Food and Agriculture
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BIOMASS WASTE MANAGEMENT STRATEGY FOR UGANDA

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Andrew McEwan

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Preparation of this document

This report has been produced under the Sawlog Production Grant Scheme Project (SPGS III) a project being implemented by Food and Agriculture Organization of the United Nations (FAO). It is being executed as a component (outcome 3) related to the downstream industrialization of processing and the utilization of forest products. Among the key assignments under this component are to:

- Develop a waste management strategy appropriate for Uganda (this report).
- Develop occupational health and safety strategy.
- Engage in downstream processing and utilisation capacity building.

The report has been produced under the general supervision of FAO representatives in Uganda, and the direct technical supervision of the International Projector Coordinator and Project LTO, and in close cooperation with Plantation Business Development Advisor. The report provides expert advice and technical assistance to support sawmill managers and supervisors to acquire skills and knowledge in downstream processing and utilization.

The biomass waste management strategy incorporates the following key components:

- Identify types of wood waste common in Uganda.
- Determine properties of the available wood waste.
- Analyse strategies to minimise wood waste.
- Estimate volume of wood residue from the sawmills.
- Suggest improvements on processing, utilisation and marketing of the wood waste.
- Write a final guideline on waste management strategies appropriate for Uganda.

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Executive summary

This report has been produced under the Sawlog Production Grant Scheme (SPGS) a project being implemented by Food and Agriculture Organization of the United Nations (FAO) on behalf of the Government of Uganda, with funding from the European Union. It is being executed as a component (Outcome 3) related to the downstream industrialization of processing and the utilization of forest products. It focusses on the development of a waste management strategy appropriate for Uganda, with a specific focus on pine sawmilling, as per the focus of the SPGS programme.

Sawmilling currently only constitutes 30 percent of estimated log processing in Uganda. The many small, mobile, informal sawmills currently produce more sawn products than the formal sawmills. There is a large amount of waste (by-product) produced each year, with both formal and informal sawmills operating at very low recovery rates. Modern sawmills are able to achieve in excess of 50 percent product output. As the plantations mature and processing commences, the amount of waste will also increase.

Very little information exists on the number of micro-sawmills in Uganda. In addition, Uganda has undergone a significant increase in plantation area since 2004. Therefore, one needs to consider the extent of the industrial forests in Uganda in order to make predictions regarding the wood that is being processed or will be processed, as well as the waste that will be generated. In order to produce a biomass strategy, two aspects must be considered:

- The current waste biomass being generated in Uganda from existing processing facilities.
- The future waste biomass to be generated in Uganda from the new processing facilities used for the expanding wood volumes.

The search for profitable markets for sawmill wood waste biomass such as sawdust, shavings and other solid wood waste is often initiated due to a need to reduce the costs of waste disposal. This material can hinder production by taking valuable storage space. It is also driven by a desire to obtain increased value from a sawlog for which a premium has been paid. It can also be a fire, environmental and safety hazard.

However, what is currently unique in the Ugandan situation is that there is no build-up of wood waste at any of the sawmill facilities (regardless of size). There is always a user or entrepreneur willing to remove the material very soon after processing. Countries with mature wood industries have managed to reduce waste through markets for waste, sawmill technology development, plywood technology development, structural composite panels, finger-jointing and edge-gluing, and composite lumber.


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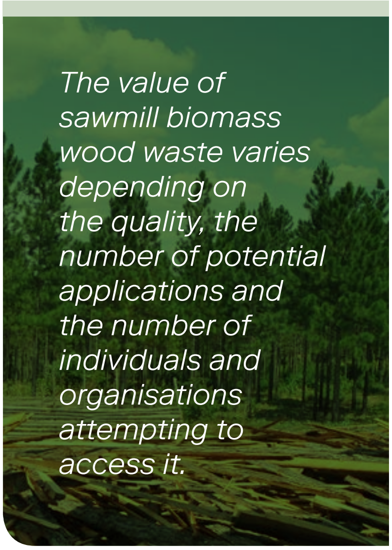
In developing nations such as Uganda, there are inadequate downstream industries to utilise the waste. In many developing countries, waste-to-energy (WtE) applications are often limited to steam generation for kiln driers in larger sawmills and for certain industries



The value of sawmill biomass wood waste varies depending on the quality, the number of potential applications and the number of individuals and organisations attempting to access it.

such as tea drying. However, no kiln drying of timber currently takes place, resulting in all biomass waste needing to find an alternative market or be stockpiled or placed on landfill. Luckily, there are many individuals and organisations needing this waste; however, very few are able to pay any worthwhile amount for the biomass. The waste biomass is often given away to avoid the disposal costs.

Every sawmilling site visited in Uganda had no problems in selling or disposing of their waste. However, the questions remain of how to minimise this waste and whether there is a more profitable opportunity for using the remaining waste. The even bigger question is whether the current users of the waste will be able to absorb the additional waste from the ramp up in timber volumes over time.

The utilisation of sawmill waste will depend on the original properties of wood from which it is derived. However, the physical and chemical properties are influenced by the characteristics of the specific type of wood residues. Therefore, it is necessary to examine each biomass waste type and determine what the range of characteristics can be.

Information on the different types of wood biomass that is directly generated as a by-product to the sawn timber being produced is documented. These are sawdust, bark, solid pieces and planner shavings. Additional information on the different types of wood biomass that is produced as a result of further processing of the sawmill by-product biomass is also included. These are wood chips and hog fuel.

The use of wood biomass to generate heat is an important part of the success of modern sawmills where waste biomass is used for kiln drying and as a potential fuel for internal or external uses. Therefore, heat and energy processes need to be fully understood if sawmills are to determine their future energy requirements and the fuel related aspects.

The value of sawmill biomass wood waste varies depending on the quality, the number of potential applications and the number of individuals and organisations attempting to access it. If wood waste from a sawmill is used for on-site energy and replaces other energy sources, it is of high value, as it avoids disposal costs and purchasing other fuels. If the wood waste is sold for non-energy purposes or for energy purposes to other users, its value decreases considerably, unless sold for reconstituted board production or pulp. To optimise the profitability of wood waste, the individual sawmill will require a detailed study as costs and specific biomass factors vary between regions and are sensitive to handling and transportation requirements.

If waste could be minimised in the sawmilling context, more of the high value primary product would be produced. Therefore, the first aim of a sawmill is to reduce the amount of biomass waste being produced (i.e. increase log recoveries). Thereafter the mills need to reuse as much of the material as possible (e.g. resawing of edges). Only then does one attempt to recycle and recover waste, because the costs of doing this are normally considerably higher than reducing or reusing. The last option is disposing, which can be very costly, hinders production, is a fire risk, and has poor aesthetics and is an environmental risk.

Five categories of improvement opportunities for waste have been identified. These are good operating practices, technology change, change in input material, change in product, and waste recycling and waste reuse/recover. The wood waste utilisation and disposal options are summarised as minimising saw kerf, wood densification into pellets or briquettes, charcoal, engineered wood, wood ash use, other sawdust uses and the use of bark in the horticultural industry.

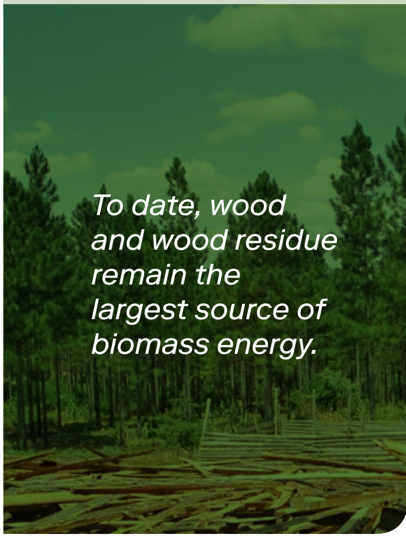
Detail is provided on the handling, processing and storing of sawmill biomass waste and its products. Storage systems for firewood and woodchips are discussed as well as the health and safety aspects.

The International Energy Agency expects bioenergy to not only be the largest source of growth in renewable production over the next five years but also to account for more than 30 percent of that growth. To date, wood and wood residue remains the largest source of biomass energy. The remainder of this sections goes into more detail regarding heating and energy systems and options for now and the future. Detail is provided on kiln drying, energy conversion processes, combustion, pyrolysis, gasification, biofuels and cogeneration.

If a specific biomass waste use is to be considered, then an action plan needs to be generated to address the applicable barriers. The general barriers are categorised into technology, trade, political and practical classes. Some of the key considerations for sawmill biomass waste are discussed. A final strategy for biomass use can only be considered when these questions have been answered, as well as an investigation into the strategies (including their market, expansion and growth and biomass waste) of the companies and growers that make up SPGS and the Ugandan forestry industry. The most important action points are:

- The quantification of available resources.
- Government, policy makers, NGOs, the private sector and stakeholders in environmental management should openly support existing and planned efforts to use the waste.
- International cooperation within the forest industries must be encouraged, with the transfer and adoption of technologies, information, best practice, experience and expertise.
- Once the Ugandan plantation industry has clearer direction regarding which future log processing options will be used (e.g. structural timber, engineered wood, CLT etc.), then there will be clarity regarding the biomass type and volumes. A proper market analysis can then be carried out and the waste management strategy updated to be more reflective of the actual conditions.
- Marketing of the processing biomass residues or their products needs to be considered. Each processing facility needs to investigate which of the waste use options pose the greatest opportunity and then compile a marketing strategy to ensure that the opportunity is realised. It may be possible for the industry to compile a high level marketing strategy for the entire industry, especially where economies of scale are required for aspects such as bio-energy or collective marketing of the use of a certain product (e.g. wood briquettes). However, experience indicates that due to the costs of waste biomass processing and transport, the consumer of the product needs to be relatively close to the processing plant.

The foundations for the waste strategy can now be laid. However, until the industry has more clarity regarding the primary processing strategy, the waste strategy will not be able to contain substantial detail. When the primary processing strategy is compiled, the use of waste will also need to be considered, because it affects the profitability of a modern mill. Better coordination within the industry regarding future processing options will result in better waste management solutions as well.



To date, wood and wood residue remain the largest source of biomass energy.

Wood is a natural material and 100 percent renewable. There is no part of the tree that cannot be used in some way.

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1 . Background

An overview of FAO/SPGS III programme, its objectives and some of its results can be accessed from the SPGS III office in Kampala, Uganda. This report focusses on the development of biomass waste strategy for downstream processing, with a specific focus on pine sawmilling, as per the focus of the SPGS III programme.

Downstream log processing is poorly developed in Uganda. By number of "sawmills", the industry is dominated by many small-scale informal sawmills, making use of basic Chinese circular saw technology. Global Woods (g-w) uses small-scale mobile band-saw technology that is semi- permanently installed in a controlled environment. Busoga Forestry Company (BFC - also known as Green Resources) possesses the newest and most advanced sawmilling technology in Uganda. This sawmill is setup to sequentially optimise the conversion of logs into timber according to customer requirements. All timber in Uganda is air-dried (if dried at all).

Table 1 shows that sawmilling currently only constitutes 30 percent of estimated log processing in Uganda (SPGS, 2019). The many small, mobile, informal sawmills currently produce more sawn products than the formal sawmills. Table 1 shows that there is a large amount of waste (by-product) produced each year, with both formal and informal sawmills operating at very low recovery rates. Modern sawmills are able to achieve in excess of 50 percent product output. As the plantations mature and processing commences, the amount of waste will also increase.

Table 1: Current log processing capacity in Uganda (SPGS, 2019)

Type of Processing Plant	Annual Round-log Intake (m^3/yr)	Product Output (m^3/yr)	Product Recovery (%)	Waste (m^3/yr)	% of Total Processing Capacity (%)
Board-particle & MDF	168 000	118 000	70	50 000	35
Plywood - Veneer & Other	169 000	92 000	54	77 000	35
Sawmills - Formal	54 000	22 000	41	32 000	11
Sawmills - Mobile	89 000	31 000	35	58 000	19
Total	**480 000**	**263 000**	**55**	**217 000**	**100**


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Very little information exists on the number of micro-sawmills in Uganda. In addition, Uganda has undergone a significant increase in plantation area since 2004 (Table 2). Therefore, one needs to consider the extent of the industrial forests in Uganda in order to make predictions regarding the wood that is being processed or will be processed, as well as the waste that will be generated. Table 2 shows that significant new processing capacity will be required in order to process the "wall of wood" which is approaching.

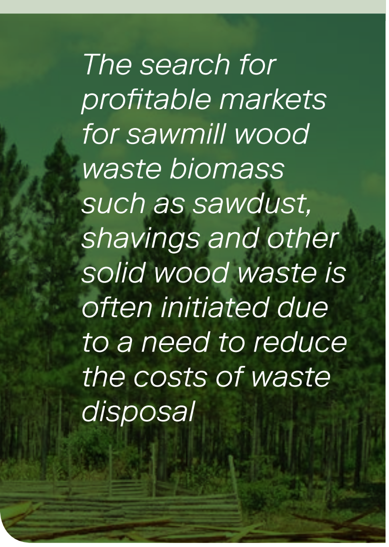
Table 2: Extent of industrial plantations in Uganda (SPGS, 2019)

Estimated Area of Industrial Plantations Established 1990 to 2019 (ha)							
Period	GRAS	g-w	NFA	NFC	Nileply	SPGS S&M	Total
1990-2003	619	7	680	0	1450	67	2 823
2004-2013	5 249	4 478	9 085	7 083	3 697	15 757	45 348
2014-2019	844	4 206	679	4 574	853	25 000	36155
Total	**6 711**	**8 690**	**10445**	**11657**	**6 000**	**40 824**	**84 327**

In order to produce a biomass strategy, two aspects must be considered:

- The current waste biomass being generated in Uganda from existing processing facilities.
- The future waste biomass to be generated in Uganda from the new processing facilities used for expanding wood volumes.

Wood is a natural material and 100 percent renewable. There is no part of the tree that cannot be used in some way. There is currently a global focus on renewable resources, especially for energy. These include solar, water, wind and biomass. Amongst these, biomass is unique (IEA Bioenergy, 2009):



The search for profitable markets for sawmill wood waste biomass such as sawdust, shavings and other solid wood waste is often initiated due to a need to reduce the costs of waste disposal

- Storage and transportation is relatively easy compared to renewable options such as wind and solar, which provide intermittent electrical power that needs immediate consumption and a connection to the grid.
- It has a cost. The procurement cost of biomass is a significant share (approximately 50 to 90 percent) of the production cost of bioenergy. The feasibility calculations are, therefore, very different from other renewable energy options that rely on free resources such as wind and sunlight. However, if the biomass is waste and can be procured for a low cost (or free), the financials usually look much more attractive.
- Conversion steps are required to transform the biomass into consumable product. Plant biomass captures solar energy and converts it to chemical energy, where it is stored. This chemical energy is released as heat via combustion or converted into various intermediate chemical and energy products, such as solid products (e.g. chips, pellets and charcoal), liquid products (e.g. biodiesel and bioethanol) or gaseous products (e.g. biogas, synthesis gas and hydrogen). These are used in various energy applications.
- Biomass is extremely varied in nature, which is unlike all other renewable energy resources. This introduces complexities, as specific technologies are required for each case.
- The search for profitable markets for sawmill wood waste biomass such as sawdust, shavings and other solid wood waste is often initiated due to a need to reduce the costs of waste disposal. This material can hinder production by taking valuable storage space. It is also driven by a desire to obtain increased value from a sawlog for which a premium has been paid. It can also be a fire, environmental and safety hazard.

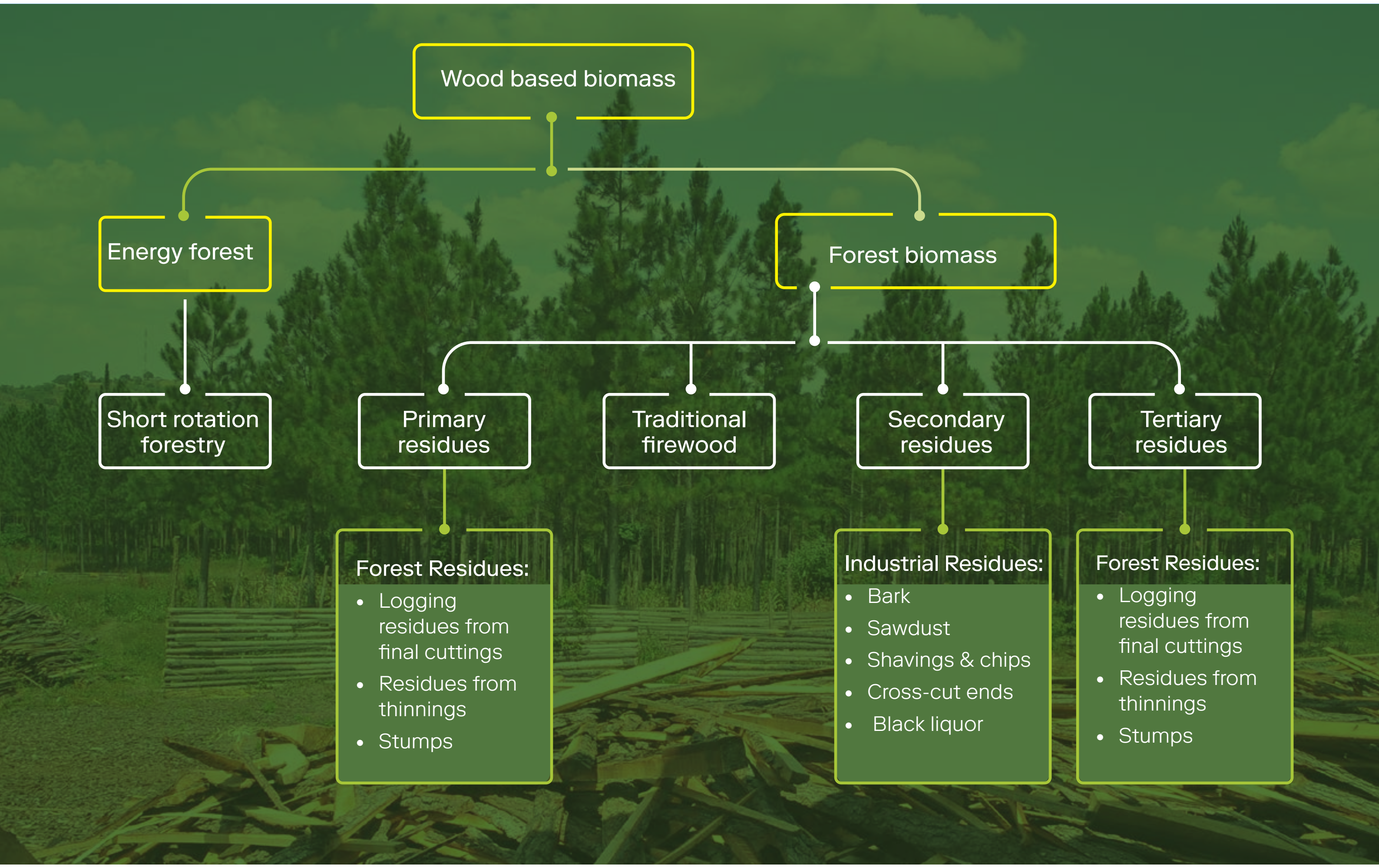
However, what is currently unique in the Ugandan situation is that there is no build-up of wood waste at any of the sawmill facilities (regardless of size). There is always a user or entrepreneur willing to remove the material very soon after processing, with trucks usually parked at sawmills waiting for material. However, this waste is either given away or very low prices are paid. Modern sawmills attempt to classify their waste biomass as a by-product, and attempt to find profitable markets or uses for the material.

