Wood-based Bio-refineries: Value adding to sawmill waste from the Forestry industry

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1. Introduction and project scope

The overall aim of this project is to develop a pre-feasibility guideline that can be used as an opportunity analysis for the FTTP industry. The guideline will focus on two major waste streams generated by the sector viz. sawdust and sludge. The guideline should be able to steer small SMMEs and large corporations to ascertain which valorisation routes could be optimal for their operations.

There is a myriad of options for deriving value from the waste materials in terms of products and associated processing routes. Unfortunately, there is little available data to help FFTP decide on which value-adding options would be most beneficial to pursue and incorporate into their operations. The value-adding routes will be dependent on a variety of factors – these include the different types of trees processed (softwoods or hardwoods), the availability and age of sawdust, the technology options appropriate to the specific waste-streams, the maturity and commercial readiness of the technologies, the market demand for various FTPP products, the integrated and combined production options, and the location of the FTPP mills relative to the wood resources and markets for products. For the proposed study, the overall approach taken will be based on a typical pre-feasibility study. This involves exploring the opportunities to add value to FTPP wastes, and an assessment of which ones are the most promising to take forward to full techno-economic feasibility studies. The main aim of a pre-feasibility study is to select the preferred option(s) for project development, which will move the project through subsequent stages of development to a final feasibility study. Such a prefeasibility study is therefore an intermediate stage between an opportunity analysis and a detailed feasibility study. The main components of such a prefeasibility study includes:

1. A description of the business by exploring the range technology options and opportunities for (new) FTPP products or services. This will enable opportunities to be defined in terms of new FTPP scenarios
2. An assessment of the technology readiness and commercialisation of various technologies and products
3. Exploring the market potential for these various product, through preliminary market research
4. Assessing the performance of the various FTPP opportunities in terms of various financial, economic, social and environmental criteria that are considered important to the FTPP industry for project development and further investment
5. Understanding the institutional capacity and policy environment that defines the corporate and legal structure of the FTPP sector.

The sawdust beneficiation strategy includes the beneficiation of hardwood and softwood sawdust waste material. The hardwood sawdust beneficiation strategy is designed with intention of extracting the hydrophilic fraction from sawdust (hemicelluloses in the form of mainly xylose) with the ultimate goal of using the xylose-rich hemicelluloses to produce xylitol. In the case of softwood sawdust beneficiation, the strategy is designed with intention of extracting the lipophilic fraction (extractives) with the ultimate goal of producing pine oil. To maximise the utilisation of the sawdust resource, whilst at the same time improving the economic viability of the proposed sawdust beneficiation strategies, it may be necessary that all valuable chemicals such as acetic acid, lignin and cellulose formed as the result of the biomass fractionation, be also recovered. Acetic acid has huge potential in the food and chemical industries. Cellulose can be used in the production of value added products such as nanocrystalline cellulose (NCC), nanofibrillated cellulose (NFC) or micro-crystalline cellulose (MCC); whereas lignin can be used in the production of value added products such as energy, carbon fibres, etc. An overview of the sawdust beneficiation strategy is shown in Figure 3. In particular, this Milestone will specifically focus on the production of xylitol (from the hydrophilic hemicelluloses of hardwood sawdust), pine oil and phytosterols (from the lipophilic extractives of softwood sawdust), and NCC (from the residual cellulose from both hardwood and softwood sawdust).

This pre-feasibility study assesses the availability of sawdust wastes and the opportunities for value-adding through the production of Pine oil, Xylose and NCC.

2. Waste from the Forestry Industry

This project aims to reduce the wastes from the Forestry Industry through the development of biorefinery technologies that add value to waste. The details of mass flow diagrams of the Forestry sector were estimated, based on either industry volumes and allometric equations to estimate plantation biomass of stem-wood, bark and branches (Dovey and Smith (2005) and Dovey, 2010). As can be seen, 80-90% of the plantation forest resource is harvested for processing (10-20% biomass left in field). Most of the Forestry biomass is used for Pulp and Paper (65% goes to pulp and paper, 35% to Timber); so that approximately 1.7 Tg of the Forestry Resource per annum is available as sawlogs for timber production. Further, of the total round-wood volume entering the saw-milling process (saw logs) ± 50% is timber product, ± 20% wood chips, ± 10/12% bark, ± 6% sawdust and ± 14% other wood waste (off-cuts). The sawdust *and* offcuts waste amounts to ± 1 Tg per annum, which means that the sawdust generated is approximately 0.4 Tg per annum- or about 4% of the Forestry Resource

It is important to note that waste are generated at the both the timber mills and the pulp and paper mills, but are separate industries with dedicated Forestry plantations and associated value chains; so the wastes are unlikely to be co-located or co-owned.

