Elizabeth, South Africa. Another Case Study relate to communication with EC Nielsen, a well-known Danish manufacturer of wood processing equipment.

3.5.1 EC Biomass

Below follows a Report of an interview with John de Wet, one of the founding technologists at EC Biomass. John de Wet was deeply immersed in the efforts to make the EC Biomass plant viable by ensuring its sustainable operations. His present day opinion is that much more prior research and investigative work could have ensured the viability and survival of the EC Biomass [and the other] operations. Rushing into what initially appeared to be a very lucrative enterprise, proved to be a fatal mistake.

Herewith a summary of the key items raised by John de Wet:

- Because of the amount of dust (S_iO_2) and other impurities on the bark of pine, it was an EU [DIN]and general requirement of EC Biomass that only debarked pine could be used in the pelletising plant at *EC Biomass,* Port Elizabeth.
- It was generally found that the sand content on SA tree bark can be as high as 4%. Sand (Silica) is part of the ash content of wood. [The DIN requirement is wood pellets with < 2% ash content and was making it impossible for EC Biomass to deliver wood pellets within the allowable ash content].
- The harder the wood, the higher the ash content. EC Biomass was thus forced to mix soft wood (low ash) with harder wood (higher ash) to get closer to the DIN ash requirements of the EU. The downstream performance of the pelletiser dropped when mixed wood was used. Increase in wear was also experienced.
- EC Biomass used *KAHL Pelletisers*, manufactured in Germany. The cost of maintaining the worn dies of the KAHL equipment became unsustainable and was one of the main causes for closing the plant down in 2013/2014.
- Three biomass wood fuel pelletising plants were built in South Africa (Sabie, Mooirivier and Port Elizabeth). All three plants are currently mothballed and for sale.
- SAPPI Umkumaas washes and de-barks harvested wood with high pressure water prior to it being chipped for the paper and pulp industries.
- Wood pellets in Australia are made of debarked and thoroughly washed soft white woods. Care is also taken to only pelletise ‘fresh’ wood. When wood is allowed to dry, it cannot be pelletised without a higher wear impact on the downstream pelletising equipment.
- It is also important to note that the pelletising temperature should not exceed 80°C. Above 80°C surface pyrolysis takes place, causing the pellets to seize or fuse in the collar-section of pellet barrel holes of the die.

- Low grade (hard wood or brown wood) pellets with a higher ash content can be successfully manufactured but is required by a different, low cost market segment, e.g. the cement industry.

A follow-up visit to EC Biomass and an interview with Mr. Matthew Joubert, also one of the founding technologists at the plant and now the caretaker of the mothballed plant, confirmed all of the above information provided by John de Wet. To an outside observer it is quite sad to witness this very impressive plant, now mothballed and with very little prospect to ever operate again. Mr. Joubert's answer to the question; "why did this happen?" concurs with that of John de Wet: "too little research and penetrating investigative work before the big money was spent!"

3.5.2 CFNielsen

CFNielsen is a well-known Danish manufacturer of wood briquetting equipment. The definition of briquettes, in their case, seems to refer to fuel or bush logs. CFNielsen has a range of machines each with a specific output potential. Communications with Mr. Hendrik B. Christiansen, Area Sales Manager, has resulted in sharing considerable information.

Hendrik Christiansen has been informed:

- Thanks for this information. I browsed your website and found it valuable. We are project developers, based in Stellenbosch, South Africa, working in the field of biomass conversion to energy and electricity. One such activity is the manufacturing of logs and pellets from biomass e.g. encroacher bush in Namibia. A major problem is the hardness of the wood aggravated by external and internal abrasives such as silica as well as corrosion agents which may arise from the extractives present in e.g. lignin. The extruder-based technologies currently used experience major problems because of these factors. We are looking at "softer" technologies e.g. compression of logs using lower temperature, high pressure systems where the wood chips are combined with the most appropriate binders. Can you offer solutions in this regard? I am copying in my associate, Thys de Wet, who will be in Namibia during the next week, where we are trying to advise manufacturers on the best technologies for the purpose of producing fire logs and pellets. We are looking forward to your response.
- A major potential consumer of encroacher bush biomass is the manufacturing of bush or fire logs which are in great demand, especially in Europe. I attach an image as an example of what these logs look like. Currently eight-sided logs with a hole through the logs are produced. Production is not optimal because of the wear on the extruder system, especially the screw tips, in use. We believe it is a combination of the hardness of the wood [which may be much harder that the invader bush of South Africa], abrasion caused by the sand [mainly wind-blown] imbedded in the bark, the silica in the wood as well as corrosion caused by the extractives from lignin in the wood, released by a pyrolysis reaction at high temperatures in the extruder. Is it possible to manufacture these logs using [as for briquettes] a low temperature, high pressure compression [as opposed to extrusion] system together with binders? We are looking into the silica content of the chipped wood and will soon have analytical results. It may be necessary

- to ship wood chips from Namibia to a plant where a compression process can be demonstrated. Your views and recommendations are appreciated.
- Dr Louis de Lange and I are part of a professional team, appointed by the *Deutsche Gesellschaft für Internationale Zusammenarbeit [GIZ]* GmbH, to investigate the effects of sand and mineral content of Namibian encroacher bush on compressed and extruded wood products. Two Namibian compressed wood manufacturers, EcoLog by Umuriro Biomass Industries [OBI]/WoodCo of Messrs Heiko Meyer, Norbert Liebiech & Olaf Liebich, as well as Dr Bruce Brewer of the Cheetah Conservation Fund [CFF], manufacturers of the *Bushblok*, are giving us their full cooperation and are eagerly awaiting the results of our investigation. The C.F. Nielsen machines are certainly seen as a possible solution to the unsustainable high wear currently being experienced by extruder-type machines in the compressed wood industry of Namibia, a country with more than 30 million hectares infested by encroacher bush. Both Mr Meyer & Liebich have visited your factory in Denmark before and samples of Namibian encroacher bush has been tested at CFNielsen.

Would it be possible to draw on your existing results to answer Dr Louis de Lange? Your efforts will be highly appreciated.

Hendrik Christiansen provided the following information:

- Your project sounds really interesting. We have previously briquetted "invader bush" in South Africa with good result. Is this a similar tree/bush? You are right about screw presses. There are many different suppliers of these presses and the quality and safety of these machines are not the best and the wear parts do not last long. Briquetting will give you several advantages compared to pellets, where most important advantages are that we can start from a lower volume, operational costs and investments are lower. You mention silica, and this will be the real challenge in any biomass densification process. Do you have ash analysis of the wood with a break-down of the ash, so we can see the silica content? Do you know whether the silica is sand from roots or cutting down the trees or silica inside the wood? If the silica is in the form of sand and outside there are different ways of removing the sand. Do you know the moisture content? You might need a drier and down-sizing equipment also? Please also inform about this. Finally, we would also like know more about which volumes you would like to briquette per hour/day/year.

When we have the answers to the above questions we will come back with a suggestion for a briquetting solution.

- Sorry for not having answered earlier, but I have been extremely busy and your mail got to far down in the row of incoming mails. Now sitting in a hotel room in Nairobi, been travelling here last week, I will try to answer your mail. We have often heard about heavy wear on screw tips in the extruder presses, but has as well seen heavy wear on our type of machinery, this of course fully dependent on silica content in the raw material. Up until we have first-hand experience on your type of raw material, we do not like to give

- any recommendations. We have at our production facility in Denmark a test press standing ready for doing test like this. If you could forward us material that are downsized and dried, we could offer to do a production run and give you the results afterwards. Could that be of interest?
- We are now back in Denmark after our visit last couple of weeks to Uganda and Kenya. I have now been able to search files at CFNielsen and can see that we in April 2014 made several trials with the Namibia Rotomould Invader bush. I see in the results, that we were able to produce very good briquettes, but I see at the same time, that no ash content measurements were done, so I am afraid that we will not be able to be of any help to you regarding this question. Could we be of any other help, please do not hesitate to come back to us.

Considering all of the above [especially the highlighted] information and the fact that CFNielsen is a well-established company in the field of wood briquetting, a number of questions now arise:

Q16: Why hasn't CFNielsen's briquetting technology become established in Namibia?

Q17: For example, CFNielsen's Briquetting Press BP 6500 HD with ABCS is a high performance press with a 1 000 - 1 800 kg/h throughput capacity range using a piston with a two compression screw feed-in system. Was this [or a similar] system ever considered?

Q18: The trials which were done in Denmark; how many briquettes were made? A 100 or 100 000? What was the wear on the machine? Which machine was used?

Answers to these questions will be helpful to determine the way forward. These questions will have to be revisited with stakeholders who, now with the benefit of hindsight, may be able to provide more valuable information.

3.6 Relevance of the gathered information to pelletised feed production for livestock and game

Encroacher bush is regarded as a potentially viable resource for feed production for livestock and game. Grazing livestock and game have through the ages used this resource, and more so when grass feeding became difficult as a result of droughts and overgrazing. The aim to produce pelletized feed from encroacher bush is motivated by increasing its viability as a stored product as well as including various animal nutrients into the pellets.

In Namibia there are strong opinions on the merits of encroacher bush pelletized feeds varying from "it serves a good purpose, especially during difficult times" to "it's useless and should not be made and used". The purpose of this Information Review is not to take sides in this debate but to highlight the fact that all the information gathered herein regarding the technologies and processes for the conversion of encroacher bush woods is as relevant for animal feeds as for the wood-based fuels.

The fact that various materials could be added to the pelletising process for feeds may make it easier to process. For example, included fresh, green material, such as sprouting new growth, with its higher moisture content into the process will mitigate its harshness. In the case of fuel pellets major aims are to achieve hardness and energy density. In the case of feed pellets, it is to achieve shelve life and transportability of balanced feed formulations for various animals.

However, the information gathered for this Review confirms that the process equipment for feed pellets should be approached with the same critical assessments as for fuel pellets.

3.7 Concluding remarks

Sand contamination is clearly not the main factor in the abrasion dilemma experienced by the biomass compression industry of Namibia. The true cause of the high mechanical failure rate of extrusion and compaction machines to date in Namibia is more likely an underestimation of the hardness and therefore high abrasiveness of Namibian encroacher bush. A quality and characteristic that would not be easy to accommodate with the current machinery.

The information gathered and knowledge gained thus far in this project clearly indicate that a rethink will be necessary to extract value from encroacher bush in Namibia and direct it to wood based products such a wood logs and pellets. The effectiveness and efficiency of current conversion technologies are questionable. The change will be technology driven, as markets exist for viably produced wood energy and feed products.

3.8 Proposed way forward

The proposed process of change should start by finding answers to as many as possible of the questions listed in this document. With the information and knowledge available, the stakeholders in the encroachment bush industries of Namibia should then apply their minds, starting with a workshop and brainstorming session as with the kick-off meeting at GIZ, and map a way forward. These action plans must then be used to recapitalize the industries towards realizing their full potential.

3.9 Literature list

Wiemann, Michael C; Green, David W. 2007. *Estimating Janka hardness from specific gravity for tropical and temperate species*. Research Paper FPL-RP-643. Madison WI: US Department of Agriculture, Forest Service, Forest Service Products Laboratory.

Panshin, A.J.; De Zeew. C. 1980. *Textbook of wood technology*. 4th Edition. New York: McGraw-Hill Book Company.

Novaes, E.; Kirst, M; Chiang, V; Winter-Sederdorff, H; Sedeerdorff, R. 2010. *Lignin and biomass: A negative correlation for wood formation and lignin content in trees*. Plant Physiol. 154(2): 555-561

Sjostrom, E. 1993. *Wood Chemistry*. Academic Press. San Diego.

Fry, W; White, JB. 1938. *Big Trees*. Stanford University Press, Stanford CA.

Shafizadeh, F; Chin, PPS. 1977. *Chemical Degradation of Wood*. In IS Goldstein ed., Wood Technology Chemical Aspects. American Chemical Society Symposium Series, Washington DC.

McLaughlin, SB; **Samson, R; Bransby, D; Wiselogel, A**. 1996. *Evaluating physical, chemical and energetic properties of perennial grasses as biofuels*. Partnership to Develop and Apply Biomass Technologies. Proceedings of the Seventh National Bioenergy Conference, Nashville TN.

Darmawan, W; Rahayu, I; Nandika, D; Marchal, R. 2012. *The importance of extractives and abrasives in wood materials on the wearing of cutting tools*. BioResources 7(4), 4715-4729.

Martawijaya, A; Kartasujana, I; Kadir, K; Prawira, S. 1989. *Atlas Kayu Indonesia*. Forest Products Research Institute, Bogor.

McKenzie, WM; Karpovich, H. 1968. *The frictional behaviour of wood*, Wood Science and Technology 2(2), 139-152.

McKenzie, WM; Hillis, WE. 1965, *Evidence of chemical acceleration of wear of cutting plant materials*. Wear 8(3), 238-243.

Kirbach, E; Chow, S. 1976. *Chemical wear of tungsten carbide cutting tools by western red cedar.* Forest Products Journal 26(3) 44-48.

Fukuda, H; Banshoya, K; Murase, Y. 1992. *Corrosive wear of wood-cutting tools. Effect of tool materials on corrosive wear of spur machine bits*. Mokuzai Gakkaishi 38(8), 764-770.

Krilov, A. 1986. *Corrosion and wear of sawblade steels*. Wood Sciences and Technology. 20(4), 361-368.

Morita, T; Banshoya, K; Tsutsumoto, T; Murase, **Y**. 1999. *Corrosive wear characteristics of diamond-coated cemented carbide tools*. Journal of Wood Science 45(6), 456-460.

Murase, Y. 1984. *Effect of tool materials on the corrosive wear of wood-cutting tools.* Mokuzai Gakkaishi 30(1), 47-54.

Darmawan, W; Tanaka, C. 2006. *Chemical and mechanical wearing of woodworking cutting tools by tropical woods*. Journal of Tropical Forest Science. 18(4), 166-172.

Huber, H. 1985. *Tool wear influenced by the content of particle board*. Proceedings of the 8th International Wood Machining Seminar 7-9 October 1985 California. 72-85.

Porankiewicz, B; Gronlund, A. 1991. *Tool wear-influencing factors*. Proceedings of the 10th International Wood Machining Seminar. 2-4 October 1991 Kyoto, 220-229.

Brebu, M; Vasile, C. 2010. *Thermal degradation of Lignin – a Review*. Cellulose Chem Technol. 44 (9) 353-363.

4. INTERIM ANALYTICAL REPORT (By Dr Louis de Lange)

4.1 Background

In MILESTONE III: LITERATURE SURVEY AND INFORMATION REVIEW extensive information was presented supporting the proposition that current available technologies and processes used for processing of Namibian encroacher bush biomass into compressed wood products totally underestimates the harshness of this type of biomass and its high wear impact on the equipment used. All information gathered since then provides further support to this proposition. Communication with Shimada Systems, supplier of the machines used at CCF for the manufacturing of fuel logs has not dispelled this view. As a matter of fact, it appears that users of the Shimada process, such as CCF, have been left to their own devices with no real and sustainable solutions being offered by Shimada. Below follow examples of some of the information provided by Shimada, extracted from their Operating Manual [in blue and Italics] with comments and questions from our technical team.

4.2 Basic operating parameters to establish quality control

In order to maintain smooth operation and maximum output careful and continual attention should be paid to the following criteria:

i. *The moisture content and particle size of your raw materials, as per the standard Shimada Guarantee. These parameters, i.e. quality control, will be established during the commissioning of the Press by the Shimada engineer. MC: 4-6%; size: 1-4 mm.*

- The question is how practical it is for a manufacturer to consistently maintain a moisture content of 4 - 6 % while also maintaining a particle size of 1 – 4 mm? All of this while aiming to maintain a high throughput of biomass materials.
- It seems that any deviation from these specifications will impact negatively on the process and equipment.

ii. *If the Heat Tube is overheated, the surface of the extrudate will lose its resistance and this will result in a loss of compression and therefore density of the end product. If under-heated, the opposite will occur resulting in higher wear on machine parts and in extreme cases the Press may clog and jam. A start-up temperature of the heater bands of up to 280°-300°C followed by an operating temperature of 260°-265°C is recommended.*

iii. Initially the raw material will flow from the Press loosely, but will quickly begin to harden into an extrudate once the correct pressure has been reached within the Press (c. 14 tonnes/cm^2). At this stage lower the temperature of the Heater Bands to c. 265°C.

- We assume that extrudate refers to the actual logs being produced.
- The question was raised before that if the heater band temperature is as high as 265^{o}C, what will the internal extruder temperature be and, will it be high enough, together with the pressure achieved, to start a fast pyrolytic reaction?
- The consequences of a fast pyrolytic reaction in the extruder with it exothermic escalation in temperature has been referred to before.

- Has Shimada or other extruder-based system suppliers in any way seriously researched the impact of a continuous pyrolytic reaction with its high heat output on their systems? Where are the detailed results?

iv. *The quality of the extrudate will now be maintained by barrel temperature and material moisture content. The press operator will soon understand the best combination of these factors for the consistent production of high quality extrudate*.

- The problem is that the press operator has no operating flexibility. Once the extruder is in operation there is very little the operator can do; at least not fast enough to make any positive difference.
- The operator cannot adjust operating conditions as these function at extreme levels.
- The aim is to maintain high production throughput to try and achieve economic viability.

v. Extrudate from the Heat Tube is soft and cracked and continues to swell after extrusion: *- The moisture content of the raw material is too high. The surface of the extrudate will be light in colour – adjust accordingly.*

vi. Extrudate from the Heat Tube is burnt and finely cracked: - The Heater Bands are set at too high a temperature, also the moisture content of the raw materials may be too low – adjust accordingly.

- The same applies as for v. and vi.

vii. Negative Taper Screw is becoming worn; depending upon your material the production life of the Screw can be between 40 and 100 hours before needing to replace the Screw for re-welding. Screw maintenance: based on historical figures from Shimada Extrudate production plants operating with hard and soft wood. The process of high pressure extrusion inevitably leads to some wear on certain parts within the compression area.

- If Shimada predicts a production screw life of between 40 production hours and 100 hours before extensive [and expensive] maintenance, a manufacturer such as CCF has little hope to achieve long, continuous runs, especially with the extreme Namibian biomass materials at their disposal.
- If Shimada claims that their screw maintenance procedures are based on historical figures from other operating plants, one can only wonder what biomass materials are used in these plants. Has Shimada any information on extreme materials which was/is being used on their systems?
- The impression is that Shimada and also CFNielsen started their businesses using the soft and easily processable woods from e.g. the European environments and that they never developed equipment specifically suitable to e.g. the Namibian environments.

- If they did this research and development work; where are these results and are they willing to translate it into performance guarantees?
- It seems that manufacturers such as CCF have been sponsoring the R&D [if R&D is actually a serious priority] of Shimada by continuously purchasing replacement screw parts.

viii. *Abrasion varies dependent upon raw materials used in the extrusion process, but the effect and remedies are the same. It is very important to maintain a stock of refurbished Negative Taper Screws so as to be able to produce continuously and minimize down-time. Each Press is supplied with spare parts comprising 1 x Negative Taper Screws and 1 x Change Guide Pipe. This amount of changeable parts ensures that, with correct maintenance, there will always be sufficient parts for continuous Press operation.*

Based on historical information from Shimada Extrusion Plants throughout the world, screw life (when operating with soft and hard woods) is anything from 40 to 100 hours plus. It is best to change screws before they have suffered too much wear as this greatly facilitates re-welding and reduces the risk of serious wear or damage. It is a typical practice to check the screw after every 40 hours of operation.

- It is of no use to an operator such as CCF to be advised that serious maintenance will be required after as little as 40 hours of operation and that a sufficient number of [expensive] spares must be maintained in stock to ensure continuous operations.

4.3 Interim actions

- The trials conducted at CCF were aimed at trying to find simple and cost effective solutions to the problems experienced at CCF. An example of a possible solution is the use of appropriate lubricants in the extruder process.
- The wood types used at CCF were analysed to determine the spectrum of chemical and physical properties of these wood types. Table 5 below already includes the results obtained.