This document is structured to first provide an overview of the different types of wood waste being generated at processing facilities. An overview is provided of the properties of this waste. Strategies to reduce and minimise the amount of waste generated are summarised. Different potential uses for the remaining waste are then discussed. Then the technologies and processes used to process wood waste into a form desired by a potential user of the biomass is provided. Other considerations for biomass waste use are covered. Finally, an action plan is presented that will need to be populated by the Ugandan forestry industry.

2. Types of wood waste common in sawmills

Figure 1 provides a general classification of the types of biomass in forestry, assuming that the primary product of the forest biomass is a log, where the utilisable portion already has a market.

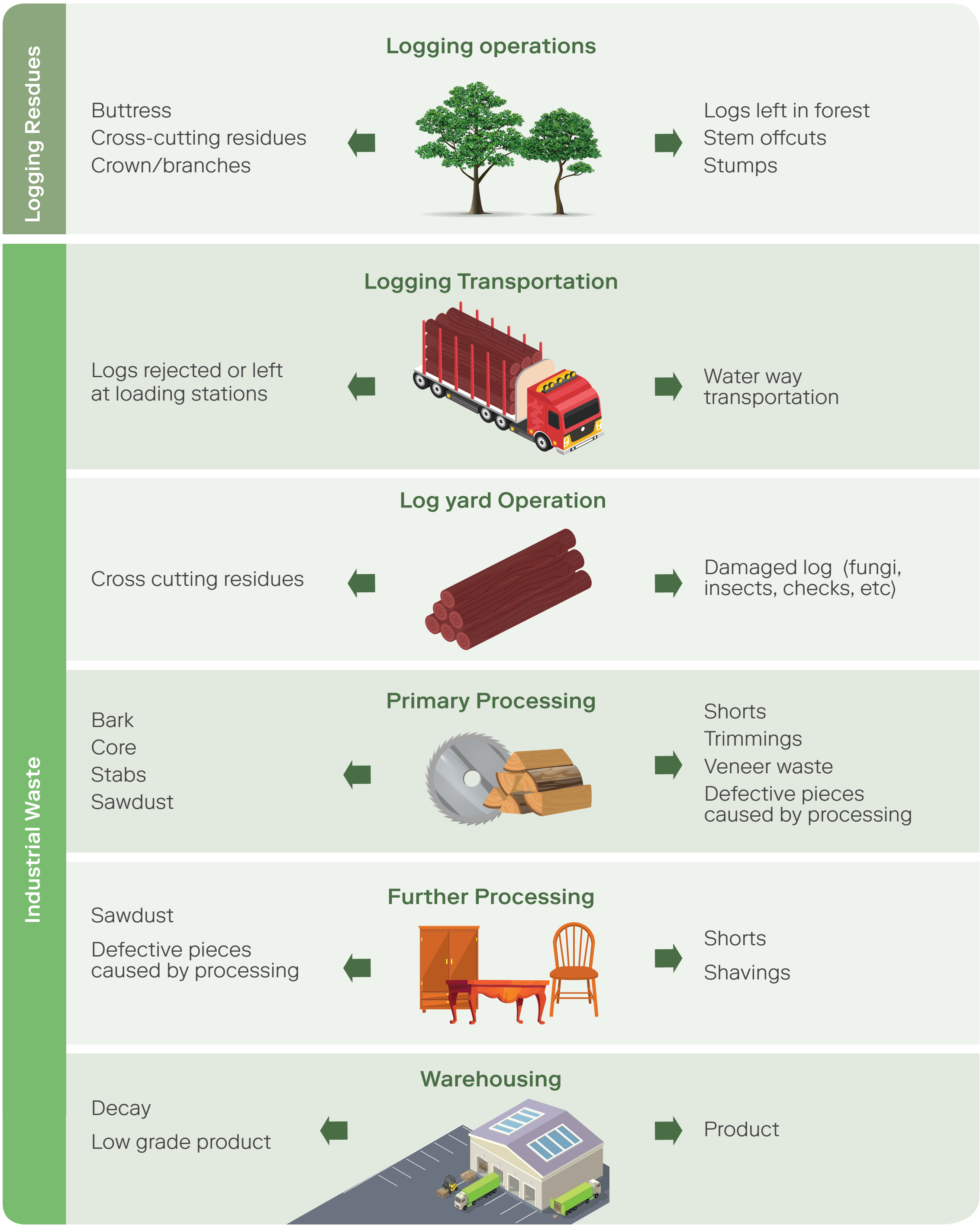
Figure 1: Categorisation of wood biomass residues



This report focusses on the secondary residues remaining after sawlog conversion. These consist of bark, sawdust, shavings and chips, and the solid pieces such as cross-cut ends and portions of the bole from other quality non-conformances. However, if a successful market for sawmill biomass waste is created in Uganda, there could be possibilities to supplement the sawmill waste with primary residues and tertiary residues. Black liquor is a by-product of the pulping process and, therefore, is not within scope of this report.

Figure 2 shows biomass waste throughout the forestry value chain. There is waste throughout and in a mature value chain there is focus on waste reduction throughout the value chain. If energy electricity generation from biomass waste is to be considered in Uganda, then it may be necessary to look wider than only the waste generated at sawmills.

Figure 2: Waste generated in the forestry value chain (Guyana Forestry Commission, 2012)



2.1. Global use of sawmill wood waste

Solid waste generation is directly related to the conversion efficiency of round wood to sawn timber or other final products. When one considers that between 45 and 55 percent (currently higher in Uganda) of the log input to a sawmill becomes waste, it is logical to wish to find a profitable use for it. Table 3 below summarises the average waste generation from sawmilling, plywood manufacturing, particle board manufacturing and integrated operations. Even though the reference is outdated, the Ugandan industry still has some distance to go to improve recoveries. Not all waste is available to use as some losses do occur in the process. However, even with improved recovery, much biomass will remain for alternative profitable use.

Table 3: Proportion of residues generated in selected forest products industries (FAO, 1990)

	Sawmilling (%)	Plywood Manu (%)	Particle Board Manu (%)	Integrated Operations (%)
Finished product (range)	45-55	40-50	85-90	65-70
Finished product (average)	50	47	90	68
Residues/Fuel	43	45	5	24
Losses	7	8	5	8
Total	**100**	**100**	**100**	**100**

All of this biomass waste, consisting of wood waste and bark, has a value, although it is produced in a large range of sizes with varying moisture contents. This is primarily comprised of the constituents found in Table 4. Table 4: Constituents of wood and bark waste at processing facilities (FAO, 1990)

Table 4: Constituents of wood and bark waste at processing facilities (FAO, 1990)

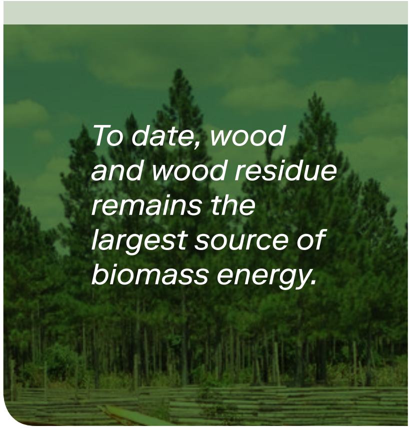
Constituent	Origin	Comments
Bark	10 to 22% of the total log volume depending on size and species	Can be a serious waste disposal problem unless it can be used as a fuel or removed prior to log preparation
Coarse residues	Slabs, edgings, off-cuts, veneer clippings, sawmill and particleboard trim	When reduced in size, make ideal fuel, especially when dry. They also have a resale value as pulp and particleboard furnish
Cores	From plywood peeler logs	Sold to sawmills or lumber or as pulp chips
Sawdust	Product of all mechanical wood processing operations, particularly sawmilling	Not good pulping material due to small size. OK for pellets and particleboard
Planer shavings	From dimensioning and smoothing sawn timber, plywood and particleboard with planers during the finishing stage	Ideal for particleboard production and are particularly good for heating kilns and dryers
Sander dust	Produced during the abrasive sanding of sawn timber, plywood and particleboard during the finishing stage	Due to its size and very low moisture content it is well suited for direct firing
Particleboard waste	Is negligible (5%) compared to that generated in other mechanical wood-based industries, as it is largely recycled within the production process	The waste from sawmilling and plywood manufacture make up a large part of particleboard furnish

2.1.1 The case study of North America

Focusing specifically on sawmills, Figure 3 shows the progression of the North American saw timber industry regarding improved log recovery and waste generation. During the 1940s, only 35 to 39 percent of the log was processed into sawn timber. Only 20 percent was used for energy or heating and 41 to 45 percent could not be used as could be regarded as true waste. By the 1970s, there was little improvement in log recovery, but the percentage of waste that could not be used had reduced to 23. This was due to markets being found for 23 percent of the biomass waste. By 1985, the log recovery had improved to 41 percent, with markets for 25 percent of the waste biomass and only 11 percent could be considered true biomass waste. By 2005, new technologies allowed 52 percent of the log to be recovered. Markets were found for 36 percent of the waste biomass and 11 to 12 percent was used for energy generation. Importantly, less than one percent was considered true waste. The situation is explained in more detail below.

Figure 3: Utilization of Harvested Wood by the North American Forest Products Industry, 1940 –2005 (Bowyer *et al.,* 2012)

1940	1970	1985	2005
35-39% Processed into lumber	37-38% Processed into lumber	41% Processed into lumber	52% Processed into lumber
20% Transferred to other facilities to use as raw materials	23% Transferred to other facilities to use as raw materials	25% Transferred to other facilities to use as raw materials	36% Transferred to other facilities to use as raw materials
41-45% Incinerated or landfilled	16% Recovered for energy production	23% Recovered for energy production	11-12% Recovered for energy production
	23-24% Incinerated	11% Incinerated	



To date, wood and wood residue remains the largest source of biomass energy.

The details of the improvements in the North American markets are important to understand, because these have input into the strategic direction of the Uganda biomass waste strategy. Some of the key factors were:

- **Waste obtains value:** Waste now had value. Sawmills chipped slabs and edgings for use in papermaking and found shavings increasingly in demand as a raw material for particleboard manufacture. Shavings were also used as animal bedding, although often provided free of charge as a means of disposal. New markets were also emerging, with rapid growth of hardboard production and establishment, in 1965, of the medium density fiberboard industry in North America.
- **Sawmill improvement programme:** The US Forest Products Laboratory began a Sawmill Improvement Programme (SIP) in 1973, with the goal of increasing saw timber yield. Mills were studied to determine yields obtained, and each phase in manufacturing was systematically examined for the purpose of identifying potential for yield improvement. By 1982, there had been a 15 percent reduction in log requirements to produce a given amount of lumber.
- **Sawmill technology development:** Parallel to the above, technology developments allowed even greater gains. Best Opening Face technology increased sawn timber yield from logs through computerised evaluation of log positioning prior to sawing. This technology along with the development of systems for electronic scanning of logs, precise positioning of logs during cutting, optimisation of trimming operations, and related technologies would eventually dominate North American production and improve sawn timber recovery. In addition, the concept of composite lumber products was born during this period, with patents issued (in 1968 and 1971, respectively) for wood structural I-beams, and for Laminated Veneer Lumber (LVL). These technologies allowed the production of large-size, high strength “lumber” from small diameter trees of species having relatively low inherent strength.
- **Plywood technology development:** Development of the retractable chuck lathe made it possible to economically peel small diameter logs to veneer. Introduced in the mid-1960s, this development led to the birth and rapid expansion of the southern pine plywood industry. A decade later, centreless lathe technology for producing veneer was introduced. This technology allowed the use of logs that previously could not be used in making veneer; this also allowed the peeling of a log down to the centre, thus increasing the volume of veneer that could be gleaned from a log.
- **Structural composite panels:** Driving advancements in structural plywood technology was the emergence of this new family of wood products. This allowed the economical use of small trees of relatively low inherent strength in the production of high-strength products that previously required large diameter logs of high strength species as raw material.
- **Finger-jointing and edge-gluing:** End-trimmings and other short sections of wood could be used to produce reconstituted sawn timber. This is a relatively high value product and the technique results in bonds that are as strong as the wood itself. Edge-gluing of narrow strips of edge trim from sawn timber production creates furniture panels or blanks for a wide range of applications. These edge and end trimmings would have been chipped or shredded for use in making paper, fibreboard, particleboard, or bioenergy.
- **Composite lumber:** In the early 1990s, a composite lumber, Parallel Strand Lumber (PSL) was developed and sold commercially in Canada. Oriented Strand Lumber (OSL), a related product, was also on the commercial market. The LVL and wood I-beams had by this point already achieved wide acceptance in homebuilding applications such as garage door headers and beams, and in commercial and industrial applications as a substitute for steel.

Lately, much attention has been turned towards the use of biomass residues and waste for bioenergy. This is primarily due to climate change issues raised by the continued use of fossil fuels, and biomass is part of the greener approach to energy. New products such as Cross Laminated Timber (CLT) is also gaining prominence. Global best practices, for example in the North America and Australian timber industry, are characterised by high recovery rates of at least 52 percent.

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2.1.2. Material flow from a modern sawmill

The material flow from these modern sawmills is described in Table 5 below, which represents a typical Nordic sawmill. The input is inclusive of bark, hence the slightly lower recovery rate. Wood chips is inclusive of solid pieces which have been comminuted (the processing of biomass into smaller average piece size). This gives a useful indication of the potential biomass available for other uses. The Ugandan proportions would be different as the recovery of sawn timber is lower, which would result in a higher wood chip percentage.

Table 5: Material flow in a Nordic sawmill

Input	Timber	2.12 kg dry (100%)
Output	Sawn timber	1 kg dry (47%)
	Sawdust	0.17 kg dry (8%)
	Wood chips	0.55 kg dry (26%)
	Bark	0.40 kg dry (19%)

In conventional sawmills such as described above, a substantial portion of the energy demand goes into the drying of the incoming timber from 55 - 60 percent moisture content to 18 percent moisture content in the sawn timber. This drying process has a high heat demand which is usually provided by combusting some of the biomass waste in a dedicated furnace. Bark usually forms a major share (85 percent) of this biomass used for heating, while sawdust and woodchips have approximately nine percent and six percent shares respectively. As indicated, the remaining shares of the biomass waste are usually sold to other biomass users such as wood pellets plants, pulp mills, and CHP plants (Nwachukwu *et al.*, 2018).

Figure 4: Utilisation of round logs in Uganda

35% - 41%

processed into sawn timber

Remainder given away or for very little value (also small amount of loss)

2.2. Ugandan use of sawmill wood waste

The Ugandan sawn timber industry “log” (Figure 4) looks slightly different. The recovered portion of the log is very low (35 percent for mobile mills and 41 percent for formal mills). No biomass waste is used for energy generation by the sawmill but there is also no waste that needs to be landfilled.

Little literature is available on recovery rates in Uganda and on the quantities of biomass waste and its proportions of bark, solid pieces, shavings and sawdust. Other examples from Africa have been explored to determine why the recovery is so low. Assumptions can be made regarding the quantities of biomass waste based on estimated recovery and the proportions provided in the section above. Information from pine sawmilling in Zimbabwe realised 40 percent sawn timber, 10 percent bark, five percent sawdust, and 45 percent offcuts and chips. The wood waste in this example is used as per Table 6. It is evident that the kilns are very important for the generation of heat and the simultaneous use of a waste material.

Table 6: Utilisation of various forms of sawmill waste using Zimbabwe as an example

Form of wood waste	Current utilisation avenues	Comments
Bark	Bought by dealers for onward sale to tobacco farmers, who use it as good manure for the tobacco seedbed. Also used for horticulture (seedlings and flowers).	A lot of bark is now being used given the growth of tobacco and horticultural activities.
Shavings	Collected by middlemen or farmers who use it as bedding for poultry.	Demand not so high. Shavings are the second most underutilised after sawdust.
Offcuts	All commercial sawmills send these to a chipper to produce chips that can be used as boiler fuel.	Not all offcuts get to be chipped in some sawmills. A good fraction is taken up by communities for firewood, furniture, building or fencing.
Chips	All commercial sawmills with kiln driers utilise most of their chips.	Buch sawmills have no kiln driers, therefore they heap sawmill wastes or burn them.
Sawdust	In some commercial sawmills it is mixed with chips for boiler fuel. Using sawdust alone would require specialised boiler designs.	Still 20 to 70% of the sawdust must be disposed, usually by incineration, along with some shavings and spilled chips.

Uganda is characterised by small scale sawmillers using basic Chinese circular saw technology. As indicated, the larger formal sawmillers use more modern, but still low technology equipment. The low level of recovery in many African countries has been found to be due to factors such as (Ogunwusi, 2014):

1. *Small log diameter, length, taper and quality*
2. *Kerf width of the sawing machine*
3. *Sawing variation, rough green-sawn timber size and size of dry dressed lumber*
4. *Product mix*
5. *Decision making by sawmill personnel*
6. *Condition and maintenance of sawmill equipment*
7. *Sawing method.*

In developing nations such as Uganda, there are inadequate downstream industries to utilise the waste. In many developing countries, waste-to-energy (WtE) applications are often limited to steam generation for kiln driers in larger sawmills and for certain industries such as tea drying. However, no kiln drying of timber currently takes place, resulting in all biomass waste needing to find an alternative market or be stockpiled or placed on landfill. Luckily, there are many individuals and organisations needing this waste; however, very few are able to pay any worthwhile amount for the biomass. The waste biomass is often given away to avoid the disposal costs.

Ugandan sawmills do not debark, resulting in the bark accompanying the offcuts and there being little current opportunity to sell the bark to specialised customers like nurseries. Because Zimbabwe has no end-use for the biomass waste beyond the kilns, they have a specific waste disposal problem. Ugandan sawmillers must not be lured into waste complacency by the abundance of end-users for the biomass waste - there needs to be a determined focus on waste minimisation and new markets and value adding.

Every sawmilling site visited in Uganda had no problems in selling or disposing of their waste. However, the questions remain of how to minimise this waste and whether there is a more profitable opportunity for using the remaining waste. The even bigger question is whether the current users of the waste will be able to absorb the additional waste from the ramp up in timber volumes over time.

Figure 5 to 8 shows examples of the different waste products being produced at different processing facilities in Uganda

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Figure 5 to 8: Solid log edgings, offcuts and short logs, and sawdust waste

3 . Properties and conversion factors of the available wood waste

3.1 Properties and characteristics of biomass waste

The utilisation of sawmill waste will depend on the original properties of wood from which it is derived. Table 7 provides the properties of wood waste and a summary of potential application. More detail on the applications are provided in the sections below.

Table 7: Properties of wood waste and potential applications

Physical and chemical properties of wood	Application
Stored chemical energy that can be converted into thermal, electrical or kinetic energy	**Combustion** of the carbon complex to yield heat which generates steam for heating or power generation.
	Gasification to obtain syngas to fuel a boiler or internal combustion engine for power generation. Syngas can also be used to produce biofuels.
	Pyrolysis to produce bio-oil or char products. Bio-oil is used to make fuels and chemicals while biochar can be used for applications such as a soil additive.
	Pelletising or briquetting makes a dense fuel for domestic heating or a small-scale power plant.
Source of organic polymers: Conversion into useful chemicals	Useful components can be extracted directly from wood species. Otherwise waste can be pyrolyzed or gasified to yield bio-oil and syngas respectively, which can be used as feedstocks in chemical synthesis.
Mechanical/structural properties of the fibrous cellulosic structure	Chips, fibres, shavings, sawdust are used to manufacture engineered wood products like panel boards.
	Soil erosion control, mulch.
Source of organic material for biological feed, water retention abilities	Soil additives in agriculture. Bark has special application in horticulture and seed beds.

However, the above physical and chemical properties are influenced by the characteristics of the specific type of wood residues. Therefore, it is necessary to examine each biomass waste type and determine what the range of characteristics can be. Table 8 provides this range of characteristics. This information is particularly important because it influences the costs of any planned biomass waste use. Most end users of biomass have specific requirements and deviations can result in cost penalties or expensive rejections.

