INVESTIGATING FUTURE MARKETS FOR FOREST PRODUCTS FOR GIPPSLAND

Report 1: A scan of products based on wood fibre

Report 2: Product option assessment

GIPPSLAND FORESTRY HUB
Promoting the Forestry Industry

Prepared by Sylva Systems Pty Ltd

Investigating future markets for forest products for Gippsland.

Report 1: A scan of products based on wood fibre.

Prepared for the Gippsland Forestry Hub Inc. by

Sylva Systems Pty Ltd

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A disclaimer:

This report is collection of information collated to present a comprehensive list of products based on wood fibre for consideration in Gippsland. This report is a high-level statement of options and it should not be relied on for any investment decisions. The intent is to assist in a journey to generate product options. It has been prepared in good faith for the Gippsland Forestry Hub Inc. as per the terms and conditions of the engagement, on a fee for service basis by Sylva Systems Pty Limited. Sylva Systems has no pecuniary interested in any of the outcomes. This report is provided solely for the use of the Gippsland Forestry Hub and for its purposes. The sources of the data and information relied on have been specifically quoted in this report. It has been prepared based on a range of published sources. To the extent permitted by law, Sylva Systems disclaims any responsibility or liability whatsoever (in negligence, contract or otherwise) in respect of any errors, misstatements or omissions in this report and in respect of any claims which may arise out of any reliance on the contents of it or its use for any purpose.

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Summary

A business, whether a forest (natural and plantations) grower or a processor, is considering product options, so where to start? This report is a starting point to such considerations and deliberations. This report is a compendium of products that can be recovered, processed and manufactured using primary products recovered from trees, or the outputs of other processing and manufacturing. This includes residue streams. Given the nature of research, development and the resulting innovations, the scope and nature of potential products is changing through evolution and revolution, hence this compendium is ‘a’ list rather than ‘the’ list. The segmentation of the products considered is presented in Table 1 with the broad divisions of products, the pre-cursor materials and the broad product categories. The detail presented for each product type varies to reflect the level of general knowledge; where a product is more routine and well understood, a lesser amount of information is provided. Where a product or group of products is novel and emerging, or not yet mainstream, a greater degree of information is presented to assist the reader in understanding such groups. To assist, an Excel database has been prepared along with a guide to the use of the database presented as stand-alone documents.

Table 1: The clustering of product types and the associated input materials.

Division	The broad pre-cursor material	The broad product category
Part A: Primary and part processed products	Selling outputs of plantations and forests	The primary products from harvesting of trees
		Next step processing of roundwood
Part B: Secondary products	Use of roundwood and other primary outputs	Sawn timber
		Veneer products
	Made from outputs of log processing	Panels
		Structural composite lumber products
	Generally made from sawn timber	Secondary wood products
		Wood fibre combined with other materials
	All processing residues	The by-products of primary processing of logs
	Made from residues	Garden and landscape products
Part C: Wood as a fuel in solid format	A range of materials	Solid biomass as biofuels
		Densified wood fuels
Part D: Non-wood products chemicals and energy	Use of roundwood and other primary outputs	Wood pulp
		Paper & paper board
		Pyrolysis
		Biorefineries
		Heat and electricity generations

Introduction

The project steps and structure

The objective of this project was to identify the broadest possible range of potential products based on forest resources that could be manufactured in Gippsland (see Figure 1). This range includes boutique and traditional products (see Edwards, 1975; Seymour, 2001), more mainstream products and novel or emerging products. Forest resources are defined as the standing trees in softwood or hardwood plantations, and natural forests. This project is in two parts; once a list of products has been prepared (this report), a process is required to define the products that are plausible or of specific interest in Gippsland. This report presents a list of potential products and the associated processing system / technology required to create the product; the two are inseparable in any sensible consideration of options. In preparing this information, a wide range of reference material was considered (see a list of references commencing on page 104). Where a direct quotation is included, the original spelling was converted in Australian English as required and any units modified to conform with this report's style. Such changes are not identified in the quotes. A full and detailed table of contents is presented in Appendix A: A detailed table of contents. To assist the reader, lists of acronyms, species, chemicals and units used in this report are presented in Appendix B: Terms and units used in this report.