TABLE 5: ANALYTICAL RESULTS FROM SELECTED WOOD SAMPLES FROM TWO TRIALS

Items Analysed	CCF, Otjiwarongo			ABC chipping trials conducted at Robertson, Western Cape, SA Jan 2016				
	Post hammer mill		Cyclone dust	Sickle bush	Purple-pot Terminalia	Mopane	Filter dust	Notes
	Sickle bush	Mix						
Most Content [%]	12.00	7.30	8.90	8.50	9.70	11.90		1.
High heating value [MJ/kg]	19.16	19.25	17.88	18.75	17.95	18.37		2.
Ash [%]	2.20	4.20	6.30	2.90	5.70	3.60	20.12	3.
Silica [ppm] [or g/ton]	115.62	679.42	763.46				532.34	4.
Lignin [%]	30.33	24.91	30.78					5.
Density [g/cm^3]				0.89	0.70	0.81		6.
Extractives [%]	12.30	10.49	17.99					7.

Note 1	• The moisture content of all the wood samples is at the level expected of wood exposed to varied atmospheric drying for a period of time. • The ideal is to have an average moisture content of 8% for processing.
Note 2	The higher heating value [CV] is as expected of dry hard woods.
Note 3	• The ash content [also including silica] varies considerably across the samples. • The higher ash content of the dust samples is indicative of sand imbedded on the bark which was separated out by the cyclone and filter systems used.
Note 4	• The cyclone dust sample has the highest silica content which may also be indicative of external sand separated out in the cyclone. • If this is the case and the sand passed through the extrusion process, the wear on the screws would even be worse. • The high silica content of the Robertson dust sample may also be indicative of sand which became adhered to the wood surface during handling.
Note 5	• On average the lignin content of the samples is as to be expected of typical hard woods. • As mentioned before the lignin content will impact on the wear of the equipment if temperatures in the barrel become exceedingly high as a result of pyrolytic conditions in the barrel. • Under pyrolytic conditions the abrasive and corrosive conditions will become severe.
Note 6	• The density levels are typical for hard woods at the moisture content levels recorded for these samples. • As mentioned before these high densities could be could be correlated with Dry Janka Hardness which could be as high as 16 000 N [Newton]. • The Dry Janka Hardness of combined wood types will impact severely on the efficacy of the extrusion process under the extreme compacting conditions necessary to extrude wood logs.
Note 7	• The high levels of extractives will also impact severely on the extruder screw if pyrolytic conditions are attained in the barrel enhancing its corrosive impact on the screw. • The presence of abrasives e.g. internal silica and silica from sand will further exacerbate the wear conditions created in the extruder.

- Reference has been made to the possible benefits, if any, of using a cyclone separator to separate fines, including sand, from the main biomass feedstock. An interesting observation in the results contained in Table 5 above is the 6.3% ash content of the cyclone dust; higher than the ash content of the other wood samples. Has a material amount of sand been separated out in the cyclone process? If so, is it true that this sand would have contributed to abrasion if it was allowed to enter the extruder. If sand is imbedded in wood bark, is a hammer mill-cyclone combination a useful way to separate sand from the bark? But, why hasn't it made much of a difference up to know in reducing wear on the screws in the extruder?
- The recent extrusion trials conducted at CCF by Mr. Thys de Wet and his team delivered a variety of bush logs produced under various operating variables. Two of the operating variables of particular importance from a chemical analytical perspective are:

  - the logs where the in-feed wood in chipped form has been washed and dried prior to extrusion and,
  - the logs where the in-feed wood has been debarked prior to chipping and extrusion.

- These two operating variables, represented by two logs, are compared with two logs of which the in-feed wood hasn't been washed or debarked.
- The impact of washing the wood as well as debarking the wood on the silica and ash content of the wood will be indicative if these actions could in any way play a role to diminish wear on the extruder screws. It is highly unlikely if it will be technically and economically feasible to debark or wash and then dry the infeed wood used in the process to make bush logs.
- With the analytical work completed at BemLab certain indications could be derived from the results. Table 6 below contains the final results with commentary.

TABLE 6: ANALYTICAL RESULTS OF SELECTED WOOD LOGS FROM CCF EXTRUDER TRIALS

Items Analysed	Log 2 Mixed bush	Log 3 Pure Sickle bush	Log 4 Sickle bush debarked	Log 5 Mixed bush washed and dried	Notes
Silica [ppm] [or g/ton or mg/kg]	175.53	146.91	55.86	123.39	1.
Ash [%]	3.30	2.75	1.45	2.75	2
Note 1	Log 4 – Sickle bush debarked results in a lower silica content. Is this as a result of sand imbedded in the bark or also from the inherent silica content of the bark? It will be interesting to determine this. Compared to Log 3 – pure Sickle bush – the silica content is materially lower. In any case, debarking wood is not a feasible solution. Log 5 – Mixed bush washed and dried resulted in slightly lower silica content. Most likely as a result of removing sand? Washing and drying may also not be a feasible solution Log 5 – Washing and drying the mixed bush has lowered the silica content somewhat. It has not materially lowered the ash content. Also indicating that washing and drying may not be a feasible solution?				
Note 2	Log 4 – Sickle bush debarked results in a lower ash content. Also, is this as result of sand imbedded in the bark or also from the inherent silica content of the bark? It will be interesting to determine this. As mentioned in Note 1, debarking wood is not a feasible solution. Compared to Log 3 – pure Sickle bush – the ash content is materially lower. Log 5 – the ash content of the mixed bush washed and dried remains high. Washing and drying may also not be a feasible solution.				

4.4 Questions raised before

During the process of the literature survey and information gathering stage, including communication with two machinery suppliers, followed by the analytical report, a number of questions were raised; the goal being that the logic expressed in these questions will indicate possible solutions. At this stage of the project it can be concluded that the questions which resulted in positive answers can contribute to possible solutions to the overall problem, but also that unanswered questions remain.

Q1: To what extent will high Janka Hardness values impact on re-densification during the extrusion processes currently used in Namibia to manufacture logs and pellets?

Woods with high Janka Hardness values will require greater force i.e. work/energy inputs than softer woods to be re-densified to deliver a solid log. The question remains if Janka Hardness was ever considered prior to selecting extrusion technologies.

Q2: What shear forces will be required and pressures generated during the processes?

The power usage measurements done during the CCF trials are indicative of the shear forces generated during extrusion.

Q3: What are the Janka Hardnesses of the various fuel logs and pellets produced especially since these represent a mixture of wood types?

The Janka Hardness of the logs produced as well as the feedstock wood was never measured before the appropriateness of the extruder technologies was determined. This is the responsibility of the technology supplier(s) and should follow from their research.

Q4: Do the extruder shear forces and pressures required for re-densification of high Janka Hardness woods generate higher temperatures in the extruder than for softer woods?

As it is not possible to measure heat development within the wood mass pressed through the extruder barrel it is not possible to correlate Janka Hardness of a particular wood or mix, with the generation of high heat in the extruder.

Q5: What are the actual temperatures in the pressure zones of the extruders?

As stated above, no measurement of actual internal temperatures can be taken for correlation with pressure(s) in the extruder.

Q6: If higher than anticipated, what will the impact of these higher pressures and temperatures be on the decomposition of the woods?

As stated before, high pressure extrusion, as required by typical Namibian hard woods, could result in temperature spikes resulting from exothermic pyrolytic conditions which will exacerbate the impact of abrasives [e.g. silica] and corrosives on the wear surfaces in the extruder. The following sequence warrants consideration:

High Janka Hardness wood → needs high pressure → generates high temperature from exothermic pyrolytic reaction → high impact from internal abrasives [e.g. silica] and corrosives [from extractives and wood decomposition] → Further impact from external abrasives [e.g. sand, to the extent present].

Q7: Have these factors been considered during the selection of the processes for the manufacturing of fuel logs and pellets, particularly by the suppliers of the equipment?
There is no information that these factors have been adequately considered beforehand by either suppliers or users of the process technologies. It is fair to state that the onus to supply the information rests with the suppliers as they should have the necessary information available based on their prior research.

Q8: What guarantees [if any] have been provided by the suppliers that their equipment will be able to process the wood from Namibian encroacher bush?

It seems clear that the suppliers of the processing equipment have not, nor are they able to provide any guarantees as a comfort to the users of their equipment.

Q9: Have the suppliers to the extrusion equipment used to manufacture fuel logs and pellets from Namibian encroacher bush adequately considered the complexity of the process described above?

All indications are that the suppliers have not adequately considered the complexity of the wood log producing process in Namibia.

Q10: Have they conducted the necessary trials to prove that their equipment can deal with the extreme conditions, which results from Namibian encroacher bush as described above?

All indications are that the suppliers of the technologies have not done adequately extensive trials with Namibian encroacher bush.

Q11: Were they prepared to provide guarantees to that effect?

As stated before, these suppliers are not in a position to provide any meaningful guarantees to manufacturers of wood logs in Namibia.

Q12: Can the existing technologies be modified/redesigned and the process be changed to mitigate the extreme conditions described above?

The efforts by the project team, such as the trials conducted at CCF, aim to find answers to these questions.

Q13: For example, can lubricants e.g. oil or molten wax, be injected into the compression zone without compromising the physical properties of the fuel logs or pellets?

The results achieved during the trials at CCF are indicative of the possible positive outcome of these suggestions.

Q14: Have any technologies and processes been considered where the extreme conditions described above will not have the destructive effect on the machinery and its materials of construction?

It appears that few, if any, alternative technologies and processes have been considered thus far.

Q15: Even if those technologies and processes still have to be developed?

A large and growing demand into export markets for bush logs will have a major impact on the sustainable clearing of encroacher bush initiative in Namibia. Just the socioeconomic benefits, at a national level, of such a project may make it worthwhile to support the development of appropriate technologies and processes.

Q16: Why hasn't CFNielsen's briquetting technology become established in Namibia?

CFNielsen tries to create the impression that their "briquetting technology" provides a sustainable solution to the challenges typically experienced in Namibia. What is the actual status?

Q17: For example, CFNielsen's Briquetting Press BP 6500 HD with ABCS is a high performance press with a 1 000 - 1 800 kg/h throughput capacity range using a piston with a two compression screw feed-in system. Was this [or a similar] system ever considered and or tested?

Has this CFNielsen Press been considered and even properly evaluated? What was the outcome of this process?

Q18: The trials which were done in Denmark refer; how many briquettes were made? A 100 or 100 000 trial? What was the wear on the machine? Which machine was used?

To produce 100 logs is not a proper trial. To produce 100 000+ logs in a continuous run, with no material wear on the system, will constitute a proper trial. What actually happened at the CFNielsen trial?

4.5 Concluding remarks

- It appears that wood processing equipment providers, such as Shimada and also CFNielsen, started their businesses using the softer wood from e.g. European environments and never developed machines specifically suitable to the much harder and severe wood types from e.g. Namibia.
- It appears that they are now improvising as they go along. Otherwise, where is the detailed research and development results?
- It also appears that they never conducted serious and dedicated research and development work [at their own expense and not based on the trial and error efforts of the users of their equipment] with the materials sourced from e.g. Namibia.
- Once the trials at CCF have been completed all the information will have to be reinterpreted within a framework of all the possible variables.

- If this information indicates that Shimada has neglected to do extensive research and development to provide manufacturing systems with optimum operating outputs, including high wear resistance, while using the extreme materials of e.g. Namibia, Shimada may have some answering to do.
- What if the likes of Shimada and CFNielsen have to admit that the high temperature and high pressure extruder systems they are offering are not the best option to process the severe biomass materials of e.g. Namibia into bush logs?
- Maybe Shimada should install one of their state-of-the-art systems, at their expense, at CCF to demonstrate that their technology can do the job.
- The following sequence, referred to before, in a sense captures the heart of the problem:

  High Janka Hardness wood → needs high pressure → generates high temperature from exothermic pyrolytic reaction → high impact from internal abrasives [e.g. silica] and corrosives [from extractives and wood decomposition] → Further impact from external abrasives [e.g. sand, to the extent present].
- Any sustainable solution must recognise the fundamental science expressed by this problem.

5. HARVESTING BIOMASS IN NAMIBIA

5.1 Background

Several methods of harvesting biomass from encroacher bush exist in Namibia, ranging from labour intensive hand cutting and felling methods to highly mechanised hydraulic tree/bush cutting methods.

A comprehensive study in this regard, culminating in a Compendium titled: "Harvesting Namibian Encroacher Bush", was sponsored and compiled for GIZ (by De Wet, M.J.) during 2015. The best known harvesting methods are listed in Table 7 below:

TABLE 7: TEN HARVESTING METHODOLOGIES

Item	Description of harvesting methods	Claimed de-bushing tempo
1.	Axe, panga, tree felling hand saw [100% manual method]	0.1 to 0.2 ha/day
2.	As above, plus hand held chain saws [Manual, semi-mechanised]	0.2 to 0.6 ha/day
3.	Horizontal & vertical trolley mounted circular saw equipment	0.3 to 0.6 ha/day including tall trees
4.	Tractor drawn slasher/rotatory cutters for small bushes [Light-mechanised with limited application]	2 to 5 ha/day small bush only
5.	As above, on extended arm with heavier duty applications/ Hedge cutter on tractor/Multi saw blade applications	3 to 7 ha/day small (low-level) bush only
6.	Circular saw on multipurpose Skidsteer front loader	2 to 4 ha/day can fell large trees
7.	Bulldozing	>5 ha/day
8.	Hydraulic grab on excavator bush lifter/tree puller & windrow stacker	4 to 5 ha/day
9.	Hydraulic grab and cutter on excavator & windrow stacker complete with three-wheel chipper loader, horizontal biomass mill and shuttle system	4 to 5 ha/day
10.	Bush combine harvester and chipper	3 to 5 ha/day

In virtually all of the approximately 10 harvesting methods used in Namibia the possibility of sand and soil contamination is prevalent and this has an impact on downstream chipping, grinding, pelletising, extrusion and other compacted or compressed wood processing operations. It is often not possible to avoid soil contamination of felled bush during the harvesting operation and methods need to be developed to curb this problem as much as possible – especially for the more sensitive downstream mechanical operations like chipping, hammer milling and bush log extrusion.

5.2 Minimising sand and other impurities during harvesting

A practical method used to minimise sand and soil contamination during commercial harvesting (mechanised felling), is to grab the bush with hydraulic grab and cutter similar to the: *Woodline Trevi Benne of TreeCycle [www.treecycle.co.za] or Woodcracker felling tools of WoodCo [www.woodco.biz]. See photographs 4 to 7 in this regard.*

Photograph 4 & 5: Felling of bush using a hydraulic cutter (WoodCo)

Photograph 6: Three-wheel logger (left) and logger fitted with a hydraulic cutter (right). Courtesy ABC Worcester

Photograph 7: Windrows being stacked with a hydraulic grab and cutter fitted to an excavator (WoodCo)

These felling tools can 'softly' stack bushes on top of one another in a windrow to dry. Three wheel loaders with hydraulic grabs are then used to feed the wet chipping machines or large dry wood grinders without touching the ground.

When dry wood chipping/grinding takes place a huge dust cloud normally surrounds the grinder giving the appearance of sand and soil contamination. See Photograph 2. As pointed out earlier in this report, this dust is mostly fine wood particles and not so much dust from sand or soil.

It is also possible for the less mechanised operations to avoid soil contamination through better windrow stacking techniques by hand. Some farmers use a layer of bush on the ground to stack bush planned to be wet chipped. Dry wood chippers (grinders) are slightly less sensitive to soil contamination.

Tub grinders, specially designed to handle contaminated bush and root stock can also be considered, but are generally huge and capital intensive machines which can only be afforded for large commercial de-bushing operations.

5.3 Post-harvest cleaning of biomass chips

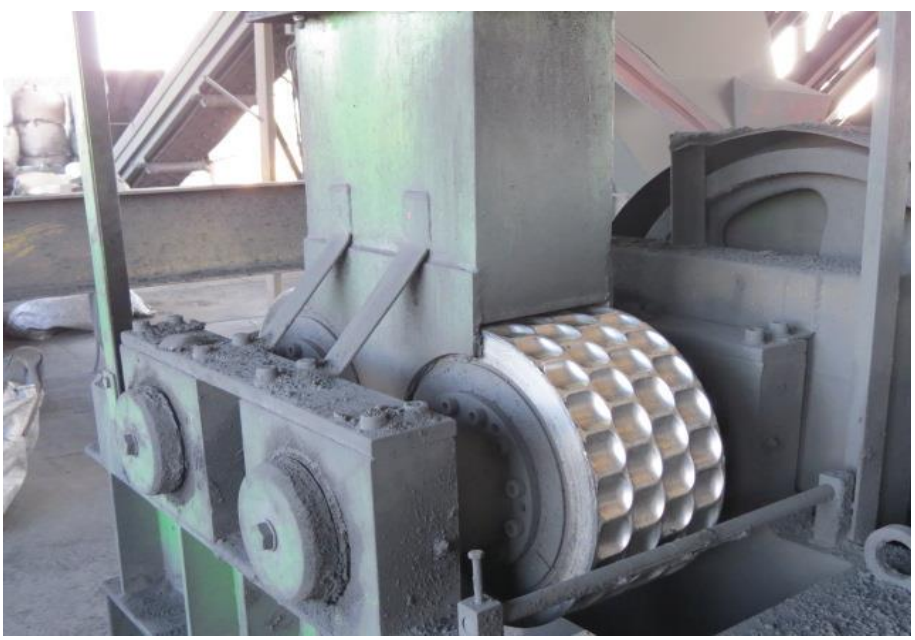
A more practical place in the value chain to clean wood feedstock would be after the chipping process. See Chapter 8 for examples of sand removal systems often employed to reduce and minimise this problem.

5.4 Sand in charcoal

The infield charcoal kiln operators are experiencing huge difficulties with sand contamination. Most of the sand is scooped in with the final charcoal product from the same spot on which the kiln was standing during the smouldering (pyrolysis) process. This sand can be screened out quite easily. A fair amount of charcoal fines is lost or heavily contaminated with sand or soil in the charcoal making process using open bottom kilns.

The newly founded *Namibian Charcoal Association [NCA]* is gearing itself to improve the infield kiln charcoal producing process with emphasis on less air and soil pollution while improving the charcoal yields at the same time.

The compacting of charcoal fines is done as per the method shown in Photograph 8 below. The two bucketed rollers experience little wear when compacting the charcoal fines and its binder into briquettes, because of its rolling and not sliding design.



Photograph 8: Charcoal briquetting machine. Courtesy Kilo 40

6. PELLETISED AND CUBED ANIMAL FEED FROM BUSH

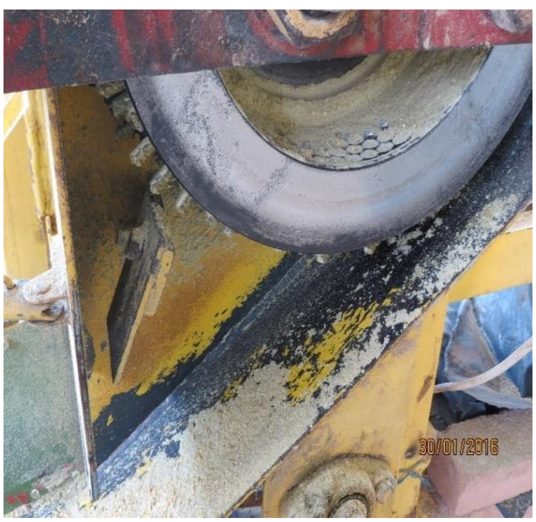
6.1 Introduction to feed from bush

In Namibia two schools of thought exist about animal feed from encroacher bush i.e. “boskos”. Some farmers and animal feed experts believe that it would be safer not to develop this option further, because only the hemicellulose and cellulose fractions of the bush would be digestible. The lignin fraction is not digestible and could be harmful to the intestines of the animal. Others believe that when done correctly; only using the soft growth and young sprouting (green) branches from the bush, mixed with seed pods and other nutritional additives, ‘boskos’ could be excellent animal feed. By chipping, hammer milling and pelletising the above would result in a shelf stable storable product which could be economically transported and used/fed to livestock. It is for this reason that the Consultants believe that the process should be investigated and developed further – especially in an arid country like Namibia with its virtually unlimited supply of encroacher bush. In fact, an integrated system to economically harvest and process encroacher bush for a combination of uses, including a balanced animal feed, should be further encouraged.