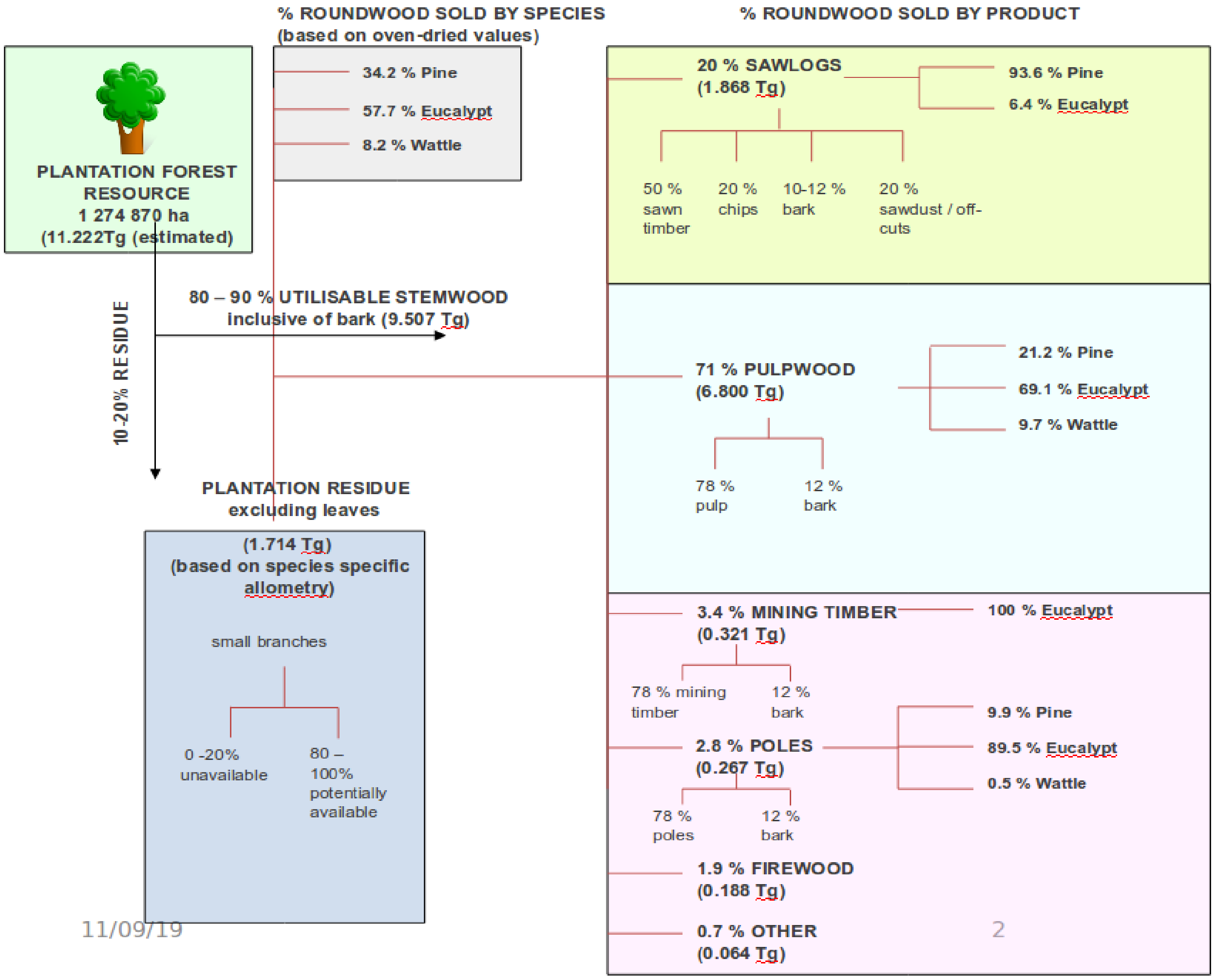
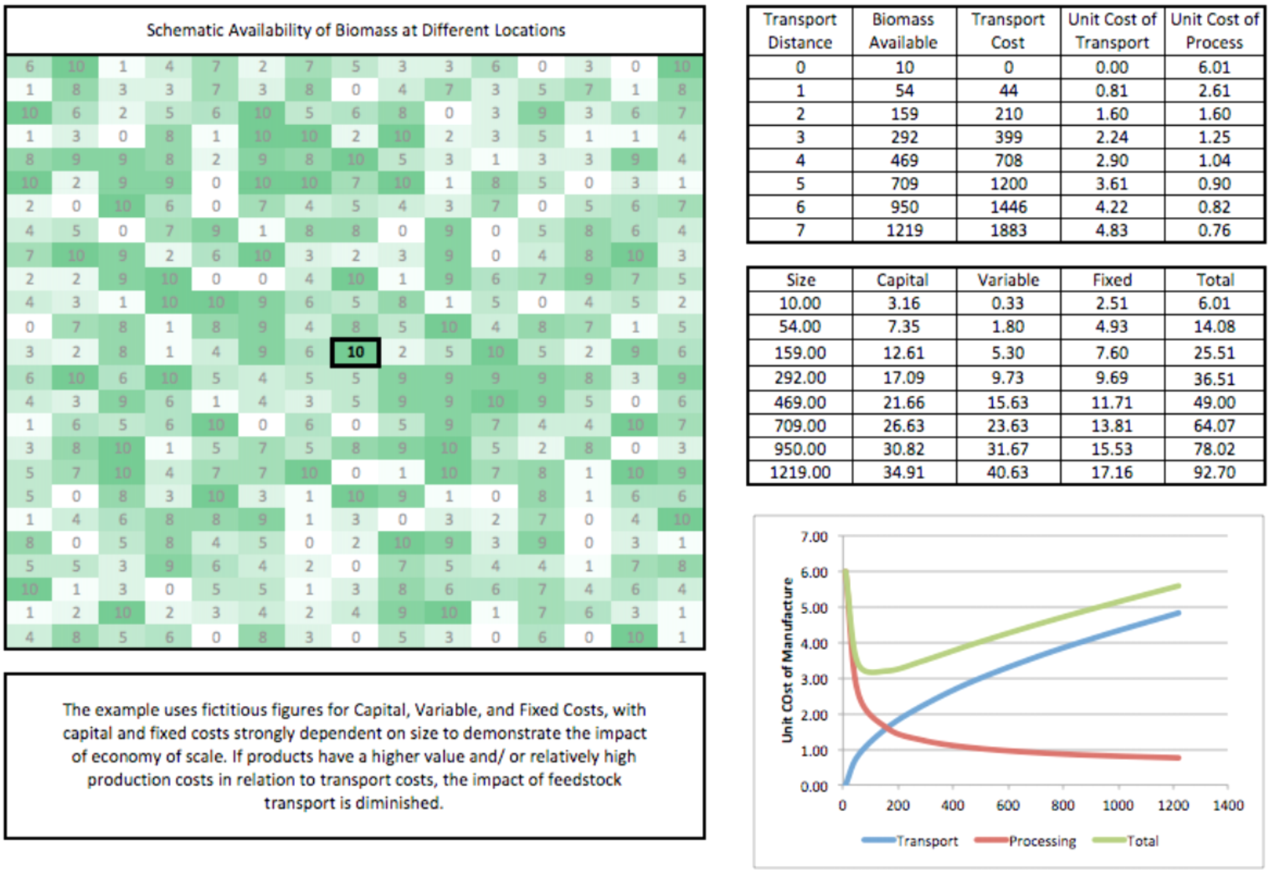


Figure 1. Mass flow diagram of plantation forest resource, related products and estimated plantation forest residue. Estimated oven-dried mass (terragrams, Tg, or millions of tonnes) (based on DAFF (2010) timber statistics for 2008/9 and using allometric ratios from Dovey and Smith (2005)

Typically, transport of the biomass is a large cost-component of a Biorefinery. Deciding on the optimal location and scale therefore requires a resource-location optimisation that takes into account the available biomass and economies of scale of production. The financial feasibility of the Biorefinery is often unattractive due to the significant costs in harvesting and transporting the biomass, which also demands smaller de-centralised technologies that have a higher production cost. There are typically large economies of scale for industrial production that does not favour small-sized production. Historical data from the chemical industry indicates that the capacity exponent is on average between 0.6 and 0.7 which is commonly known as the six-tenth rule of thumb[i]. The optimal techno-economic solution (lowest unit cost of manufacture) is therefore a trade-off between local biomass resource availability, economies of scale for production of a specific biorefinery product, and the transport costs involved- see Figure 2.