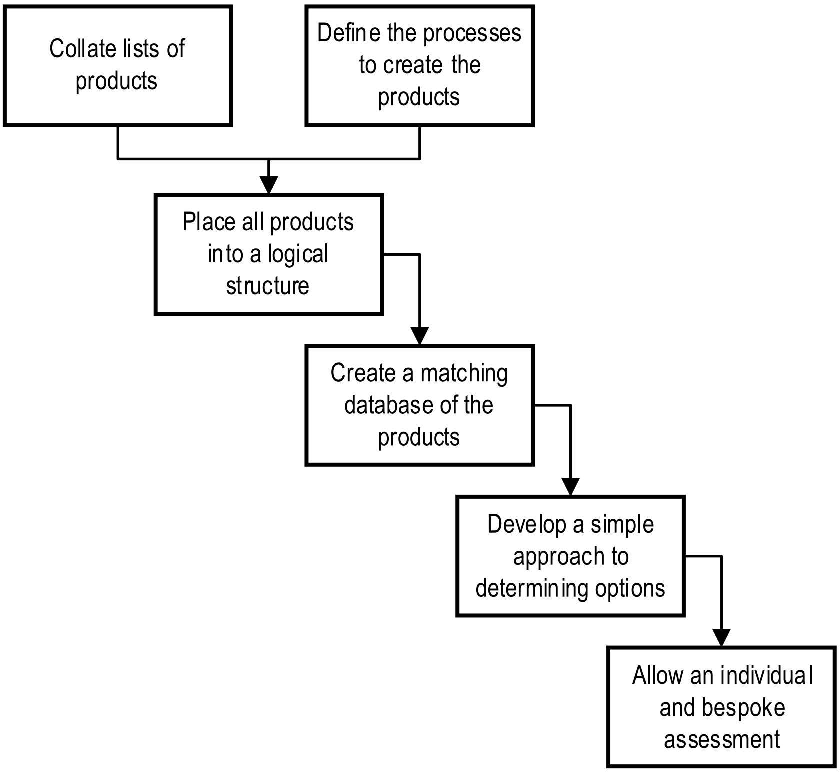

Figure 1: A schematic of the overall project process and steps.

Definitions of key terms; value and supply chains, physical components and activities undertaken

There are two supporting considerations in regard to supply of a product; the value and supply chains (see Box 1). A value chain is focused on the product creation, whereas a supply chain has a focus on movement of products to end users or consumers. For example, sawn timber output can be directly consumed or can be an input into the manufacture of an engineered wood product (EWP).

Box 1:The definition of a value chain (Tardi, 2024) and a supply chain (Hayes, 2024a).	
A value chain	*'A value chain is a series of consecutive steps that go into the creation of a finished product, from its initial design to its arrival at a customer's door. The chain identifies each step in the process at which value is added, including the sourcing, manufacturing, and marketing stages of its production.'*
A supply chain	*'A supply chain is a network of individuals and companies that are involved in creating a product and delivering it to the consumer. Links on the chain begin with the producers of the raw materials and they end when the van delivers the finished product to the user.'*

Given the potential for a product to be either an input to a next step in a value chain or a good ready for consumption, it is important to understand the various types of products and inputs. Box 2 presents definitions of products at various stages in a value chain. Figure 2 presents a simple schematic of the three generic production systems. The first is where the lignocellulose biomass (e.g. all parts of a tree and wood as a material) is processed resulting in a product for ready for consumers and generating residues and waste. The residue stream can be an input raw material for a separate process generating a product for consumption. The outputs of the primary processing step can generate intermediary goods used in a secondary processing system to generate a consumer good. It is possible that an output can be both a consumer good (e.g. woodchips used as mulch) and an intermediary good (e.g. woodchips as an input to pulping).

Box 2:The definition of a raw material (Banton, 2023), intermediate good (Kenton, 2024a), consumer goods (Investopedia team, 2024), a normal good (Kenton, 2024b), a luxury item (Kenton, 2024c) and the principle of cross elasticity of demand (Hayes, 2024b).	
Raw materials	*'Raw materials are materials or substances used in the primary production or manufacturing of goods. Raw materials are commodities that are bought and sold on commodities exchanges worldwide.'*
An intermediate good	*'An intermediate good is a product used to produce a final good or finished product—also referred to as a consumer good. Intermediate goods - like salt - can also be finished products, since it is consumed directly by consumers and used by producers to manufacture other food products.'* *'Intermediate goods are sold between industries for resale or the production of other goods. These goods are also called semi-finished products because they are used as inputs to become part of the finished product.'*
Consumer goods	*'Consumer goods are finished products bought by individual buyers for their use. Also called final goods or retail goods, consumer goods are the end result of production and manufacturing. Clothing, food products, and appliances are all common consumer goods.'* *'Consumer goods are broadly categorized as durable, non-durable, and service goods. Non-durable goods include such essentials as food and clothing.'*
A normal good	*'Normal goods are consumer products such as food and clothing that exhibit a direct relationship between demand and income. As a consumer's income rises, the demand for normal goods also increases.'*
A luxury item	*'A luxury item is not necessary to live, but it is deemed highly desirable within a culture or society. Demand for luxury goods increases when a person's wealth or income increases. Typically, the greater the percentage increase in income, the greater the percentage increase in luxury item purchases.* *Since luxury goods are expensive, wealthy people are disproportionate consumers of luxury goods. Those who are not wealthy don't usually buy luxury goods since a greater percentage of their income goes to need-based expenses in order to live. Luxury goods can be considered conspicuous consumption, which is the purchase of goods mainly or solely to show off one's wealth.'*
Cross elasticity of demand	*'The cross elasticity of demand is an economic concept that measures the responsiveness in the quantity demanded of one good when the price for another good changes. It's also referred to as cross price elasticity of demand.'* *'The cross elasticity of demand for substitute goods is always positive because the demand for one good increases when the price for the substitute good increases.'* *'The cross elasticity of demand for* ***complementary goods*** *is negative.'*