6.2 Pelletising bush animal feed

6.2.1 The effect of sand and dust on pelletising bush

Mr Larry Bussey of the farm Tambuti Wilderness, Otavi, Namibia, is currently manufacturing animal feed pellets from bush and has successfully compressed partially dried and hammer milled encroacher bush, mainly for own use at this stage.



Photograph 9 & 10: Pelletising Operation (Larry Bussey)

For more photographs in this regard refer to **Annexure B**.

Little wear has been experienced on the die (See **Annexure B**, Photographs 6 & 7) of the pelletiser die since operations started in 2014. It is believed that the relative young growth Mr Bussey is using when pelletising, as well as some of his secret nutritional additives, are probably the contributing factors for the low wear experienced as the young growth is less abrasive and the additives my act as soft lubricants. It should also be noted that when young growth is used, especially after the rainy season, there was little time for dust to settle on the branches. It is further believed that by pelletising the chipped and hammer milled bush at the relative high moisture levels of >20% applied here, could also have a favourable impact on the minimal wear patterns observed.

6.2.2 The likely effect of temperature

Although the working temperature of the die can only be controlled[1] by the throughput tempo, the Consultant witnessed the pelletising operation with the die temperature estimated at between 80°C and 90°C, this being regarded as the ideal working temperature for the die.

6.2.3 Other observations made in Namibia

Mr. Marius Cronje of Burgers Equipment did several trials on a range of pelletisers and experienced high wear when attempting to pelletise hammer milled biomass chips with a high lignin (woody) content. It appears that when older bush (not young growth) is pelletised, high fuel consumption (energy) and high wear is experienced.

6.2.4 Findings regarding manufacturing of pelletised feed from bush

The following findings can be recorded regarding the manufacturing process of pelletised animal feed from Namibian encroacher bush:

- **Use young wet bush:** Less wear (and a safer final feed product) is experienced when young and practically wet bush (± 20% moisture content) material is used.
- **Temperature:** The throughput of the pelletiser should be so regulated that the die does not heat up to above approximately 100°C (Water droplets should not boil and evaporate from the surface of the die when sprinkled with water).

  The die should also not be too cold or <80°C, because a pasteurizing effect is required to "sterilise" the feed. As also seen from the Literature Study, 80°C - 100°C is required to fuse and bind the greenwood particles together.

- **Use softer and less abrasive additives:** Less abrasive additives like maize, brewers' grain, straw, molasses, etc. will not only improve the nutritional value of the feed, but will in most cases also reduce the wear tempo of the die.

[1] Wood extruders control temperature through its barrel by means of a barrel heater, while die-type pelletisers heat up automatically when in use because of the friction between the die holes and the feedstock during the compression action.

6.3 Cubing

6.3.1 Background

John Deere, the famous USA based agricultural machinery company, oversaw the use of the *Warren & Baerg Cuber* to compact alfalfa straw directly into small (± 30 mm x 30 mm x 50 mm) 'cubes'. John Deere used its alfalfa windrow lifter to feed the sundried harvested straw into the Warren & Baerg Cuber being pulled directly behind it to cube the straw into medium density bricks or cubes. This method became very popular in the United States because a shelf stable[2] animal feed product could now be produced and delivered directly from the fields.

Over the past nearly 50 years the Warren & Baerg Cuber was modified and improved to compact a wide range of agricultural fibres, paper, cardboard and waste woods.

6.3.2 Visit to a local cubing operation

The Consultant traced a cubing operation near Moorreesburg in the Western Cape and on 31 May and 17 June 2016 visited the owner, Mr Kobus Bergh, of this animal feed operation. See photographs below:

Photographs 11 & 12: Cuber machine in operation

Further photographs of Mr Bergh's animal feed operation are displayed in the second half of **Annexure B.**

[2] The friction through the cuber dies causes sufficient heat to pasteurize the sundried alfalfa to make it safe for long term storage.

6.3.3 The advantages of the cuber

The replaceable dies of the Warren & Baerg Cuber and its square slot design are regarded as its biggest advantage over the cylindrical multi hole die of a pelletiser. When the dies of a cubing machine get worn, they can be rebuilt (hardfaced) and replaced individually (One radial die per square slotted hole). See photographs below:

Photographs 13, 14, 15 & 16: A Cuber machine with its front wear plate removed to expose the 66 removable dies and excentric press wheel

The one by one replacement method of the cuber dies is more economical than replacing the multi-hole cylindrical die of a pelletiser. The design of the large square slotted passages of the cuber dies wears less in the presence of dust and residual sand. In fact, in the USA, windrows are picked up mechanically from the fields and fed directly into the cuber for compacting.

A further advantage of a cuber machine over a cylindrical pelletiser is the fact that it can handle coarser infeed, whereas a pelletiser needs to have a pre-hammer milling stage to reduce the infeed to a meal like (< 3mm) substance. The total energy and wear part cost of a cuber operation is much lower than that of a similar throughput pelletiser.

6.3.4 Disadvantages

Although cubers are designed and manufactured to produce smaller cubes (± 20mm x 20mm), the cubes cannot practically be made smaller at this stage. This is a disadvantage for producers of animal feed for small animal units (sheep, goat, springbok, etc.) and chickens.

Although the cuber can be designed to compact biomass fibre and small chips, it does not render the same natural binding compaction forces than for example a Shimada extruder. Binders are often required for biomass compaction to better solidify compressed wood products because buyers require a high structural integrity of the cube.

6.3.5 Recommendation

Although not yet tested in Namibia, the Consultants are of the opinion that the cuber type machines would outperform most pelletisers on animal feed production for larger animals with special reference to throughput volumes, running costs of wear parts and energy consumption per unit mass of final product.

The cuber is widely used throughout the world to produce compacted solid waste fuels, or *Refuse Derived Fuels [RDF],* for boiler and other thermal applications. It is therefore recommended that trials be conducted to produce boiler fuel from encroacher bush biomass and to test the potential/acceptability of a cubed biomass fuel for the local and international thermal energy applications.

A comparison analysis between Cuber technology and that of Extruders and Pelletisers for the production of woody biofuels for thermal applications can be found in Chapter 10 of this report.

7. EXTRUDED *BUSHBLOK* TRIALS CONDUCTED AT CCF

7.1 Background to the trials

The *Cheetah Conservation Fund [CCF]* is manufacturing compressed (extruded) fire logs ("Bushbloks") from encroacher bush. The encroacher bush is harvested from a more than 40 000-hectare conservancy in an effort to restore the savannah and improve the habitat for the endangered cheetah. Harvested bush is chipped and dried prior to transporting it from the conservancy to the CCF Bushblok processing plant in Otjiwarongo.

Dried encroacher bush chips are hammer milled into a coarse wood meal at the CCF factory prior to being fed into the Shimada Extruder Presses (Type SPMM 850K) for the production of the popular Bushbloks. See photographs below.

Photograph 17 & 18: CCF's Bushblok factory, Otjiwarongo

See **Annexure C** for a detailed photographic display of the above operation in more detail.

The trials at the CCF factory took place during the week of 25 April 2016 and consisted of measuring the energy consumed by the Nr 1 Shimada machine during 12 sampled production runs. The main induction motor power rating of the machine is 37 kW and its main screw rotates at 800 rpm. The machine has a production capacity of approximately 500 kg/hour of final product. It has two electrical ceramic heater bands, each requiring 3 kW for operation and has an integrated T-shaped stirrer with a 0.18 kW motor. Each press has its own electrical control panel and is fitted with a standard 3 phase, neutral and earth electricity power supply.

To maintain smooth production of compressed wood meal logs ('Bushbloks'), requires an ideal moisture content of the infeed raw material at approximately 8% and the sizing of the wood particles at between 1 - 4 mm. A moisture content close to 6 - 8% was maintained throughout the three trial run days.

According to the Shimada Operating Manual, overheating of the heat tube or barrel will cause the extrudate to lose its surface resistance against the output barrel, resulting in loss of compression and therefore density of the end product. If under heated, the opposite will occur resulting in higher wear on machine parts and in extreme cases the extruder may clog and jam. An average barrel temperature of between 160°C and 184°C were maintained for Samples 2 to 12. Only during the first Sample the barrel heated up to above 200°C. This sample was rejected.

It's interesting to note that the Shimada Operating Manual suggests the barrel heater temperature to be set much higher, at 240°C to 265°C. During the setting up of the trials the test team experienced blackening of the extrudate and excessive smoke when the barrel heater temperature was approaching 200°C. The outer surface of the blocks began to turn into a charcoal like and burned appearance. This unwanted burned appearance damages the clean aesthetics of the block and would dirty the hands of future clients. The higher temperatures did improve the integrity of the block and it was decided to keep the barrel temperature setting at approximately 170°C. A thermostatic controller keeps the barrel heater between 160°C and 185°C.

An infrared scanner was used to measure the surface temperature of the Bushblok as it exits the barrel. See Photograph 19.

Photograph 19: Measuring the surface temperature of a Bushblok exiting the heated barrel

See **Figure 1** for a section through the extruder and **Figure 2,** showing the major wear parts of the Shimada machine.

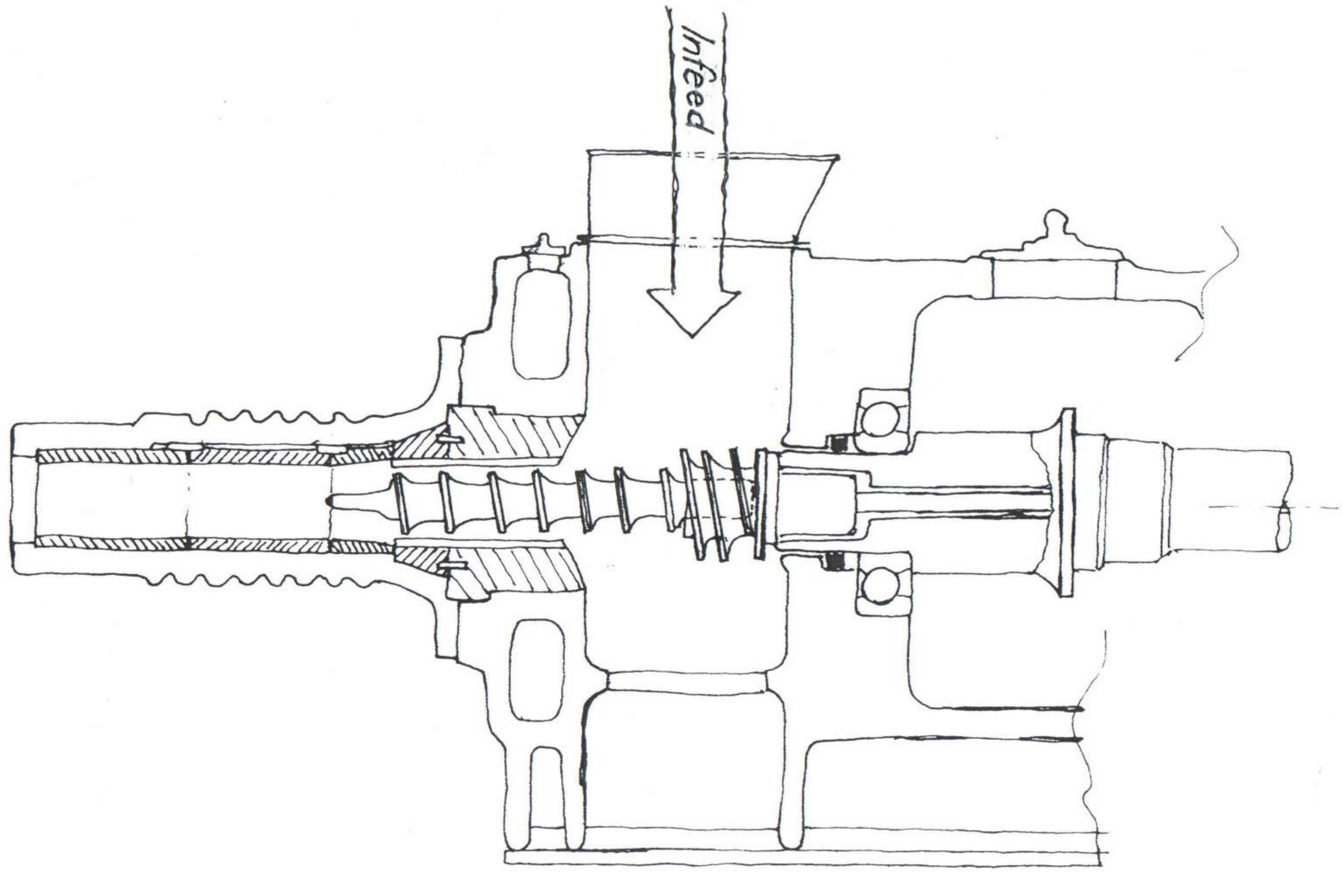


FIG. 1: Section through the extruder part of the SHIMADA

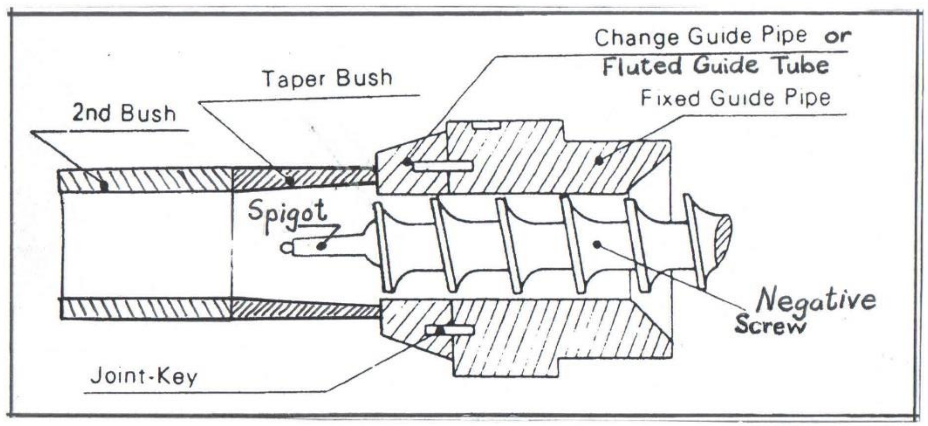


FIG.2: The major wear components of the SHIMADA EXTRUDER

7.2 Apparent main cause of the high wear patterns

It is generally believed that the main cause of the high wear experienced by the above machines is caused by sand, dust and other abrasive minerals contained in the Namibian encroacher bush.

Correspondence and communication with Mr. Pat Roddy, Managing Director of New Air Technical Services Ltd, Leicester, England, postulated that the average life of machines operated in the UK, Europe and elsewhere extruding biomass such as sawdust, wood shavings, bagasse, corn husks, coffee husks, rice husks, sunflower seeds and other agricultural wastes, are obtaining > 40 hours' production between hardfacing runs of the Negative Screw.

The highest pressure and therefore wear, is experienced at the end of the *Negative Screw* and over the length of the *Fluted Guide Tube*. See Figure 2. As soon as the powder coated and hardfaced wear surface of the Negative Screw is worn off, it needs to be removed and hardfaced again.

An analysis of several previously used Negative Screws indicates that the rebuilding and hardfacing of the screws were often done too late. In some cases, the screw, spigot base and fluted guide tube were so worn out that the spigot began to wonder till it eventually breaks off.

In theory, a screw can be hardfaced many times over, but should be done earlier in its wear pattern. All the broken screws inspected at CCF were allowed to wear off too much.

Analysing these breakages at CCF show a thermal heat zone and metal fatigue. Most of the screws at CCF are finally scrapped because of this spigot tip breaking off after a few hardfacing cycles and often after less than 40 to 80 production hours.

It was also suggested by Mr. Roddy that a single dust removal cyclone above the hammer mill would not nearly be efficient enough to remove residual sand and dust from the raw material prior to being fed into the Shimada extruder.

Laboratory analysis of the cyclone dust (See Table 5) confirms that most of this dust consist of fine wood particles, with a dry calorific value of 17.88. Just over 763 grams/tonne of free Silica was found in the cyclone dust bag. This indicates that most of the dust extracted by the cyclone system at CCF consist of wood particles.

(Please refer to Chapter 13, **Figure 8**, at the end of the report to better understand the relationship between infeed particle size and energy required to produce a sound Bushblok).

7.3 Challenges experienced at the CCF Bushblok factory

7.3.1 Cost of wear parts

The major challenge experienced by CCF is the high wear on parts of the extruding machine. See Figure 2 for a section through the heart of the machine. High wear and subsequent down time and breakages are occurring within 40 to 80 hours of production, depending on the quality and timeous replacement of rebuild screws and guide pipes, with special reference to the following parts:

- The negative screw @ ₤ 764.00 each

- The fixed guide pipe @ ₤ 320.00 each
- The change guide pipe or fluted guide tube
- The taper bush

The above parts are manufactured by New Air Technical Services Ltd, England, and are not only expensive (> N$ 70 000 per wear set), it is also costly to import to Namibia (> N$ 45 000 per set).

The high costs of the above wear parts and the subsequent down time impact negatively on the economics of the Bushblok manufacturing process.

7.3.2 Cost of electrical energy required

Since the kWh and total energy needed to extrude various mixes of encroacher bush wood meal were measured and recorded in detail, it was possible for the consultants to see that the large (37 kW) induction motors of the extruders ran on a low (< 0.7 average) power factor. The poor power factor results in a larger electricity supply requirement and in CCF paying a high premium for connected kVA costs to CENORED, the local electricity supply and distribution authority.

Further electrical energy (and labour) costs can be saved by planning Bushblok production in such a manner that the hammer mill (45 kW) and the extruders (37 kW each) are not operated simultaneously – Batch, rather than continuous production is advised.

See **Annexure E** for a short report by the Electrical Engineer, Mr Dirk du Toit, of the power supply situation at CCF's factory for further background.

7.4 Methodology proposed by the consultant to compare wear patterns of various raw materials

After a thorough analysis of the extruder process, the consultants came to the conclusion that there would be a correlation between the power (or energy) required to produce a compressed wood log and the wear experienced on the screw and fluted guide tube of the extruder machine. It was therefore decided to measure and record the total electrical power required in kWh/kg final product produced for each trial run.

It was decided to record the power and energy required to convert the following (See Table 8) infeed samples into Bushbloks:

TABLE 8: SAMPLES OF RAW MATERIAL USED IN TRIALS

Sample No	Date	Description of raw material	Remarks
1.	26/4/2016	Mixed bush	Calibrating power recorder
2.	27/4/2016	Mixed 'run of the mill' bush	Was tested successfully
3.	27/4/2016	Sickle bush with bark	Was tested successfully
4.	27/4/2016	Debarked Sickle bush	Was tested successfully
5.	27/4/2016	Washed and dried mixed bush	Was tested successfully
6.	27/4/2016	Mixed bush with ± 1% grape seed oil as lubricant	Was tested successfully
7.	27/4/2016	Mixed bush with ± 2% grape seed oil as lubricant	Was tested successfully
8.	28/4/2016	Sickle bush with ± 2% grape seed oil as lubricant	Not a fully reliable trial
9.	28/4/2016	Debarked Sickle bush with ± 2% grape seed oil as lubricant	Was tested successfully
10.	28/4/2016	Washed mixed bush with ± 2% grape seed oil as lubricant	Not reliable results obtained
11.	28/4/2016	Sickle bush with ± 1% Sunflower oil as lubricant	Was tested successfully
12.	28/4/2016	Sickle bush on long trial run	Was tested successfully
All	29/4/2016	Wrap and mark representative sample logs from some of the trial runs for laboratory analysis	Collect and transport samples for laboratory testing

The detailed data collected and results obtained during the trials are contained in **Annexure D** of this report.