Table 8: Range of characteristics of typical wood residues (FAO, 1990)

Biomass waste	Size (mm)	Moisture content (%)	Ash and dirt content (%)
Sander dust	Less than 1	2 - 10	0.1 - 0.5
Shavings	1 - 12	10 - 20	0.1 - 1.0
Sawdust	1 - 10	25 - 40	0.5 - 2.0
Bark (hogged)	1 - 100	25 - 75	1.0 - 2.0
Log-yard clean-up	up to 100	40 - 60	5.0 - 50
Forest residuals	needles to stumps	30 - 60	3.0 - 20

3.2. Conversion factors for wood biomass

Table 9 and Table 10 gives the conversion factors for different wood biomass. Many mistakes have been made in biomass quantity calculations due to inadequate understanding and application of the conversion factors. The important factors to understand and apply are when comminuting rounder wood into smaller material which can no longer be measured individually.

Table 9: Conversion factors for different wood fuels (FAO, 2015

Assortments	Round Wood	1m Long wood	Logs (25-30cm)		Wood Chips	
			Stocked	Loos	Fine	Medium size
	Soild m^3	Soild m^3	Soild m^3		Loos m^3	Loos m^3
1 m^3 round wood	1	1.4	1.2	2	2.5	3
1 stock m^3 of Im long logs	0.7	1	0.85	1.4	1.8	2.15
1 stock m^3 of logs (25-30 cm)	0.85	1.2	1	1.67	2	2.5
1 loos m^3 of logs (25-30 cm)	0.5	0.7	0.6	1	1.25	I.5
1 loos m^3 of fine wood chips	0.4	0.55	0.5	0.8		I.2
I loos m^3 of medium size wood chips	0.33	0.47	0.4	0.67	0.85	1

Table 10: Conversion factors for selected wood residues (FAO, 2015)

Conversion factors for wood residues:	
1 stock m3of bundle slabs	0.65 m' round wood equivalent
1 loos m'wood chips	0.33 nr' round wood equivalent
1 loos m''sawdust (~Smm)	0.33 nr' round wood equivalent
1 loos rn''shavings	0.20 mJ round wood equivalent
1 loos rn'bark	0.30 1115 round wood equivalent

3.3. An overview of biomass waste types in unprocessed form

This section provides additional information on the different types of wood biomass that is directly generated as a by-product to the sawn timber being produced.

3.3.1. Sawdust

Sawdust is the wood residue generated when a log is cut by a saw to make sawn timber. Sawdust is usually produced from a green log (not dry) and is fairly uniform in size and shape. Green sawdust has limited uses because of its moisture content and handling characteristics. Sawdust is often problem for smaller timber sawmillers who do not have kiln drying, including bush mills and Chinese sawmills. This can result in the aesthetic appearance of an area and release unpleasant odours. It can also be a fire hazard since piles can spontaneously ignite if conditions are correct. Fires in large piles can take up to three years to burnout as they continue to burn underneath. During the rainy season, outdoor heaps produce wood residue leachate which contain high concentrations of Dissolved Organic Matter (DOM) which are able to mobilise transition metals such as iron and copper from soils and contain toxic pollutants for aquatic life. Decomposing residues also encourage microbial or insect activity which can threaten nearby aquatic habitats by increasing Biochemical Oxygen Demand (BOD) levels in water bodies.

Sawdust (and shavings) from machining dry wood provide the best opportunity for marketing waste material. Uniform particle sizes (achieved by screening) are required by some users. For most uses, only fresh sawdust is acceptable. Sawdust (and shavings), when exposed to the weather, deteriorate rapidly, and lose much of their value. Mixed dry sawdust is acceptable for briquetting for fuel.

After drying, sawdust can be utilised via gasification, combustion, and pyrolysis processes to generate electricity, heat and oil. Sawdust also has desirable qualities for fibre composite manufacturing. Sawdust (and shavings) are often chosen for use because they are:

- **Absorbent:** for liquid spill clean-up, mud control, floor coverings, oil spills, sweeping compounds, or as a carrier of liquid manure.
- **Abrasive:** for hand soaps, metal polishes, fur cleaners, or sweeping compounds.
- **Bulky and fibrous:** for wood flour, cushioning, packaging, or lightweight cement aggregate.
- **Nonconductive:** for insulation.
- **Granular:** for textured surfaces.
- **A mulch:** for soil moisture retention and road embankments to prevent erosion and to aid the establishment of a permanent vegetative cover.
- **Suitable for compost:** In horticulture and mushroom production.
- **Suitable for food curing:** Meat curing.

Sawdust for mulch has become particularly popular for an increased focus on minimum tillage and organic agricultural, nursery and garden systems. It can decompose to produce organic manure. However, the soil should be tested before using this type of manure since some of these manures are highly acidic. The recycled sawdust can also be used for mulching garden paths. Another benefit of using sawdust as a mulching material is that it provides comprehensive soil cover, preventing soil erosion from taking place. Sawdust mulch can be very effective in suppressing weed growth.

The volume of sawdust produced depends on sawkerf thickness, product line (number of saw cut lines), and log diameter. For a given log size and kerf, a mill producing smaller sawn timber will generate more sawdust than a mill cutting large timbers.

The sawdust (and shavings) of the planing mill are dry and light, and easily removable by suction. This also keeps the air pure and reduces the fire hazard. The pneumatic conveyor consists of a network of metal tubes, with smaller branches to each saw or planing machine. The tubes link up with a large central tube, which sucks and blows the material by means of a powerful fan to a cyclone dust catcher at the top of the fuel bin. The dust catcher separates the air from the solid material, which then drops into a bin. Sawdust and shavings which fall onto the mill floor are swept through floor openings, which are connected to the suction system. Figure 9 shows a pile of sawdust collected from various sawmills for processing into wood pellets. Figure 10 shows sawdust produced from a small sawmill. Because of the soil (and other) contamination, it is difficult to use this sawdust for much beyond animal husbandry.

Figure 9 and 10: Sawdust ready for processing into pellets or briquettes; and low quality sawdust from smaller sawmills

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In Uganda, sawdust is only collected by air at one site (Busoga Forestry Company). At all other sites, sawdust is collected by hand and loaded onto trucks.

3.3.2. Solid pieces

Solid pieces biomass such as offcuts and chunks are created at several steps in the lumber production process. Figure 11 shows typical solid offcuts from sawmills ready to be chipped for other purposes. Figure 12 to 14 shows the sections of logs that can remain due to quality non-compliances, incorrect log lengths and poor log length decisions. Some of these lengths may be suitable for uses such as engineered wood, pallets or small wooden boxes.

Figures 11 to 14: Sawmill offcuts

3.3.3 Bark

Bark is the outermost part of woody stems and branches and constitutes approximately 9 to 15 percent of a log's over-bark volume. Bark volume varies with species, position on the tree, and tree size. Average bark volume can be estimated either as a percent of total volume (including bark) or as a percent of wood volume.

Bark of certain species has been used to produce tannins, dyes, resins, flavourings and medicinal products. Bark is often contaminated by soil during harvesting and handling. Bark is used in mulching or as a soil amendment. Bark can also be used as a fuel source. Approximately 10 tons of completely dry bark is the equivalent of nearly seven tons of coal. Bark is also used in building materials such as fibre and particleboard and for insulation board because it conducts heat less readily than wood. Bark is commonly sold to horticultural companies. Sawmills often burn pine bark in boilers for kiln operation. Ring debarkers are commonly used in sawmills. Logs are debarked before entering the wet mill.

Figure 15: Ring debarked pine sawlogs

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3.3.4 Planer Shavings

Shavings usually come from air-dried or kiln-dried wood. This is produced when dried sawn timber is smoothed and shaped into its final form in a planer mill. Shavings differ from other sawmill wastes in that they are produced from dried lumber and have a higher energy content. The volume of planer shavings obtained depends on the fraction of sawn timber output that is planed and the difference between the rough and surfaced dimensions.

The uses of planer shavings are the same as sawdust.

3.4. An overview of biomass waste types in processed form

This section provides additional information on the different types of wood biomass that is produced as a result of further processing of the sawmill by-product biomass.

3.4.1 Wood chips

The quality of wood chips is determined by water content, tree species, the quality of the wood itself, particle size and the amount of dirt (e.g. stones, soil and plastic). These parameters have an important influence on caloric value, bulk density and share of ash. Usually only low quality and small diameter round wood, forest residues and wood wastes are used. The biggest disadvantage of wood chips is their lower energy density, which is caused by the lower bulk density of this type of fuel. All of this will influence the size of storage needed.

Woodchips seem to be a simple to understand form of wood biomass, but closer examination reveals many different types of chipper technologies and brands and many specific quality requirements of the end user. Wood chips are not a primary waste product of a sawmill. Wood chips need to be produced from other sawmill biomass waste.

Pulp chips are obtained primarily from whole logs, sawmill slabs, sawmill edgings, sawmill trimmings, veneer mill scraps and peeler cores, depending on availability. This is because pulp chips generally need high consistency in terms of size dimensions and clean fibre (little bark, ash and other contamination). Figure 16 shows the good quality material that can be produced from the waste that remains after sawing debarked pine. This can be used in many applications.

Wood chips are sold in bulk cubic metres or absolute dry mass (tons). One bulk cubic metre corresponds to 200 kg to 450 kg, depending on the respective wood type, size and water content. The net caloric value of one bulk cubic metre is between 630 kWh and 1 100 kWh, depending mostly on water content. Table 11 shows how water content influences the bulk density and calorific value of wood chips. Because of this, wood chips should be bought and sold based on weight and water content (FAO, 2015).

Table 11: Example of the influence of chip moisture content on calorific value (FAO, 2015)

Water content	Bulk density in kg/m^3				Net calorific value in kWh/ loosem^3			
In %	Beech	Oak	Pine	Spruce	Beech	Oak	Pine	Spruce
20 %	277	280	216	188	1 048	1 062	867	759
30 %	316	320	246	216	1 022	1 034	846	740
40 %	369	374	287	251	986	998	818	716
50 %	443	449	345	302	936	948	780	682

Wood chips are sold in bulk cubic metres or absolute dry mass (tons). One bulk cubic metre corresponds to 200 kg to 450 kg, depending on the respective wood type, size and water content.

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3.4.2. Hog Fuel

Hog fuel broadly refers to a mix of bark, sawdust, and planer shavings that have been comminuted using a grinder. The proportion of each depends on the sawmills internal wood biomass needs and market demand for biomass of a specific category. If an estimate of the contents of the hog fuel is needed with a high degree of confidence, samples of the hog fuel need to be analysed.

3.5 Heating properties

The use of wood biomass to generate heat is an important part of the success of modern sawmills where waste biomass is used for kiln drying and as a potential fuel for internal or external uses. Therefore, heat and energy processes need to be fully understood if sawmills are to determine their future energy requirements and the fuel related aspects. Besides the generation of secondary energy, heat and energy is used in the following production processes in Table 12. Plywood and particleboard use more energy in the production process than kiln-dried sawtimber.

Table 12: Heat applications and specific energy requirements (FAO, no date)

Process/product	Heat application	Range of process energy requirement (GJ/m^3)
Sawtimber	Timber drying	Air-dried – 0.06 to 0.20 Kiln-dried – 1.00 to 2.85
Plywood production	Log conditioning, Glue preparation Veneer drying, Hot pressing	4.00 to 7.50
Particleboard production	Particle drying, Resin preparation, Hot pressing	2.00 to 4.50

Table 13 provides information on the broad applications of different heating mediums

Table 13: The selection of appropriate heating mediums (FAO, 1990)

Heating medium	Possible applications
Hot air – for direct drying of:	Sawn timber.
	Plywood veneer.
	Particleboard furnish.
Hot water and thermic oil – for indirect heat supply for:	Log conditioning.
	Sawn timber and veneer drying.
	Glue and resin preparation.
	Hot pressing of ply and particleboard.
	Space heating.
Steam – for above applications, and:	Transmission power to the sawmill through the use of a system of line-shaft and belt drives.
	To directly drive plant, such as boiler feed water pumps, induced draft fans, large air compressors, etc., by way of small steam turbines.
	Steam which is excess to the mill's requirements may be sold to neighbouring consumers for industrial, commercial and community use.
	Produce electricity by way of a turbine-generator to help meet the power demand of the integrated complex.
	In the case of non-integrated sawmills and plywood plants, in which their residue production far exceeds their actual heat energy needs and market demand, consideration may be given to on-site power generation to meet their own requirements, with the sale of the surplus to the public utilities.

Figure 16: Chipped debarked offcuts

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Table 14 examines some of this information from the end-user requirements. It is clear the opportunities are starting to emerge for those sawmillers that have scale within the biomass waste volumes.

Table 14: Solid biomass fuel supply chain options according to end-user sector (Alakangas and Virkkunen, 2007)

End-user and average annual fuel consumption	Biomass fuel	Quality requirements	Technology for energy conversion
Households (<50 kWh) Annual fuel consumption <30 MWh	Wood pellets	Good mechanical durability Low ash content	Pellet boilers Pellet stoves
	Wood briquettes	Low ash content, packaged	Stoves and fireplaces
	Wood chips	Low moisture content, <35w-%	Stoker boiler
	Log wood	Low moisture content, 15-20 w-%	Stoves and fireplaces, boilers
Farms, large buildings (<1 MWh) Annual fuel consumption <3 GWh	Wood chips from whole trees or delimbed trees	Low moisture content, <35w-%	Stoker burners Grate firing
	Straw bales	High quality bales, low moisture content (<18w-%)	Grate combustion also whole bales
	Wood pellets	Good mechanical durability Low ash content	Pellet boilers Stoker boilers
District heating plants (<5 MWth) or power plants (<5 MWe) Annual fuel consumption <35 GWh (DH, CHP) or 85 GWh (power only)	Wood chips from forest residues or whole trees	Moisture content usually <40w-%	Grate combustion Fluidised bed combustion Gasification
	Straw or energy grass bales	Moisture content <20w-%	Cigar combustion Grate combustion, also whole bales
CHP and power plants (>5 MWe) Annual fuel consumption from 85 GWh to several TWh	Wood fuels from forest residues, stumps	Boiler and handling equipment-based requirements	Usually co-firing with coal or peat Fluidised bed combustion Gasification
	Wood or straw pellets	Boiler and handling equipment-based requirements	Co-firing with coal Pulverised combustion
	Herbaceous biomass (straw or energy grasses)	Big bales, moisture content <20w-%	Cigar combustion Grate combustion Fluidised bed combustion Co-firing with coal
	Olive residues	Boiler and handling equipment-based requirements	Grate firing Co-firing with coal in fluidised bed boiler

4. Strategies to minimise wood waste and improve waste value

The value of sawmill biomass wood waste varies depending on the quality, the number of potential applications and the number of individuals and organisations attempting to access it. If wood waste from a sawmill is used for on-site energy and replaces other energy sources, it is of high value, as it avoids disposal costs and purchasing other fuels. If the wood waste is sold for non-energy purposes or for energy purposes to other users, its value decreases considerably, unless sold for reconstituted board production or pulp. To optimise the profitability of wood waste, the individual sawmill will require a detailed study as costs and specific biomass factors vary between regions and are sensitive to handling and transportation requirements (Nielsen *et al.*, 2002).

However, the most valuable waste is normally that which is not produced. In other words, if waste can be minimised in the sawmilling context, it means that more of the high value primary product is being produced. Figure 14 shows the waste management hierarchy. Therefore, the first aim of the sawmill is to reduce the amount of biomass waste being produced (i.e. increase log recoveries). Thereafter, the mills need to reuse as much of the material as possible (e.g. resawing of edges). Only then does one attempt to recycle and recover waste, because the costs of doing this are normally considerably higher than reducing or reusing. The last option is disposing, because this can be very costly, hinder production, be a fire risk, have poor aesthetics and be an environmental risk.

Figure 17: The Waste Hierarchy (University of Exeter, 2017)

Options for recycling of wood waste can exist using waste as inputs for secondary products in other industries or as a fuel for heat and power generation. The best recycling options depend upon local market conditions and the size (e.g. sawmill chips or sanding dust) and dryness of the material. However, the larger-dimensioned wastes are usually more profitably utilised as fibre by-products than fuels. The value and disposal options for sawmill waste are usually better if the waste is bark-free, which may necessitate log debarking before primary breakdown (IFC, 2007).

Figure 18: Reducing overall wood waste (Sygut, 2016)

Cleaner production should also be considered as it is a management strategy aimed at reducing the losses associated with wasted energy and raw materials. As per Figure 18, cleaner production focuses on waste prevention and not the way of its utilisation. The sawmill needs to examine each of the contributing bubbles to effect waste minimisation.

Technology change introduces technology that is more efficient, produces better quality, is less polluting, uses all resources in a more sustainable manner and reduces wastes in a more acceptable manner.

4.1. Opportunities for waste minimisation and use

Five categories of improvement opportunities for waste have been identified. These are good operating practices, technology change, change in input material, change in product, and waste recycling and reuse/recover (Eshun, 2012).

4.1.1. Good operating practice

Good operating practice is a strategic management term for good production practices. Operating practices need to be identified which can be implemented at relatively low cost, resulting in a good return on investment in a relatively short time. This includes many procedural changes that can easily be implemented. The main components of good operating practices are: waste management, cost-accounting, inventory management, procedural scheduling, material handling improvements and loss prevention, waste stream segregation, and personnel education, communication, and involvement (Eshun, 2012).

4.1.2. Technology change

Technology change introduces technology that is more efficient, produces better quality, is less polluting, uses all resources in a more sustainable manner and reduces wastes in a more acceptable manner. Waste minimisation technologies can however be capital intensive and expensive. Reduction strategies involving industrial technology and process-specific changes require a good understanding of the details of the industrial operation. Categories of technological changes to achieve waste reduction include process changes, equipment, piping or layout changes, and additional process automation (Eshun, 2012). Figure 19 and 20 shows the higher-level technology used at BFC to optimise sawn timber recovery from the log.

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Figure 19 and 20: Laser technology to improve recovery

The use of modern equipment and trained staff can increase efficiencies by up to 70 percent. Technical (and operational) measures to increase wood conversion efficiency and minimise wood waste include (IFC, 2007):

- Optimizing primary log breakdown technology and techniques, e.g. consideration of bandsaw or framesaw use and use of crosscut before rip cut to increase usable wood volume;
- Use of log scanning equipment to establish the optimum cutting pattern, based on the raw log dimensions and the product mix required for the log. Computerized real time sawing algorithms are available for this purpose;
- Use of scanning technology to maximise utilisation of sawn boards and cutting according to predetermined algorithms;
- Use of finger-jointing in downstream operations to combine scrap or low value wood into products. Use of large dimension waste products in glued laminated boards (glulam);
- Operator training and monitoring to ensure awareness and implementation of measures to improve conversion, such as:
  1. Log measurement and categorization by diameter, with framesaw blades spaced to appropriately maximize conversion efficiency
  2. Logs fed perpendicularly into framesaw blades
  3. Minimisation of the use of hooks for movement of logs or boards, to avoid damage to the product.

4.1.3. Change in input material

Input material change is the means of finding environmentally friendly and economically low alternatives to material input in production (Eshun, 2012). However, with sawlog processing this can be difficult as the mills are often dependent on what their forests are producing. Three main options exist:

- With vertically integrated companies, improved log input size and quality from own forests through improved forestry genetic programmes (good genetic material, site species matching and tree selection processes to improve quality during tree breeding), improved silvicultural practices (optimal tree size, less growth stresses and good practices such as pruning), improved fire protection (reduced non-usable portions of the tree or rejects due to carbon) and improved harvesting activities (minimises waste and breakages).
- With sawmills which procure logs, better quality management to prevent non-compliant logs from being purchased. Sawmills should also distribute very clear log quality parameters to potential suppliers of logs as well as their procurement personnel.
- With sawmills with outgrower schemes, extension and technical support should provide good guidance as to the practices which improve tree growth and resultant log quality. The support may even include the provision of better genetic material (seedlings).