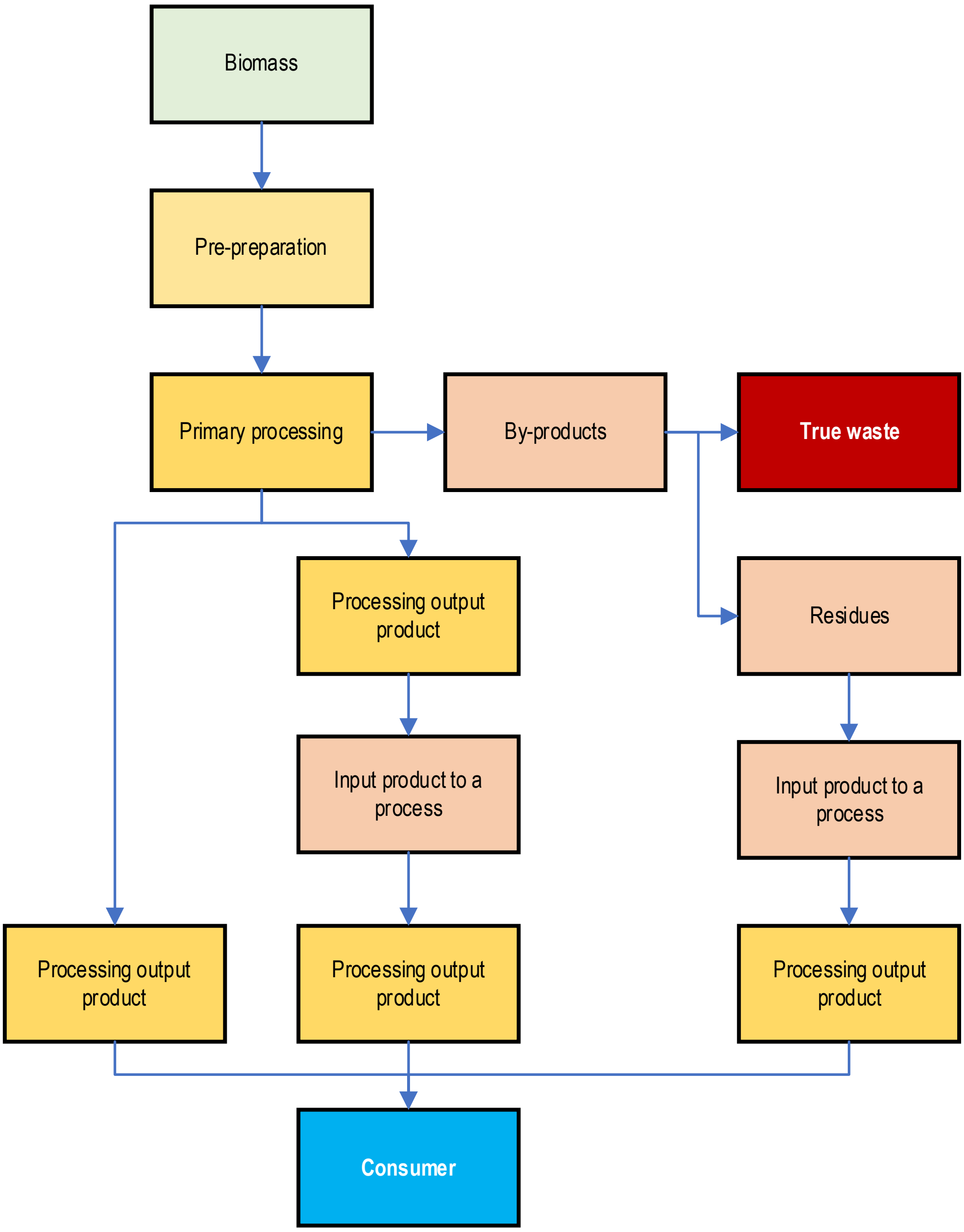

Figure 2: A schematic of the three types of product production systems.