Table 9 contains a summary of the actual readings and measurements taken during the trials at CCF Bushblok Factory in Otjiwarongo. Some of the results are highlighted below:

- **Matching particle size with optimum energy consumption**
  After all of the results of the trials were worked through and analysed, plus the research on better pre-cleaning methods (dust and sand removal) were concluded, the Consultant endeavoured to summarise this large amount of information into a single graph. Refer to Chapter 13**, Figure 8** at the end of this report to see the correlation between particle size and energy required. Dust particles (wood powder and to a lesser extend dust from soil contamination) of less than 0,5 mm in length requires much more energy to compress into a log than particles of > 1.5 mm and < 3.0 mm in length. The energy required to compress larger than 3 mm particles begins to rise again as particle size increase. For best energy consumption figures, particle sizes should ideally be between 1.5 mm and 3.0 mm. This can be achieved with a multi-deck screening system (See **Chapter 8** for more details in this regard).
- **Matching dust and sand removal systems with particle size:**
  Figure 8 (Chapter 13) also displays the best particle size band widths for sand removal systems in the "ideal" compressed wood log factory:

  - **Cyclone dust removers (**See **Figure 6):** Operates from microscopic < 100 micron to approximately 0.75 mm particle size to remove wood dust (± 70% of sample) as well as soil dust (± 30% of sample from dust collector)**.**
  - **An air knife application (**See **Figure 7):** Operates best to remove lose or residual sand on wood meal infeed from approximately 1.0 mm and larger. The wood particle must be larger than the perforated conveyer belt and heavier than the sand grains to be blown through the belt. Likewise, the wood particle must be light enough to be effectively agitated (tumbled) by the (soft, low energy) air stream.
  - **Vibratory screens** (See **Figure 5):** Works well to remove sand from larger than 3.0 mm particle size wood infeed. Smaller applications, < 400 kg/h throughput, could install fine aperture screens as small as 2.0 mm, but blinding of the lower deck could occur.

TABLE 9: SUMMARY OF ENERGY MEASUREMENT RESULTS OBTAINED DURING TRIALS CONDUCTED AT THE CCF BUSHBLOK FACTORY, OTJIWARONGO

Sample No	Description of sample	% H_2O Content of infeed	Useable mass of Bushblok produced [kg]	Useable length of Bushblok produced [m]	Energy required [kWh]	kWh/kg & Wh/kg	kWh/m & Wh/m	Average barrel temp. [°C]	Surface temp. of exiting Bushblok [°C]	Observation during trial run
1.	Mixed bush (To calibrate amp & energy recorder)	6.3	28.1	7.11	3.47	0.12 123.56	0.49 488.33	203	185	Unreliable trial (setting up)
2.	Mixed bush (First reliable run. New Screw)	7.2	148.0	38.79	9.71	0.07 65.61	0.25 250.32	164	185	Reliable trial
3.	Sickle bush (No other bush species)	6.3	116.0	28.90	6.92	0.06 59.66	0.24 239.45	184	191	Reliable trial
4.	Debarked sickle bush	7.8	155.5	38.92	9.39	0.06 60.39	0.24 241.26	173	197	Reliable trial
5.	Washed & dried mixed bush	<8	119.3	29.27	8.15	0.07 68.32	0.28 278.44	161	208	Infeed shows signs of decomposition
6.	Mixed bush with ± 1.0% grape seed oil	<8	99.0	25.41	5.83	0.06 58.89	0.23 229.44	174	215	Reliable trial
7.	Mixed bush with ± 2.0% Grape seed oil	<8	104.0	25.13	6.89	0.07 66.25	0.27 274.17	175	213	Reliable trial
8.	Sickle bush with ± 2.0% grape seed oil	<8	86.0	22.88	5.19	0.06 60.35	0.23 226.84	159	205	Bushblok brittle initially
9.	Debarked sickle bush with ± 2% grape seed oil	<8	99.0	25.26	6.84	0.07 69.09	0.27 270.78	164	196	Reliable trial
10.	Washed mixed bush with ± 2% grape seed oil	<8	62.0	15.83	4.20	0.07 67.74	0.27 265.32	166	211	Not a reliable trial. Breakages due to semi-decomposed meal
11.	Sickle bush with ± 1% sunflower oil	<8	96.5	23.73	4.93	0.05 51.12	0.21 207.88	160	197	Reliable trial
12.	Sickle bush (Still with original screw in Shimada)	<8	141.5	34.11	9.57	0.07 67.63	0.28 280.53	160	184	Reliable trial

7.5 Interpretation of the trial results

*The following interpretations follow from the trial results as summarised in **Table 9,** of which the detailed measurements are recorded and saved as part of **Annexure D** of this report:*

- **Sample 1: Mixed bush**
  Trial to calibrate the ampére, volt, power [kW] and energy [kWh] recorder connected to the power supply of the test rig and the Bushblok production line Nr 1. This trial run was mainly to set up and calibrate the machine and the data was not used for further interpretations.
- **Sample 2: Mixed bush**
  This trial started at 09:43:07 on the morning of 27 April 2016 and ran smoothly. The Shimada machine was serviced and fitted with a complete new set of wear parts.
  A total of 9.71 kWh of electrical energy was used to produce 148.0 kg or 38.79 meters of Bushblok, translating to 65.61 Watt hour/kg and 250.32 Watt hour/m to become the first reliable sample produced.
- **Sample 3: Sickle bush**
  Notably less energy (59.66 Wh/kg and 239.45 Wh/m) was used to produce Bushblok from encroacher bush meal consisting of the Sickle bush (Dichrostachys cinerea) only. This came as no surprise to the CCF crew, since it's a known fact to them that Sickle bush produces a better Bushblok at less wear and at less power consumed.
- **Sample 4: Debarked Sickle bush**
  No notable difference between Sickle bush with bark and debarked Sickle bush could be measured in energy consumption, leading to the conclusion that the sand and silica contained in the bark has no measurable effect on the machine. In fact, the absolutely clean, sand-free debarked Sickle bush required slightly more energy to be extruded.
  This observation shows that it is the inherent hardness of the Sickle bush, and not external sand or contamination that causes the machine parts to wear.
- **Sample 5: Washed and dried mixed bush**
  The infeed meal showed signs of decomposition, causing the bloks to be more brittle than required, confirming the school of thought that cleaning of bush infeed by washing would not be a practical solution for Namibia. It is also believed that some of the natural binding material was washed out, because these Bushbloks were brittle and broke easily when handled.
- **Sample 6: Mixed bush with ± 1% grape seed oil**
  This low mixture of grape seed oil caused a slight drop in energy required. From 65.61 Wh/kg (Sample 2) to 58.89 Wh/kg on mixed bush, which was to be expected.
  Initially it was thought that a very high flash point [3] (food grade) oil should be used for this lubrication test not to cause fire or even an explosion in the barrel. It was later (See Sample 11) proven that a low flash point cooking oil, like sunflower oil, could have the same result without fear of an internal fire.

[3] The internal temperature of the barrel of the Shimada can easily rise to temperatures of 200°C or more for prolonged periods of production. Most food grade oils have a flash point of lower than 200°C, which could cause spontaneous combustion of the oil in a totally enclosed space, or at the point of exit into free air. From this trial Grape Seed Oil, with a flashpoint of 220°C was used.

- **Sample 7: Mixed bush with ± 2% grape seed oil**
  The additional oil did not result in notable drop in energy required. Larger surface cracks in the block appeared, causing the team to feel that too much lubrication was used.
- **Sample 8: Sickle bush with ± 2% grape seed oil**
  The extrudate cracked open and was too brittle to regard this trial as successful. The general feeling amongst the team was that no significant improvement in the power consumed could be observed vs. the non-lubricated Sample 3.
- **Sample 9: Debarked Sickle bush with ± 2% grape seed oil**
  Surprisingly, higher energy is required to extrude lubricated Sickle bush vs. clean Sickle bush.
- **Sample 10: Washed mixed bush with ± 2% grape seed oil**
  Little binding of the material in the barrel, causing the bloks to break up. This trial cannot be regarded as successful.
- **Sample 11: Sickle bush with 1% sunflower oil**
  The least amount of energy (51.12 Wh/kg and 207.88 Wh/m) was required to produce a good Bushblok during this sample run. A lower barrel heater temperature (160°C) vs. the non-lubricated case Sample 3 (184°C) was observed.
- **Sample 12: Sickle bush (Longer run, lower barrel temperature)**
  A good Bushblok was produced but at a notably higher energy requirement (67.63 Wh/kg) and a barrel temperature of 160°C, as was the case (59.66 Wh/kg) when the same Sickle bush was used at a barrel temperature of 184 °C. This is in line with the Shimada Operating Manual.

7.6 Analysis of the wear situation

An analysis of the screw wear and its breakages indicates the rebuilding and hardfacing of the screws are often done too late. It appears as if the screws are often worked until the front end spigot (tip-part) of the Negative Screw is so worn that it starts to wonder inside the Taper Bush (See **Figure 2**), resulting in a fatigue crack at the spigot base were it forms part of the exit end of the screw. Technically, it would not be too difficult for the screw manufactures to modify this part with a removable and replaceable spigot (See **Figure 3**). In fact, it is proposed that the Negative Screw be re-engineered into two sections: a front, high wear section, and a rear, slower wear section to fit into the positive screw.

It is interesting to discover that the energy required to extrude 'bloks' or logs from the bush species: "Sickle bush" and the energy required by the same Shimada machine on the same day with *debarked* Sickle bush of virtually the same moisture content, shows little notable difference in energy per kilogram log produced. Debarked Sickle bush can be regarded as free of residual sand and soil contamination. This result is a firm indication that the wear problem experienced by these machines cannot be directly attributed to sand contamination alone. In fact, the Consultants can now, with reasonable certainty, conclude that the major contributor to wear of the extruder parts are caused by the inherent hardness of the Namibian encroacher bush species. The main reason for the longer life of the wear components of the above machines with European woods is the fact that these woods are generally softer, with a lower Janka hardness and lower density.

The slight drop in energy consumed when the infeed wood meal was lightly mixed with oil was to be expected and this supports the theory that a form of lubrication could have benefits when applied correctly near the high wear spots at the high pressure contract zones between the Negative Screw and the Fluted Guide Tube. See **Figure 4** for a suggestion.

Initially, it was thought that food grade oil lubrication with a high flash point (above 200°C) should be used to minimise fire risks, leading to the use of *grape seed oil.* During the trials it was discovered, when experimenting with cheaper, off the shelf sunflower cooking oil, that the same results were obtained. And although the sunflower oil has a much lower flash point (±120°C) than the grape seed oil, no excessive smoking or fires were experienced. This leaves the future open to consider lubrication with an industrial wax or other cheaper lubricants, like recycled cooking oil.

It’s important to note that the lubricant should be of a food grade specification or of substance (wax) which will not cause bad odours when the logs or extruded blocks are burned for barbeque or domestic heating purposes. [The charcoal industry are currently exporting some of their product lines coated or impregnated with wax for quicker burning purposes when ignited as a barbeque fire].

A correctly applied, lubricant, as suggested in **Figure 4**, could be viable if the working life of the front portion of the Negative Screw can be say doubled or quadrupled. However, it may, be more sensible to implement the following actions first before re-engineering the machine to accommodate a high pressure lubrication system:

(i) Replace the Negative Screw and hardface it as soon as it shows wear. This can be done without really effecting production by temporarily switching production over to the standby machine.

To replace a worn screw with a hardfaced one does not take longer than 10 - 15 minutes on a hot machine. After removing the bolts holding the barrel in line with the screw, the whole barrel front end of the machine is swung open to reach the negative saw. Routine (every say 4 production hours) inspections of the screw to check wear should be part of the daily operation.

(ii) The manufacturer of the screws should seriously consider re-engineering these parts to make it less costly to replace a full Negative Screw when only its extreme frontal area has been worn.

(iii) The Fluted Guide Tube or Change Guide Pipe as well as the Taper Bush should also undergo metallurgical modifications to give a better life when used on hard woods.

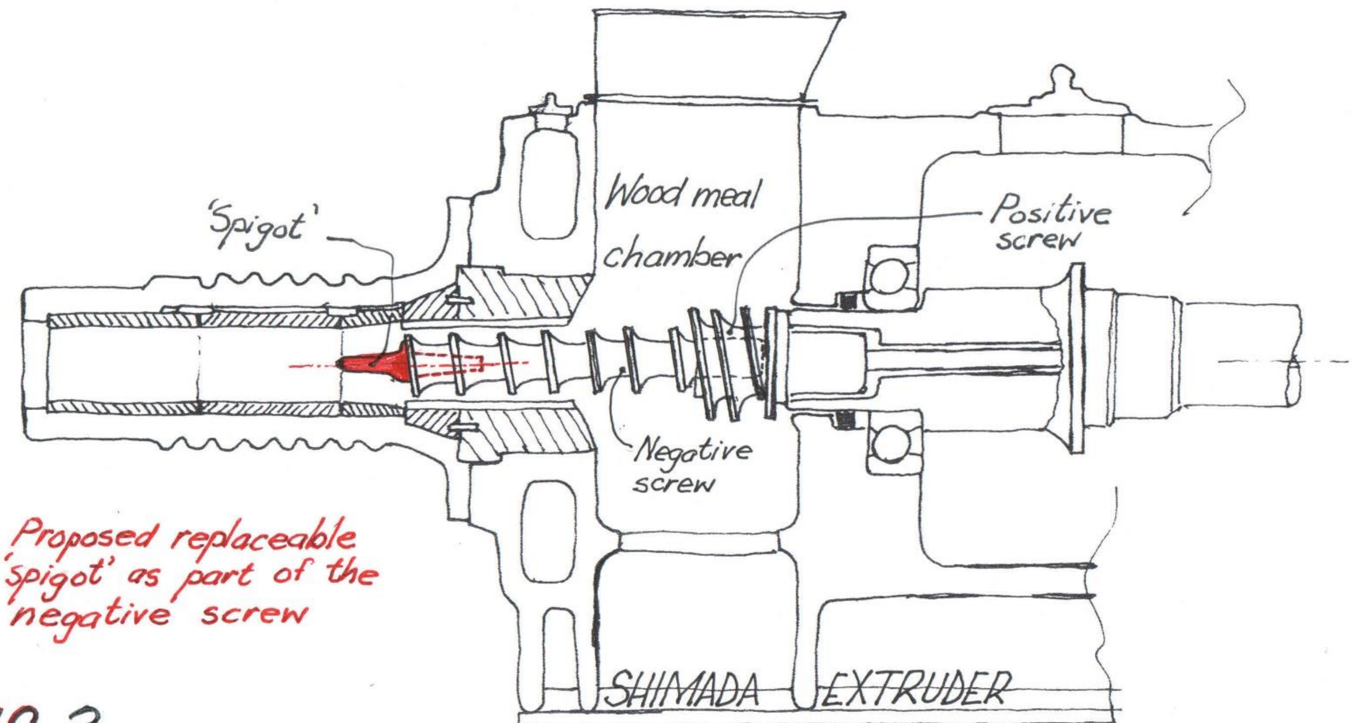


FIG. 3:

PROPOSED REPLACEABLE SPIGOT MODIFICATION

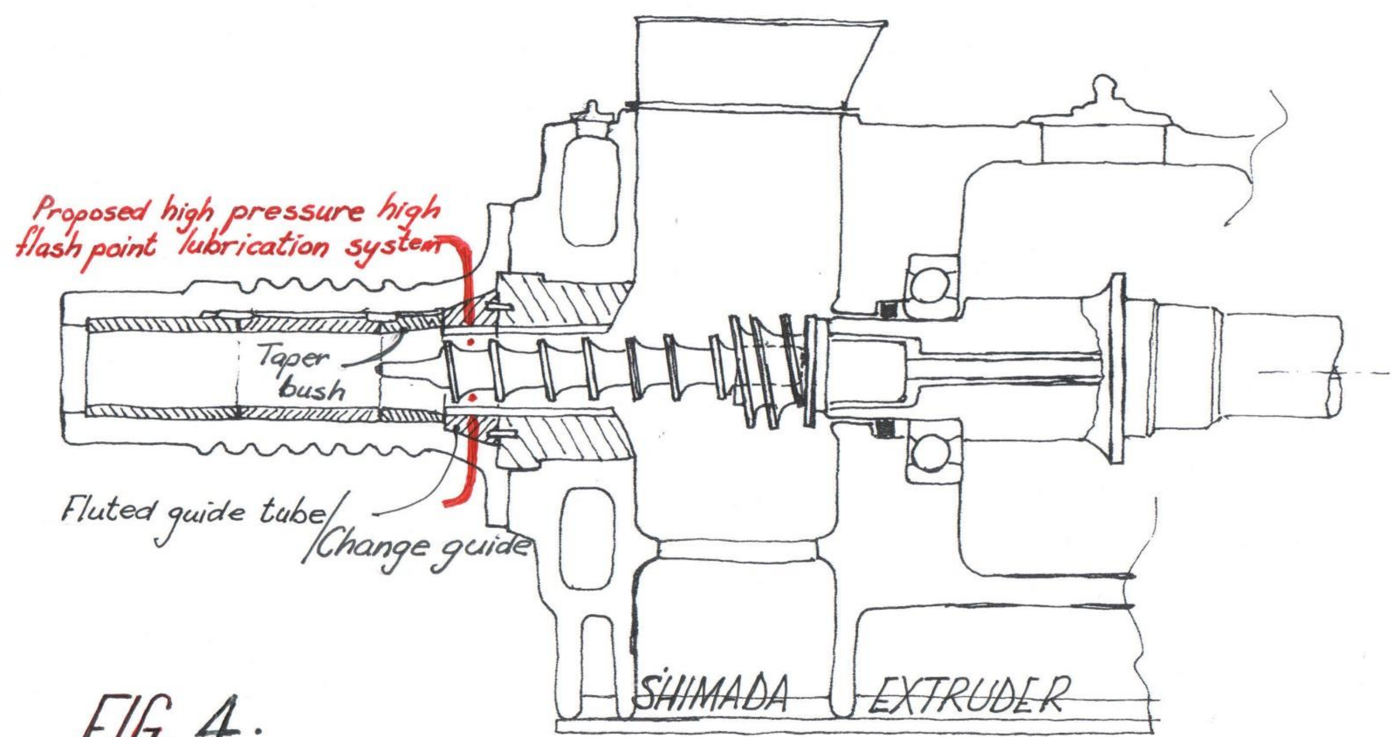


FIG. 4:

PROPOSED LUBRICATING MODIFICATION

7.7 Findings and conclusions

7.7.1 Findings of the CCF trials

The findings reached during the trials and experimentation at CCF, Otjiwarongo can be summarised as follows:

- Sickle bush when extruded on its own is using approximately 8% less energy per kg logs produced than mixed bush.
- Sickle bush when debarked uses approximately the same energy per kg logs produced, and would therefore have approximately the same abrasive effect on the wear parts of the extruder as Sickle bush with bark.
- The washed and dried infeed produces an extrudate which was more brittle, mainly because decomposition started to deteriorate the wood. It also appears as if the natural binding component(s) of the wood was washed out, causing the extruded log to break up during subsequent handling.
- In most of the cases when lubricant was applied, less kWh/kg log was consumed. Care should however be taken not to over-lubricate. In fact, lubricating the high wear points of the machine should not be seen as priority.
- In the case of pure Sickle bush mixed with ± 2% grape seed oil, the bloks were more brittle and would not withstand downstream handling well, with increased breakages and fines.
- The washed mixed bush with ± 2% grape seed oil was unacceptably brittle and can be regarded as too soft for further handling.
- In all cases the machines had an electrical power factor of less than 0.75, showing that factories paying for maximum demand and kVA would experience higher electricity bills unless the power factor caused by the large (37 kW) induction motor(s) of the extruders are addressed.
- Although the Shimada wear parts as well as on-site hardfacing thereof with special high metallurgical hardness hardfacing rods is costly, it does not really cause down time. The screw, taper bush and other wear parts can be changed in a few minutes on a cool machine. These parts can also be changed on a hot machine using welding gloves.
- It was found that the costs of wear parts and the cost of electricity were the two most outstanding operational cost components of the total production process, apart from the raw material itself.
- The production operation is straight forward and well organised and can be maintained for hours, stopping only for lunch and other planned occasions.

7.7.2 Conclusions

The following conclusions can be made:

- The Shimada Extruder, manufactured and serviced by New Air Technical Services Ltd, England can be regarded as a well-designed and highly productive machine, easy to operate and maintain.
- The Shimada Machines were selected and installed at CCF without many trials and pre-testing with specifically Namibian encroacher bush prior to its commissioning.
- To date, breakages were mainly blamed on residual sand and soil believed to be part of the infeed material, which appears not to be the case. Sand and soil contamination can be regarded as a relative small contributor to the high abrasion type wear experienced on the extruders at CCF.