Schematic Availability of Biomass at Different Locations

6	10	1	4	7	2	7	5	3	3	6	0	3	0	10
1	8	3	3	7	3	8	0	4	7	3	5	7	1	8
10	6	2	5	6	10	5	6	8	0	3	9	3	6	7
1	3	0	8	1	10	10	2	10	2	3	5	1	1	4
8	9	9	8	2	9	8	10	5	3	1	3	3	9	4
10	2	9	9	0	10	10	7	10	1	8	5	0	3	1
2	0	10	6	0	7	4	5	4	3	7	0	5	6	7
4	5	0	7	9	1	8	8	0	9	0	5	8	6	4
7	10	9	2	6	10	3	2	3	9	0	4	8	10	3
2	2	9	10	0	0	4	10	1	9	6	7	9	7	5
4	3	1	10	10	9	6	5	8	1	5	0	4	5	2
0	7	8	1	8	9	4	8	5	10	4	8	7	1	5
3	2	8	1	4	9	6	**10**	2	5	10	5	2	9	6
6	10	6	10	5	4	5	5	9	9	9	9	8	3	9
4	3	9	6	1	4	3	5	9	9	10	9	5	0	6
1	6	5	6	10	0	6	0	5	9	7	4	4	10	7
3	8	10	1	5	7	5	8	9	10	5	2	8	0	3
5	7	10	4	7	7	10	0	1	10	7	8	1	10	9
5	0	8	3	10	3	1	10	9	1	0	8	1	6	6
1	4	6	8	8	9	1	3	0	3	2	7	0	4	10
8	0	5	8	4	5	0	2	10	9	3	9	0	3	1
5	5	3	9	6	4	2	0	7	5	4	4	1	7	8
10	1	3	0	5	5	1	3	8	6	6	7	4	6	4
1	2	10	2	3	4	2	4	9	10	1	7	6	3	1
4	8	5	6	0	8	3	0	5	3	0	6	0	10	1

Transport Distance	Biomass Available	Transport Cost	Unit Cost of Transport	Unit Cost of Process
0	10	0	0.00	6.01
1	54	44	0.81	2.61
2	159	210	1.60	1.60
3	292	399	2.24	1.25
4	469	708	2.90	1.04
5	709	1200	3.61	0.90
6	950	1446	4.22	0.82
7	1219	1883	4.83	0.76

Size	Capital	Variable	Fixed	Total
10.00	3.16	0.33	2.51	6.01
54.00	7.35	1.80	4.93	14.08
159.00	12.61	5.30	7.60	25.51
292.00	17.09	9.73	9.69	36.51
469.00	21.66	15.63	11.71	49.00
709.00	26.63	23.63	13.81	64.07
950.00	30.82	31.67	15.53	78.02
1219.00	34.91	40.63	17.16	92.70

The example uses fictitious figures for Capital, Variable, and Fixed Costs, with capital and fixed costs strongly dependent on size to demonstrate the impact of economy of scale. If products have a higher value and/ or relatively high production costs in relation to transport costs, the impact of feedstock transport is diminished.

Figure 2. A schematic of an example biomass resource with resource-location optimisation. The unit cost of production/manufacture depends on the availability and cost to transport biomass to the Biorefinery, and scale of production (economies of scale).

Therefore a combination of biomass resource assessment, appropriate technology and techno-economic studies are needed to ensure that viable Biorefineries are those that will be financially feasible (have a positive net present value), while also contributing to job-creation, skills development, inclusive socio-economic development, and environmental protection. The cost of biomass supply to the Biorefinery is typically a large proportion of the overall project cost and is a key determinant of overall financial feasibility. However, in this initial assessment we have not included such as spatial resource-location optimisation so as to reduce transport costs and tailor the solution to the current wastes at the mills. Therefore, we have matched the scale Biorefinery technology with the amounts of waste currently being generated by a typical small and large mills.

3. Sawmill waste quantities, location and scale

Sawmill sizes are usually expressed in terms of their total annual log intake. The number of mills and size are shown in Table 1. There are 176 sawmills with an individual mill volume up to 50 000 m^3 per annum; but these mills only account for 39% of the saw-milling industry's volume. The remaining 25 sawmills, having intakes of more than 50 000 m^3 p.a. account for 61% of annual production. The distribution of the number of sawmills per province who are registered Sawmilling South Africa (SSA) members, is provided in Table 1 and Figure 3.

Table 1. Number of sawmills and size in terms of volume intake per annum (SSA website)

Volume intake (m^3 per annum)	**Number of mills**	**% of volume production**
0 – 5 000	18	2.9%
5 001 – 10 000	122	19.7%
10 001 – 20 000	22	7.1%
20 001 – 50 000	14	9.0%
50 001 – 100 000	16	25.8%
100 001 – 150 000	5	16.1%
150 001 – 200 000	4	19.4%
200 001 Plus	0	0.0%
Total:	**201**	**100.0%**