4.1.4. Change in product

The amount of waste generated from the manufacturing of a specific product may be reduced by the substitution of one product for another or altering the composition of the product (Eshun, 2012). This is usually difficult to achieve in plantation forestry as the log input into the sawmill and the sawn timber demand from the sawmill can be difficult to manipulate.

4.1.5. Waste recycling and reuse

Waste recycling is the use, reuse or reclamation of all or part of wastes after they have been generated. Recycling is primarily considered to reduce the use of, or prevent the increase in demand for, new round wood supplies. Recycling has the additional benefit of avoiding wastes associated with primary production. Recycling and reuse option are often high priority options when log supplies are limited (Eshun, 2012). An abundance of cheap log supplies can make processes inefficient which can increase waste.

The best options are to implement technological changes, good operational practices and recycling measures. These selected wood waste minimisation options also have the potential to address process execution/management-based factors and technological based factors which are major causes of wood waste in the timber sector (Eshun, 2012).

4.2. Specific options for biomass wood waste reduction and use

Considering the information presented in Section 3, the wood waste utilisation and disposal options are summarised as follows:

- Use of bark-free wood chips and other wood waste as a raw material input for the pulp and paper or board-making industries. Particleboard manufacturers may also accept sawdust and chips with bark;
- Use of wood and bark chips as mulch for gardens, highway verges, and agriculture.
- Use of sawdust and wood shavings for animal bedding;
- Production of nursery growing media from bark;
- Use of wood waste as fuel to generate heat/power for the facility's space heating and process needs, and/or for export;
- Production of fuel pellets and briquettes;
- Manufacture of charcoal and other char products.

If all other feasible and beneficial uses have been considered, then wood waste should be disposed of through controlled incineration. Allowing the waste to accumulate in a dump or landfill at the sawmill is not desired.

The subsections below provide more detail on some of the specific focus areas within the Ugandan sawtimber industry. The use of wood for energy is, however, discussed as a separate heading as it is more involved and complicated, and holds much potential for the Ugandan plantation forestry industry.

4.2.1. Minimising saw kerf

A thinner sawblade produces a narrower kerf, which means a larger number of boards will be produced from the same log. It will, eventually, produce a somewhat larger amount of chip, but a significantly smaller pile of sawdust. Thinner sawblade options are available from reputable saw suppliers, but often need to be incorporated into a new process that includes new sawing technology. Figure 21 demonstrates how more board can be cut.

Figure 21: A narrower kerf will produce more board out of the log (Sandvik, 1999)

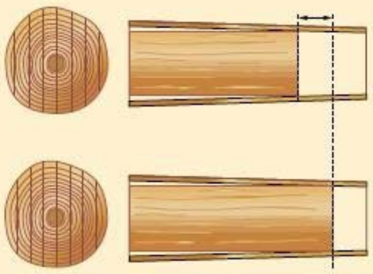

Figure 22: Thinner sawblades improve the economy of the sawing operation (Sandvik, 1999)

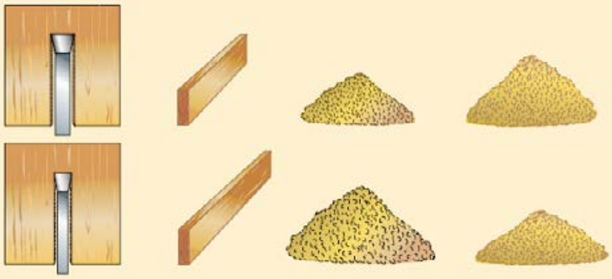

Figure 22 shows how thinner sawblades produces more boards and more chip, but less sawdust and will improve the economy of the sawing operation.

4.2.2. Densification – wood pellets

Wood pellets are usually made from clean conifer sawdust and planer shavings. The wood must have been debarked prior to passing through the sawmill. Sawdust of hardwoods can be mixed with that of softwood, but successful production of hardwood pellets without binders is more difficult. If at all possible, dry sawdust and shavings (less than 15 percent moisture content) are used, because then the drying process is not required. If the sawdust is wetter, a drying process is needed before pellets can be pressed (Kofman, 2007b). To give consumers of pellets confidence in their use, standardised and certified pellets are recommended.

4.2.2.1. The pellet manufacturing process

Table 15 gives an overview of the process for pellet manufacturing and the technology used within the process.

Table 15: The pellet manufacturing process in terms of technology (Sygut, 2016)

	Process	Description
1	Storage	Raw material for the production of pellets in the form of shavings and waste after production from sawmill is stored in a designated and prepared place on a raw material storage yard.
2	Transport	Wheeled loader.
3	Drying the sawdust	Belt dryer equipped with heat exchangers which generate the appropriate drying temperature. Sawdust humidity after drying should be less than 10%.
4	Purification	Removal of foreign bodies from the shavings, such as sand and metals using a solenoid mounted on the belt and screens.
5	Milling	Process of homogenisation of sawdust pieces, which takes place in hammer mills equipped with the ankle to shredding material.
6	Filtering	Dust resulting from the previous grinding operation is removed and retained in filter bags.
7	Pressing	1 to 2% water is added in the form of vapor. Dust is heated to 70 °C for easier formation of granules and then compressed by a piston through a die.
8	Granulation	The raw material is subjected to high pressure and moulded into granules of a fixed size depending on the diameter of the holes in the die and is cut off to the desired length using a knife.
9	Cooling	Cooling pellets to ambient temperature takes place in a cooling device which uses compressed air to enhance the stability of granules.
10	Dust removal	By means of screens which separate dust and small particles from the finished product. The waste from this operation is returned to the beginning of the recyclable production process.
11	Packaging	Takes place on the automated line where pellets are packed and weighed.
12	Transport	Transport of pellets into a warehouse for finished products.
13	Storage	Finished product packed in bags is stored in the warehouse or in the open air under the protection so that moisture does not penetrate. Pellets are stored in bulk in large silos at 15 to 30 °C and proper humidity.

Figure 23 to 26 shows some of the equipment used in the pelletising.

Figure 23 to 26: Sawdust drying, dry sawdust storage, pellet press, pellet storage

4.2.2.2. Wood pellet characteristics and specifications

Pellets have a high energy properties and low moisture content. It is environmentally friendly as the production of pellets does not cause any additional sourcing of trees if waste is used. It is a clean fuel generating little ash and is easy to handle and transport. Low CO2 emissions are produced during combustion. Combustion may be in a maintenance-free boiler. They are not harmful to humans and do not cause allergies (Sygut, 2016). Table 16 provides the most common specifications and characteristics of wood pellets.

Table 16: Wood pellet specifications and characteristics (Sygut, 2016 and Kofman, 2007)

Specification/ Characteristics	Description
Dimensions	Most pellets produced as fuel are either 6 or 8 mm in diameter and about 3 to 4 times the diameter in length
Moisture content	8 to 10%
Ash content	<0.7%
Bulk density	This measures the weight of a certain volume of loose wood pellets and should be in the order of 650 kg/m3 loose volume. If the weight is too low, the pellets have not been compressed enough which might result in increased amounts of fines.
Calorific content	~14.19 gJ/Mg
GHG emissions	The GHG emissions of wood pellet derived electricity in the U.K. were estimated as 227 kgCO2e per ton fuel consumed, equivalent to 0.13 kgCO2e/kWh. This emission rate can be much lower, on a case-by-case basis, at locations where waste heat recovery is practical (i.e., combined heat and power systems (Boundless Impact Investing, 2020).
Mechanical durability	This is a measure of how well the pellets can stand handling. Every time pellets are handled, some of them break and all of them show some wear, which will increase the amount of fines. A durability of 97.5 should be required.
Amount of fines	Fines hinder pellets from tumbling down to the in-feed auger, thus disturbing fuel feed to the boiler. Boilers are adjusted to burn wood pellets, but if fines arrive in the burning chamber, the flame may get too hot as fines particles burn faster than pellets. In the worst case the ash might sinter, which means that the burner must be cleaned after it has cooled down. The amount of fines should preferably be declared for each bulk delivery, and is measured at the final point in the factory production chain. Fines should preferably be less than 1% by weight. Pellets are usually screened before leaving the production facility. Pellets in bags tend to have less fines than those delivered in bulk. Pellets stored in silos can have an increased amount of fines on delivery.
Binding agent	If the proper feedstock, such as conifer sawdust, is used, it should not be necessary to use a binding agent to make wood pellets. However, a binding agent is often used where broadleaved species are the material. If an agent has been used, the kind and amount should be declared.
Packaging	Pellets are packed in bags of 15 kg for small scale users or big-bag packaging of 1 000 kg or 1 200 kg. They can also be stored and transported in bulk for large scale users.
Storage	Pellets should be stored dry and free from moisture. Atmospheric moisture should be kept low and the floor surface kept dry.
Transport	Pellets should be protected from the weather during transport, especially against humidity. Pellets can also be transported in bulk tankers suitable for transport in a loose and granulated form.

4.2.2.3. Pellet energy values and GHG emissions

When considering the entire life cycle, electricity generated using wood pellet-based biomass emits far less GHG emissions per kilowatt-hour than coal (87 percent reduction) and natural gas based (71 percent reduction) electricity. Reports showed that wood pellet electricity's GHG intensity was somewhat higher than rates commonly reported for wind and solar technologies. However, each was far below the emission rates for coal and natural gas. Based on estimated and reported values, a

1:1 replacement of coal electricity with wood pellets would yield an 87 percent% GHG emission reduction using wood pellets, a 92 percent reduction using solar electricity and a 97 percent reduction using wind turbine generation (Boundless Impact Investing, 2020).

4.2.2.4 Estimates of pellet production costs

The literature has varying costs for pellet production, even for similar design assumptions such as the production country and type of feedstock used. Optimisation strategies result in trade-offs between cost components and impacts vary strongly depending on the pellet plant location. Depending on location, costs of feedstock transportation to pellet plants varies between 9 and 54 EUR/ tonne pellets. Cost calculations based on actual prices paid for feedstock by US pellet plants, for round wood/ pulpwood and sawmill residuals, result in 8 EUR/ tonne pellets higher costs for pulpwood. Using residues instead of pulpwood can save an additional 3 EUR/ tonne pellets in reduced capital costs for grinding and drying equipment and can realise savings from unquantified operational expenditures. The economies of scale vary between a cost penalty of 46 EUR/ tonne and a cost saving of 22 EUR/ tonne pellets for larger pellets plant. The average calculated costs for a 500 000 tonnes per annum pellet plant was EUR136/ tonne pellets (2017), compared to EUR 143/ tonne pellets (2017) for a 50 000 ton per annum pellet plant. The most important components across the entire chain are feedstock costs and pelletising operating costs, including additional feedstock use for drying (Visser *et al.,* 2020).

4.2.2.5 Summary of pellet potential

Although pelleting produces a product with excellent handling and storage characteristics, with four times the energy concentration of woodfuel, thus greatly reducing transport costs and improving boiler efficiency, it has been found that high capital investment in the processing plant and operating costs only prove economically attractive if transportation distances of the fuel exceed 250 km from the source of the raw material, and is normally not warranted for site-generated fuels (FAO, 1990).

4.2.3 Charcoal

Charcoal is traditionally produced in earth-pits or earthen, brick or steel kilns in batches of 1 to 5 tonnes (Foley, 1986). Fuelwood is gathered and cut to size and placed in an earth-pit or an above-ground kiln. When the pit or kiln is fired, the fuelwood heats up and undergoes pyrolysis, a process that may take a few weeks. About half of the energy in the fuelwood is typically lost in the process but the charcoal produced has higher energy content per unit mass (FAO, 2010). This low efficiency method is clearly not suitable for sawmill biomass waste.

The efficiency of current charcoal production across the globe varies considerably. Efficiency is dependent on many factors, such as kiln type, moisture content, species, wood density, the arrangement of the wood inside the kiln, the skill and experience of the producer, and even the climatic conditions. The earth-pit method has a maximum efficiency of 15 percent. Kilns usually have higher yields, averaging around 25 percent on a wet or air-dry weight basis (FAO, 2010).

Charcoal retains 40 to 60 percent of the energy content of the wood feedstock and most of the remainder is released as gases. In most traditional methods, the recovery of these by-products is not economically feasible. Nevertheless, charcoal has a higher heating efficiency than wood and some of the energy lost during manufacture is offset by a reduction in the energy needed to transport it to markets (FAO, 2010). In recent years, more efficient charcoal production methods have been developed to meet environmental and energy norms and to improve carbonisation yields. Nevertheless, charcoal production is not deemed to be viable for sawmill wood waste, especially those processing pine. The efficiency levels are too low and the biogas is not captured.

4.2.4 Densification-briquettes

Briquetting is a process of binding together pulverised materials into a solid block of compressed material under pressure, often with the aid of a binder such as cassava starch. Briquettes are generally formed by forcing dry sawdust or shavings through a split cylindrical die using a hydraulic ram. The exerted pressure, approximately 1 200 kg/cm2, and the resultant heat generated bonds the wood particles into “logs” (FAO, 1990).

Wood briquetting is usually regarded as a high-grade source of energy due to its high heating value which is four times the energy concentration of wood fuel (FAO, 2001). Briquetting also has lower transportation costs, especially when the distance is less than 250 km from the source of raw material. Briquette production is shown in Figure 27 and 28.

Figure 27 and 28: Briquette production from sawdust at Green Resources, Tanzania

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4.2.4.1. Manufacturing wood briquettes

Gemco Energy (2020) describes the basic process to manufacture briquettes from wood raw materials:

- **Step 1:** Grind larger wood raw material into sawdust. The sawdust itself does not need grinding. If the sawdust contains moisture, it will need to be dried by a dryer. The dryer can decrease the water content to 8 – 16 percent. Dryers are often used in large briquetting plants. For small briquetting lines, air drying can be sufficient if the material can be spread on a clean and dry location.
- **Step 2:** The sawdust is placed into the wood briquette machine. This step is often done by an elevator that can feed the sawdust into the hopper evenly. Smaller briquette machines can be fed manually, but the feeding speed must be correct to prevent blockages. There are two types of hot sale wood briquette machines: one is mechanical stamping wood briquette machine that can make both thin pellets and thick briquettes (only the mould is different and changeable). The other is a screw briquette machine which is often used to make high quality charcoal briquettes or wood briquettes from sawdust. There are also other machine types available.
- **Step 3:** After briquetting, the briquettes may be cooled for storage and packed for sale.

Table 17 gives a summary of the main features of briquette technologies available to guide options based on production capacity.

Table 17: Summary of features of briquette technologies (FAO, 2018)

Technology	Efficiency	Production capacity (kg/h)	Operating hours per year	Equivalent annual production (tonne/yr)	Production mode
Agglomerator (manual technology)	95%	4	2 400	9.6	Manual
Screw press	95%	40	2 400	96	Mechanised
Roller press	95%	400	2 400	960	Mechanised
Piston press	95%	4 000	2 400	9 600	Mechanised

Figure 29 shows that overall the production costs for briquettes per unit of energy produced are higher than the cost for charcoal. The production costs of briquettes from an agglomerator (manual technology) are twice as high as the production cost of charcoal from an oil drum per unit of energy. If both set-ups are paying the same amount for feedstock collection and transportation, this result can be attributed to the differences in technology level which causes differences in capital investment needs and feedstock use (FAO, 2018).

Figure 29: Comparison of production costs per energy unit of charcoal and briquettes technologies (FAO, 2018)

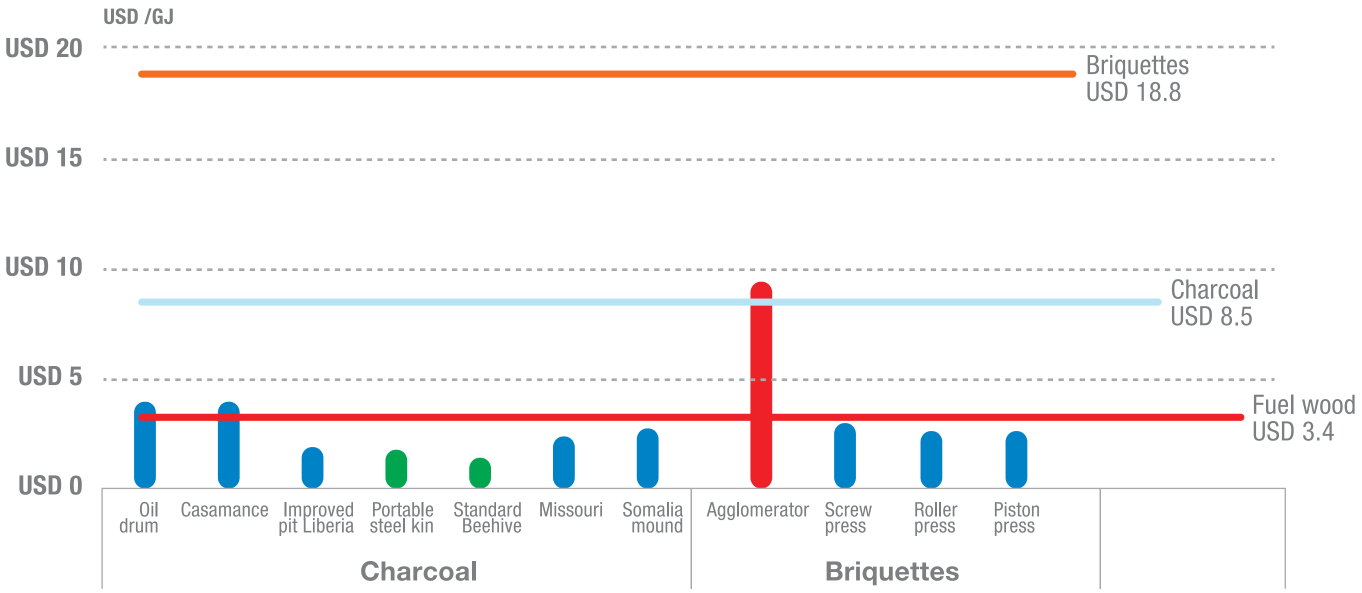

Figure 30 below provides a comparison of investment per production capacity for briquettes and charcoal technologies (FAO, 2018)

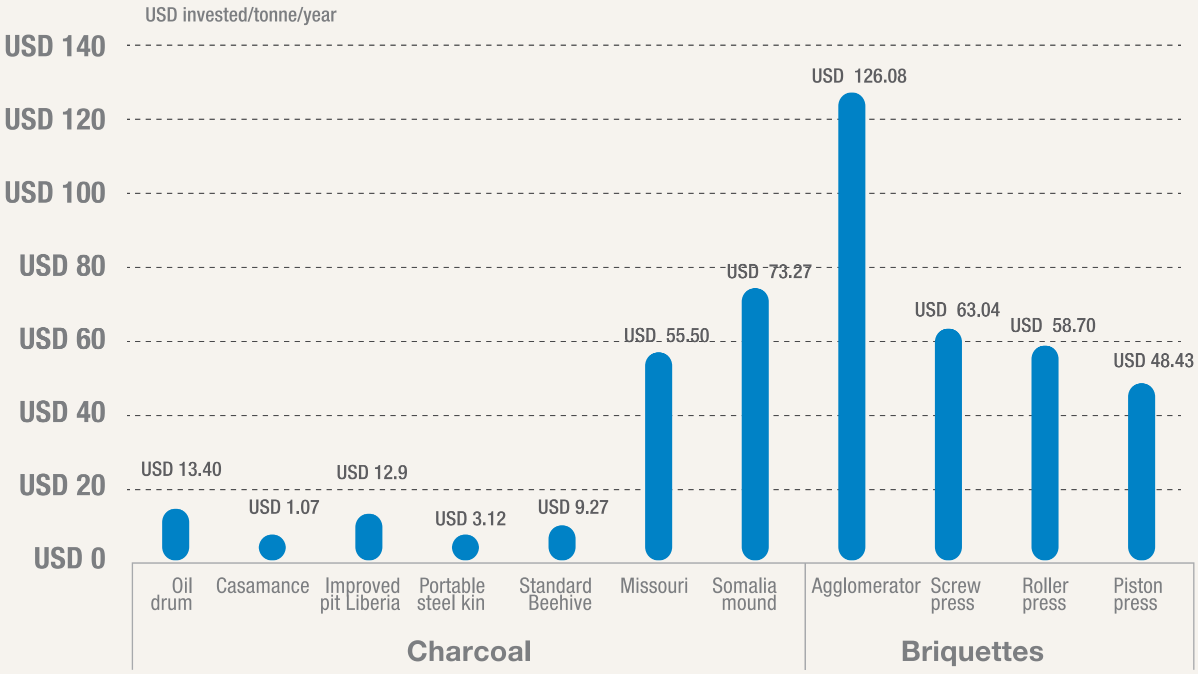

Figure 30: Comparison of investment per production capacity for briquettes and charcoal technologies (FAO, 2018)

As increased formal wood processing takes place in Uganda, the amount of waste generated will allow for more detailed investigations into the production of wood briquettes. As wood fuel for household energy becomes more scarce in Uganda, this product could receive much interest. The wood would be available in a centralised location at a wood processing plant and be produced in a dense format suitable for long distance transport. The cost of the raw material would also be relatively low and is energy rich.