- Hardfacing of the negative screw and its spigot should be done earlier on a scheduled (preventive) basis. A routine power coat hardfacing maintenance plan could reduce the costs for buying new screws significantly. In fact, it is believed by the Consultant that by using a rotational maintenance plan of three screws for hardfacing, could lead to virtually no further purchasing of new screws.
- The main cause of wear on these machines is the high density and hardness of Namibian encroacher bush and its high inherent silica content, which cannot be removed mechanically.
- The operating staff at CCF are well versed in the operation, maintenance and upkeep of these machines, although more care could be applied regarding the intervals to pull out and rebuilt the screws prior to the breaking off of the spigot, rendering the rest of the screw useless.
- The cost of energy required to extrude Bushbloks from chipped and hammer milled encroacher bush is high and the overall positioning, planning and layout of such a factory should not be underestimated.
- It can be concluded that although the hammer mill at CCF is equipped with a partially ineffective cyclone to remove dust from the infeed, residual sand and soil is not the major cause of the high wear experienced on the wear parts of the extruder. It is however important to extract the wood dust out of the factory area for occupational health and safety reasons.
- It was also determined recently, after all the energy consumption figures were analysed in detail, that more energy is required to extrude finer particles into a sound Bushblok. See **Figure 8** in Chapter 13**.** It is therefore essential for the dust removing cyclone to be effective. By removing all particles < 0.5 (wood particles + sand + dust) the electricity consumption would be better.

7.8 Recommendations pertaining to the CCF Bushblok Factory

The following recommendations can be made to improve the production costs at the CCF Bushblok factory:

- The professional team is of the opinion that the manufacturers of the Shimada Extruder can improve the design of the screw, and in particular the negative screw to improve its life between hardfacing runs by spitting it into a high wear frontal part and a low wear rear part where it fits into the positive screw. See § 7.9 for a concise proposal to improve this problem.
- *New Air Technical Services Ltd,* England should make itself available to test several tonnes of Namibian encroacher bush, once a number of modified 'pilot' screws are ready for testing at no cost to CCF. In fact, the Consultants believe that it would be in the best interest of *New Air Technical Services* to do the above research and development in order to improve their machine for more abrasive products like hard woods – commonly found in the more arid areas of the world.
- Residual sand and soil can easily and effectively be removed from harvested and chipped bush by means of double or triple deck vibratory screens, (See the next chapter as well as **Figure 8**, Chapter13, for further detail) but this is not seen as the major cause of the current wear problems experienced at CCF.
- Lubricating the high friction area of the extruder should not be regarded as a top priority.

- Because of the high fixed cost of the electricity supply to the industrial site of the CCF in Otjiwarongo and the long distance (± 40 km) for wood chips to be carted to the factory, the CCF is planning to move the factory closer to the biomass source at the Conservancy's campus. Power is generated at the campus with diesel generating sets and this capacity will have to be considerably enlarged. It is strongly recommended that the CCF should consider to replace the planned enlarged diesel powered operation with an *Organic Rankine Cycle [ORC]* fired on biomass. The systems are available in mobile (containerized) packages as small as 350 kVA and could fit the total de-bushing and savannah restoration vision of the CCF like a glove, but a separate feasibility study would be required.

7.9 Solution to reduce costs of wear parts of the Shimada machine

A thorough analysis of the inside workings of the Shimada Extruder reveals that the highest wear occurs where the *Negative Screw* rotates within the Change Guide Pipe (See **Figure 2** and **Figure 3**). As soon as this frontal part of the Negative Screw and the Change Guide Pipe or Fluted Guide Tube is slightly worn, the Spigot (extreme front end of the Negative Screw) starts to wonder around the centre line and eventually breaks off due to metal fatigue, rendering the entire and costly Negative Screw useless and irreparable.

It would be relatively simple engineering to significantly enlarge (both in diameter and length) of the Positive Screw, operating in the low pressure zone and wood meal chamber (**Figure 3**) of the extruder. This would shorten the length and significantly increase the stability (sturdiness) of a much shorter Negative Screw without impacting on the efficiency of the machine.

A removable and replaceable 'Spigot' (See **Figure 3**) would further improve the design and subsequent reparability of these costly wear parts.

A rough estimate made by the Consultants indicates that replacement and repair costs of this high wear area of the machine could be reduced between 50% and 75% if the above modifications can be implemented. A detailed proposal was send to New Air Shimada in England for comments.

In a telephonic reply, Mr Pat Roddy [MD of New Air Shimada] explained that the above modifications are available from his factory, although the manufacturing costs thereof is about the same as the parts currently used by CCF.

The best way forward for CCF over the short term would be to consider the following:

(i) Identify an engineering shop in Namibia or South Africa to *hardface power coat* the above parts with a super hard tungsten carbide layer. These parts need to be removed and repaired (hardfaced) on a pro-active basis long before the base of the spigot-area has started to wear down.
(ii) Find an engineering shop in South Africa (Several shops in the Western Cape are capable to perform such tasks) to manufacture and hardface these components at a much lower cost than the imported parts, and at an equal foreign exchange rate.
(iii) Improve and upgrade the dust extraction cyclone system at the hammer mill to ensure removal of all particles < 0.5 mm, whether these micro particles are wood dust or soil dust, it will not only improve the energy required at the Shimada it would also remove more of the abrasive sand particles.

8. QUANTIFYING AND MANAGING SAND AND MINERAL CONTENT

8.1 Introduction

Harvested encroacher bush is often contaminated with sand and soil during the harvesting and post-harvesting operations. It is also known that sand particles can be entrapped in the bark of some of the encroacher bush species, especially in Sickle bush bark. A further phenomenon is termites building their nests with soil and clay in and around tree trunks and the lower branches of the tree or bush. See Photograph 20 below. Felled bush material attracts ants and termites to assist with the natural decomposing process.

Photograph 20: Termite nests

8.2 Residual and imbedded sand versus inherent silica

In shot:

- **Residual sand:** Lose sand as part of the soil contaminated harvested biomass. Can be removed mechanically with screens and or air knives.
- **Imbedded sand:** Sand granules entrapped in the bark of some tree species. Can be removed mechanically by expensive debarking methods.
- **Inherent silica:** Part of the chemical composition of wood and cannot be removed mechanically.

Apart from the fact that most (almost all) Namibian encroacher bush species can be regarded as hardwoods (wood with a high density, often with a dark core and of a high Janka hardness), it also has a high ash content. From the samples taken for analysis it can be seen that a total ash content of between 3.6% and 5.7% was measured (Table 5). The sand, mostly consisting of silica (S_iO_2) and minerals, forms part of the ash content. Most of this silica (S_iO_2) is however entrapped in the bark of the bush species and cannot successfully be removed mechanically, unless the harvested branches are debarked. [Debarked Sickle bush samples formed part of the trials conducted by the

Consultant at CCF to investigate this phenomenon, but the results (surprisingly) indicated no real (measurable) gain was achieved by the expensive debarking exercise].

Residual or lose sand, soil and dust can be removed from chipped bush and various mechanical systems can be used for this purpose.

Samples taken by the Consultant at a representative number of harvesting sites and at places where chipped encroacher bush has been stockpiled, indicated that the percentage of lose sand and dust present in the feedstock is generally less than 0.5% by dry mass of the total sample.

Inherent silica (S_iO_2) and mineral content of the woods sampled, cannot be successfully removed through mechanical means, and can only be separated from wood chemically. It forms part of the overall chemical composition of the wood. It can therefore be concluded that imbedded sand cannot be removed from wood chips or wood meal without completely changing the chemical composition of the wood. Residual sand and dust can however be reduced mechanically by shaking, screening, air knives, washing, cyclones, debarking, etc.

8.3 Residual sand and dust removal systems

The following residual sand and dust removal systems exist to pre-clean wood feedstock:

8.3.1 Vibratory screens

Sand and dust can be removed relatively effectively from wood chips by using single or multi deck vibratory screens. The wood chips are conveyed to the top of a single or multi deck vibratory screen usually powered by a motor fitted with an adjustable excentric flywheel to generate the vibration of the deck suspended on a set of springs. See **Figure 5** for a typical example of such a screening device.

By using more than one screen, starting from the coarser screen on top, the screening load per fraction is reduced to improve the screening efficiency of the system. The sand and finer fraction can be used as a valuable soil conditioner.

8.3.2 Washing plant

Washing systems, using water to wash off the sand and dust from wood chips are not recommended in water scarce Namibia. A further reason is the fact that water will wet the stockpile of cleaned wood chips, triggering the fermentation process unless the feedstock is effectively dried before decomposition starts to take place. During the trials at CCF's Bushblok factory, two water washed samples were tested and both showed notable signs of degrading. In fact, the bushblok product was brittle, as if the binding qualities of the wood had been washed out.

8.3.3 Cyclones

Figure 6 shows a simple form of cyclone for the removal of unwanted fines. In the case of the positive pressure (blower type) cyclone, a rotary motion is given to the airstream carrying the sand and dust particles which causes the heavier particles to travel to the outside radius of the cyclone and to pass down in a spiral motion to the dust collector at the bottom. The rotation may be caused by a tangential entry into the cyclone or by axially mounted swirl blades. The efficiency of the cyclone is not constant and varies with the size, density and shape of the dust particles.

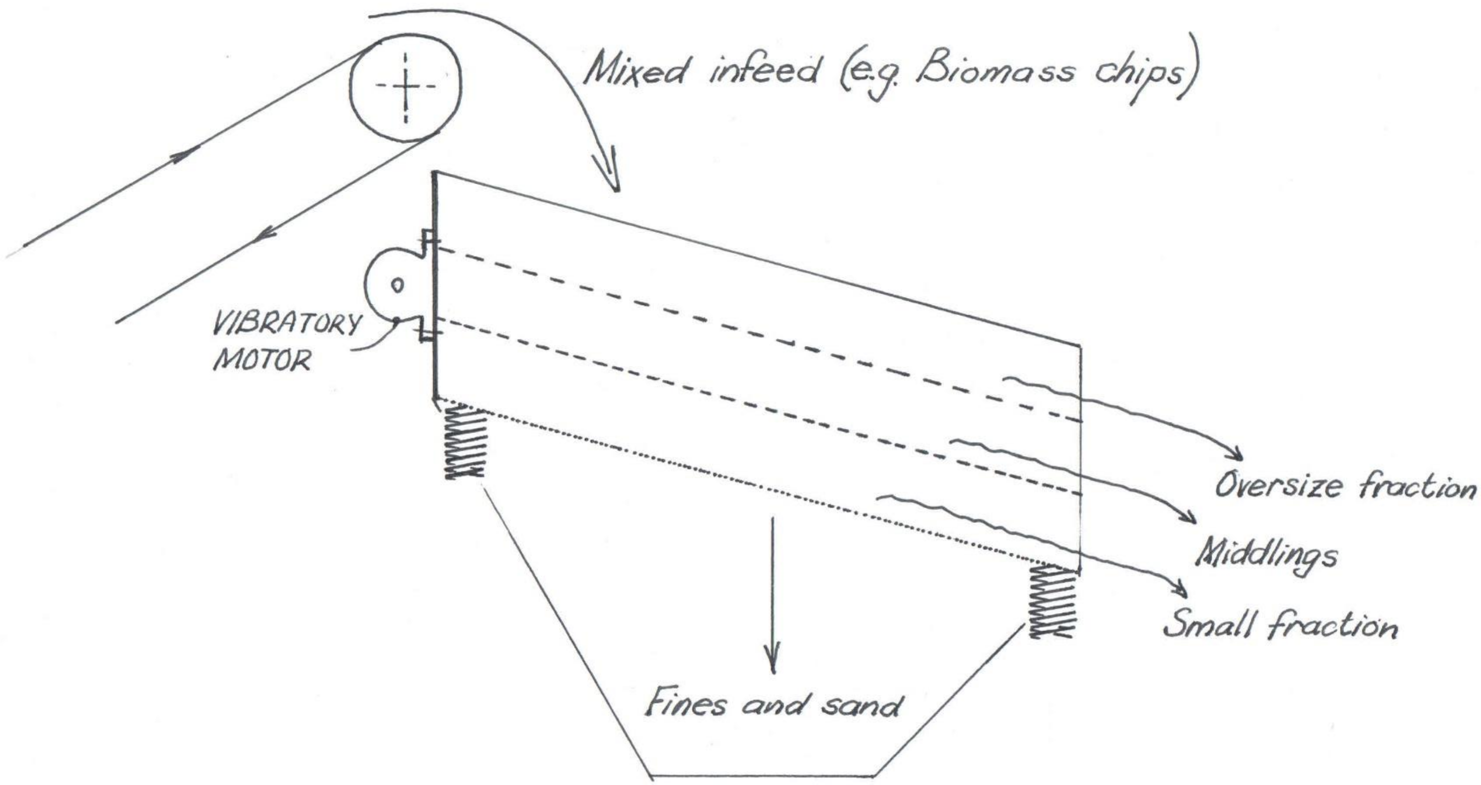


FIG. 5: MULTI-DECK VIBRATORY SCREEN (for sand removal)

8.3.4 Air knives

High pressure air knives are often used to blow away dust or drive off residual water from products. Its however important to note that the material conveyed on the perforated conveyor belt should be heavier than the particles to be removed. See **Figure 7** for a self-explanatory sketch of an air-knife cleaning system.

Air is blown into the air box (1.2 to 1.3 bar) from where it is squeezed through narrow openings just above the product on the perforated conveyor belt. The biomass chips are then agitated and sand particles are blown through the perforations into the dust collector chute underneath the product infeed conveyor.

8.3.5 Debarking

Many commercial wood chipping operations, mainly found in the high volume paper and pulp industries are using high pressure water or other mechanical means to debark and pre-clean tree trunks and large logs specially grown for a specific target market. Although the main reason for this is to get better consistency in the core wood product, it contributes to obtaining longer life from the high speed high volume chippers and shredders used to produce wood chips for further downstream processing.

In most cases in the sawmill and timber industry, debarking is also done prior to the logs entering the sawmill itself where planks are cut. Relative high percentages of sand and soil is entrapped in especially pinewood bark, which need to be removed prior to the precision cutting operations.

None of the Namibian compressed wood operations and none of the encroacher bush species would economically lend itself to a pre-process debarking operation. The reason why a small sample (less than 500 kg) of Sickle bush was debarked for the CCF trials, was to obtain a truly residual sand and dust free sample in order to compare it with its run-of-the-mill equivalent.

8.3.6 Air classifier

A comprehensive air classifier system was proposed by the manufacturers of the Shimada. A full description of this and rotary brush screen device can be found as part of **Annexure G.**

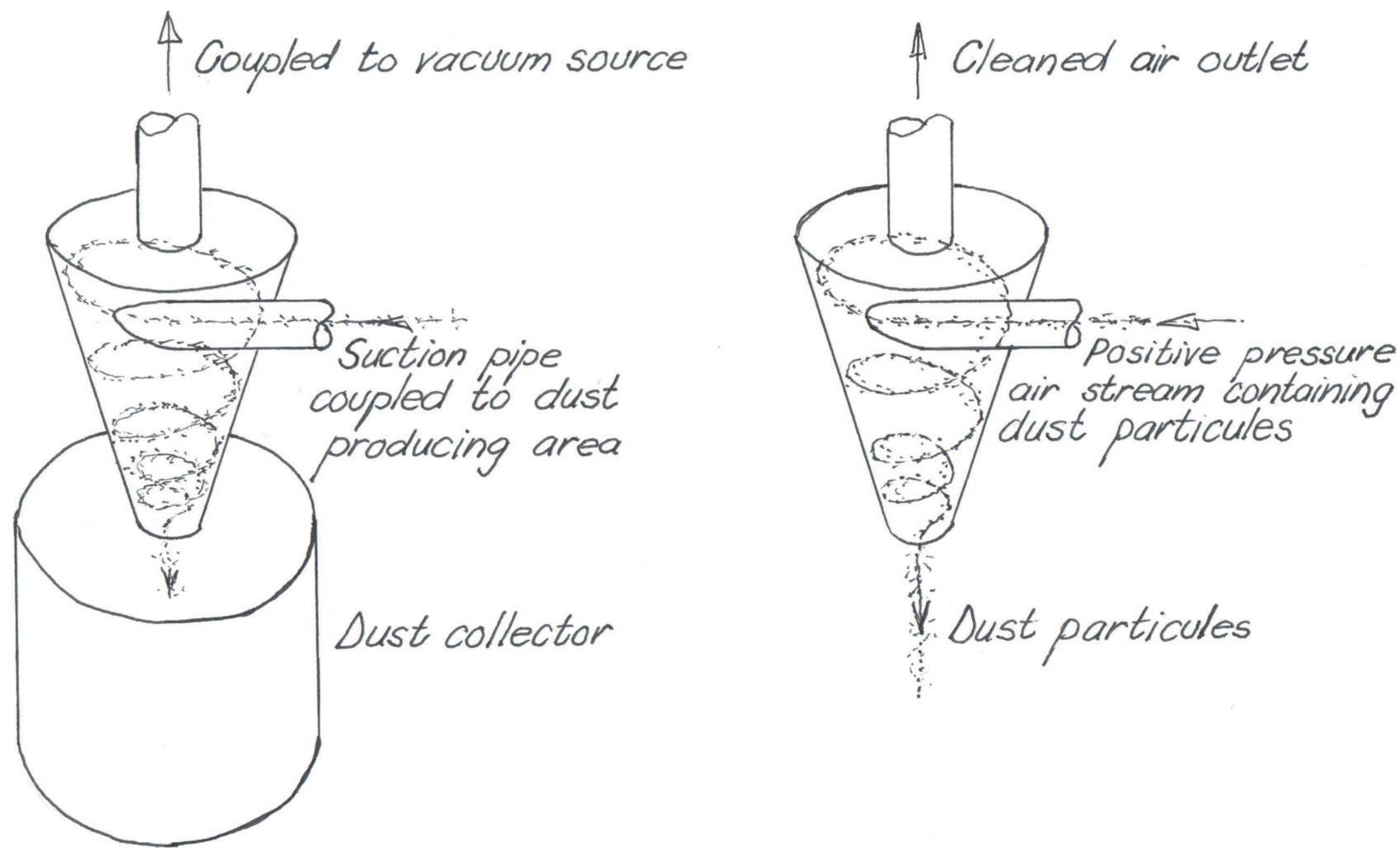


FIG. 6: CYCLONE SEPARATION (for dust removal)

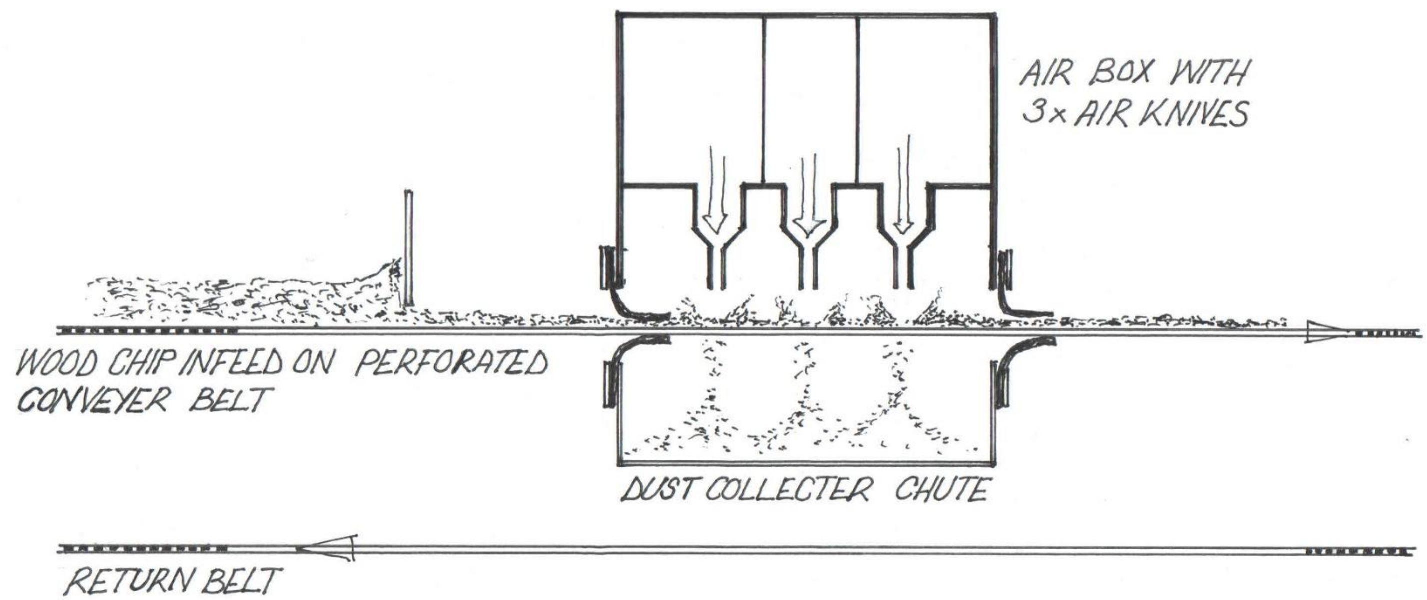


FIG. 7: TYPICAL AIR KNIVE SYSTEM

9. ADDRESSING THE SAND ISSUE

8.4 How to sustainably reduce sand/soil from harvested bush

The more sensitive (to abrasive wear) downstream bush processing operations (excluding animal feed from bush, which will be handled separately) include:

- Chippers
- Hammer mills
- Dry or white wood pelletisers
- Bush log extruders
- Cubers

The value chain for the above operations starts with bush felling, followed by chipping of the bush into flakes. See photographs below, showing that various settings and chipping tool arrangements can produce various shapes and screening envelopes of wood chips. The chipper machine is the first operation of the value chain towards reducing the bush branches and often whole bushes are reduced into a transportable chipped format as shown in Photographs 21 - 24. The bulk density of dry wood chips ranges from approximately 200 kg/m^3 to nearly 250 kg/m^3 for denser bush species when chipped quit fine. Some bush species chip better when wet. A blade-type chipper is then used. Blades need to be sharpened every 3 to 4 production hours or even more frequently when the bush is contaminated with dust or during the dryer winter months.