Creating a potential product list

A deep scan of current, in-development and potential products based on lignocellulose biomass (e.g. all parts of a tree and wood as a material) was undertaken by collating internationally agreed product nomenclature as follows. The International Convention on the Harmonized Commodity Description and Coding System (the HS Convention) was reviewed based on information presented by the World Customs Organization (WCO)[3] and the relevant products and codes are presented (see Appendix C: Internation wood product coding). This was combined with the Food and Agricultural Organization of the United Nations (FAO) published series of classification systems; forest resource assessment terms and definitions (FAO, 2023), a forest product classification system (FAO, 2022) and a bioenergy classification system (FAO, 2004). The FAO classification system addresses all parts of a tree except needles and leaves, as a potential raw material for forest products. It defines the

[3] See https://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs_convention.aspx accessed on 25/02/2025.

potential processing or uses of the main above ground stem biomass; branches, tops, small branches and twigs; stumps and roots; and bark (FAO, 2022, p.38). An item can be a product when sold to another party or the input to a next stage of manufacturing resulting in more complex and diversified supply chains. Fitzer *et al.* (1995) presents an agreed set of terminology in regard to solid carbon products. For completeness, this scan included non-timber forest products (NTFP). To assist, past reviews of product options were considered; for example, see Ahlqvist *et al.* (2012a,b&c). This information was used to create a structure to present the range of products derived from wood fibre and include details of each. It is important to consider that some processes and therefore products, are based on the residues of other systems, hence the precursor processes and products are considered. Figure 3 presents a high level summary of the production systems and relationships linked by residues of one system as an input to a subsequent system and these are the processes considered by this analysis.