For a more comprehensive understanding of the entire briquette manufacturing process, please access *http://www.fao.org/3/T0275E/T0275E00.htm#Contents,* with the document titled "The briquetting of agricultural wastes for fuel".

4.2.5. Engineered wood

Engineered wood is the term given to materials derived from smaller pieces of wood that are bound together by a variety of glues, resins, and other chemicals to form wood like products. Examples of engineered wood products are oriented strand board, glue laminated timber, laminated lumber, wood 1- joist and finger jointed studs. The most important of these is Medium Density Fiberboard (MDF) which is formed by breaking wood residues into fibres in a defiberator and mixed with wax and resin binders. These are converted into panels by applying high temperature and pressure. The MDF is denser than plywood and can be used in similar applications.

Cross laminated timber, crosslam, CLT, X-Lam, BSP, mass timber and multiply are common names for sheets, panels, posts and beams made of glued boards or planks layered alternately at right-angles. It is unlikely that CLT will be manufactured from any sawmill waste and it is, therefore, not discussed in this report.

4.2.6. Other sawdust uses

The uses for sawdust, besides for energy, have been covered in Section 3. The use of biomass for energy is covered in Section 5.

4.2.7. Use of wood ash

Pure wood without bark contains very little ash, wood with bark contains more ash, and if the fuel is made of whole trees with needles or leaves, then the ash level will be at its highest. Good wood ash is light grey; if the ash is black, it means that the fuel has not completely combusted. The wood ash contents of some wood fuels is provided in Table 18. It is evident that most sawmill biomass generated ash will result in little ash if good combustion is achieved.

As increased formal wood processing takes place in Uganda, the amount of waste generated will allow for more detailed investigations into the production of wood briquettes.

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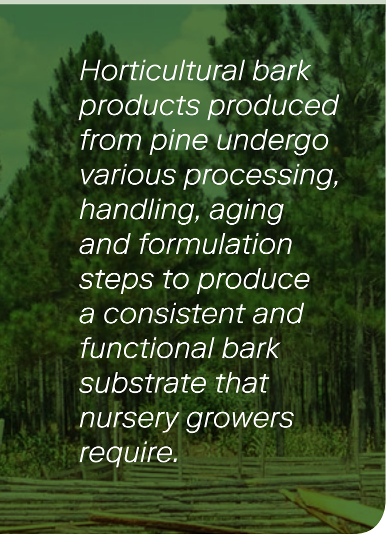
Table 18: Typical ash contents for a range of wood fuels (Kofman, 2016b)

Fuel type	Ash content hardwood % dry weight	Ash content softwood
Wood pellets (wood only)	0.7	0.5
Firewood (wood with bark)	1.2	1.0
Wood chips (round wood with bark)	1.2	1.0
Wood chips (whole tree)	1.5	1.2
Hog fuel from stumps	6 to 8	6 to 8
Hog fuel from garden waste	6 to 10	6 to 10

Wood ash should not be applied where products are grown for the human food chain. However, wood ash can be used as forest fertiliser. Wood ash should be applied during the growing season and the best opportunity is normally just after the first thinning. If the wood ash is not used as a forest fertiliser, it should be deposited in a controlled land fill (Kofman, 2016b).

4.2.8. The use of pine bark in horticulture

Pine bark is commonly used in horticultural industries as a compost or growing media. Horticultural bark products produced from pine undergo various processing, handling, aging and formulation steps to produce a consistent and functional bark substrate that nursery growers require. There are often various additives to the bark substrates on site at the nursery. The bark substrates are often tested for chemical, physical and biological properties to ensure good quality. Advances in bark engineering allow pine bark substrate producers to create substrates of any air, water, or density parameters for any container type or size, irrigation delivery method or production system.



Horticultural bark products produced from pine undergo various processing, handling, aging and formulation steps to produce a consistent and functional bark substrate that nursery growers require.

Bark products are commonly used in greenhouse substrates and consumer soil and soilless products. These include as compost or substrates for floriculture production, vegetable production and even Cannabis and small fruit production (blueberries, strawberries, oranges, figs). The pine bark in these mixes provides good airspace porosity and drainage, which is often required to improve production management strategies and control plant growth.

4.3 Processing and handling wood waste

This section provides details on the handling, processing and storing of sawmill biomass waste and its products. Sawdust, planer shavings and sander dust may be burnt directly without the need for further processing. Other forms of wood waste have to be reduced in size in order to facilitate efficient handling, storage and metering to the combustion chamber (if being burnt). By achieving a uniform particle size, combustion efficiency will be improved due to the uniform and controlled fuel feed rate and the ability to regulate the air supply. With fuels that have a high moisture content, the reduction process exposes a greater surface area of the particle to the heated gases, thus releasing the moisture more rapidly, thereby enhancing its heating value (FAO, 1990).

4.3.1 Collection and handling

Waste collection and handling options can range from labour intensive to highly mechanised and sophisticated. The technologies selected and used need to be appropriate to the size of the sawmill, the amount of waste generated, the potential market price for the waste product, the characteristics of the waste and the ability of the sawmill to raise capital. In small-scale forest industries in developing countries, the collection and handling of waste is often manual, aided by a tractor or bulldozer to both convey and push the residues to a belt conveyor. This helps avoid the need for big capital outlays and allows the optimal use of readily labour (FAO, 1990).

The way in which mill residues are most optimally removed and handled is also dependent on economics, availability of labour and the quantity and type of waste produced. It is usually carried out using a combination of belt and pneumatic conveyors, front-end loaders and trucks. Manual gathering predominates in mills with an input log capacity of 20 000 m3/annum and below (FAO, 1990).

Slabs, edgings, peeler cores, veneer waste and trimmings would normally be transported by mechanical conveyors or carried manually to a chipper and, after screening, conveyed to storage piles for use as either furnish for pulp or particleboard manufacture or as fuel. Bark, panel trim and waste from ply glue spreaders would be hogged and conveyed to the hog-fuel storage area. Sawdust and sander dust, depending on the quantities produced, would be pneumatically extracted and conveyed to a separate covered storage area. Retrieval is normally achieved using belt, drag link, flight or pneumatic conveyors, in conjunction with front-end loaders, which may also be used to build-up the piles (FAO, 1990).

4.3.2 Chippers

The choice of machine for comminution is determined by the material, quality requirements relating to the chips, and where the comminution is to take place. Chippers can only be used to chip forest fuel that does not contain any contaminants, while grinders can comminute all types of forest fuel, regardless of whether they contain contaminants (Skogforsk, 2016).

A chipper is a machine that is specially built to reduce wood to chips and can either be stationary or mounted on a carriage, on a trailer, on a truck or on the rear three-point hitch of a tractor. It can be equipped with its own engine or activated by the tractor power take off. Chippers need to be selected according to the predominant types of biomass waste supplied and whether they are delivered in the form of logs, slabs, trim or peeler blocks, as these all influence power requirements. Conveying systems have to be designed to allow for a uniform and controlled flow of wood to be fed endwise into the chipper to avoid the risk of blockage in the chipper throat and to keep energy consumption within acceptable limits.

Depending on the chipping unit, it is possible to differentiate between disc chippers, drum chippers and feed screw chippers. Disc and drum chippers are described in the paragraph below, but the following classification of chipper is also made according to the required power (FAO, 2015):

- Low power: Usually installed on the rear three-point hitch of a tractor or on a trailer. They are powered by the tractor power take off or by an independent engine (~50 kW). They can only process small diameters (20 cm max) and can produce no more than 10 bulk m3 of wood chips per hour. They are mainly for small-scale use;
- Medium power: Trailer-mounted, usually with independent engines (50 to 110 kW), or installed on the rear three point hitch of a large tractor; they can chip diameters up to 30 cm and produce up to 50 m3 of bulk wood chips per hour;
- High power: Installed on trailers or on trucks, these chippers are sometimes activated by the truck's engine, but normally they are provided with an autonomous engine (>110 kW); they can chip large diameters (>30 cm) and easily produce more than 100 m3 of bulk of wood chips per hour.

Disc chippers are the most specialised chippers and are designed for use at terminals such as pulp mills. Productivity is usually high and fuel economy good, and they produce high-quality chips from energy wood. However, chip quality is often unacceptable when tree parts or partly delimbed thinning wood are chipped, as the chips often contain too many splinters (Skogforsk, 2016).

Drum chippers are available in many different sizes; medium-sized machines are designed for use on or beside a landing, and the largest are used at large terminals or at heating plants. Productivity depends on the size and engine power of the machine. Fuel economy is good, although more fuel is used than in disc chippers. Even if the chip quality is better for stem wood than for biomass waste, the drum chippers produce an acceptable chip of all uncontaminated forest fuels (Skogforsk, 2016). Figure 31 shows a large and powerful drum chipper processing stems with bark on and Figure 32 shows a smaller drum chipper for smaller pieces and lower volumes of waste.

Figure 31 and 32: Large drum chipper processing stems with bark on and small drum chipper for smaller material

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The quality requirements for wood chip depends on the size of the installation in which it is to be used (Kofman, 2006):

- **Small boilers** (<250 kW) require high quality wood fuel with a low moisture content (<30 percent) and a small, even chip with few, if any, oversize or overlong particles. A low level of fungal spores is required.
- **Medium boilers** (>250 kW and <1 MW) are more tolerant of moisture content (30 – 40 percent) and can handle a coarser chip than small boilers. Still, the amount of oversize and overlong particles should be limited. A low level of fungal spores is required.
- **Large boilers** (>1 MW) are tolerant of both moisture content (30 – 55 percent) and chip quality. The level of fungal spores can be higher because these installations usually take their combustion air from the chip silo which reduces spore concentrations in and around the storage area.

4.3.3. Grinders

Size reduction for combustion can be carried out in several stages in a grinder (also called a hog in some regions and countries) or attrition mill, with screening before and in between (FAO, 1990):

The hog comprises of a set of knives or swing hammers mounted on a rapidly rotating shaft within a robust casing. The impact of the rotating impellers on the wood waste against the breaking plate reduces it to a standard size of approximately 20 to 50 mm.

- Screening, directly before or after the hog, separates the dirt and fines and conserves energy in the subsequent reduction stages by removing those particles of acceptable size which would otherwise be reprocessed.
- Attrition mills are used to reduce residues still further in size, by passing them between a stationary and a rotating disc, each fitted with slotted or grooved segments. The particles produced may, after screening, then be burnt in direct-fired suspension burners to produce hot gases for drying lumber, plywood and particleboard furnish and other such heating requirements.

Grinders are available in many sizes but are generally larger than drum chippers. Grinders smash or crush the material, so they are not as sensitive to contaminants as chippers. However, more energy is used to crush or break up wood using blunt tools than to chip it using sharp knives, so grinders generally have higher fuel consumption. However, the hammers or teeth of a grinder do not need replacing as often as the knives in a chipper. Ground material is less uniform than chips produced by a chipper and, although it´s chip size distribution may meet the requirements of some customer, it may be unsuitable for some customers (Skogforsk, 2016).

Sieves are important tools for the selection of chips according to their size, thus refining the material but at the same time lowering productivity.

4.4 Storage

For the production of quality wood fuels (wood chips of logs), it is important that the fuel wood processed is as dry as possible. Wood biomass is best dried naturally in the sun and wind. Technical drying is usually a difficult process from an economic point of view and is generally only worthwhile if cheap waste heat from energy generation or process heat (e.g. from a biogas plant) is available (FAO, 2015).

Air-drying of logging residues under good climatic conditions can bring about a moisture loss of some 10 to 15 percent, and the level may even drop further to 25 percent should the residues be left in clear-felled spaces open to the action of wind and sun. Air-drying of mill waste (if there is space and time) should be under covered in a well-ventilated area, especially for the smaller-sized residues such as sawdust, which is more liable to absorb rainfall and takes longer to air-dry than mixed wood waste (FAO, 1990).

Green whole chips and mixed waste, when stored outside in piles for several months, may lose up to 10 to 25 percent of their moisture content by way of the drying effect of wind, sun and spontaneous internal heating due to bacteriological action on the materials in the interior of the pile (FAO, 1990).

The type of wood waste storage will be largely determined by (FAO, 1990):

- The form and moisture content of the residues;
- The frequency and reliability of year-round deliveries to the mill and production of residues;
- The availability of land;
- Climatic conditions;
- The need for air drying;
- The volume of wood waste fuel involved;
- The system of waste handling and treatment adopted.

As mentioned above, stored waste can take up much space at a sawmill. Table 19 compares the storage requirements of different materials for the equivalent of 20 000 kWh stored energy. It is evident that the denser the material, the less space required.

Table 19: Comparison of storage requirements – volume required for 20 000 kWh stored energy (FAO, 2015)

Fuel	Heating oil –2000 litres	Log wood	Wood chips	Wood pellets
Size of storage building	2 to 3 m^3	12 m^3	24 m^3	6 m^3

Storage systems may be divided into two distinct categories, namely (FAO, 1990):

- **Outdoor storage:** In piles on prepared concrete or gravel pads to allow drainage and reduce contamination. It is the least expensive way of maintaining stocks. This storage is suited for stocks of 20 to 30 day’s capacity of green forest residues, bark, moist wood slabs or chips.

However, unless adequate preparations and precautions are taken, deterioration and fires from overheating and biological action can take place. Residues should, therefore, be monitored and those that do not benefit from drying with time should have a fast turnaround and be used on a first-in-first-out basis. Where a large variety of residue sizes are to be stored, it is preferred to segregate according to size, either before or after storage. It is also preferable to reduce the larger-sized waste in grinders or chippers at an early stage to make handling easier. Mixing of wet and dry waste should be avoided or the efficiency of combustion will be reduced. It is better to have dual storage and feed systems to segregate the feed to the burners according to moisture content (FAO, 1990).

- Covered storage systems: Used to safeguard against loss and damage due to wind and rain. It is normally provided for materials which are readily wind-borne or freely absorb moisture, such as dry sawdust, planer shavings and sander dust. Open-sided buildings, hoppers, bins or silos are usually located close to the combustion plant, with approximately 48 hours capacity to sustain a continuous operation (FAO, 1990).

Storing wood waste presents three high risks that need to be managed (FAO, 2015):

- The growth of mould, which poses a health hazard;
- Losses in mass through decomposition;
- Losses of energy value

Firewood, wood chips and health and safety aspects are discussed in more detail below.

4.4.1. Firewood

Firewood is not usually considered as a sawmill waste product due to the size of the waste pieces, the type of wood (low calorific value) and the low value of the product. However, it is evident that there is high firewood demand in Uganda, and it is therefore discussed as a possibility to provide sawmill managers with management solutions. Included is more mechanised options of firewood preparation. This may have application when there are many waste logs delivered to the sawmills or for fire damaged timber.

Firewood should be well seasoned and dried to less than 25 percent moisture content before used. If it is too wet, there is poor combustion, leading to the emission of smoke and fine particles, and soot formation in chimneys. The energy content of firewood is directly related to the moisture content. Natural drying is the simplest and cheapest method. Natural drying can achieve a moisture content of approximately 18 to 20 percent. At this moisture content, the moisture between and within the cells has evaporated and only the water chemically bound to the cell wall remains (Kofman and Kent, 2009).

There are two basic methods for professional firewood production. Delimbed stems or logs are cross- cut either with circular saw or shearing machines. Different devices with various sizes and productivities are available for cross-cutting and splitting, depending on the scale of firewood production. The quality of firewood made with circular saw machines is better. However, higher productivity can be reached with shearing machines, especially with small stem diameters. There is also no sawdust produced with shears. The split firewood packages can be artificially dried to the desired moisture content if required. Investing in drying machinery is required if year-round firewood production is required (Alakangas and Virkkunen, 2007).

The most important factor for drying is the position of a pile (whether sunny or shady), followed by the shape of firewood (split or non-split) and finally whether or not the pile was covered. Firewood stored in sunny positions will dry in less than six months. In these piles, split logs dry faster than non- split wood (with bark) (FAO, 2015). For efficient drying, the wood should be split into thinner pieces. Un-split wood requires up to twice as long for appropriate drying than split wood. To achieve low water content, firewood should be stored as follows (FAO, 2015):

- The drying area should be in a sunny and windy position.
- The pile should be lifted at least 10 cm from the ground, so the circulation of air is ensured, and the influence of ground moisture is lower.
- Fresh wood should not be stored in closed rooms or storage houses (or even in basements) where water cannot evaporate and fungi and bacteria thrive, which can also represent a health hazard.
- Wood piles should be covered to protect against rain.
- The distance between different piles and between piles and walls of storage houses should be at least 10 cm so that the air can circulate.

Long pieces of round wood take longer to dry. Most evaporation takes place from the exposed ends of the logs. Bark traps moisture in the wood. To speed up the drying process, firewood is usually crosscut into short lengths and split as soon as possible. This increases the surface from which the water can evaporate and reduces drying time. Short logs with a diameter less than 10 cm dry well whether they are split or unsplit, so there is no need to split small diameter firewood logs. Storage under roof or other cover is needed. Pallets with firewood that were left uncovered in the open dried well initially, but then reabsorbed moisture during the wet. Firewood stored outdoors under plastic sheeting did not dry as well as that placed indoors (Kofman and Kent, 2009).

4.4.2. Wood chips

Wood chips that are used in small or medium sized boilers should be dry (water content should be lower than 30 percent). The main recommendations for producing and storing wood chips are (FAO, 2015):

- Wood should be stored for at least three months (during summer) in a dry, windy and sunny position (natural drying).
- Wood that is properly stored during summer should have water content of less than 30 percent.
- After the dry season (at the beginning of autumn) wood piles should be covered.
- Only dry wood chips (water content below 30 percent) can be stored in closed storage.
- Wood chips should be removed from storage following the simple FIFO “first in - first out”
- **Rule :** Avoid storing wet wood chips with many needles and leaves. The temperature in the pile of this kind of wood chips (green wood chips) will increase (activity of microorganisms). Decomposition will start in less than three weeks. Wood chips should be stored in piles with a maximum height of 7 m and for only two to three 3 weeks.

Figure 33 shows covered storage for wood chips. When store dry under such conditions, the chips can be stored for significant period. Figure 34 shows ground material stored in the open, but on a prepared concrete surface. If the material is piled in a dry state and the shape pile is conical, only the outer layer becomes wet during rain.