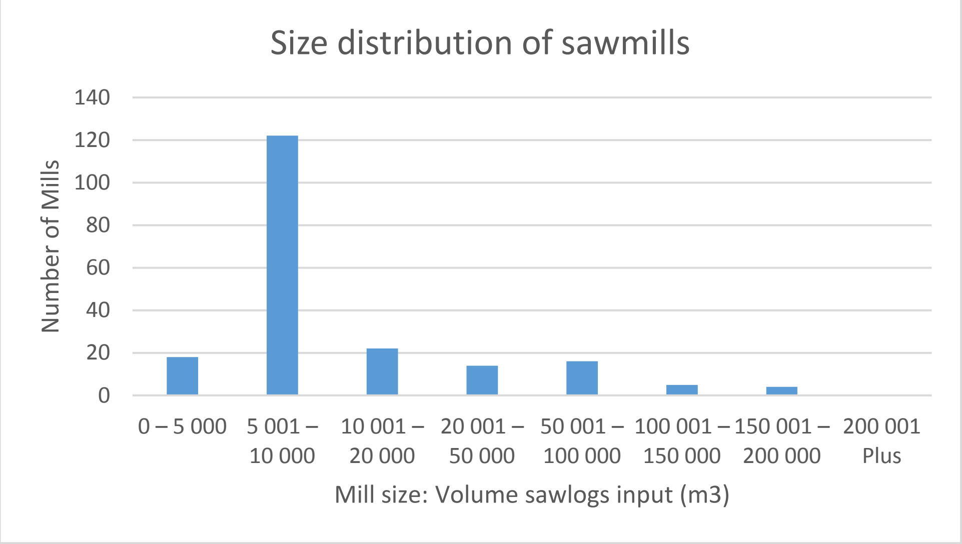


Figure 3. Number of sawmills with volume of sawlogs processed per annum

Most sawmills process 5 000-10000 m^3 sawlogs input per annum (Figure 3), but sawmills processing >50 000 m^3 sawlogs input per annum size mills are the greatest contributor to the overall saw timber production (Figure 4). Therefore, while the average sawmill processes 33 333 m^3, the mode or most frequent sawmill process 5000-10000 m^3 sawlogs input per annum. In other words, there are many small and medium sized mills and a few large ones. The large ones make a significant contribution to the overall timber production.

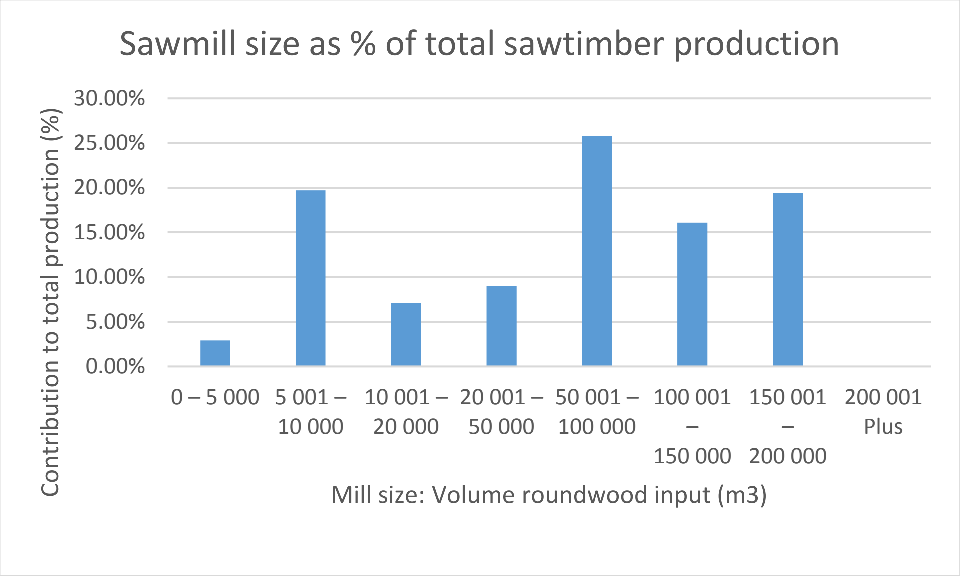


Figure 4 Sawmill size and contribution to total timber production

Most of the mills are located near Forestry areas, i.e. most mills in Mpumalanga, followed by KZN- Table 2 and 3.

Table 2. List of sawmills per province (SSA members) (Wood SA &Timber Times, 2011)

Type	**Total number of sawmills**				
	KZN	**Limpopo**	**E. Cape**	**Mpumalanga**	**W. Cape**
Swd	0	0	0	0	0
Hwd	0	1	2	2	0
LCM	21	7	18	17	0
Formal	13	6	7	16	4
Hwd-mine	1	2	0	4	0
Hwd LCM	6	7	2	4	0
Hwd-bush	1	3	1	1	0
Bush	2	9	3	8	0
Undeclared	1	1	2	9	11
Total (192)	45	36	35	61	15

LEGEND	
Swd	Soft wood (a mill cutting only softwood (pine)
Hwd	Hard wood (a mill cutting only hard wood (eucalyptus)
LCM	Low-cost sawmill cutting soft wood
Formal	Formal sawmill
Hwd-mine	Hard wood mining timber sawmill
Hwd LCM	Hard wood low-cost sawmill
Hwd-bush	Hard wood bush sawmill
Bush	Bush sawmill soft wood

Table 3. Geographical distribution of production by sawmill category (August 2011) (M. Allpass, pers. comm.[1])

Region	Formal		Informal (estimate)		TOTAL	
	No. of mills	Approx. volume produced (saw timber) (m^3)	No. of mills	Approx. volume produced (m^3)	No. of mills	Approx. volume produced (m^3)
Mpumalanga, Limpopo & NW	16	659 558	34	214 438	50	873 996
KwaZulu-Natal *	12	358 790	26	213 373	38	572 163
Western/Northern Cape	5	161 382	23	102 347	28	263 729
Eastern/Southern Cape & Border	5	256 845	7	42 410	12	299 255
TOTAL saw logs (timber)	38	1 436 575	90	572 568	128	2 009 143
Waste (Sawdust, bark, chips)		1 436 575				2 009 143
(* includes Swazi mills)						
The table excludes bushmills as a category and now only includes informal as a category.						

Of the total round-wood volume entering the saw-milling process, approximately 35 to 50% is a by-product (waste material in the form of sawdust, chips, or bark). Saw-logs entering the saw-milling process, produce: ± 50% saw timber product, ± 20% chips, ± 10/12% bark, ± 6% sawdust and ± 14% other wood waste (off-cuts) (Southey, Pers. Comm.[2]). All formal sawmills and some small-scale sawmills use a large proportion of their by-product in fuel boilers that create steam for drying the timber.

An estimate of available of sawmill 'waste' (sawdust, off-cuts) and bark from saw-logs is provided in Table 4.). Notably, only 4% of the sawmill waste is hardwood Eucalyptus while 96% is softwood Pine

Table 4. Estimated availability of sawmill 'waste' (Olivier and McEwan, 2010)

Round-wood resource	**Saw-log demand in 2008**	**tonnes**			
		Sawmill 'waste' (sawdust and offcuts)	**Bark**	**Estimated usage**	**Available for bioenergy**
Pine Saw-log	5 414 000	2 600 000	500 000	2 000 000	**1 100 000**
Euc Sawlogs	235 000				

This has important consequences in terms of sawdust waste availability for the different technology options (see suitability section)

Based on the above, the sawdust waste produced at the mills can be calculated- Table 5 and Figure 5.