Although not all of the chipping companies would agree, surveys conducted by the Consultant between late 2014 and Sept 2015 when compiling the GIZ Compendium on harvesting techniques in Namibia found that the best wear and production results were obtained when dry chipping (grinding) of denser bush types were conducted. By installing the dry wood grinder/impact type cutting tools onto larger type grinder/chippers proofed to give the best chipping costs per tonne. Impact type cutters of dry wood (< 12% moisture content) also displayed a better useable production life than its wet chipping type counterparts.

Photographs 21 & 22: Wood chips

Photograph 23 & 24: Wood chips and fibre

Sand and soil contamination in dry encroacher bush chips can easily and quite effectively be removed by using double or triple deck vibratory screens. These screens are relatively inexpensive and can be ordered from a host of suppliers in Namibia, South Africa and Botswana. Vibratory screens are an essential component in the mining and materials handling industries and are readily available. Screen deck apertures can be ordered and changed to suit the application.

The screened-out fines and sand can be returned to the harvesting area or can be used as a soil conditioner, since it would contain small wood particles which would decompose to carbon.

Generally, the so-called *oversize fraction* is re-chipped or grinded down to a smaller size to reduce the load on the downstream hammer milling operation. Also refer to **Figure 5:** Multi deck vibratory screen.

9.2 Effectiveness of screens

The above screening equipment can be engineered and selected to be highly effective and could remove virtually all of the residual (lose) sand and soil contamination. A dry screening process is recommended for Namibia. In cases of severe contamination, the implementation of air-knives could form part of the overall pre-cleaning action. See **Figure 7**.

Some bush, like Purple-pot Terminalia (Terminalia prunioides), has a bark type that generates a wool-like fluff when dry chipping or grinding is done. This fluff is very light and tends to blind the top deck of the vibratory screen, causing most of the infeed to be classed as oversize. The fluff can be separated from the heavier particles in several ways including cycloning. A slight variation to the cyclones drawn in **Figure 6** is however needed for this purpose.

9.3 Processes available to reduce silica and minerals

Several dry pre-cleaning processes are available to reduce *residual* or lose sand and soil contamination from harvested encroacher bush chips, as discussed and illustrated earlier. The reduction of inherent silica and other minerals from the biomass infeed is however not possible by means of mechanical systems like screens, air classifiers, air knives and or cyclones. These minerals are an inherent characteristic of Namibian hard woods/encroacher bush and can be chemically identified as mostly S_iO_2 (silica), amongst other minerals as part of the ash content of the wood.

9.4 Is the high sand/silica content a man-made phenomenon in Namibia?

The Consultants are of the opinion that most of the 'man-made' sand and soil contamination found in harvested Namibian encroacher bush can easily be removed from dry chipped biomass by using vibratory screens. The effect of the man-made sand and soil contamination was however not found to be the main cause of downstream machine wear in the extruder tested at CCF's Bushblok factory in Otjiwarongo.

By far the biggest cause of wear came from the natural high silica content and high density (hardness) of the biomass tested through CCF's Shimada extruders.

9.5 Using less sensitive compacting machines

The next chapter will compare four compacting techniques with one another. The *cubing* machine or *cuber* could proof to be less sensitive to contamination because it was originally designed to cube alfalfa straw directly picked from the harvesting fields by means of a mechanical gatherer.

The cuber would definitely be the best machine to produce animal feed from green bush when larger cubed animal feed cakes for larger animal units are required. See § 6.3 for more detail on the cuber.

9.6 Cubed boiler fuel

Although not yet tested in Southern Africa, the Consultant believe that the cuber can be adjusted and modified to produce boiler fuel from Namibian encroacher bush and would be able to compete with low grade fossil coal in terms of cost per energy unit [N$/GJ], delivered to Windhoek.

In fact, the Consultant is confident that *Cuber Compacting Technology* would become the preferred future option in Namibia for boiler fuels.

10. COMPARISON OF FOUR COMPRESSED WOOD TECHNOLOGIES

10.1 Introduction

The four technologies referred to in this chapter, which can be considered for compacting/ compressing Namibian biomass meal, were originally designed to compact animal fodder and to manufacture compressed animal feeds. Agricultural wastes such as rice, soya, peanut and other husks, maize, maize bran, dried brewers' grain, hay, alfalfa, etc., have been compressed into cubes and pellets, or being extruded by means of screw or piston type extruders for decades. Later on, the design of the feed equipment was adjusted to accommodate wood wastes like planer shavings, sander and saw dust. Further developments followed to serve the need for co-firing coal fired boilers with biomass, but limited success was achieved with high density wood types.

Denser, heavier and harder wood types, like most of the Namibian encroacher bush species, would require higher energy inputs to process and would result in a higher wear impact on compacting equipment than most of the animal feeds. The Consultant found that the wear patterns observed on the Shimada extruder screw used at CCF, displayed a similar wear tempo to that of rice husks, which is also high in silica content. This observation was confirmed by Mr Pat Roddy, MD of New Air Shimada, Leicester, England, the manufacturer of the Shimada extruder. It is therefore important to note that although some progress has been made to cater for harder, denser and thus more abrasive infeeds like denser wood meal, care should be taken to allow for a much higher wear tempo than when the infeed consists of softer animal feed components.

10.2 Reasons for compacting wood meal

Several reasons exist for compacting/compressing or pelletising wood meal particles into the products as described in this chapter. *The primary reasons are*:

- To produce a final product with a higher ***energy density*.** Energy density is normally expressed in MJ/m^3 and is calculated by multiplying the heating value in MJ/kg with the bulk density of the solid fuel expressed in kg/m^3 – The more energy (Joules) that can be transported or stored per cubic meter, the better.
- To make the final product more **shelf-stable**. Most compacting processes produce heat, which has a pasteurizing effect on the product. Most countries accept the compacting processes described in this chapter as equivalent to fumigation to kill off any unwanted bugs or plant deceases.
- Compacted wood products can be stacked more densily in trucks and containers than their natural equivalents, making the handling thereof easier and more economical.
- It is often required by high volume users of the compacted biomass product to be augered into boilers. They would therefore prefer a pelletised or cubed product which can be fed mechanically and will not create fines when handled and will not jam mechanical infeed systems.
- Lower volume clients, like the bushblok retailers, can cope with the handling of the uniform larger log types which are normally stacked on barbeque and fireplace fires by hand.

10.3 Brief description of each technology type

Four compressed wood meal technologies were investigated for the thermal market segment:

(i) Screw type extruders to produce compressed wood logs.
(ii) Piston type extruders to produce logs.
(iii) Cam wheel type cubers to produce bricklike 'cubes'.
(iv) Roller and die type pelletisers to produce small cylindrical granules or pellets.

All four of the above wood meal compactors/extruders/pelletisers rely on the binding of small wood particles (<4mm in length) under high pressure and, in the case of the log extruders, also under relative high temperatures (160°C to 200°C).

10.3.1 Screw type extruders

Dry (± 8% moisture content) biomass meal is fed through an intake hopper into the screw chamber. The screw, much like a meat mincer, compresses the wood meal through a fluted guide tube and into a heated barrel, set at between 160°C and 200°C, to compress and bind the wood particles into a continuous log. The extruded log is then cut to the desired length for packaging. See **Annexure C** for a photo display of this technique as used by CCF in Otjiwarongo.

The target market for these logs generally is the household barbeque, wood fired stove and domestic warming fireplace. See Photographs 25 & 26 below showing two samples of logs extruded by means of a screw type press from grape seed and mixed encroacher bush respectively.

Trails on the Shimada Extruder of the CCF were carried out by the Consultant to analyse its wear patterns and energy consumption – See Chapter 7 for more detail in this regard. These trials can be regarded as providing a benchmark against which the other three compression technologies can be compared.

Photographs 25 & 26: Bushblok extrudate and logs from grapeseed

10.3.2 Piston or cam type extruder or briquetting press

The best known briquetting presses are manufactured by C.F.Nielsen in Denmark. A pamphlet of one of their models is displayed on the next page.

A piston or cam action is used to ram the wood meal under high pressure through the single barrel die. See photograph 27 below for images of the final product.

Photograph 27: Log type briquettes produced by a CFNielsen press

Because of the cam and/or piston ramming action used by the above presses fewer wear surfaces are exposed to the wood meal. This should be an advantage over the screw type extruders in terms of wear maintenance costs. Unfortunately, despite several attempts, it was not possible to physically compare the extruder (Shimada) technology with that of a similar output Piston Press (CFNielsen). Tests were carried out by CFNielsen and WoodCo of Namibia, but none of the results could be made available to the Consultant. The information contained in Table 10 of this chapter is therefore based on theoretical assumptions and deductions made by the Consultant product from brochures and correspondence with CFNielsen.

BRIQUETTING PRESS

NEW DESIGN
NEW MODEL

TECHNICAL SPECIFICATIONS

TYPE	BP 2000	BP 3000	BP 4000	BP 5000
Diameter of briquette	50 mm	60 mm	60 mm	75 mm
Capacity, dependent upon raw materiel	175 kg/h	500 kg/h	800 kg/h	1300 kg/h
Power of main motor...........	15 kW	18,5 kW	30 kW	37 kW
Weight	1260 kg	1500 kg	3215 kg	3660 kg
Number of flywheel	1	1	1	2
Humidity of material	6-16 %	6-16 %	6-16 %	6-16 %
Central lubrication system	x	x	x	x

Subject to manufacturing alterations and misprint

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10.3.3 Cubers

The photographs below illustrate the cubes produced by a *Cuber.* Although the cubes in the photographs were made of alfalfa and wheat straw, it illustrates the compacted shape of the final product. John Deer and the company Warren & Baerg (USA) originally designed the cuber after World War II, to make animal feed for larger animal units (dairy cows and horses). They soon realised that several other raw materials can also be compacted into cubes ranging from 25 x 25 mm to 38 x 38 mm cross sectional area. Selected solid waste such as paper, cardboard, carton, low density plastics and shredded jute are cubed in several cities in the United States as *Refuse Derived Fuel [RDF],* mainly for use in boilers and industrial heating systems.

Photograph 28: Cubes of wheat & alfalfa straw

Cubers cannot compact the raw material infeed to the same level of compaction hardness as e.g. pelletisers and some extruders (without using binders), but can deliver sufficient levels of cube structural integrity at high throughput tempos to manufacture boiler fuel. A single 37 kW Warren & Baerg Cuber can produce at an output tempo of > 5 000 kg/h compared to a Model BP5000 CFNielsen Press (37 kW) at 1 300 kg/h and a Shimada Extruder Model SPMM850 (37 kW) with 65 mm dia die at 500 kg/h, which impacts dramatically on the cost of energy per unit of production.

The next set of photographs clearly shows how the John Deer/Warren & Baerg cuber works. The raw material is fed into an auger chamber which convey the coarse biomass material (no pre-hammer mill action required) to the eccentric press wheel which runs in a groove at the base of each of the 66 replaceable radial dies. As the press wheel rotates, it forces the biomass into the square slots of each of the 66 dies around the circumference of the die ring and frontal wear plate. To replace the dies (for hardfacing of the square die slots during maintenance cycles) the die-ring is removed. The design of the cuber caters for regular and relative simple overhauling (hardfacing) of the wear surfaces, which is a regular occurrence for the harder infeed materials (other than soft animal feed components.)

Photograph 29 & 30: A cuber with its front -end wear plate removed

Photograph 31: Removable cuber die and animal feed cubes

The above photographs illustrate the working principal of the cuber, using alfalfa straw. Several cuber operations in the United States compact wood waste into boiler fuel cubes and the Consultant is confident that it should succeed (with a few minor modifications) in compacting small chips (<8 mm) of Namibian encroacher bush into useable boiler fuel.

The design of the cuber is such that its wear parts can be serviced and hardfaced by local engineering shops and, in the case of a high volume plant using a number of cubers, the necessary in-house infrastructure and specialist boiler maker/fitter/welder can be acquired and trained to maintain the machine.

Although the above cuber-technology may not reach the same compaction hardness in its final product (comparable to the extruders or pelletisers) it would certainly compete well in terms of production energy per unit and the maintenance/replacement costs of wear parts and would outperform its competition terms of production tempo. A further, and perhaps the most important advantage of the cuber over its nearest rival, the cylindrical die pelletiser, is that the cuber has a replaceable die segment per slotted hole as opposed to the multi-hole concept of the pelletiser. A disadvantage of the cuber is that its final product (a compacted cube of say 30 x 30 x 30 mm is much larger than a large cylindrical pellet of say 16 mm dia x 20 mm long. Pellets as small as 6 mm dia x 8 mm long can be produced by a pelletiser, giving it a better bulk and energy density than that of a cuber.

10.3.4 Pelletisers

A wide range of industrial pelletisers, capable of compacting 'soft' biomass into pellets are commercially available. Pellets as small as 6 mm diameter can be produced in fair volumes of up to 900 kg per hour by a 37 kW pelletiser. See photograph 32 below.

Photograph 32: White wood pellets ready to be used in a central heating system (Courtesy Italcotto)

See **Annexure B,** Photographs 6 & 7 of Mr Larry Bussy's animal feed pelletiser and observe the configuration of rollers pressing the biomass radially through holes in the cylindrical die. An adjustable knife cuts the pellets off at a pre-set distance from the outer circumference of the die. Once the holes in the die are worn out a costly rebuilding and re-drilling overhaul of the die takes place which can only be performed by specialist engineering machine shops. Most of the dies of smaller pelletisers (< 37 kW) are scrapped and replaced, because of the high cost of repairs.

There are many animal feed pelletiser manufacturers in the world. In Southern Africa two well-known manufacturers of pelletisers are found:

- Rumax, 1 Samuel Walters Street, Worcester (+27 23 342 6070)
- Drotsky, 33 Barium Street, Alrode, Alberton, Johannesburg (+27 11 908 2056)

Agencies and representatives of several international companies are present in Namibia.

Lately, the Chinese manufacturer; Zhengchang, represented by GRAMEC (Mr Torb Ellefsen gramec@gramec.com) Johannesburg, are making inroads into the African animal feed market with their affordable pelletisers and cubers.

Kahl, Germany, supplied the industrial (> 10 tph) horizontal pelletiser to EC Biomass, Port Elizabeth. Kahl is one of the leading large (> 500 kW) biomass pelletiser manufacturers in the world, but they would be the first to advise against trying to pelletise high silica content infeed and high density wood species like the Namibian encroacher bush types. Despite the fact that the pelletising technique could supply the highest final product structural integrity and best bulk density it can simply not pelletise denser wood types economically. Pelletisers can only be used on softer wood types like pine, when debarked or clean saw dust, to produce 'white wood' pellets.

10.4 Comparison analysis between four compressed wood technologies

Table 10 gives an overview of the four best known compressed wood technologies. From Table 10 it follows that both the Shimada type extruder and the CFNielsen type piston press can be used for woody biomass to manufacture a log-type extrudate for the domestic barbeque and heating markets. Great care is however required to maintain the wear (hardfacing) surfaces of its compacting components and to ensure a clean uncontaminated infeed. A much higher wear rate will be experienced on these machines with the high density (high silica content) Namibian encroacher wood species than for instance the softer white woods of Europe.

To *pelletise* any of the Namibian encroacher bush species would not be sustainable. The wear rate of the holes in the die would simply be too high. This technology cannot be recommended for Namibia.

Probably the best, but still untested, scenario for compacting Namibian encroacher bush types into boiler fuel, is the cuber technology. Tests and trials in this regard are recommended, although the only cuber which the Consultant could track down was found in the Western Cape producing alfalfa cubes for horses. This cuber could be made available for testing of other substances, but would require ample notice and an agreement to cover costs.