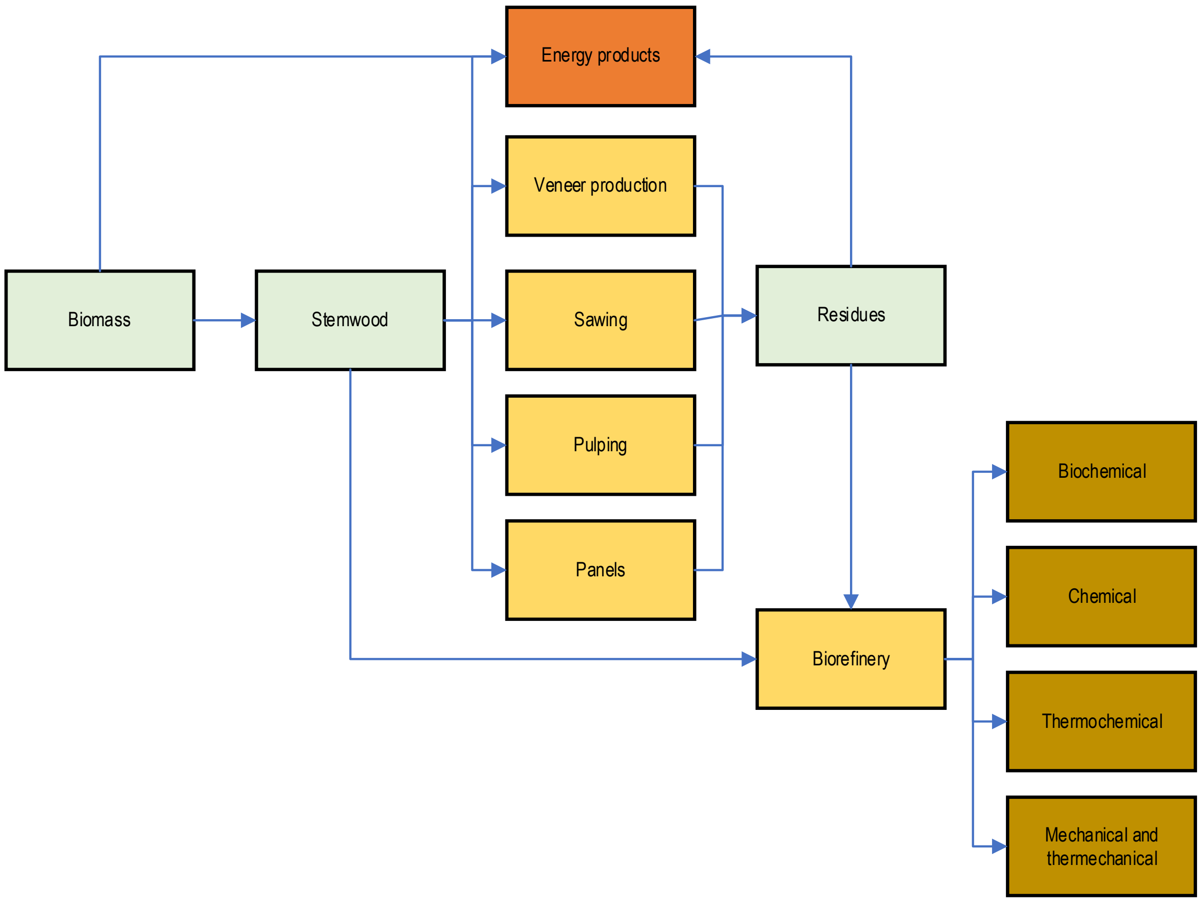

Figure 3: A simple schematic of the different production systems considered in this report.

Use of this product list

The fit-for-purpose of any product is defined by the nature and requirements of a party. Figure 1 presents a schematic that encapsulates the process of seeking a product option and in this example, it is for a processing site, but it could be for a party with a plantation or natural forest. The intent is to match the needs of a 'site' with the product options as solutions. A key point is that the end of this process is not an investment, but the undertaking of the full due diligence process.

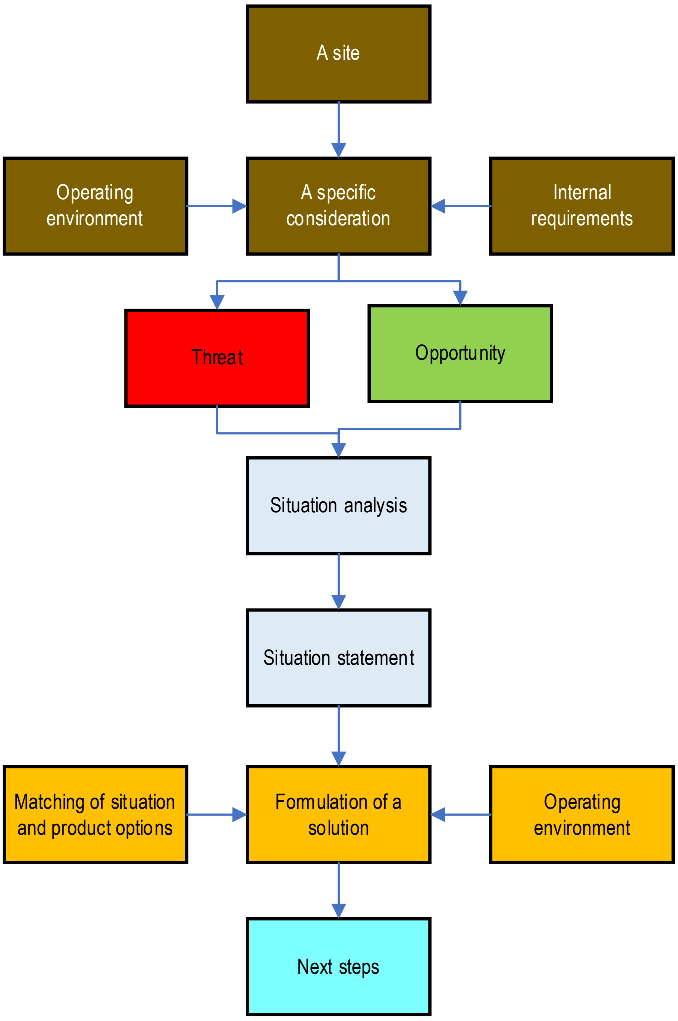

Figure 4: The approach taken to match a product solution to address a threat and/or opportunity.

Wood as a resource

Resource fundamentals; softwoods or hardwoods

In determining product and therefore processing options, the input raw materials is a consideration. The raw materials will define the product options and identifying a product and determining the raw materials is required. A primary segmentation is the nature of the raw materials as either a softwood or a hardwood tree; see Table 2.

Table 2: A summary of the two broad groups of trees; softwoods of hardwoods.