Table 5. Sawmill wastes estimated on a volume and mass basis ($0.94m^3$=1 tonne)

Mill production VOLUME (m3) per annum			
Number mills	Informal	Formal	
218	90	128	

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[1] Mandy Allpass, Crickmay and Associates, (Pty) Ltd. Private Bag X9118, Pietermaritzburg, 3200

[2] Roy Southey, Executive Director Sawmilling South Africa, P.O. Box 1118 , Sedgefield, 6573

VOLUME (m3)			
Roundwood	2875150	4018286	%
Saw timber	1437575	2009143	0.5
Chips	575030	803657	0.2
Off-cuts	402521	562560	0.14
Bark	287515	401829	0.1
Sawdust (m3)	172509	241097	0.06

Mill production MASS (m3) per annum			
MASS (tonnes)			
Roundwood	3058670	4274772	
Saw timber	1529335	2137386	
Chips	611734	803657	
Off-cuts	402521	598468	
Bark	305867	427477	
Sawdust (t)	183520	256486	total sawdust
			440 006

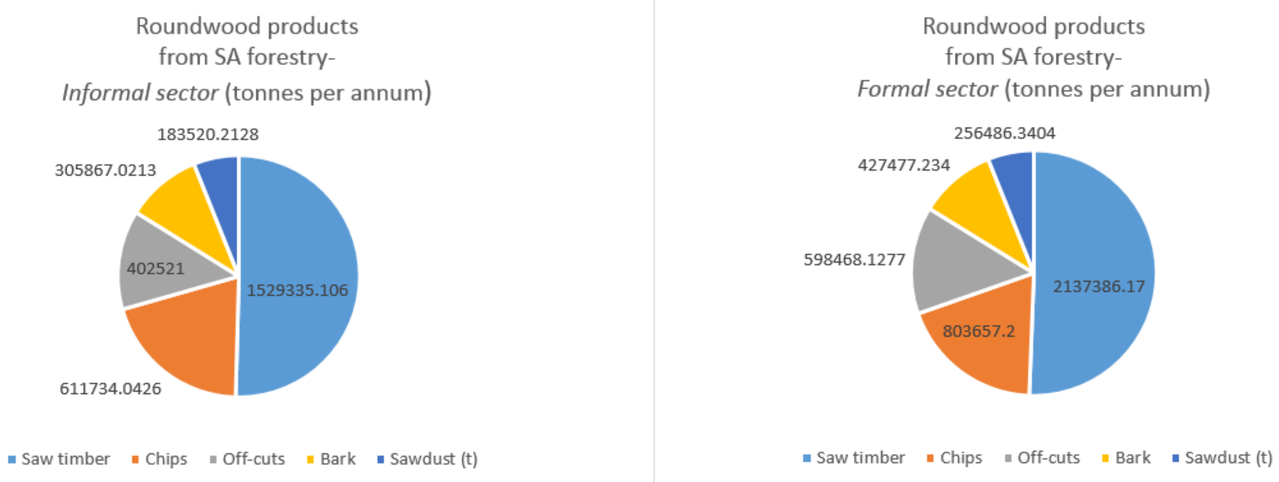


Figure 5. Sawlog products (data from Table 3 and 5)

We can summarise the waste sawdust amounts produced at the sawmills as follows:

- Sawdust waste is 6% of the roundwood going into a sawmill
- Only 4% of the sawmill waste is hardwood Eucalyptus, while 96% is softwood Pine
- From all the sawmills in SA, 440 006 tonnes per annum sawdust waste from 218 mills
- Most of the mills are small-medium sized of 5 000-10 000m3 roundwood input (sawmill waste 300 -600 tones annum), but the larger mills of >50 000m3 roundwood input are the greatest contributors to overall saw timber production (and sawdust waste generation).
  AVERAGE (mean) mill processes 33 333 m3 roundwood input and 2000 tonnes per annum sawmill waste (5.5 tonnes per day),

MODE (most frequent) mill processes 10 000 m3 roundwood input per annum and 600 tonnes per annum (1.6 tonnes per day).

Using 1 and 10 tonnes per day sawdust capacity will cover the technology range required of small and large mills respectively.

4. Suitability of sawmill waste for new biorefinery products]

The Pine oil, Xylose and NCC have certain suitability requirements in terms of the sawdust resource and yield. Any sawdust-derived material remaining after these processes will need to be discarded as waste. This is summarised in Table 6.

Table 6. Suitability of Biorefinery products to sawmill waste: Only shaded boxes with yield are suitable in terms of products and resource type.

Sawmil waste type	Pine oil	Xylose	Nanocrystalline cellulose (NCC)
Softwood Pine	▨		▨
Hardwood Eucalyptus		▨	▨

The suitability of the process will dictate the amount of resource available. The above poses limitations on the amounts of Xylose that can be made from sawmill waste since it is only suited to only hardwood waste which is 4% of the sawmill waste resource. It also only allows NCC to be easily combined with Xylose or Pine oil but not both (unless the sawmill waste is transported from one location to another). The potential yield of the biorefinery products will also determine the overall value add and profitability from the sawmill waste resource. It will also dictate the financial feasibility of the production, since unutilised sawmill resource will mean lost revenue and there will disposal costs incurred for any remaining sawdust derived waste. The suitability of hardwood and softwood for the various products and the claimed yields, allows for the calculation of the total amounts of biorefinery products from all the sawdust or the Timber Industry as a whole to be calculated (Table 7). Similarly, the amounts of biorefinery products that could be produced by a typical small and large sawmills can be calculated (Table 8). The total sawdust resource utilisation, if the three technologies were combined, would be 49%- leaving 51% for other possible products or to be discarded as waste (in its current form in a liquid, so water may need to be removed).

Table 7. Biorefinery product potential for the Timber Industry. The Suitability and yield of Biorefinery products to sawmill waste is shown- Only shaded boxes with yield are suitable in terms of products and resource type. Yields (% w/w) are shown in square parenthesis

	Sawmil waste tonnes per annum	**Biorefinery products: Maximum annual production potential from sawmill waste (tonnes per annum)**				
Total	**440006**	Pine oil [5%]	Xylose [4%]	Nanocrystalline cellulose [40%]	Other products/ heat and power	Waste
Softwood Pine	422406	21120	~~16896~~	168962	?	?
Hardwood Eucalyptus	17600	~~880~~	704	7040	?	?