Figure 33 and 34: Covered chip storage and open ground material storage

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Table 20 below gives a clear indication of how moisture content of wood chips affects how long the chips can be stored for. Dry chips can be stored for several years while very wet chips can only be stored for up to a month.

Table 20: Storage periods for wood chips at increasing moisture content (Kofman, 2016)

Moisture content (%)	Indicative storage period
<15	Very long periods of time – several years
16-25	Several years
26-35	Up to a year
36-45	Months
<46	Days to weeks, maximum 1 month

High moisture content of chips results in self-heating. Self-heating is a very fast process. A pile of wood chips with 45 percent moisture content and sufficient nutrients can reach a temperature of 60 to 80 °C in as little as 24 hours. The elevated temperatures can be maintained for weeks and take many months before the pile returns to the ambient temperature. During self-heating, bacteria and fungi consume the wood and thus dry matter is lost. In piles of very wet, nutritious wood chips (such as chips with lots of bark and leaves), losses of dry matter of over 3 percent per month have been measured. In normal forest chips, particularly those with moisture contents in excess of 35–40 percent, dry matter losses of around 1 percent per month can be expected. The effect of raised temperature in the pile is that the centre dries out as the moisture in the wood evaporates. However, the moisture, together with moisture released as the wood is consumed by bacteria and fungi, condenses at the colder surface of the pile, creating a very wet outer layer (Kofman, 2016).

Self-ignition of a pile of wood chips is the result of a chemical reaction that takes over after the biological processes. Chemical oxidation produces even more heat, moisture and carbon dioxide, and eventually the temperature reaches the ignition temperature of wood which is around 250 °C. Self- ignition of wood chip piles only occurs in exceptional cases and usually in very large chip piles, and then only when a well-established set of pre-conditions come together. Piles of wood chip that self- ignite are typically in excess of 1 000 m3 loose volume and contain at least some concentrations of wet chips. Often the piles have been compacted by driving across them. In almost all cases, a metal object in the pile results in the initiation of the fire. The metal acts as a catalyst and there are metal pieces possible from many sources that include parts that fall off machinery to chipper knives that were accidentally included in the pile. To prevent self-ignition, wood chips that are stored for more than 2 to 3 weeks should have moisture contents of less than 35 percent, should not contain tree needles or leaves, should not be compacted and should be free of metal objects. The pile should be kept as small as possible, with a regular shape. When a pile has an irregular shape, water may concentrate in “valleys” and increase the moisture content there, and lead to self-ignition processes beginning and accelerating (Kofman, 2016).

The correct approach to controlling fire in a wood chip pile is to remove as much of the sound chip away from the area which is burning and spread it on an adjacent surface, so that it can cool down. Once the fire itself is located, then water can be pumped onto it to put it out (Kofman, 2016).

4.4.3 Health and safety aspects of using wood chips, sawdust and ash

Wood chips are as safe, and in some cases a safer fuel than oil, gas or even coal. Like any fuel, however, safety rules apply (Kofman, 2016):

- Never store wood chips that are wet (>45 percent moisture content) for any length of time.
- Store all chip for as short a time as possible.
- Never store chips that contain needles or leaves.
- Use the “first in-first used” rule when combusting wood chips.
- Use a face mask with a P3 filter when handling wood chip or stay inside a closed cabin with overpressure and a good filtering system.
- If a fire starts in a wood chip pile, remove the sound chips from around the fire, and then tackle the fire. Use minimal amounts of water, otherwise one will destroy the fuel value of the chips.
- If a fire burns on the surface of a wood chip pile, the most workable solution in many cases is to contain the fire cordon-off the area and let it burn out.
- Only work in silos that have been sufficiently vented.
- Handle wood ash with care; the material is highly alkaline and contains a lot of fine dust.

Ash results from the burning or gasification of wood and consists of silica, minerals that the trees have taken, and in some cases soil and other contaminants. Ash is a very alkaline substance with a pH of around 12. It is corrosive and should only be handled when wearing protective gloves. The fine dust and high pH generated by ash necessitates a filter mask to prevent inhalation. A lot of the minerals in the ash are water soluble and therefore the ash should be stored under roof so that rain will not wash out these minerals and pollute the ground water (Kofman, 2016). Water in ash also results in it becoming very hard.

5 . Using biomass for heating and energy

The International Energy Agency expects bioenergy to not only be the largest source of growth in renewable production over the next five years but also to account for more than 30 percent of that growth. To date, wood and wood residue remains the largest source of biomass energy (Boundless Impact Investing, 2020). In its simplest form, biomass contains stored energy from the sun. Biomass can be burned by thermal conversion and used for energy in the form of heat or electricity production.

Fuels such as biomass are not only suitable for direct use by sawmills but are also attractive for grid operators. This is because wind and solar energy resources only give intermittent energy and therefore create stress on electricity grids when they do not produce. Biomass power provides a flexible and reliable form of renewable electricity to balance this supply and demand. Wood pellets are particularly attractive in this regard because existing coal-based power plants can be retrofitted to utilise this fuel relatively easily and cost-effectively. Even though Uganda does not have coal power stations which can be co-fired with pellets, there are still electrification problems with big new projects in certain rural areas in many East African countries, and this may present a distinct opportunity.

Countries with pulp, paper and engineered wood industries can absorb some of the biomass waste produced by sawmills. Even though Nileply does produce MDF, it may be expensive to transport waste to their facilities and therefore alternative uses must be considered (Caris *et al.*, 2019). This has been the drive behind initiatives to move beyond generation of boiler steam to the construction of cogeneration plants to utilise the bio waste.

To understand the energy requirements of a typical sawmill, one first needs to map out the basic process flow of a sawmill. Figure 35 provides this and indicates where waste is generated (which is throughout the process). In the Ugandan context, because there is currently no debarking, bark is not available as a standalone biomass waste resource. The process flow also assumes that some of this waste wood is chipped and used in a boiler to provide steam for sawn timber drying. Therefore, all waste residues produced currently in Uganda have to be disposed of.


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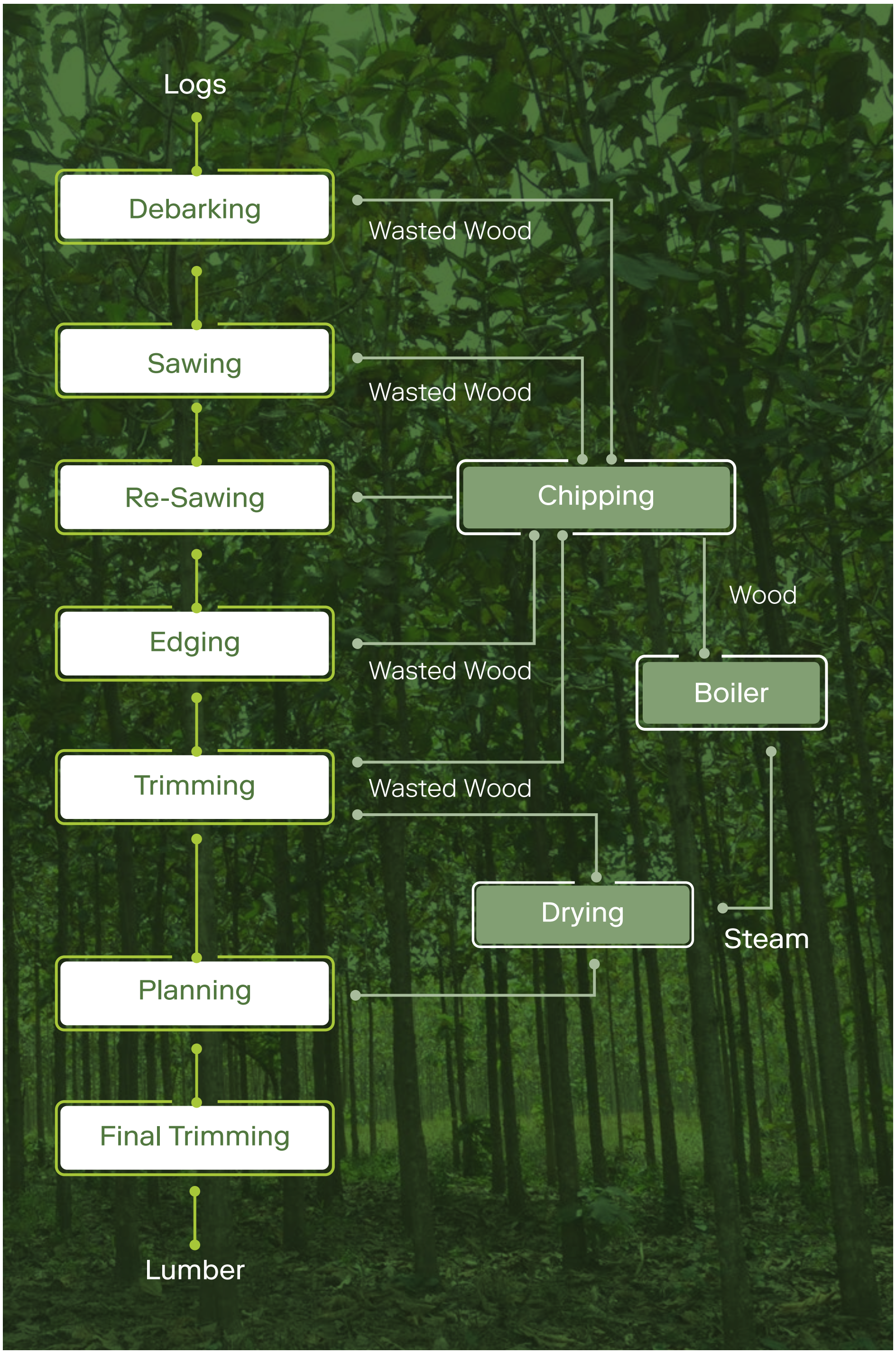
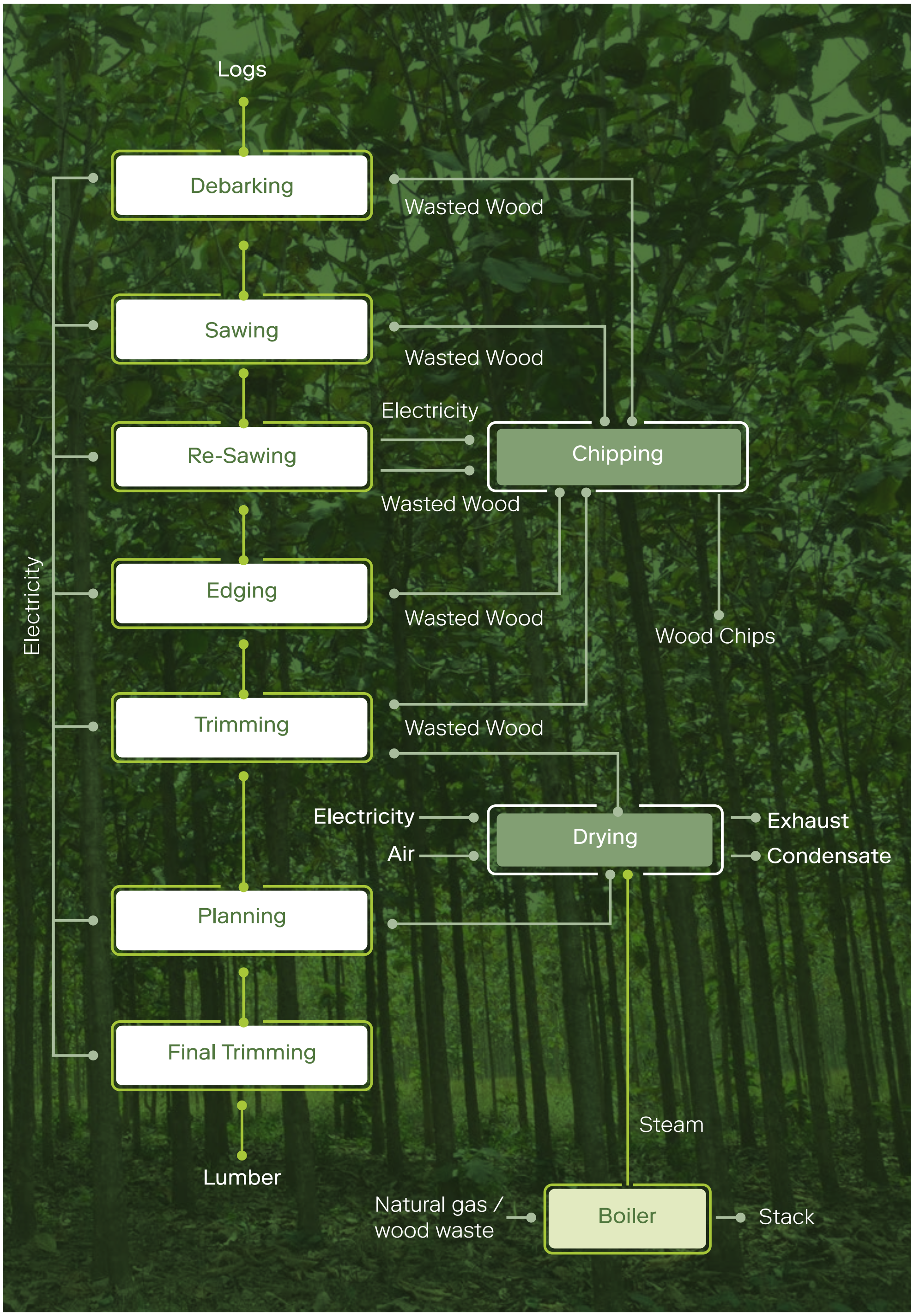
Figure 35: Process flow diagram for sawmill operation (Gopalakrishnan et *al.,* 2012)



Sawmill operations such as debarking, sawing, edging, trimming, chipping, and drying require energy- consuming equipment and machinery. Common sources of energy utilised in sawmills are electricity, natural gas, wood waste and fuel oil (often diesel). Electricity is required to operate motors in equipment such as the debarker, head saw, re-saw, edger, trimmer, chipper, planer, fans and pumps as well as in material handling equipment such as conveyors and belts. Normally, natural gas and/or wood waste is used in the boiler (steam generator) to generate low pressure steam. This steam is used to dry the lumber in a kiln. Figure 36 shows the sawmill energy flows in a typical sawmill. Therefore, even though residues can be easily used in the boiler, the first prize would be to also generate electricity that can be used in the sawmill and supplied to neighbouring users (or the grid), as well as supply excess steam to neighbouring industries as well. Because most Ugandan sawmills are small, the opportunities for this are limited. However, as the larger volumes of timber are processed, these opportunities will arise.

Figure 36: Sawmill energy flow diagram (Gopalakrishnan et *al.*, 2012)



The remainder of this sections goes into more detail regarding heating and energy systems and options for now and the future.

5.1 Kiln drying

Kiln drying is well understood by the global sawmilling industry. Kiln drying is a high energy consuming process which accounts for approximately 70 to 90 percent of the sawmill's total energy needs. It is very important that attention is given to the kiln's design and operation or the drying process could lead to a substantial waste of energy. Kiln drying obtains its energy from two main sources, being electrical energy to drive the circulation fans and heat for the drying operation. The most common fuels used are oil, gas or sawmill waste. If sawmill residues are used and have little other value, this needs to be considered during the design stage to ensure the adoption of high temperature drying, which will improve the overall energy efficiency of the kiln by increasing the kiln's potential capacity and reducing the amount of air needed to circulate and therefore have a lower demand for electricity (FAO, 1990).

5.2 Energy conversion processes

This section covers the main energy conversion systems which can be used for heat and energy generation. Technology is developing quickly in this area and therefore base assumptions can also change within a few years. The Ugandan forestry industry will need to continually strive to stay up to date with processing technologies. Table 21 summarises the main energy conversion processes for wood biomass. This consists of biochemical and thermochemical pathways.

Table 21: Main energy conversion processes for woody biomass (FAO, 2010)

Pathways	Process	Primary energy products
Biochemical	**Fermentation** Acid pre-treatment is used to break down hemi-cellulose and make remaining material accessible to saccharification (breakdown into sugars Cellulase enzymes are introduced to hydrolyse carbohydrate material into sugars Sugars are fermented to produce ethanol Remaining lignin (unreacted) is recovered for use as fuel or thermochemical feedstock	Ethanol, methanol, residual cellulose and lignin used as boiler fuel for generating heat and steam for electricity
	Anaerobic digestion Biomass is placed in a digester, where it is broken down by bacteria under fixed temperatures and anoxic conditions to produce gases that can be used to produce energy	Biogas, methane
Thermochemical	**Direct combustion** Unprocessed (raw wood, branches etc.) biomass is burned directly for domestic cooking and heating Unprocessed or processed (e.g. chipped or pelletised) biomass is used for co-combustion or full combustion in steam plants, for heat production in small to medium-sized boilers, and for heat and steam production in small-scale combined heat and power plants	Heat, electricity
	Gasification High temperatures decompose lignocellulosic material Partial oxidation produces raw synthesis gas Syngas is cleaned, conditioned and catalytically reacted to produce either mixed alcohols or Fischer-Tropsch hydrocarbons Resultant hydrocarbons are refined to produce biodiesel	Combustible gases (carbon monoxide and hydrogen), biodiesel
	Pyrolysis Involves thermal decomposition similar to that involved in gasification but at lower temperatures and in the absence of oxygen	Liquid fuels (primarily bio-oil), charcoal

The biochemical pathway is seldom used for sawmill waste residues. The scale of raw material needed to justify such a process is usually beyond what even a large sawmill can supply. The logistics of transporting biomass waste from numerous sawmills to a centralised location is usually not economically feasible. Thermochemical pathways are usually more feasible as some of the processes can take place at a scale appropriate to the sawmill waste biomass generated. Some of these processes are discussed more in the sections below. Figure 37 expands on the thermochemical pathway by providing the conversion process, the primary product, the conversion technology and the market.

Figure 37: Products from thermal biomass conversion (Bridgwater, 2011)

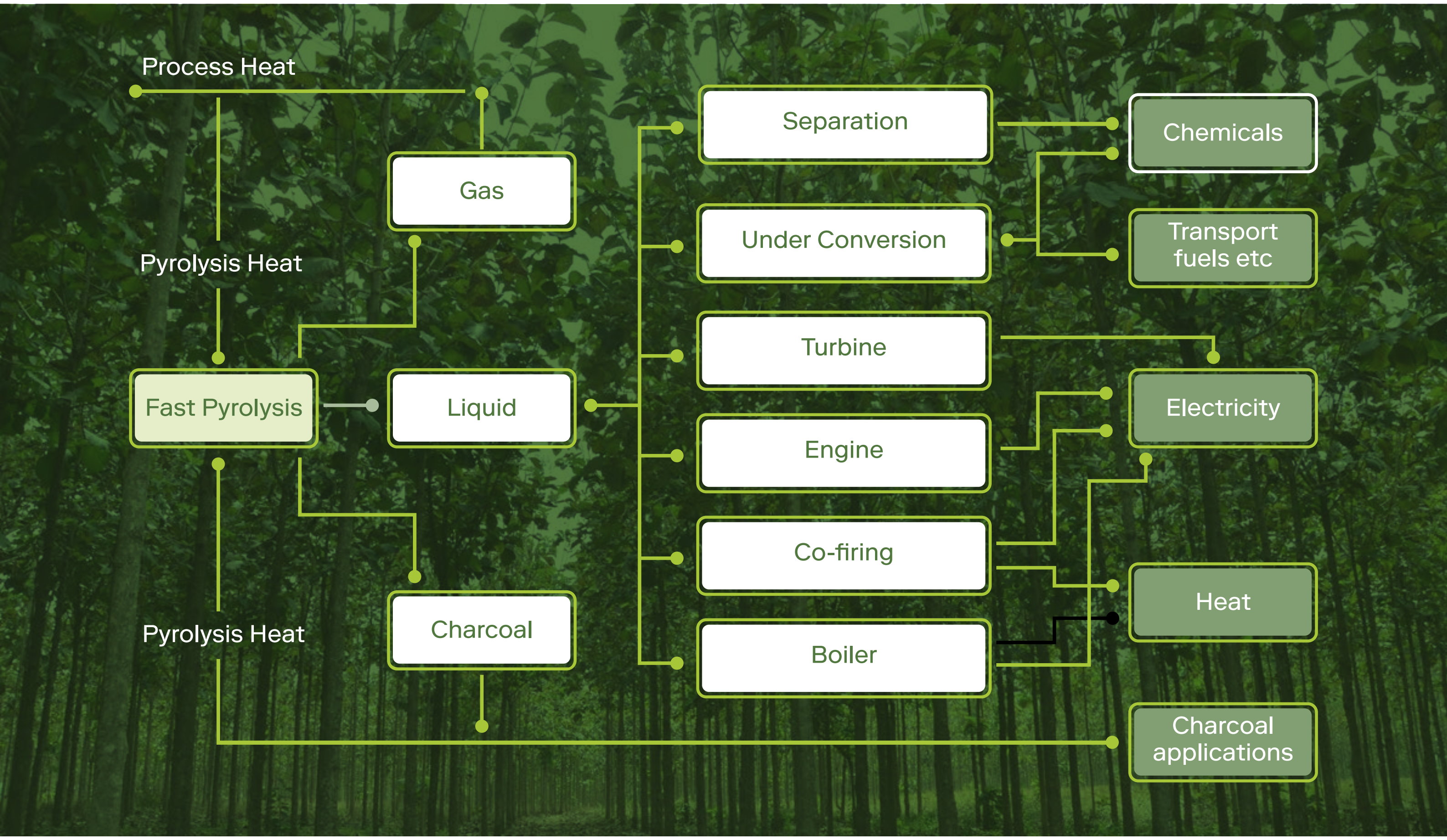


Table 22 emphasises that biomass products has very specific waste feedstock specifications if they are operating at the desired efficiency and cost.