Attributes	Softwood	Hardwood
Reproduction	Plants producing cones (e.g. *Pinus radiata*).	Plants producing flowers (e.g. *Eucalyptus globulus).*
Wood density*	*P. radiata* basic density of 400 kg/m^3 (age 10 y) to 485 kg/m^3 (age 30 - 40 y).	Plantation grown *E. globulus* basic density of 480 to 550 kg/m^3.**
Carbon storage***	For Victorian and NSW, *P. radiata* 0.84 t/m^3 CO_2-e (at age 30 y).	For Western Australian, *E. globulus* 1.05 t/m^3 CO_2-e (at age 10 y).
Saw and veneer logs	Roundwood harvested for framing materials through to furniture.	Natural forest sourced roundwood harvested for framing materials through to furniture. Minor use of plantation grown resources.
Paper making	Long fibres give paper strength (e.g. tissue paper).	Short fibres give paper a smooth surface (e.g. photocopy paper).
Reconstituted products	Wood-based panels made from thinnings and clearfall logs.	Wood-based panels.
Bio-energy (by combustion)+	A calorific value of 21 MJ/kg for oven-dry softwood.	A calorific value of 19 MJ/kg for oven-dry hardwood.

* From Ilic *et al.* (2003).

** Sylva Systems Pty Ltd data sets of published information.

***Calculated based on DCC (2008, p. 57) assuming a basic density of 440 kg/m^3 and 550 kg/m^3 for *P. radiata* and *E. globulus* respectively. A carbon in dry wood ratio of 52% was applied with an assumed ratio of 3.67 CO_2:C.

+Bio-energy includes firewood, the use of residues in boilers and purpose grown trees. See Bootle (1996, p.209) for data.

Tree and wood anatomy

A tree's above ground components

The next step in considering product options, is to address the components of a tree that are the inputs to manufacturing of a product. Figure 5 presents a stylised tree indicating the various components.

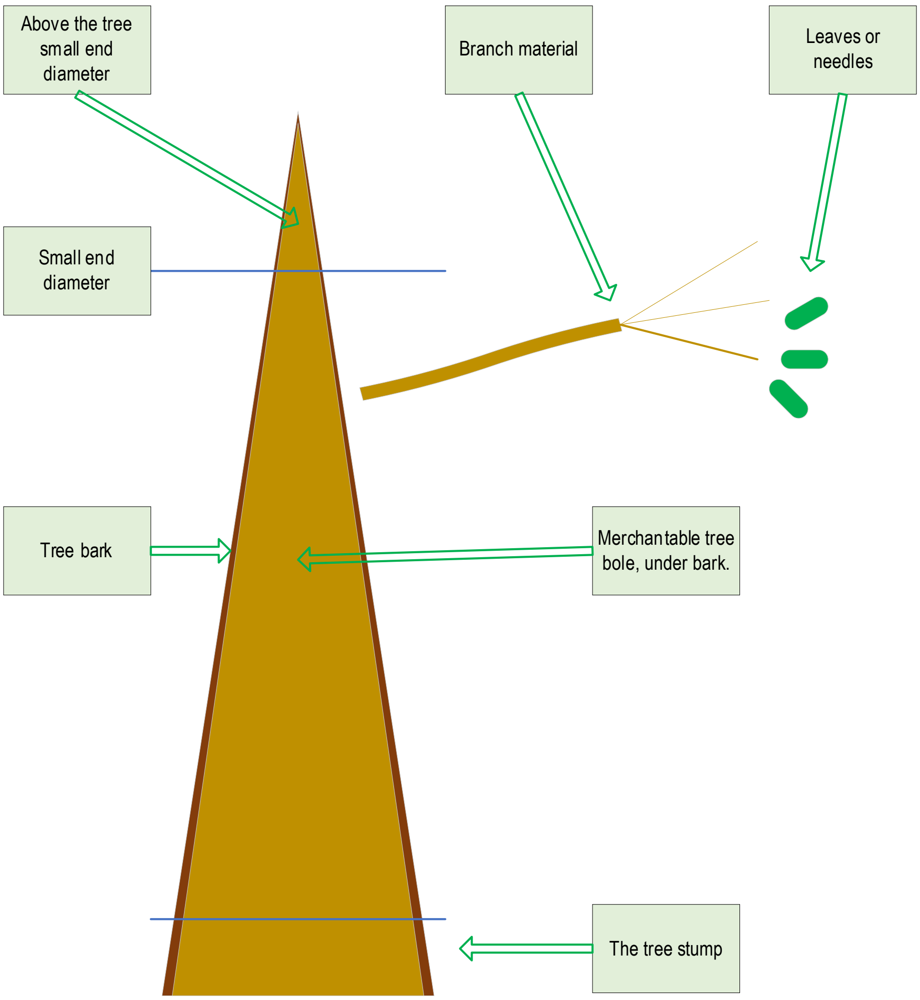

Figure 5: A summary of the above-ground standing lignocellulose biomass components of a tree (Prepared by Sylva Systems Pty Ltd).