The small and large mills would therefore produce the following (Table 8):

Table 8. Biorefinery product for small and large mills. Only shaded boxes with yield are suitable in terms of products and resource type. Yields (% w/w) are shown in square parenthesis.

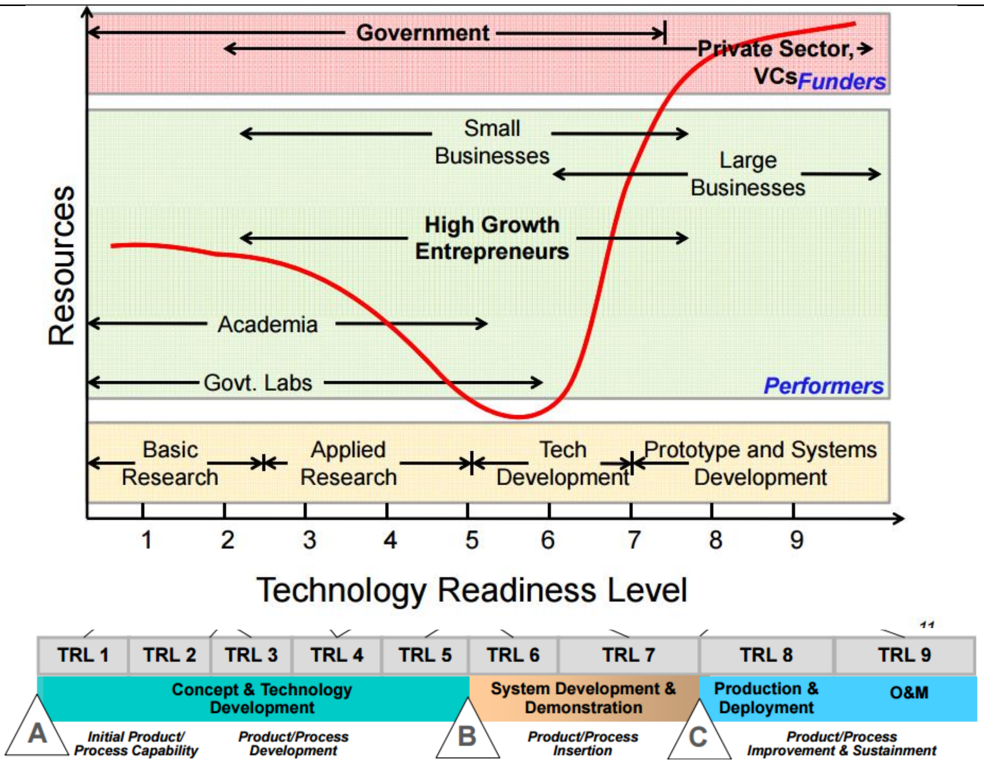
	Biorefinery product potential from small and large sawmills (tonne per annum)				
Product	Pine oil [5%]	Xylose [4%]	Nanocrystalline cellulose [40%]	Other products/ heat and power	Waste
Small mills (1t/day or 365 t/annum)	18	14.6	146.0	?	?
Large mills (10t/day or 3650 t/annum)	183	146.0	1460.0	?	?

5. Technology readiness and commercialisation

The Technology Readiness Level (TRL) scale is a metric for describing the maturity of a technology. The scale consists of 9 levels. Each level characterises the progress in the development of a technology, from the idea (level 1) to the full deployment of the product in the marketplace (level 9). This scale was developed by NASA in the 1970s to assess the maturity of a technology prior to integrating this technology into a system. The advanced biofuels pathways can be defined by the technology readiness level (TRL) and can be classed at in 4 stages (NASA 2017):

- **Research and development (TRL0–TRL4).** Bringing new technology pathways to fruition requires a substantial amount of research, planning, and experimentation. In this phase, unproven concepts are tested, principles postulated from observations, and specific applications formulated. Subsequently, applied research is conducted at laboratory scale and the technology developed into a proof of concept via small-scale prototyping.
- **Pilot and demonstration (TRL5–TRL7).** Larger-scale prototypes and pilot plants are developed in order to determine the scaling potential and the intended operating environment of new technologies.
- **Early commercial deployment (TRL8).** For any technology developed at commercial scale it is necessary to create first-of-a-kind systems and flagship plants. This phase proves to consumers and investors the viability and commercial readiness of the proposed technology. Early adopters and market uptake play a crucial role during this phase to ensure a technology overcomes the developmental 'valley of death' before full commercial success.
- **Commercially established –(TRL9).** A technology is considered to be commercially established when it is readily available to consumers, comes with performance guarantees and economically competitive with similar market items.

The text box below summarises the current status of technology readiness levels are shown below for the biorefinery technology under consideration.



Biorefinery technology	**TRL**	**Evidence/Comments**
Pine oil	8	CSIR process uses the established distillation of essential oils using stainless steel stills. History of commercial application before the extensive production of mineral turpentine from fossil fuels replacing wood turpentine and other extractives like pine oil. However, not currently established at commercial scale for sawdust
Xylose	7	Technology at established commercial stage with several suppliers that produce xylose by acid-hydrolysis and then convert it to xylitol by chemical catalysis. Established commercial plant, but the the CSIR process uses sawdust and has not been demonstrated at 1-10t/day for sawdust
NCC	6	Technology under development. A few early commercial plants. However, the CSIR process has some novelty and has not yet been demonstrated at 1-10t/day for sawdust

6. Financial viability of biorefinery products from sawmill waste

A basic financial viability assessment of an enterprise implies a systematic account and subtraction of the cost associated with the operations of the enterprise from the income been generated from the operations. The relative size of the remaining profit and the time required to realise said profit, is compared to alternative investment options and is then used to evaluate the financial viability of the operation. Comparison is done in standard aggregates such as IRR and NPV.

- IRR is a specific type of rate of return, i.e. the INTERNAL (i.e. ignoring inflation and interest) rate of return which is just the discounted cash flow rate of return.

- NPV is the difference between the present value of the cash inflows and outflows of a product/service over a period of time. NPV is used in capital budgeting (i.e. does the income stream from the product/service justify the capital outlay).