Table 22: Desired feedstock specification for biomass conversion technologies (Woo and Han, 2018)

Biomass conversion Technology	Product	Desired feedstock specifications		
		Particle size (cm)	Moisture content (% wet basis)	Ash content (%)
Gasification	Biochar	0.25 - 10.00	<25%	<15%
Torrefaction	Torrefied chips	0.25 - 2.50	<30%	No limit
Densification	Briquettes	<5.00	4 – 15%	No limit

It can be seen from the above that the range of conversion systems available to the forest products industry is quite considerable, with a large choice of equipment existing within each category. Some of the conversion processes and conversion technologies are explained below.

5.3. Combustion

A brief description and summary of the basic combustion systems is given in Table 23

Combustion class	Technology	Description
Boilers	Firetube	Used where steam pressures of not more than 20 kg/cm2 are required in small to medium- sized operations, and are well suited for the heat requirements of the mechanical wood- based industry. They are relatively inexpensive and operate on the principle of hot combustion gases passing through steel tubes set in a water jacket.
	Watertube	Consist of tubes welded together to form complete walls enclosing the combustion chamber, through which flows the water to be heated. It is almost exclusively used where steam pressures above 10 kg/cm2 are employed, especially in providing motive power to turbine-generators.
Pile burners (burn the fuel in piles either on a refractory floor or grate)	Heaped pile burning furnaces	Such as the tee-pee burners and clutch ovens are fed with fuel from the top of the furnace in batch form via chutes located across the grates or, continuously by way of variable screw feeders, to be burnt in a pile on a refractory floor or grate. Primary air for combustion is introduced through ports located on all four sides of each chamber and the heat transmitted to the boiler surface situated above and behind the combustion chamber. Can be used to burning fuels of up to 65% MC regardless of size or shape, although they do require much attention and time to build-up and burn down the pile. They have low efficiencies in the order of 50 to 60%.
	Thin pile furnaces	They burn hogged fuel, up to 55 to 60% MC as a thin bed spread across the grate. Sloping grates, pinhole grates, travailing grates are examples of the systems currently used to enable the fuel to progressively advance along the grate through the combustion chamber, whilst being exposed to primary air from below, to be then discharged by an assortment of removal systems as ash.
Burners	Suspension	Burns fine wood particles in suspension, in either special combustion chambers or boiler fireboxes, in a highly turbulent environment caused by forced combustion air. To operate efficiently, the wood particles need to be no more than 6 mm in size and have a maximum MC of 15%. These units are well-suited for use with sawn timber kilns, veneer and particleboard furnish dryers and boilers.
	Cyclone	Pulverised wood fuel, of a maximum 3.5 mm size and 12% MC is mixed in the first stage of the burner and combusted in an external cyclone burner.
Fluidized-bed combustors		Capable of burning untreated hog fuel, with MC levels as high as 55 to 60%, in a turbulent mixing zone above a fluidised bed of inert silica sand. The fuel is maintained in suspension during combustion by a high velocity of air forced through the bed of sand, which results in the sand adopting free-flowing and fluidized properties.

Ideally two smaller boilers are preferred to one large partially used unit, which allows flexibility of operation to cater for load variations which occur due to changes in seasons or production capacity demands. However, capital costs usually prohibit such a luxury in the smaller mills (FAO, 1990). Modern wood fired boilers combine automated fuel-feed supply with efficient low-cost, low- emissions operation. Some installations have a walking floor fuel supply and automated ash removal. Modern systems have an extensive sensor suite which allows operational monitoring to very fine detail.

Besides the end use of the heat, particle size plays an important role in determining the combustion plant. Whereas fine sander dust and wood shavings may be burnt in suspension, larger-sized wood waste, in the form of chips, coarsely hogged residues and slabs need longer to burn which is generally undertaken on grates. The decision whether to select the combustion plant to suit the available fuel or, process the fuel to the requirements of the preferred plant, can only be made after a thorough analysis has been carried out

5.4 Pyrolysis

Pyrolysis is the controlled thermal decomposition of biomass occurring at around 500 °C in the absence of oxygen (anaerobic environment). It produces a liquid bio-oil, a mixture of gas (syngas) and charcoal (biochar). There are two main types of pyrolysis processes, being fast and slow. These are characterised by different residence times in the pyrolysis reactor, and lead to different proportions of the liquid, gas, and solid fractions. Slow pyrolysis favours the production of biochar, which can be substituted in any applications using coal. Fast pyrolysis is given more attention as it maximises the production of bio-oil which can be converted into fuels or specialty chemicals (IEA Bioenergy, 2009). The fast pyrolysis process has good potential since it is quite cheap for the pyrolysis stage. However, most downstream upgrading technologies are capital intensive and under development.

5.4.1 Torrefaction

Torrefaction is a high-efficiency thermal process occurring at 200 to 300 °C by which biomass (usually wood) is chemically upgraded into a dry product that resembles coal in appearance. Torrefied biomass has a high energy density and is hydrophobic, which allows it to be transported over long distances and stored outside without absorbing any significant amount of water and losing calorific value. Torrefied biomass can be pelletised to further reduce its handling and transportation costs. Torrefied pellets are expected to be even more cost competitive than traditional pellets (IEA Bioenergy, 2009).

5.5 Gasification

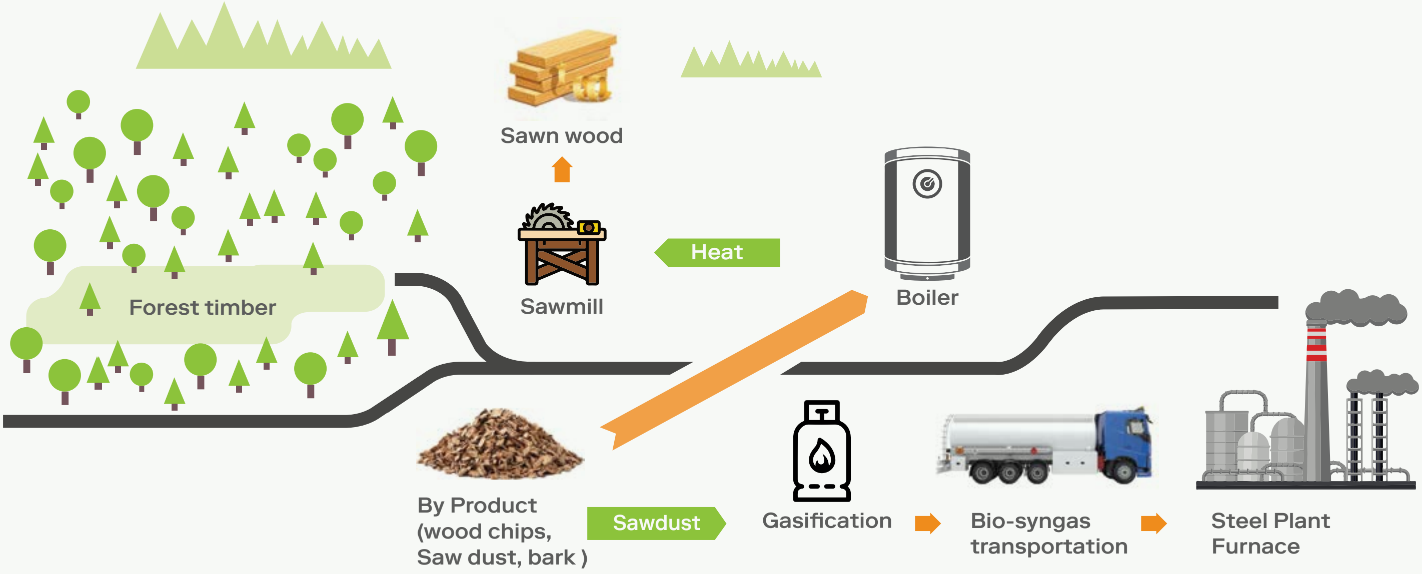
When producing biogas, the energy content of biomass is concentrated and converted into a substance that is broadly usable in a variety of applications. Gasification technology has been put to limited use in coal-fired plants to reduce pollution and increase the efficiency of electricity production. When adapted for biomass, gasification applies air to the feedstock in a high-temperature reactor to produce gaseous fuel, which can be used to generate electricity from standard gas turbines.

Biomass gasifiers have the potential to be up to twice as efficient as conventional boilers to generate electricity. For even more efficiency, heat from the gas turbine exhaust can generate additional electricity with a steam cycle. These improvements in efficiency can potentially make environmentally clean biomass energy available at costs more competitive with fossil fuels. Two types of gasifiers are currently in development:

- Direct-fired gasifiers: Use air to produce a low-heating-value gas.
- Indirect-fired gasifiers: Heated sand surrounds the biomass and gasifies it. This process gasifies biomass at low pressure, using indirect gasification to produce gases with medium heating values, which is approximately half that of natural gas. Little or no modifications are required to the turbine combustors to bum the resulting gaseous fuels. Sand is used to carry the biomass and the char and to distribute the heat. Using sand as a heat carrier keeps out the air. This results in a higher quality fuel gas. A second reactor combusts the char to heat the sand. Remaining traces of condensable matter formed during gasification are removed in a chamber where a catalyst cracks and converts them into fuel gas. The clean biogas is then pressurized before it reaches the gas turbine.

Figure 38 shows how a gasifier would potentially fit into a sawmills process and supply biogas to nearly industries that require energy.

Figure 38: System description for integrated biomass gasification at sawmill (Nwachukwu *et al.*, 2018)



Large, commercial-scale gasifiers will use about 1 500 tons of biomass per day to generate up to 120 Megawatts of electricity, enough for about 120 000 households. Because it is a clean technology that uses renewable agricultural crops or manufacturing waste products as an energy source, gasification is ideal for community use and rural economic development (DOE, 1997). The large quantities of input biomass clearly mean that energy generation from large scale gasifiers would only occur where there is concentrated biomass from forests and the sawmills, as well as waste from other industries such as agriculture.

5.6 Biofuels

An option is to convert biomass waste into biofuels like ethanol or methanol through biochemical or thermochemical routes. However, this will be very capital intensive and is unlikely to be considered for sawmill biomass waste.

5.7 Cogeneration

Cogeneration (or combined heat and power (CHP)) is the use of an engine or power station to generate electricity and useful heat at the same time. Trigeneration (or combined cooling, heat and power (CCHP)) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector. Cogeneration and trigeneration can also be applied to the power systems simultaneously generating electricity, heat, and industrial chemicals (e.g., syngas).

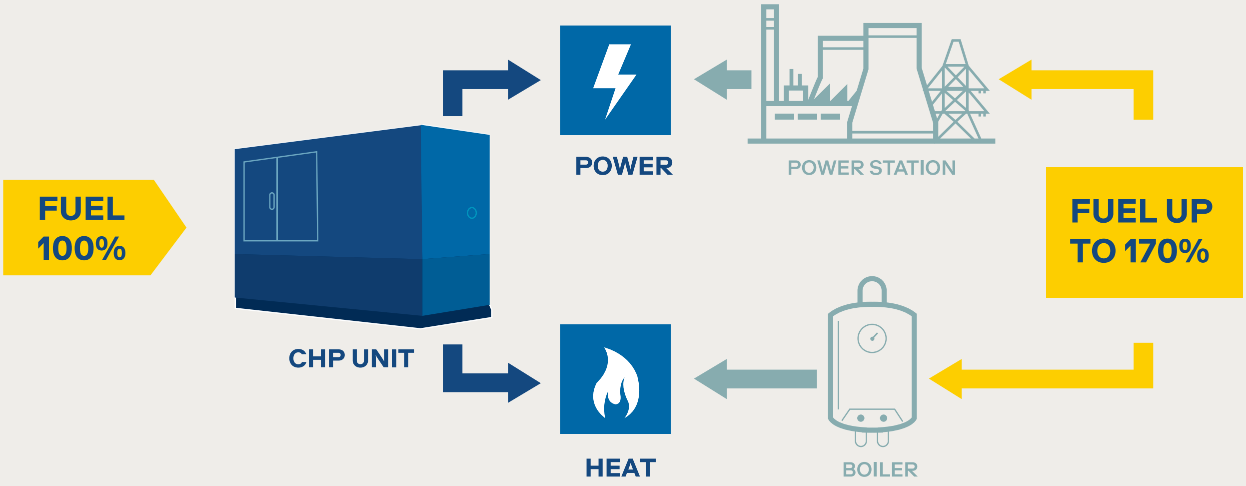
The CHP can be achieved by generating high pressure steam in a hog fuel boiler, which would then be passed through a turbine generator for power, before being used as exhaust steam in drying or heating process. Instead of only generating electricity from wood waste with a conversion efficiency of 25 to 30 percent, cogeneration increases the efficiency of energy utilisation to some 75 percent (FAO, 1990).

Cogeneration is a more efficient use of fuel because often-wasted heat from electricity generation is put to some productive use. The CHP plants recover otherwise wasted thermal energy for heating. The CHP is particularly useful in colder countries where smaller power plants can generate electricity and supply heated water to towns. Small CHP plants are an example of decentralized energy and would probably be more applicable to the Ugandan context. The by-product heat at moderate temperatures (100 – 180 °C, 212–356 °F) may even be used in absorption refrigerators for cooling.

The supply of high-temperature heat first drives a gas or steam turbine-powered generator. The resulting low-temperature waste heat is then used for water or space heating. At smaller scales (typically below 1 MW), a gas engine or diesel engine may be used. Trigeneration differs from cogeneration in that the waste heat is used for both heating and cooling, typically in an absorption refrigerator. Combined cooling, heat, and power systems can attain higher overall efficiencies than cogeneration or traditional power plants. Heating and cooling output may operate concurrently or alternately depending on requirements and the way the system was constructed.

Figure 39 shows how cogeneration can be more efficient in the correct application compared to a traditional fuel-fired power station. With the example below, the traditional systems produced electricity and this electricity is then sent via the grid to a house, where it heats the boiler which provides the buildings hot water needs. This results in many energy inefficiencies. With CHP, the electricity and heat is generated simultaneously, which significantly improves efficiencies. However, if there is no productive use for the heat from cogeneration, then the business case changes. Therefore, if CHP is to be considered in the Ugandan timber industry as a solution for biomass waste, a use will have to be found for the heat (e.g. some heat intensive industry that is close to sawmills, or can be established close to sawmills.

Figure 39: CHP compared to traditional power station energy (Tedom, no date)

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used as exhaust steam in drying Using a condensing turbine generator with single or double automatic extraction or a back-pressure turbine generator are options for sawmills, though the latter is often favoured. The fuel potential of the biomass waste generated from sawmilling may exceed the mills heat and power requirements. However, energy self-sufficiency in electricity in an integrated operation is more difficult to achieve due to there being a given ratio between the power output and the output of industrial heat generated by a back-pressure power plant (approximately 1:1.5). This shortfall may be overcome by (FAO, 1990):

- Designing a power plant in which the ratio between power and heat production meets that of the mill's consumption ratio. However, this option involves costly and sophisticated plant and therefore is not considered suitable for developing countries.
- Supplement the mills own hog fuel production with purchased wood and wood waste or fuel oil. However, this places an increased load on existing waste treatment and combustion systems or required larger mill capacity, with heat production being in excess of what is required.
- Making-up the balance of the mill's power requirements by either using diesel generating sets or purchasing power from the national grid.

It is technically feasible to use biomass waste as fuel for power generation. However, the economics often prove to be the limiting factor. There are clear benefits from burning wood waste to reduce a sawmills fuel oil and electricity costs, they may be off-set by the high capital costs involved, low plant efficiencies and increased personnel levels. The economics of wood waste energy generation becomes more viable as traditional fuel/electricity prices increase. The real value of the wood biomass waste as a fuel source must consider its available heat content, the investment and operating costs of the plant needed to handle and convert it to useable energy, before any comparative studies can be made (FAO, 1990).

In addition to the above, the capacity of most energy generation plant options available to the sawmills, especially for cogeneration, exceeds that which can be economically utilised by most mills. Additionally, the limited finance available to the small- and medium-scale mills tend to be a major deterrent in their considering cogeneration as a viable option, regardless of the possible long-term gains (FAO, 1990).

It is often not viable, in spite of a sawmills self-sufficiency in self-generated fuel, for an individual sawmill of less than 150 000 m3/annum log input capacity to generate their own power, unless they are part of an integrated production unit consisting of sawmilling, plywood and particleboard manufacture (etc.), with shared services (FAO, 1990).

6 . Barriers to and considerations for waste use

6.1 Barriers to biomass use

The barriers that generally prevent waste use need to be well understood. If a specific biomass waste use is to be considered, then action plan needs to be generated to address the applicable barriers. The general barriers are categorised into technology, trade, political and practical classes, as per Table 24 below.

General barriers for biomass waste use			
Technical	Trade	Political	Practical
• Quality of the biomass feedstock for electricity production – various types of biomass are unsuitable. • Lack of continuous heat demand required for optimal use of efficient combined heat and power production. • Costly fuel-gas cleaning for small-scale installations. • Lack of commercial-scale processes that can convert lignocellulosic and waste biomass to transport fuel at reasonable cost.	• Import tariffs. • Non-tariff trade barriers such as different technical requirements and logistical barriers.	• Policies, including targets for CO2 mitigation, are typically national rather than global. However, global biomass trade reduces emissions in the receiving county (when replacing fossil fuels) but may increase them in the exporting country. • Differences in biomass support policies between countries lead to inefficient trading and transport of biomass between countries. • The risk of changing policies over time is a barrier to investments by the industry. • Different support policies per sector, leading to artificial price increases and biomass demand in specific sectors that may not be optimum. • Potential political reactions to impacts on geopolitical issues and fossil fuel demand.	• Different domestic priorities in the countries or regions where the biomass is produced. • Problems with supply chain interaction, e.g. owing due to price volatility, lack of (reliable) information on technology, markets, etc., and financing. • Restrictions on infrastructure development, e.g. regarding pipeline networks for biomethane, transport options for biofuels, problems with financing of investments in infrastructure, etc.