General structure of a tree stem

Wood is a collective of cells arranged in rings, with rings concentrically arranged in zones of similar wood properties. Wood cells are specialised in form and function. It consists of cells or wood elements that have passed through various phases; cellular division, differentiation, and maturation which together constitute wood formation. Numerous factors inside and outside a tree result in variation in type, number, size, shape, physical structure, and chemical composition of wood during formation (Larson, 1969, p.2). Figure 6 presents a schematic of a cross-section of a tree stem and Box 3 presents the descriptions of the function of the components (based on Bootle, 1996, p.3&7; Hood, 2010, p.8, Figure 8). Figure 7 presents a schematic of wood to the molecular level. Anatomically, wood is the xylem of a tree produced by the cambium.

Box 3: The attributes of a cross section of a tree.	
Outer bark	The outer bark has a protective role.
Cambium	Cambium tissue is a thin layer of cells which produces all wood cells and separates bark from the wood.
Phloem	Phloem is bark-like tissue which transports food materials downwards to the tree roots from the foliage. It is located on the outer side of the cambium.
Sapwood	On the inner side of the cambium, new cells are added and are referred to as xylem or sapwood. The xylem is woody tissue which transports mineral nutrients and water upwards in a tree from the tree root system to the leaves.
Heartwood	Heartwood provides structural support to a tree. The cells of heartwood become blocked with deposits on transition from sapwood, which contribute to the strength and durability of wood.

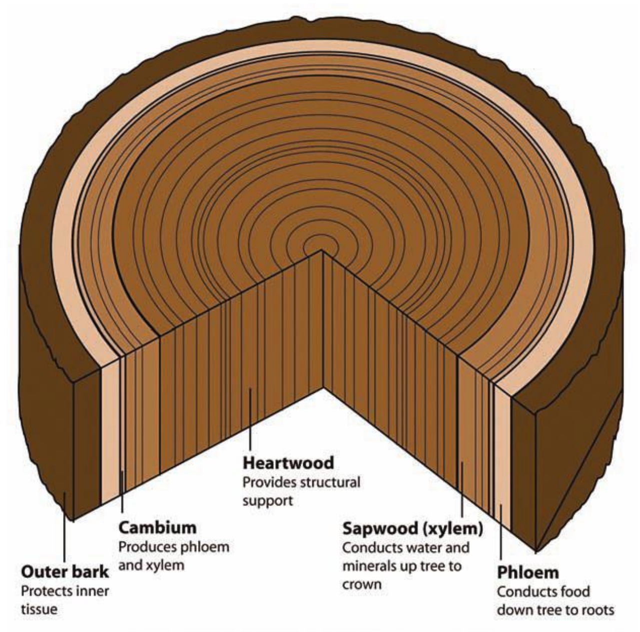

Figure 6: A cross section of a tree stem (Hood, 2010, p.8, Figure 8).

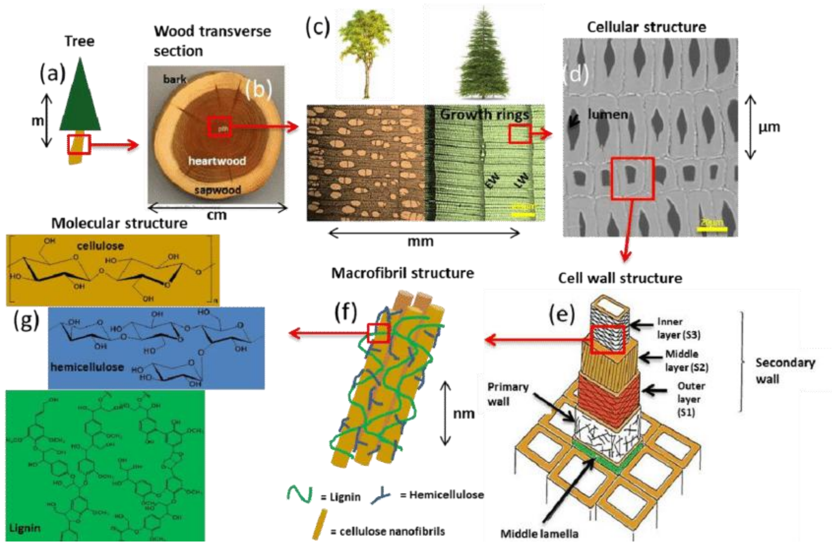

Figure 7: A schematic of wood elements from a tree to the constituent molecules (Ermeydan, 2014, p.8, Figure 1.1).