TABLE 10: COMPARISON ANALYSIS BETWEEN FOUR COMPRESSED WOOD TECHNOLOGIES FOR THE THERMAL MARKET

Description of items to be compared per technology	Extruders (Screw type)	Extruders (piston or cam type)	Cubers	Pelletisers
Best known manufacturers	Shimada by New Air Technical Services, UK	C.F.Nielsen, Denmark	• John Deere, USA • Warren & Baerg, USA • Zhengchang, China (SA Agent: Cramec, Johannesburg)	• Kahl, Germany • Drotsky, SA • Rumax, SA
Machines originally designed for	• Agricultural waste; like maize bran, rice husks, grape seed • Saw mill wood wastes; like shavings, saw dust (pre-cleaned)	• Saw mill and timber soft wood wastes; shavings, sander dust and saw dust (pre-cleaned) • Chipped and hammer milled wood	• Animal feeds from alfalfa hay, wheat straw, soya cake • Solid wastes; like mixed paper, cardboard, paper sludge, plastic • Planer shavings, sander dust	• Animal feeds from mixes including maize, bran, soya meal, straw, etc. • Selected and pre-cleaned soft wood wastes
Typical final product when targeting the thermal market	'Bushbloks', 'EcoLogs', and compressed wood meal from encroacher bush, targeting the barbeque and domestic heating markets	Logs mainly for the barbeque and domestic heating market	• Boiler fuel cubes for steam and power generation • Furnace fuel cubes for large industrial dryers and heaters	• Boiler fuel • Domestic heating and central heating systems
Typical shapes and sizes of the most popular final product aimed at the thermal market	Log shaped, 55 or 65 mm dia logs with 4 flat sides x typically 200 mm long and with a 16 mm dia hole through the middle of the log for better combustion	Log shaped, 50 to 80 mm dia x 10 to 200 mm long. Can also produce a log with flat sides and a hole through the middle	• Brick shaped with a range of cross sectional dimensions from 25 x 25 mm to 32 x 32 mm. Length of the cube/brick can be adjusted to fit the application • Typical boiler feed dimensions 25 x 25 x 30 mm	Cylindrical pellets or granules, typically 8 mm to 18 mm dia x 12 to 20 mm long. The length of the pellet can be adjusted to suit the application • Typical boiler feed dimensions: 16 mm dia x 20 mm long
Energy consumption when producing at full load, manufacturing its most popular shaped biofuel from pinewood shavings [kWh/t]	50 to 70	45 to 55	35 to 45	70 to 80
Estimated **Bulk Density** when optimally stacked, based on pinewood infeed [kg/m^3]	960 to 1 000 or 0.98 t/m^3 (average)	850 to 950 or 0.90 t/m^3 (average)	600 to 700 or 0.65 t/m^3 (average)	1 000 to 1 100 or 1.05 t/m^3 (average)
Approximate **Energy Density** of an optimally stacked final product sample from pine-wood @ 13 GJ/t heat value	13 GJ/t x 0.98 t/m^3 = 12.74 GJ/m^3	13 GJ/t x 0.90 t/m^3 = 11.70 GJ/m^3	13 GJ/t x 0.65 t/m^3 = 8.45 GJ/m^3	13 GJ/t x 1.05 t/m^3 = 13.65 GJ/m^3

TABLE 10 (CONTINUED): COMPARISON ANALYSIS BETWEEN FOUR COMPRESSED WOOD TECHNOLOGIES FOR THE THERMAL MARKET

Description of items to be compared per technology	Extruders (Screw type)	Extruders (piston or cam type)	Cubers	Pelletisers
Integrity of final product of pine shavings against crumbling and forming fines	High	Medium	Medium to low	High
Wear rate of critical compacting components using high density and high silica content infeed (e.g. rice husks)	High	Medium to high	Low to medium	High
Estimated cost to perform a hardfacing overhaul on worn surfaces of a typical 37 kW machine	N$ 8 000	N$ 6 600	N$ 60 000	N$ 75 000
Time between hardfacing overhauls, measured in average production hours	40 h	80 h	250 h	80 h
Average estimated production in tonnes achieved between hardfacing overhauls with pine biomass infeed	20 t	25 t	500 t	40 t
Approximate hardfacing costs per tonne on a 37 kW machine using rice hush as infeed	N$ 400/t	N$ 264/t	N$ 120/t	N$ 1 875/t
Throughput performance on softer woods like pine shavings	Good	Good	Excellent	Reasonable
Rating as production machine for the compacted biofuel thermal market segment using clean high density Namibian encroacher bush meal as infeed	Reasonable	Reasonable	Good	Poor

11. CONCEPT NOTE TO DEVELOP EXPORT MARKETS IN EUROPE FOR NAMIBIAN WOOD FUELS (by Dr Louis de Lange)

11.1 Background

The recovery of grazing and agricultural land resulting from by the removal of encroacher bush is an important socioeconomic priority in Namibia. Such a strategy can only be sustainable if the economic value of the harvested encroacher bush is fully realised. Also, the recovery of the land must be done in a coordinated and systematic way which will only happen if the outputs of harvesting [supply] can be channelled to large and growing centres of demand. The largest economic potential of the wood from the encroacher bush is to use it as a fuel for the generation of heat and electricity. Currently the products derived from the encroacher bush include:

- Firewood logs of uniform size cut from the thicker branches of encroacher bush.
- Charcoal made from a wider spectrum of encroacher bush branches
- Briquettes made from charcoal fines
- Compressing or extruding waste wood meal into uniformly sized products, namely:
    - Bush Logs, also known as ‘EcoLogs’ or ‘Bushbloks’
    - Pellets (still at an experimental stage)

The current markets for these products are the domestic markets in Namibia and exports, mainly into South Africa. In the case of charcoal and briquettes, markets have been developed in selected European countries. These products are used in the domestic and small commercial market segments.

Chipped wood from encroacher bush is also a potential fuel, but its use is constrained by the cost of transporting a product with low average bulk density of less than 230 kg/m^3. The full value of this product can only be realised when Namibia embarks on a strategy of small scale electricity generation using decentralised wood-fired power plants of 5 to 25 MW_e per site.

To achieve its de-bushing goals, Namibia will have to embark on the development of export markets for its manufactured wood fuel products. On the one hand the challenge is to develop these markets [the demand side] but, on the other hand, an equally important challenge is to develop the capacity to provide sustainable and consistent delivery of these products into these markets [the supply side]. This *Concept Note* aims to highlight certain actions which have to be considered during such a process.

11.2 Introduction

Importation of wood fuels into the EU and other European countries is subject to various conditions as embodied in regulations and specifications. These conditions are a result of the fact that there is an established wood fuel industry, which arose from a well-developed forestry sector, in these countries. Furthermore, also because wood fuels from foreign countries often present technical difficulties to the users, especially the large scale industrial users.

If a market for wood fuels has to be developed in these countries, in order to provide the "demand-pull" for the encroacher bush in Namibia, a proper technical market survey, followed by a market development strategy and implementation plan, will have to be compiled for the targeted countries in Europe. A number of challenges will have to be faced during such a process. One major challenge is the fact that wood fuels from Namibia, in particular, but also South Africa, have a chemical composition which may compromise its compatibility, when combusted together with wood fuels from plantations from European countries, but also coal from various sources. This incompatibility may be centred on the fact that wood fuels from e.g. Namibia and South Africa produce a high level of ash when combusted.

11.3 Consider the challenge of high ash content

This challenge was highlighted by the experience of EC Biomass in Couga, Port Elizabeth, South Africa and its sister projects in that country. The operations of EC Biomass and its sister projects ground to a halt for the following reasons:

- They underestimated the abrasive effect of the levels of imbedded sand [contained in bark] and the inherent [contained within the wood structure] silica content of the woods on the pelletising equipment used to produce wood fuel pellets for the European markets. These levels of inorganic compounds also manifested themselves as the high ash content of the wood after combustion.
- The EC Biomass wood fuel pellets were predominantly aimed at the large scale co-firing [combustion together with coal] boiler market in Europe. The high residual silica containing ash presented problems with boiler fouling and slagging, resulting from the melting of the wood ash, in various types of boilers. This problem is not as severe with low ash containing wood fuels.
- It was generally found that the sand content on SA tree bark can be as high as 4%. Sand (Silica) is part of the ash content of wood. [The EU (DIN) requirement is for wood pellets with < 2% ash content and this was making it impossible for EC Biomass to deliver wood pellets within the permissible ash content].
- The harder the wood, the higher the ash content. EC Biomass was thus forced to mix soft wood (low ash) with harder wood (higher ash) to get closer to the DIN ash requirements of the EU, eventually leading to raw material supply difficulties.
- Adding to its demise, the large horizontal pelletisers experienced excessive wear of its dies and became too expensive to maintain/renew.

From Chapter 4, Table 5 and 6, follows that of the samples analysed of encroacher bush infeed material obtained from CCF Otjiwarongo and ABC Robertson, Sickle bush has a lower ash content (between 2.20% and 2.90%) than Purple-pot Terminalia (5.7%), Mopane (3.6%) and a mixture of several species used at CCF (@ 4.2%). It is interesting to note that debarked Sickle bush had an ash analysis of 1.45% (Table 6) and washed mixed bush at 2.75%.

By comparison, the ash content on a dry basis [%] in a number of foreign wood species, used as wood fuel, are:

- Aspen: 0.43%
- Yellow Poplar: 0.45%
- White Oak: 0.87%
- White Oak bark: 1.64%
- Douglas Fir bark: 1.82%

The ash content of wood fuel from Namibia is considerably higher. The wood fuel from Namibia was either in Bushblok form or intended to be processed into Bushblok at CCF. Wood fuel in pellet form is not yet produced on commercial scale [refer to the EC Biomass experience] in Namibia, for local use or exports. Bushblok exports into Europe will be targeted mainly for the domestic or small commercial market segments. If the aim is to target the large scale consumers of wood fuel in Europe, the requirements of energy and electricity generators will have to be met.

- **Important properties**

The properties that need to be declared for most forms of solid biofuels are:

  - Biomass origin i.e. what is it made of and where does it come from – tree (stemwood, branches, stumps), waste wood, straw, etc.
  - Dimensions (diameter, length, proportions of chips in different size ranges, etc.)
  - Moisture content
  - Ash content i.e. the non-combustible mineral content of the fuel and consists predominantly of oxides of alkali and alkaline earth metals, such as potassium, calcium and magnesium. The ash content of biomass can vary considerably, with low levels in the heartwood, and much higher levels in bark.

Some boilers and stoves are designed to be able to burn high ash content fuels, but some cannot do so. In addition to the quantity of ash, some ash tends to melt at a lower temperature, which can give rise to the formation of lumps of clinker or slagging. This can block air flow through the grate of the combustion chamber of large and small boiler systems.

- **Pellet quality: Standards and certification**

The purpose of the following example of an existing standard and certification framework for pellets demonstrates that it will be a challenge, from a regulatory perspective, to try to penetrate the European market with wood fuel pellets. Several European countries such as Austria (ÖNORM M 7315), Sweden (SS 187120) and Germany (DIN 51731) have introduced pellet-related standards in the past, but experience in these countries showed that standards need to be accompanied by a control system that certifies pellet production and minimum pellet quality. In Austria, for example, the pellet standard is connected to a certification label ("ÖNORM tested") that certifies pellet producers and guarantees unproblematic pellet usage for the end-consumer. This did not work in Germany where production in accordance with DIN standards is usually certified by the

"DIN tested" label. However, this label is granted without external controls at the production site. Furthermore, the minimum requirements of DIN 51731 are not always strict enough for unproblematic pellet combustion in small-scale applications. This standard also lacks a threshold level for mechanical durability. This led to the development of the standard-independent certification scheme *DIN-plus* for wood pellets by *DIN CERTCO* which combines features of the German and the Austrian standard, including external controls and strict quality requirements. As the DIN standard did not prove to be useful, *DIN CERTCO* developed the *DIN-plus* certification scheme for high quality wood pellets in 2002. It combines characteristics of both the German DIN 51731 (e.g. testing of heavy metal contents) and the Austrian ÖNORM M 7135 (e.g. high quality requirements in general). This scheme includes the establishment of internal quality management and annual, external controls without pre-warning announcement. *DIN-plus* contributed substantially to the promotion of the residential pellet market in Germany and today it is the most important quality label for high quality wood pellets worldwide. In total, 102 pellet producers are *DIN-plus* certified (October 2009) and 61 of these are based in Germany. The *DIN-plus* certified producers with known annual production capacities represent a total capacity of around 3.5 million tonnes. Considering the other 40 small and medium scale producers with unknown capacities, the total production capacities for *DIN-plus* pellets certainly exceeds 4 million tonnes p.a. This confirms that pellets remain the wood fuel of choice for large scale users, also because there are already credible standards and certification directives in place.

- **Bush Log quality**

It will have to be determined if similar standards and certification requirements exist for wood fuel products such as bush logs and cubes. This will require close interaction with certification authorities.

11.4 Consider the opportunities presented by ash derived from wood fuel

There is no question that the demand for biomass generated heat and electricity will increase as targets for generating energy from renewables and decreasing the emission of fossil CO_2 will continuously be set higher. As a result of the increasing use of biomass as renewable energy resource, there will be an increase of ash production from biomass. The opportunities presented by biomass ash must be seriously considered.

Several options exist for possible utilisation of ash derived from either biomass or coal, or combinations thereof. The opportunities are not constrained by technical issues. However, in reality, there is only a limited amount of biomass ash utilized and a large part is still disposed of in many countries. Examples of successful applications of ash in the European environment are:

- Coal and co-firing bottom ashes [for up to 20% (m/m) biomass/coal] have successfully been applied in road construction and as a concrete aggregate, replacing natural stone, while fly ashes from co-firing with up to 20% (m/m) biomass/coal are used as an additive in cement or as a concrete and asphalt filler. Regarding the use of coal fly ash as cement replacement, the European technical standard for the use of fly ash for concrete, EN-450, is currently being revised to include the use of ash obtained from co-firing percentages up to 50% (m/m, fuel input) for clean wood.

- A common application for bottom ashes, or mixtures of bottom and coarse fly ashes, from clean biomass fuels, currently is the direct use as fertiliser on agricultural or forest soils. These ashes are also used as additives for compost production in Austria and as a liming agent for forest soils in Austria and Germany.
- Ash from biomass contains a usable amount of potassium which could be supplemented and blended into balanced fertiliser formulations.
- The potential of large scale use of biomass ash in fertilisers should encourage the domestic market [households] to use the ash produced in their small combustion applications of e.g. Bush Logs, in their gardens and compost production.
- In Sweden, some ashes are used as construction material for landfills. In many countries however, most of the ashes are still disposed of directly into landfills.

Next to applications currently in use, many other options for ash utilisation exist. Research and development should be supported to develop more ways for the utilisation of pure biomass ash.

Promising applications for biomass ash utilisation include the more widespread use in the building industry (e.g. cement clinker production, production of bricks), civil engineering (e.g. binding material for soil stabilisation, landscape management) as well as the use as raw material for the production of synthetic aggregates, fertilisers or liming agents.

Available information indicates that the main motivation for such an approach relate to environmental, sustainability, low market volumes and differences and variations in ash quality. In addition, there are limitations in technical and regulatory issues as well as logistics. Finally, there is a lack of awareness, knowledge, willingness and motivation of plant operators, potential end-users and authorities alike to improve utilisation.

In order to overcome the barriers against more widespread ash utilisation, it is advisable to perform additional research and development on ash utilisation options, take measures to provide a consistent ash quality, intensify collaboration between producers and end-users, increase awareness with market actors and harmonise national regulations and technical standards.

Any new entrant into the European wood fuel market, such as Namibia, should recognize that the growing application of wood ash in the European environment will be an integral part of the acceptability of the product and thus demand-pull which needs to be created for its products.

11.5 Concluding thoughts and proposal

Based on the information presented in this Concept Note, the following is clear:

- Should Namibia be able to develop a viable market of significant size in Europe for its range of wood fuel products, it will constitute a significant demand-pull for the sustainable use of its encroacher bush biomass resource.
- The success of such a strategy will be an important contributing factor in realizing the overarching national strategy of reclaiming grazing and agricultural land in Namibia.
- If the development of a European market for a range Namibia of wood fuel products could take place parallel to creating capacity for the decentralised generation of electricity from biomass in the country, it will result in the creation of a mutually beneficial critical mass in biomass beneficiation in the country.
- It will be to the benefit of the Namibia economy if a market development strategy for the export of wood fuel products to Europe, or for that matter other multinational regions in the world within viable logistical reach of Namibia, could be designed and implemented, giving consideration to the issues raised in this Concept Note.
- It will be critical that a sustainable manufacturing capacity of wood fuel products is created in Namibia while serious market penetration into e.g. Europe is attempted with these products. It will be a strategic constraint and serious impediment to market development if demand in Europe cannot be consistently satisfied by supply from Namibia.
- It is proposed that the Namibian Government, with the necessary financial support from e.g. GIZ, initiates a process of integrated market research into targeted markets, starting with Europe, with the aim to implement a strategy to become a material and long term viable and sustainable supplier of wood fuel products into these markets.

11.6 Literature references

- Alakangas, E. New European Pellet Standards. European Pellet Conference. 3 - 4 March. Wels. Updated 10 March, 2010.
- Development and promotion of a transparent European Pellets Market. Creation of a European real-time pellet Atlas. WIP Renewable Energies, Germany and Holtzforschung, Austria. 2010.
- Options for increased utilisation of ash from biomass combustion and co-firing. IEA Bioenergy Task 32. RJ van Eijk. KEMA Report, March 2012.

12. ANALYSES AND CHEMICAL COMPOSITIONS OF MATERIALS – CONCLUDING REMARKS (by Dr Louis de Lange)

12.1 Namibian hard woods and wood hardness

The following bullets reflect on the feedback received on the Draft Report:

- There seems to be confusion on the use of the terms hard woods and hardwoods. In this project the term hard wood is used meaning that the wood (from Namibian encroacher bush) is hard.
- There is no relevance to either hardwoods related to angiosperm species or softwoods related to coniferous species.
- The Janka Hardness test and values are referred to only to highlight the proven fact that wood types with high densities [as, for example, many of the Namibian encroacher bushes] also has a high Janka Hardness i.e. are hard. This fact has obvious consequences if these woods need to be manufactured into products e.g. bush logs. An extensive bibliography has been provided before on these topics. See Chapter 3.
- No Janka Hardness determinations of Namibian hard woods are necessary to support the fact that most, if not all, of Namibian encroacher bush delivers hard woods. Monitoring densities, however, will be useful.
- Obviously, the higher the Janka Harness of a wood, the more force/energy/work will be required to press it through e.g. an extruder. The measures of these factors are a practical determination of wood hardness together with abrasive and corrosive factors inherent to the wood. Proper monitoring of manufacturing machines and processes will provide the necessary information to minimize the impact of all these aforementioned factors.
- It is a fact, and has been reported as such, that silica content is a factor in the hardness of wood. Furthermore, silica, external and/or internal, is a proven factor in the abrasive/corrosive impacts on manufacturing tools. Obviously, silica content will be a factor in Janka Hardness.
- Rather than determining the Janka Hardness of Namibian encroacher bush wood, it will be more useful to monitor silica content as this is a primary factor in abrasiveness.
- The ash content of the wood of encroacher bush species is also an important factor especially if the wood fuel products manufactured from these woods are directed towards markets where high ash content could present problems in application e.g. pellets co-fired with coal in high capacity boilers.
- The high ash content of Namibian hard wood from encroacher bush may present a different opportunity as the ash could be used in various downstream applications, such as fertilisers.

12.2 Sampling

Notes on the Consultant's approach re sampling:

- Only a selection of encroacher bush species identified in Namibia has been used to do all the analytical work for material and chemical composition during the project. This selection is well representative of the bulk of the encroacher bush species in Namibia. In any case, encroacher bush biomass presented for manufacturing will generally be a mix of a number of species. Several mix wood meal samples were analysed.
- In order to design a strategy for effective and efficient manufacturing of wood fuel products it is not necessary to sample all the encroacher bush species which are potentially to be used.

12.3 Analytical work

The following comments reflect on the analytical work conducted by the author:

- All analytical work reported on were undertaken by reputable laboratories in the Stellenbosch district. These laboratories routinely do such analytical work on wood samples.
- The samples presented to these laboratories were representative of the selected Namibian encroacher bush species. See **Annexure F** for the results obtained by Stellenbosch University and BemLab.
- These laboratories consistently use well established and calibrated analytical procedures and methodologies.
- The laboratories are not required to do experiments i.e. they do not use experimental variables but determine and compare the composition and inherent values of e.g. wood samples using well established standard methodologies and equipment.
- *Higher Heating Values [HHV]* have for example, been determined and expressed in the accepted SI value of MJ/kg. This represents the heat liberated on combustion of e.g. a wood sample. The HHV's are determined after the wood samples have been completely dried in an oven. The HHV's of the selected samples have been included in the laboratory reports. The results obtained are directly comparable with results obtained in other laboratories. No *Lower Heating Values [LHV]* have been determined i.e. where the moisture contents of the wood samples are high. It is obvious that wood which could be naturally dried to deliver optimum HHV will have a higher commercial value.
- To analyse samples against controls are only necessary if a new analytical procedure is to be used or a new variable [e.g. new reagent or instrument] is incorporated into an analytical procedure. The number of samples tested and the repetitiveness of analyses

provide adequate comparative results and certainty about the integrity of the analyses done. No controls are necessary for comparative purposes. The goals, as stated above, can be pursued with the methodologies used routinely by certified laboratories with verifiable results obtained at any date, on different samples from a variety of sources.

12.4 Results

The results obtained from all the analytical work confirm that the hard woods from the encroacher bush in Namibia have the properties necessary for the manufacturing of wood fuels usable in various applications and markets.:

- The consistently high HHV's, as well as the high densities of these woods, mean that the wood fuels could be aimed at small and large scale markets for the generation of thermal energy and electricity.
- Bush logs, a major product currently being manufactured from encroacher bush, will be aimed at the domestic and small commercial market segments. Pellet and cubes, produced in bulk, will be ideally suited for the large industrial segment which includes power stations and boilers for the delivery of thermal energy and electricity.
- It will be ideal if these markets could be found in export markets e.g. Europe. The demand-pull for wood fuels which could result from such a strategy would impact favourably on actions in Namibia aimed at developing supply-push capacity e.g. increasing bush-log or other forms of compressed/compacted biomass products like cubes or pellets.
- Export markets do have specifications and certifications for the use of wood fuels e.g. the DIN series in Europe. These specifications and certifications need not be insurmountable barriers; the development of an export strategy for wood fuels will require a close involvement of the wood fuel industry in Namibia in the supply-demand chains of these markets.