Calculating the gross margin is the first step towards calculating either the NPV or the IRR. However, embedded in this seemingly simple calculation is the scale of operations which have a determinative impact on viability. This is mainly due to the difference between variable and fixed cost of operations. Variable cost is defined as costs that vary with the number of units produced, e.g. the costs of raw materials and labour. Fixed costs are costs that are independent of the number of units produced; such as rent, insurance and depreciation.

Typically fixed cost component decreases as a percentage of total cost as output levels increases, whereas the variable cost component is not affected. I.e. as the total output increases, fixed cost represents a decreasing proportion of total cost (Figure 6). For example, at output level "b", the total fixed cost "a" is equal to the total variable cost "av". However, at output level "e", the total fixed cost "a" is smaller compared to total variable cost "d". This implies that fixed costs are the main determinant of profitability if output levels are low, i.e. below "b" (i.e. small scale operations); whilst variable cost become the most important determinant of viability as scale of production increases, i.e. above "b" (large scale operations).

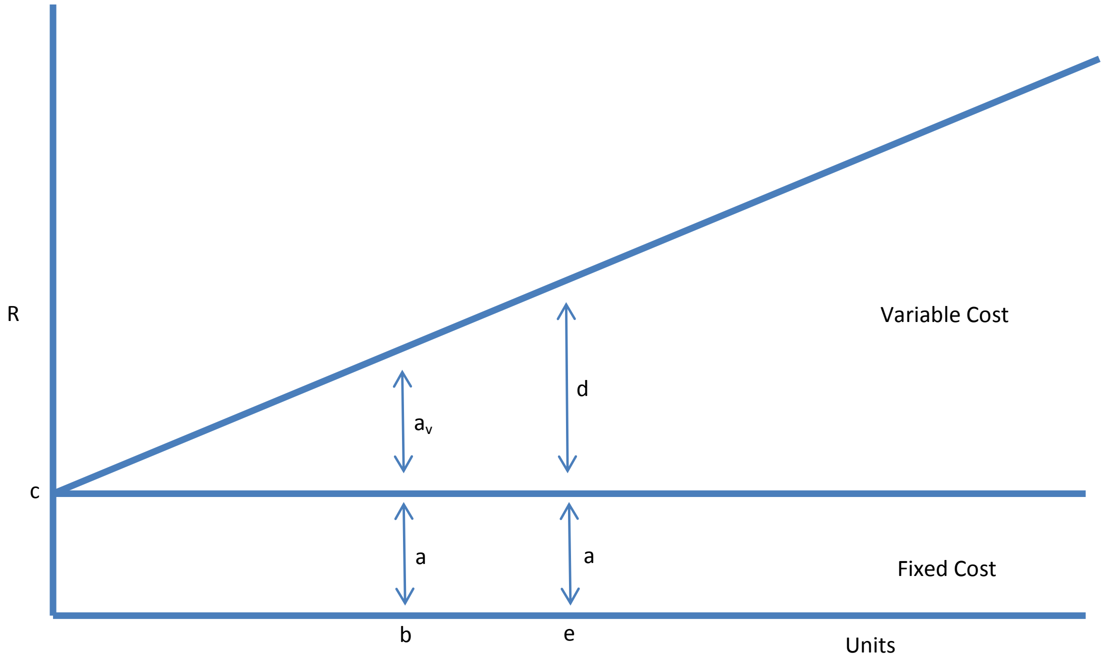


Figure 6: Fixed and variable cost

The minimum requirement for unit profitability is a positive margin above cost. The consequent minimum required scale of operations is the level of the turn-over that breaks even with the fixed cost component of the business (point "c"). Once the minimum requirements are met, the scale of operations is determined by the relative size of the market (demand for the product or service), and the ability of the entity to meet the demand for the product (supply of the product or service).

It should be clear that both unit profitability and scale of production have a determinative effect on the financial viability of a business – which is of course an important consideration in deciding as to whether or not investment in such endeavour make sense from an financial perspective. Financial viability cannot therefore be argued without referring to these variables. Furthermore, such viability is subject to a number of constraints (i.e. contextual reality), which is why previous sections presents the context, constraints and assumptions required to discuss the viability of the above-mentioned beneficiation options.

This report is not intended to delve too deep in the theory, but it should be clear that unit profitability and the scale of operations are important determinants of the financial viability of a product / service. There is some substitutability between these two components once the minimum requirements for both are met – i.e. a higher scale of production can compensate for lower unit profitability (and vice versa), if the market conditions allows for it. Scale of production has therefore a big impact on viability and determines, along with the production process (cost), and market prices, the financial viability of any production/processing orientated enterprise.

It should be clear that the financial viability of pine oil, xylose and NCC from sawdust cannot be calculated in standard financial indicators (NPV and IRR) until the technical challenges (mainly related to changes in operations as the scale of production increases) associated with upscaling have been resolved. Using the current supply estimates, production potential and mill-size, an initial decision has been made in terms of suggested scale of operations. Financial viability will be assessed for a 1 tonne sawdust per day processing unit and a 10 tonne sawdust per day processing unit. These units will be regarded as modular and scalable to the current scale of production of most mills in South Africa. The financial assessment will therefore be based and presented in terms of these two processing capacities. This is work in progress, and it should be made clear that the assessment is currently not complete. However, some sketchy information on the income-side of the equation can be presented (see Tables 9, 10 and 11).

Table 9: Market estimates: Pine oil

Variable	**Unit**	**value**
Supply of softwood sawdust	tonnes per year	440 000
Amount of pine oil from 1 tonne of softwood sawdust	tonnes	0.05
Total amount of pine oil that can be produced per	tonnes per year	22 000

year in South Africa assuming all available softwood sawdust is used to produce pine oil		
Current market commodity price of pine oil	Rands per tonne	38 830
Total potential production value of locally produced oil	Rands per year	854 260 000
Total size of the pine oil market - global	Tonnes per year	600 000
Local production as percentage of global	percentage	3.6%

Table 10: Market estimates: Xylose

Variable	**Unit**	**value**
Supply of hardwood sawdust	tonnes per year	80000
Amount of xylose from 1 tonne of hardwood sawdust	tonnes	0.04
Total amount of xylose that can be produced per year in South Africa assuming all available hardwood sawdust is used to produce xylose	tonnes per year	3160
Current market commodity price of xylose	Rands per tonne	35 269
Total potential production value of locally produced xylose	Rands per year	111 449 250
Total size of the xylose market - global	$ per year	270 000 000
Local production as percentage of global	percentage	3.7%