The national legislative framework must encourage the re-use, recycling or recovering of material previously classified as waste. It can occur that the cost of obtaining licences and the extended timeframes associated with the processes (often leading to challenges to obtain finance for projects) can be key barriers to investing in biomass waste options. Other important barriers include (Pineo *et al.,* 2016):

- Feedstock insecurity. If the mill does not produce sufficient biomass waste of their own, obtaining sufficient feedstock is challenging given alternative (and competing) uses for feedstock (e.g. animal feed, compost, biogas).
- Insufficient economies of scale, which is vital for financial feasibility.
- The cost of logistics, which drives the provision of feedstock and therefore limits the economic feasibility of operations. Feedstock for a large biomass powerplant is generally widely distributed as the waste from one mill will not suffice, requiring aggregation to obtain economies of scale; however, the cost of transport makes aggregation beyond the immediate surroundings too expensive.
- Lack of markets (e.g. for excess energy, fertilizer, value-add products) which would be required for financial feasibility. The reasons for this are numerous and depends on the value-add option but include (local) scale of and access to markets, as well as acceptability or familiarity of the service/product as an alternative to other established services/products.

The national legislative framework must encourage the re-use, recycling or recovering of material previously classified as waste.

Some of the reasons for a lack of focus on wood waste from processing facilities are as follows:

- A lack of bankable studies on economic returns from wood waste processing.
- A lack of incentives for wood waste utilisation.
- Inadequate enforcement of environmental regulations and absence of policy on wood waste management in the country.
- Absence of technological knowhow on waste utilisation and processing techniques.
- Inadequate vertical and horizontal integration in business strategies.

6.2 Considerations for biomass waste use

Some of the key considerations for sawmill biomass waste are discussed. A final strategy for biomass use can only be considered when these questions have been answered, as well an investigation into the strategies (including their market, expansion/growth and biomass waste) of the companies and growers that make up SPGS and the Ugandan forestry industry.

- What are the most important current and future biomass feedstocks? The current sawmill wood biomass waste output will look very different in the future when the large volumes of new plantations are harvested. The industry will need to determine to what extent they are prepared to share their strategic plans regarding timber processing and biomass waste use. The waste strategy depends on the sawn timber strategy. If the industry focusses mainly on structural sawn timber, then waste levels will be relatively high. However, if engineered wood products receive more attention, then waste biomass will be significantly reduced.
- What are the main factors determining the long-term biomass potential for energy? The industry needs to engage with key energy

role-players in Uganda to determine that the government has developed biomass energy as part of the country's future energy policies and goals.

- How significant could the contribution of biomass be to the Ugandan (and East African) energy mix by 2050? Government and energy players need to be made aware of the potential of biomass for energy and thereafter attempt to influence the long-term energy plans of Uganda, as well as investigate regional energy opportunities.
- Local or large-scale conversion? Conversion close to the source of the biomass has the advantage of reduced transport of the raw biomass, which saves costs and reduces emissions. It can also benefit local or regional economic development and employment. If the resulting bioenergy or biofuel is used locally as well, it can reduce energy imports or, in the case of developing countries, less efficient use of firewood. However, the costs of small-scale biomass conversion are typically higher than those of large-scale conversion, because of the relatively small scale of the conversion process and the often-lower efficiencies of conversion. The economics of biomass conversion plants become more favourable with increasing scale. Feedstock costs rise as required feedstock volumes increase, due to longer transport distances. A trade-off between these two factors determines the economic optimal plant size. Advanced pre-treatment technologies such as further densification (briquetting or pelletising) or thermochemical treatment (such as pyrolysis or torrefaction) can further increase the energy density, which makes long transport distances more economical, and thus may allow larger plant sizes (IEA Bioenergy, 2009).
- Domestic use or export? The choice between export or domestic use is typically a socio- economic one and depends on the opportunities for local use (local demand), transport costs and the associated potential revenues of biomass or bioenergy export, and respective impacts
- on employment. Government policies, both domestic and in other countries, can have a significant impact on this choice (IEA Bioenergy, 2010).
- What logistical constraints do biomass supply chains have to tackle? The critical issues in biomass logistics needs to be investigated and solutions developed. These must consider some of the specific properties of biomass such as low energy density, often requiring drying and densification; and seasonal availability and problematic storage requiring further pre- treatment. Also factors limiting the supply such as the availability and appropriateness of mechanised equipment and inadequate infrastructure to access conversion facilities and markets.

7. High level actions

The starting point for a comprehensive timber waste utilisation strategy is the quantification of available resources, including the spatial and temporal dynamics of the waste. This would determine sustainability of future supply, costs of transportation, optimal location and sizing of energy conversion facilities, profitability of such ventures and optimal raw material management strategies. These supply chain factors are important to optimise the socio-economic viability and sustainability of biomass utilisation opportunities (Charisa *et al.,* 2019).

An accurate national database and an effective means to collect and record information enables government departments, programmes such as SPGS and the private forestry sector (including UTGA) to draw up effective policies, monitor results and effect adjustments as needed. Information should include product types, plant capacity and output, production methods, generation and use of residues, sources of energy, energy consumption and trends and conservation measures adopted. This will provide an overall picture of Uganda's forest products industry (FAO, 1990).

Furthermore, the government, policy makers, NGOs, the private sector and stakeholders in environmental management should openly support existing and planned efforts to use the waste. Initiatives to use waste biomass products should be welcomed and endorsed by these various stakeholders as they can provide socio economic benefits like enterprise development, job creation, electrical power generation and reduction of expenses for the sawmill. Institutional support should be extended to identify potential biomass processing and/or energy generation sites (Charisa *et al.,* 2019).

International cooperation within the forest industries must be encouraged, with the transfer and adoption of technologies, information, best practice, experience and expertise. Government encouragement and financial support for applicable national studies, and research and development in energy related activities of the forestry sector, combined with the dissemination of the data would lead to improved economic activity in Uganda and improved grower and processor profitability (FAO, 1990).

Once the Ugandan plantation industry has clearer direction regarding which future log processing options will be used (e.g. structural timber, engineered wood, CLT etc.), then there will be clarity regarding the biomass type and volumes. A proper market analysis can then be carried out and the waste management strategy updated to be more reflective of the actual conditions. This is a rather complicated undertaking, because each grower will wish to maximise their own profitability regarding wood waste based on their future energy requirements and other local opportunities. Some of the waste options, such as engineered wood, pyrolysis plants and pelletising plants, will likely require wood waste from a number of sawmills to reach the desired economies of scale. Table 25 provides an indication of the options available for biomass wood waste type based on sawmill size in Uganda.

Sawmill biomass waste type	Sawmill size	Future products (output)	Comments
Bark Log debarking machines	Small – static	None	Logs will probably not be debarked at small mills. Debarking capacity will probably be installed at medium and large mills in the future. The light weight of bark usually makes transport uneconomical. Use will be at the mill (boiler fuel) or a close by market (compost of mulch).
	Small - mobile	None	
	Medium	Boiler fuel Compost Mulch	
	Large	Boiler fuel Compost Mulch	
Shavings wet and dry	Small – static	None	Shavings unlikely from small mills. Animal husbandry more likely if a large market is available. If used for boiler fuel will be mixed with other waste biomass. Briquettes can be manufactured on site. Wood pellets probably manufactured off site - will need to be close to pellet plant or transport costs will be very high.
	Small - mobile	None	
	Medium	Animal husbandry Boiler fuel Briquettes Wood pellets	
	Large	Animal husbandry Boiler fuel Briquettes Wood pellets	
Wet sawdust Sawing logs	Small – static	Animal husbandry	Animal husbandry most suited to small mills. If used for boiler fuel will be mixed with other waste biomass. Briquettes can be manufactured on site. Wood pellets probably manufactured off site - will need to be close to pellet plant or transport costs will be very high.
	Small - mobile	Animal husbandry	
	Medium	Boiler fuel Briquettes Pellets	
	Large	Boiler fuel Briquettes Pellets	
Dry sawdust Sawing dry timber	Small – static	None	Animal husbandry more likely if a large market is available. If used for boiler fuel will be mixed with other waste biomass. Briquettes can be manufactured on site. Wood pellets probably manufactured off site - will need to be close to pellet plant or transport costs will be very high.
	Small - mobile	None	
	Medium	Boiler fuel Briquette Pellets	
	Large	Boiler fuel Briquettes Pellets	
Sander dust Product finishing	Small – static	None	Animal husbandry more likely if a large market is available. If used for boiler fuel will be mixed with other waste biomass. Briquettes can be manufactured on site. Wood pellets probably manufactured off site - will need to be close to pellet plant or transport costs will be very high.
	Small - mobile	None	
	Medium	Boiler fuel Briquette Pellets	
	Large	Boiler fuel Briquette Pellets	
Offcuts/ ends Log processing	Small – static	Firewood	Small mill offcuts have limited market options due to low volumes and no debarking. Medium and large mills more market options due to debarking. Mill size and waste volumes will determine whether gasification or pyrolysis will take place on site. If markets are offsite, distance will determine whether offcuts are sent or whether it is chipped at the mill.
	Small - mobile	Firewood	
	Medium	Chips - gasification Chips - pyrolysis Chips - mulch Engineered wood	
	Large	Chips - gasification Chips - pyrolysis Chips - mulch Engineered wood	
Logs Out of spec logs	Small – static	Firewood Engineered wood Chips-mulch	Small static mills have increased options due to logs being concentrated. Small mobile mills unlikely non-spec logs will be transported for higher end use due to low volumes.
	Small - mobile	Firewood	

Sawmill biomass waste type	Sawmill size	Future products (output)	Comments
	Medium	Chips – gasification	Medium and large mills more market options due to debarking. Mill size and waste volumes will determine whether gasification orpyrolysis will take place on site. If markets are offsite, waste will probably be transported as logs due to transport costs.
		Chips – pyrolysis Chips - mulch	
		Engineered wood	
	Large	Chips – gasification	
		Chips – pyrolysis Chips - mulch	
		Engineered wood	

Finally, marketing of the processing biomass residues or their products needs to be considered. Each processing facility needs to investigate which of the waste use options pose the greatest opportunity and then compile a marketing strategy to ensure that the opportunity is realised. It may be possible for the industry to compile a high level marketing strategy for the entire industry, especially where economies of scale are required for aspects such as bio-energy or collective marketing of the use of a certain product (e.g. wood briquettes). However, experience indicates that due to the costs of waste biomass processing and transport, the consumer of the product needs to be relatively close to where the processing plant.

Figure 40 uses a bioenergy scenario to highlight the opportunities for encouraging wood biomass waste use, but the same is true for the general opportunities for all use of wood biomass waste. Technical, institutional and social and economic actions are identified. If these are realised, then there can be significant social, economic and environmental opportunities (IEA Bioenergy, 2015).

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Opportunities to encourage sustainable bioenergy supply chain mobilization	
Technical	• Research and development of improved technologies and supply chain optimization • Technology transfer from experienced regions to regions with minimal bioenergy deployment • Learning-by-doing (e.g., starting small and scaling) • System design optimizing local conditions and using existing infrastructure • Biomass production that is aligned with existing silvicultural and agricultural practices
Institutional	• Clear and consistent policy definitions and goals for renewable energy • Coordinated policies for forestry, agriculture, renewable energy and climate change • Cooperative organizational structures along the supply chain • Internationally accepted sustainability standards • Good governance systems to guide sustainable practices • Guaranteed long-term support (e.g., feed-in tariffs, renewable energy credits, subsidies)
Social & Economic	• Competitive business case incl. valuation of co- and by¬products & available financial investment capital • Broad societal stakeholder consensus on pathways to achieve energy system transformation

Social, economic and environmental opportunities

- Reduced greenhouse gas emissions through replacement of fossil fuels
- Increased domestic energy security
- Rural economic development and employment opportunities
- Potential improvement in local environmental conditions
- Possible contribution to improving renewable resource management practices
- Added value to lands maintained in forestry and agriculture

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8 . Conclusion

Due to the use of obsolete equipment and small-scale production processes, the wood processing industry in Uganda has low recoveries and therefore generates high quantities of waste. The best way to deal effectively with waste is to reduce it at the source and after that find potential use for the waste generated.

While sawmill wood waste (by-product) supply chains are complex and challenging, the key elements for success can be easily summarised. The first aspect is to understand the biomass waste supply including the amount, locations and quality. Then the supply chain must realise the best value by connecting the waste biomass to the right market and use, while adding the optimal value at the appropriate place along the supply chain with pre-processing, amalgamations and volume efficiencies. Scaling and integration with existing and future supply chains that both leverage expertise and create synergistic efficiency results in the optimal solution.

Currently Ugandan sawmills produce no waste, as all of the by-product is used by a multitude of small entrepreneurs. However, there are more profitable uses for this waste. As the industry scales up to harvest the wall of wood that is approaching, the quantum of by-product will increase significantly and it is likely that the current consumers of the waste will not have the capacity to use it all.

The foundations for the waste strategy can now be laid. However, until the industry has more clarity regarding the primary processing strategy, the waste strategy will not be able to contain substantial detail. When the primary processing strategy is compiled, the use of waste will also need to be considered, because it affects the profitability of a modern mill. Better coordination within the industry regarding future processing options will result in better waste management solutions as well.

Therefore, once this is finally done, the industry needs to return to this strategy document regarding the primary products produced from the round wood. The strategy can then be fine-tuned for the best waste biomass options available and carry out more detailed work, including developing a marketing strategy.

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Annexure: Glossary of terms and acronyms

Definitions

Biodiesel: Biodiesel is called the mixture of esters obtained from the transesterification of triglycerides contained in oleo chemical feedstock such as vegetable oils, tallow and greases. Biodiesel can be used as substitute of diesel fuel.

Bioenergy: Renewable energy produced from the conversion of organic matter. Organic matter may either be used directly as a fuel or processed into liquids and gases.

Biofuel: Fuel produced directly or indirectly from biomass. The term biofuel applies to any solid, liquid, or gaseous fuel produced from organic (once-living) matter.

Biogas: Biogas is a mixture of gases, mainly composed by methane (50 – 60 percent) obtained from the anaerobic digestion of biomass. In general, most of the organic wastes can be digested (excepting lignin). Among the most common biogas substrates can be counter livestock residues, Municipal Solid Wastes (MSW), water treatment plants sludges.

Biomass: Organic matter available on a renewable basis. Biomass includes forest and mill residues, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes.

Biomass assessment: Biomass assessment analysis the production, availability and accessibility of biomass feedstock for energy production. The assessment considers all uses of the potential feedstock, such as their use in maintaining soil fertility, or as feed for livestock before calculating the amount of biomass available for bioenergy production. This is essential to avoid any adverse impact that bioenergy production may have on agricultural sustainability. The result of the assessment is the identification of the main types of biomass feedstock available for bioenergy production as well as their geographical distribution within a specific region or country.

Briquettes and pellets: Solid biofuel obtained by compressing biomass in order to increase density. The primary difference between briquettes and pellets is shape and size. Briquettes are generally bigger than pellets.

By-product (waste): A by-product, or co-product, is a substance, other than the principal product, generated as a consequence of producing the main product. Examples include animal feed, food additives, specialty chemicals, charcoal, and fertilisers.

Charcoal: A porous black solid obtained from biomass. It is an amorphous form of carbon obtained by the thermal decomposition of wood or other organic matter in the absence of air.

Chips: Woody material cut into short, thin wafers. Chips are used as a raw material for pulping and fiberboard or as biomass fuel.

CHP, Combined Heat and Power: Combined Heat and Power. The simultaneous production of electricity and useful thermal energy from a common fuel source.

Combustion: Combustion is the most common way of converting solid biomass fuel to energy. Around 90 percent of the energy generated from biomass is obtained through combustion, which is traditionally used for heating and cooking. Moreover, biomass combustion technologies are actively used for electricity generation at rural and industrial scales by means of steam.

Ethanol: Ethanol is a short chain alcohol, which can be directly used as fuel or blended with gasoline. It can be produced through the fermentation of glucose derived from sugar-bearing plants (e.g. sugar- cane), starchy materials after hydrolysis or lignocellulosic materials (e.g. crop residues, Miscanthus) after pretreatment and hydrolysis.

Firewood: Cut and split oven-ready fuelwood used in household wood burning appliances such as stoves, fireplaces and central heating systems. Firewood usually has a uniform length, typically in the range 150 to 500 mm.

Forest residues: Material not harvested or removed from logging sites in commercial hardwood and softwood as well as material resulting from forest management operations such as pre-commercial thinnings and removal of dead and dying trees.

Fossil fuel: Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.

Fuelwood (energy wood): Wood fuel where the original composition of the wood is preserved.

Green chips: Wood chips made of fresh logging and thinning residues, including branches and tops.

Gasification: A thermochemical process at elevated temperature and reducing conditions to convert a solid fuel to a gaseous form (CO, H2, CH4, etc.), with char, water, and condensibles as minor products.

Gasifier: A device for converting solid fuel into gaseous fuel.

GHG: Greenhouse gas. Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapour and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

IEA: International Energy Agency.

Log (round) wood: Cut fuelwood in which most of the material has a length of 200 mm and above. Wood in the rough. Wood in its natural state as felled, or otherwise harvested, with or without bark, round, split, roughly squared or other forms (e.g. roots, stumps, burls, etc.). It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period – calendar year or forest year.

Particulate: A small, discrete mass of solid or liquid matter that remains individually dispersed in gas or liquid emissions. Particulates take the form of aerosol, dust, fume, mist, smoke, or spray. Each of these forms has different properties.

Pellet: Densified biofuel made from pulverised biomass with or without pressing aids usually with a cylindrical form, random length typically 5 to 30 mm, and broken ends. The raw material for biofuel pellets can be woody biomass, herbaceous biomass, fruit biomass, or biomass blends and mixtures. They are usually manufactured using a die. The total moisture content of biofuel pellets is usually less than 10 percent of mass.

Pyrolysis: The thermal decomposition of biomass at high temperatures (greater than 400 °F, or 200 °C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

Residues: By-product of agricultural cultivation (e.g. bagasse), farming activities (e.g. manure) or forestry industry (tree thinnings).

Sawn wood: Sawn wood, unplanned, planed, grooved, tongued, etc., sawn lengthwise, or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboards, "lumber", sleepers, etc.) and planed wood which may also be finger jointed, tongued or grooved, chamfered, rabbeted, V-jointed, beaded, etc. Wood flooring is excluded.

Torrefaction: Mild pre-treatment of biomass at a temperature between 200 – 300 °C. During torrefaction of the biomass, its properties are changed to obtain a better fuel quality for combustion and gasification applications.

Whole-tree chips: Wood chips made of whole trees (i.e. wood chips containing stems with bark, branches, needles/leaves).

Wood briquette: Densified biofuel made with or without additives in the form of cubiform or cylindrical units, produced by compressing pulverised biomass.

Wood chips: Chipped woody biomass in the form of pieces with a defined particle size produced by mechanical treatment with sharp tools such as knives. Wood chips have a sub-rectangular shape with a typical length 5 – 50 mm and a low thickness compared to other dimensions.

Woody biomass: Biomass from trees, bushes and shrubs.

Wood fuels, wood based fuels, wood-derived biofuel: All types of biofuels originating directly or indirectly from woody biomass.

Wood pellet: Densified biofuel made from pulverised woody biomass with or without additives usually with a cylindrical form, random length and typically 5 to 40 mm, with broken ends.

Wood processing residues: These residues include sawdust, slabs and chips generated as residues during the wood processing. The amount of residues generated in a sawmill depends on the type of technology used and its efficiency. Often, these residues are not fully utilised due to the lack of demand in the immediate vicinity of the processing plant.

Wood fuels: Wood fuels arise from multiple sources including forests, other wooded land and trees outside forests, co-products from wood processing, post-consumer recovered wood and processed wood-based fuels.

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