13. KEY FINDINGS

The key findings of the report, the literature study and field survey work carried out over the past six months can be summarised as follows:

- The sand and high abrasive mineral (S_iO_2) content of the Namibian encroacher bush species analysed, are more a natural than a man-made phenomenon.
- Although the Namibian encroacher bush species analysed have a higher ash and silica content than its European biomass counterparts, it has a much higher *High Heating Value [HHV],* and could therefore, when compacted, aim to compete with coal, which is a fossil fuel with an even higher ash content. The clean ash of woody biomass products can be (unlike ash from coal) safely disposed of as a soil conditioner. Coal ash has to be handled as a solid waste and, in some countries, as a toxic solid waste material.
- The swing in thermal fuel applications towards cleaner, renewable biofuel will continue to grow stronger across the world as older coal and heavy furnace oil boilers are more often being replaced with wood fired systems instead of fossil fuel fired applications.
- Europe's energy density specifications, measured in MJ/m^3, (the product of bulk density [kg/m^3] and HHV [MJ/kg]) is currently favouring small cylindrical *wood pellets.* The sustainable manufacturing of pellets from (most, if not all) Namibian encroacher bush species would however not be viable. The energy required and the wear on the pelletiser dies would simply be too high for the process to be performed economically. This is due in general to the hardness and high inherently abrasive qualities of the Namibian encroacher bush. Three of South Africa's pelletising plants contacted have been moth balled – mainly because of the above reasons. The remaining operating pelletiser in Pietermaritzburg is using washed and debarked pine infeed.
- **Cuber technology** (See Chapter 10; § 10.3.3) would most likely be a better process to try out for the hard Namibian encroacher bush. This technology is based on an eccentric *roller-press-wheel* which compresses the wood fibres through radially positioned dies equipped with slots. These dies can be individually repaired (hardfaced) and replaced. Because of its larger cross sectional area, less friction or wear and thus less energy is used to compress the wood fibres into cubes. The cubes are not of the same density and structural integrity as that of pellets made of the same wood, but are widely used in the USA as boiler fuel and for other thermal applications.
- **Compressed wood logs** manufactured by *extruders* can be done successfully and economically using Namibian encroacher bush by taking better care of the high wear components. Several mechanical improvements and possible ways to lightly lubricate the high pressure areas of the Shimada machine were investigated and discussed with the manufacturers. The most cost effective solutions to the mechanical wear areas however remain:
    - To hardface powder coat the wear areas on a preventative (regular/routine) maintenance basis as soon a wear is detected. Each extruder should have at least three sets of wear components – one working, one being hardfaced and one overhauled set ready to replace the working set. Each set can be hardfaced for several times.
    - To clean the incoming wood chips as best as possible using screens and air-knifes prior to entering the hammer mill. (Chapter 8).
    - During the hammer milling operation, a cyclone could perform further removal of both wood and soil dust. (Chapter 8).

    - By removing the dust (wood and soil dust) particles < 0.50 mm would not only reduce wear, it would also improve the power consumption of the extruder (See Figure 8).
    - The three phase electricity supply to the extruder process should also be so designed that it can economically match and supply the maximum demand [kVA] required by the operation. Care should therefore be taken not to start more than one large machine at the same time thus causing a high maximum demand cost.
- A comprehensive **comparison analysis** was conducted of the four most popular compressed wood technologies:
    - Screw type extruders
    - Piston/cam type extruders
    - Cubers
    - Pelletisers

  Table 10 (Chapter 10) summarises the findings of the above comparison analysis and illustrates that the pelletiser technology would be problematic for Namibian encroacher bush.
- From the above comparison analysis (Table 10) it is also clear that the best technology (although not tested on Namibian bush to date) appears to be the *cuber type machine*, for the production of boiler fuels. See § 10.3.3 for more information about the Cuber.
- Sand and dust contamination can be removed quite effectively from harvested biomass in chipped format by introducing one or more of the following dry systems prior to entering the hammer mill:
    - Multi-deck vibrator screens.
    - Air-knife blowers. See Chapter 8 for further detail in this regard.
- The hammer mill reduces the chips to biomass meal (< 4 mm particle size) so that the screw or piston-type extruders can compress the meal into logs. For further removal of dust, the hammer mill can be equipped with a cyclone which remove and collect the particles as explained in Figure 6, Chapter 10.
- The thermal export market for Namibian charcoal (both lumpy and in briquette format) is well established and growing. Fewer difficulties are experienced in most of these markets with the high ash content of Namibian charcoal, mainly because of the non-industrial nature of these household applications.
- Charcoal briquetting machines show little wear when compacting charcoal fines and its binder (mainly starch) into the cake type briquette, as shown in Photograph 8, Chapter 5. This is because little wear (no sliding action) is experienced when the two rollers compress the stream of charcoal fines infeed into the briquette. It should however be noted that fines with a higher ash content, because of poor kiln management, will result in a greyish looking, instead of a black briquette, which would lead to poor combustion and complains from the end user. Briquettes with a high (> 0.5%) sand content would lead to small sparks and a crackling noise (micro explosions) during the combustion process, and further complaints from the end users. Its therefore in the best interest of the charcoal industry to ensure that its producers take good care against over-burning (making ash) in their kilns and also to ensure that when charcoal is loaded from the ground (from the open ended kilns) that sand is not loaded into the bag as well.

Table 11 overleaf presents a summary of the key findings of this investigation into various techniques to better cope with the high abrasiveness of sand contamination and the inherent mineral content of the Namibian encroacher bush.

Figure 8 graphically summarises the expected energy consumption required to extrude *Bushbloks* (compressed wood meal logs) at various screening envelopes or particle sizes ranging from dust powder size to a coarse (> 4 mm) particle size, with the majority of the particles between 1.0 mm and 3.5 mm in length. Figure 8 also position the best contaminant removing technology per fraction with special reference to cyclones, air knives and vibratory screens – all dry-cleaning (waterless) and simple mechanical technologies.

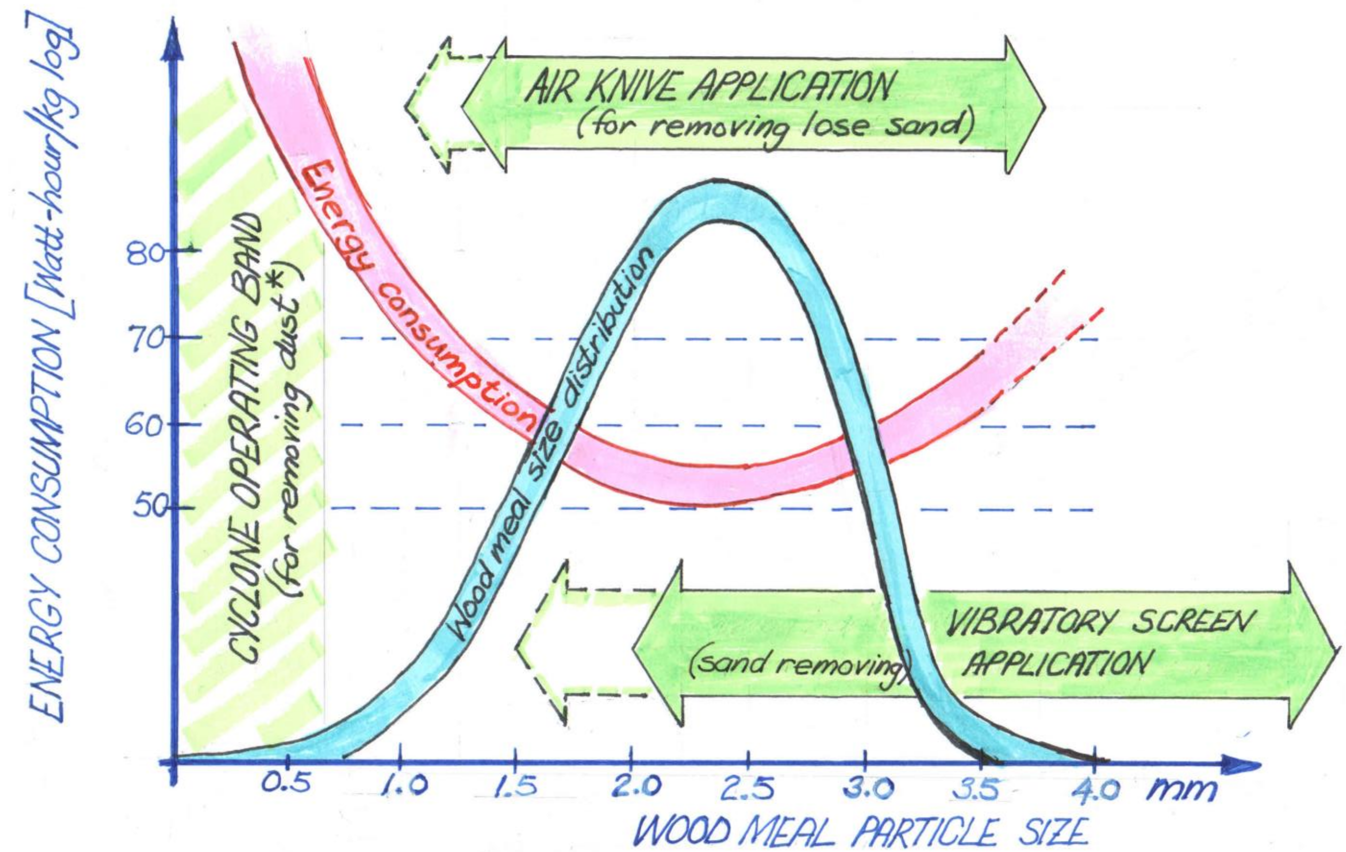
From Figure 8 it can also be deducted that energy consumption can be optimised by removing dust (wood dust and soil dust) out of the infeed of an extruder, thus emphasising the role of an effective pre-cleaning cyclone air classifier (dust removing system).

TABLE 11: SUMMARY OF KEY FINDINGS PER CRITICAL BIOMASS OPERATION REGARDING SAND/SOIL CONTAMINATION AND POSSIBLE WAYS TO REDUCE WEAR ON MACHINE PARTS

Item	Operation/technique	Extent of sand/soil contamination impact	Possible rectification method to reduce sand/soil contamination	Recommendations to reduce mechanical wear
1.	Felling of bush using labour based techniques	**High.** Bush is felled randomly and make contact with the soil	• Light branches can be stacked on top of branches felled earlier • A better awareness of the negative impact of contaminated bush on downstream equipment is required	Once chipped, feedstock can be screened to remove most of the residual sand and soil
2.	Felling of bush using hydraulic grab and blade cutter – Highly mechanised techniques	**Low**. Bush is cut and stacked in windrows. Little contaminating soil contact	As above	As above
3.	Charcoal production with in-field kilns	**Medium.** Logs are often contaminated with soil. Kilns stand on open soil. Charcoal gets contaminated with sand when shovelled into bags	• New generation kiln design required. Air (oxygen) regulation can be done on better enclosed kilns with inlet air vents above the soil	Kiln can be designed with bottom discharge when lifted over bulk bag
4.	Briquetting of charcoal fines	**Medium**. Charcoal fines often arrive at packing plants with sand, soil and ash contamination present rendering the fines useless	See Item 3	Little mechanical wear on charcoal briquetting machines because of its compacting roller design. No further improvement required for briquetting plant
5.	"White" wood pellets using a pelletising machine	Could not be measured. No Namibian operation currently	See Item 6	High mechanical wear was experienced in South African pelletising operations, leading to the moth balling of these plants. It is recommended that future Namibian operators familiarise themselves with EU market requirements and have their feedstock thoroughly tested for this high wear application. Pellet production is not recommended for Namibian encroacher bush feedstock at this stage using pelletising machines. A different wood compaction methodology is proposed for the thermal market. See Item 8 below

TABLE 11 (CONTINUED): SUMMARY OF KEY FINDINGS PER CRITICAL BIOMASS OPERATION REGARDING SAND/SOIL CONTAMINATION AND POSSIBLE WAYS TO REDUCE WEAR ON MACHINE PARTS

Item	Operation/technique	Extent of sand/soil contamination impact	Possible rectification method to reduce sand/soil contamination	Recommendations to reduce mechanical wear
6.	Extruded bush logs using an extruder	**Low to medium**. Biomass meal tested at CCF's Bushblok factory shows little (0.25% by mass) residual sand/soil contamination	• Wood chips can be screened so that residual sand and soil is removed. Further and improved dust extraction can be implemented at the hammer milling operation using cyclones • Air classifiers and air knife technology can also be considered	Wear of the screw and fluted bush will continue, even if all residual sand and soil is removed from the feedstock. It is recommended to improve the design of the Shimada *negative screw* so that a smaller, removable portion of this wear part can be dismantled for hardfacing on a more regular basis. By hardfacing the screw on a preventative maintenance schedule would improve the current situation significantly. The temperature setting of the barrel heaters is critical
7.	Animal feed from young growth of selected encroacher bush using a small pelletiser	**Low.** Sand, soil and dust contamination is low on young growth and when harvested cleanly before wet chipping	• Not required if harvesting of 'bush-feed' is handled correctly • Only young green growth to be used, preferably with soft additives like brewers' grain, etc.	The current production method used by Mr Larry Bussey (the only known bush feed pelletising operation in Namibia at this stage) is reportedly found to be working very well with little notable wear on the pelletiser
8.	Using compacting technology less subject to abrasion like the Cuber	**Low.** The Cuber is better suited for lightly contaminated infeed. (See § 6.3 for more information on the cuber machine)	See Item 6	The individually removable and repairable dies of the Cuber would make this application more suited for Namibia wood meal. It is recommended that this technology should be tested and evaluated



*Wood dust plus soil dust

FIG. 8: WOOD MEAL PARTICLE SIZE vs. ENERGY CONSUMPTION TO PRODUCE A BUSHBLOK

14. RECOMMENDATIONS

14.1 The way forward in order to improve on the current status

14.1.1 Extruded wood logs for the international energy markets

The current methodology used to extrude and compress biomass wood meal into logs for the international domestic heating and barbeque markets are on the right track, barring a few essential modifications to improve the life cycle of the high pressure wear parts. The CCF's Shimada Extruder can be modified with relative ease to reduce the costs of wear parts, as explained in § 7.9. These parts can be modified by a number of engineering shops in South Africa, if required. This should make the production of Bushbloks more viable, thus assisting sustainability and ability to penetrate the aforementioned international markets.

An immediate production cost improvement in the screw type Shimada extruder operation at CCF can however be implemented by doing the following:

- Make more regular/routine use of the powder coating method, as supplied by the manufacturer (or similar, by others), on the wear parts (the Negative Screw in particular) as soon is this wear surface has been worn off. This should happen every 30 to 40 production hours and is mainly caused by the inherent hardness and abrasiveness of the Namibian bush types processed. These wear parts can be overhauled as described, many times over, and this should be done long before the spigot breaks off and rendering the negative screw useless.
- Do not start the hammer mill and the extruders during the same peak-time hour in order to bring the electricity costs down.
- Extract the wood and dust particles by means of an improved cyclone or classifier, thus reducing wear and power consumption further. (See Figure 8) for more clarity this in regard.

Some of the international energy markets however require a very low (< 2%) ash content, which is not always possible with hardwood and high wood densities of the Namibian bush. However, several European countries are less stringent on ash content, with large enough volumes required by these markets to be economically exploitable by Namibian producers. A thorough market research action is therefore necessary to identify these markets and to fully understand their specifications, with special reference to ash and silica content.

14.1.2 Hard wood pellets or cubes for the international energy markets

Several companies and the South African *Industrial Development Corporation [IDC]* have unsuccessfully tried to penetrate the international biomass to energy markets. Prices of between €4.00 and €6.00 per GigaJoule [€/GJ] are mentioned for (white) wood pellets delivered to Rotterdam. However, stringent specifications and high volumes need to be adhered to over prolonged and uninterrupted delivery periods. To date, no know South African entity could achieve lasting long term contracts in this regard. Failing to do so was mainly contributed to one or more of the following reasons:

- High cost of local production, mainly due to extremely high wear on pelletising equipment (due to the high inherent abrasiveness of most of the local wood species).
- Transport and harvesting costs of raw material delivered to the pelletisers.
- Stringent EU specifications with special reference to ash and silica content, the durability and structural integrity required of the pellet itself for materials handling purposes.

Further research and development in this field is required in order to pelletise or compact Southern African hard woods into an acceptable pellet or cube for the International (energy) markets, starting by:

(a) Carefully analysing and understanding the requirements of this markets better.
(b) Find international compacting machine builders to test Namibian biomass raw materials in order to prove that, the wear components of their machines are able to sustainably produce the required pellets or cubes for those markets not so stringent on high ash content.

It is therefore recommended that parallel to an EU market research action, a scientific trial and breakeven analysis be carried out on the Cuber-technology, using mixed Namibian encroacher bush (See 14.1.4 below).

14.1.3 Using other compacting technologies for logs

CF Nielson's piston presses were the next best other compacting technique (to the Shimada extruder) found thus far which demonstrated reasonable success on the production of EcoLogs. High wear patterns also exist in the CFNielsen equipment due to the intrinsic hardness of the Namibian encroacher bush species. Further testing and a willingness to adjust and modify these machines for the compacted biomass markets, would however remain a challenge, with specific reference to continuity in supply and cost of maintenance.

14.1.4 Using cuber compacting technology for boiler fuel

The John Deer/Warren & Baerg Cuber (or similar) should be tested on Namibian encroacher bush infeed. Cubers are less sensitive to wear than pelletisers and have been producing boiler fuel from selected solid waste and biomass in the USA for decades. Although the cuber process produces a cube with a lower density as a pelletiser, the energy densities achieved can be more than double that of chips from the same tree/bush species. It is therefore recommended that comprehensive trials be done on a cuber machine, while recording, analysing and evaluating energy consumption and wear rate. Tests of the cubed fuel is also advised at a reputable boiler manufacturer/operator.

14.2 A bold recommendation for the way forward for CCF's Bushblok

Two of the outstanding operating cost elements at the CCF Bushblok factory are:

a) The cost of the Shimada wear parts (dealt with before in § 14.1.1).
b) The cost of electricity.

The CCF is planning to move their Bushblok operation closer to the conservancy and to power the factory with diesel powered generators. Technology is however available which can generate electrical power from waste heat, produced by waste wood or by stationary charcoal making processes at a lower cost per kWh than a diesel powered equivalent.

It is therefore recommended that consideration be given to the Bushblok factory to be powered by electricity generated on site using its own harvested biomass. This would require a focussed investigation and viability evaluation.

14.3 The charcoal industry

Sand and ash contamination is present in both lumpy charcoal products and in briquettes manufactured from charcoal fines. In the case of lumpy charcoal, a good percentage of the sand and ash is screened out by the producers and the packing facility, In the case of the briquetting process, it is slightly more complex to purify the charcoal fines from said contaminants. It is recommended to start at the source of the charcoal making process by improving the design of the simple kiln by considering a new generation enclosed design with adjustable air inlets and outlets and a bottom discharge when the kiln is mechanically lifted over the bulk bag.

More advanced designs for larger, centralised kilns (hot gas pyrolysers) exist, but is not recommended for small operators. For a hot gas pyrolyser to be economically a viable, a use for the waste heat (hot gas) is required.

14.4 Animal feed

For small greenwood animal feed operations, and especially those who would add softer animal feed components like grass (straw, hay), maize brand, molasses, etc. to the biomass meal infeed, the pelletising technique for compacting the feed into a shelf-stable product is recommended for small animal units and poultry.

The cuber technology is however the preferred option for compacting animal feed for larger animal units and can be done on an industrial scale of several tonnes per hour production tempo. It should also be possible to make cubes directly from wet chipped biomass, without the hammer milling stage in between, thus saving on energy costs.

It is therefore highly recommended that trials be carried out on a small (< 37 kW/50 hp) cuber to analyse the appropriateness of this technology for Namibia.

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