Table 11: Market estimates: NCC

Variable	**Unit**	**value**
Supply of sawdust	tonnes per year	440 000
Amount of NCC from 1 tonne of sawdust	tonnes	0.4
Total amount of NCC that can be produced per year in South Africa assuming all available sawdust is used to produce NCC	tonnes per year	176 000
Current market commodity price of NCC	Rands per tonne	623 058
Total potential production value of locally produced NCC	Rands per year	109 658 145 363
Total size of the NCC market - global	Tonnes per year	4950
Local production as percentage of global	tonnes	3500%

It should be clear that due to the low input-output ratios, both pine oil and xylose does not look promising from the income side. I.e. the yield ratio of current production methods are too low, such methods will struggle to recover the fixed cost component of operations. NCC however, looks promising and if the production cost can be minimised, should prove profitable. South Africa can indeed become a major market player for this commodity for as long as the technology remains the competitive advantage (i.e. all countries have sawdust, but not all countries have the technology to realise a 40% input-output ratio) and if costs can be kept in check. Being a major market player also implies that South Africa will be able to impact the market price of NCC. A strategic decision will need to be made regarding the best price – supply volume ratio for the industry. An increase in supply and consequent decrease in price could increase research in terms of potential new applications thereby increasing the demand on the medium and long term. However, a regulated supply will maintain the price and increase short term profit. This trade-off will need to be discussed between government and major producers.

The cost side of the equation is currently uncertain (mainly because of the uncertainty regarding the processes associated with a 1 and 10 tonne per day scale of operations). Linear up-scaling cannot be used because of significant differences required between lab-scale operational protocol and commercial scale operational protocol. For example, the lab scale assessment has confirmed that approximately 3.35 kWh of electricity is used to produce 8 grammes of pine oil (direct electricity usage). This amounts to approximately R4.52 for 8 grammes of oil, or if scaled linearly, R565 worth electricity per kilogram of pine oil. Given the current market commodity price of pine oil of approximately R38/kg and a input-output ratio of only 5% (i.e. 50kg of oil per day from a 1 tonne per day sawdust), it means that by accounting for electricity cost alone a **loss** of R526/kg of pine oil will be realised, clearly not profitable and a clear indication that linear scaling is not suitable and/or that a change in operational protocol is required for upscaling.

The same argument and similar losses (approximately R420/kg) will be made for xylose (market commodity price of only R35/kg) and unfortunately, at this stage, the same can be said for NCC as well. With a market price of R623/kg and a 40% input-output ratio (i.e. 400 kg of NCC per day for the 1 tonne sawdust plant) a value of R249223 is generated for every tonne of sawdust currently being processed to NCC. NCC therefore seemed to have significantly more scope to realise a positive margin. However, when the electricity cost of R7.1m to process one tonne of sawdust is accounted the margin changed to a loss of R6.9m per tonne. **However, a positive margin might be realised if an affordable substitute for the energy can be found and if the process and/or equipment of making NCC can be changed.**

The model to be used to determine the gross margin will be as follows (Tables 12, 13 and 14):

Table 12: *Commodity costing: Pine oil*

Income	**Unit (all Rands per day unless specified)**	**Scenario for 1 tonne sawdust per day**	**Scenario for 10 tonne sawdust per day**
Input mass of sawdust	Tonne per day	1	10
Output mass of pine oil	Tonne per day	0.05	0.5
R-value of output mass		1942	19420
Variable costs			
sawdust		assumed to be R 0	assumed to be R 0
chemicals		**	**
electricity		565313	5653125

water		**	**
labour		**	**
Waste treatment and disposal		**	**
Total variable cost		**	
Fixed costs			
Administrative / marketing costs		**	**
Depreciation of equipment		249	658
Cost of buildings (rent or repayment on loan)		R 0	X10
Researcher/manager salaries		R 0	**
**		**	**
Total fixed cost		**	**
Gross margin for 1 tonne sawdust per day		-564884	-5634368

Note: all ** should be considered as placeholders until the process is finalised.

Table 13: *Commodity costing: Xylose*

Income	**Unit (all Rands per day unless specified)**	**Scenario for 1 tonne sawdust per day**	**Scenario for 10 tonne sawdust per day**
Input mass of sawdust	Tonne per day	1	10
Output mass of xylose	Tonne per day	0.04	0.4
R-value of output mass		1393	13930
Variable costs			
sawdust		assumed to be R 0	**
chemicals		**	**
electricity		421875	4218750
water		**	**
labour		**	**
Waste treatment and disposal		**	**
Total variable cost		**	**
Fixed costs			
Administrative / marketing costs		**	**
Depreciation of equipment		**	**
Cost of buildings (rent or repayment on loan)		**	**
Researcher/manager salaries		**	**
**		**	**
Total fixed cost		**	**
Gross margin for 1 tonne sawdust per day		-420473	-4204730

Note: all ** should be considered as placeholders until the process is finalised.

Table 14: *Commodity costing: NCC*

Income	**Unit (all Rands per day unless specified)**	**Scenario for 1 tonne sawdust per day**	**Scenario for 10 tonne sawdust per day**
Input mass of sawdust	Tonne per day	1	10
Output mass of NCC	Tonne per day	0.4	4
R-value of output mass		249223	2492231
Variable costs			
sawdust		assumed to be R 0	**
chemicals		**	**
electricity		7133265	71332650
water		**	**
labour		**	**
Waste treatment and disposal		**	**
Total variable cost		**	**
Fixed costs			
Administrative / marketing costs		**	**
Depreciation of equipment		**	**
Cost of buildings (rent or repayment on loan)		**	**
Researcher/manager salaries		**	**
**		**	**
Total fixed cost		**	**
Gross margin for 1 tonne sawdust per day		-6985689	-69856890

Note: all ** should be considered as placeholders until the process is finalised.

7. Conclusion regarding financial viability

As to the question whether or not it make sense to invest in processing sawdust into the above-mentioned three commodities, we would argue that NCC shows potential if the process and associated cost structure can be optimised for the commercial scale. Such optimisation will need to focus on decreasing the energy cost by either increasing the energy use efficiency or decreasing the cost of energy of the process.

More fundamental redesign of the processes for pine oil and xylose is required to not only increase the input-output ratios for these two commodities (which are simply too low at this stage) but also to focus on realising an at least two orders of magnitude decrease in the energy cost. To achieve this both the energy use efficiency will need to increase and the unit cost of energy will need to be decreased.

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