The original author's Notes: (a) A tree with an elongated stem with supporting branches (b) Transverse section of a softwood tree indicating heartwood, sapwood and bark (c) Left: Birch, a hardwood tree and light microscope image of its cellular structure with vessels. Right: Spruce (*Picea abies*) a softwood tree and light microscope image of the wood tissue indicating growth rings, earlywood and latewood cells (d) Scanning electron microscope image of several latewood cell walls of spruce wood in micron range (e) Structure of a single cell wall including primary and secondary cell wall layers (f) Microfibril structure of crystalline cellulose bundles surrounded with lignin and hemicellulose matrices (g) Molecular structures of cellulose, hemicellulose and lignin polymers.

The composition of biomass from woody plants

Biomass derived from woody vegetation is a lignocellulose structure (see Figure 7). This biomass is composed of solids, moisture and air voids when 'dry'. Sawn timber production makes use of wood as a whole and may seek to control wood moisture content whereas paper makers target wood fibres used in paper making, and potentially the embodied energy in wood (as by-product of pulping or when used as an energy source). In wood, lignin bonds the various types of cells together producing a degree of rigidity that enables woody plants to attain their large size (Bootle, 1996, p.1). Wood can be 22 to 30%

lignin as complex chain polymers of high molecular weight; consisting of c. 65% carbon, 6% hydrogen and 29% oxygen (Bootle, 1996, p.4). For example, Figure 8 presents a break-down of the wood components of a hardwood. Lignin is virtually impossible to dissolve without being broken down into simple substances (Bootle, 1996, p.4). Larson (1969, p.2) provides a fundamental insight for considering wood quality; *'wood quality is the arbitrary classification of these variations in the wood elements when they are counted, measured, weighed, analysed or evaluated for some specific purpose. Wood quality is therefore a concept - an idea formulated by generalization from particulars, the particulars in this instance being the wood elements produced in wood formation'*. It is the components of wood that will define the suitability and potential products.

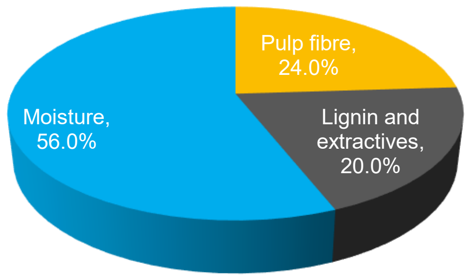

Figure 8: The composition of 8-year-old *E. globulus* wood (after Tibbits *et al.*, 1990).

Biomass as a feedstock

'Lignocellulosic biomasses are sustainable and abundantly available feedstocks for the production of biofuel and biochemicals via suitable bioconversion processing' (Yogalakshmi *et al.,* 2023, p.1). It typically contains c. 80% volatile matter and 20% fixed carbon on a dry mass basis (Cremers *et al.*, 2015, p.5). Lignin is up to 30% of the weight and 40% of the energy content of lignocellulosic biomass and is an extremely abundant raw material (Holladay *et al.,* 2007, p.2). Holladay *et al.* (2007, p.1&2) noted that cellulose has a relatively simple substructure of glucose subunits, whereas lignin differs from these sugars by having a complex aromatic substructure. Its structure varies with the biomass source and the recovery process used and is reactive (and to some degree less stable thermally and oxidatively) compared with other biomass streams. Therefore, there is a need for a best method to cost-effectively separate lignin from biomass to use lignin as a raw material.

Wood attributes

Wood basic density

Basic density is the weight of oven dry wood per green volume of wood. It is a fundamental attribute driving many uses of wood and the price paid for that wood. Wood basic density is constant, whereas wood moisture content varies as noted in Box 4.

Wood moisture content

Moisture content (MC) of wood (see Figure 8) is a key attribute in regard to utilisation and products. Bootle (1996, p.3) notes that '*moisture content of wood has a most important effect on its strength and stability*'. Moisture content percentage can be expressed as the weight of water per weight of green or dry wood; with a dry wood basis is the usual convention (Bootle, 1996, p.90). Quoted moisture contents will be defined as to the basis. There are four key wood moisture contents relating to wood products (see Box 4).

Box 4: The different moisture contents associated with wood products.	
Term	Narrative
Green moisture content	The moisture content of green wood (e.g. freshly felled logs or sawn timber) which varies. It is the moisture of wood that is not bone dry.
Air-dry moisture content	The moisture content of wood after a period of exposure to outside atmospheric conditions and reaching a harmonisation with such conditions.
Kiln dried moisture content	Kiln dried timber that has been dried below fibre saturation point (FSP) to c.10 to 15% DRY BASIS.[4]
Bone dry moisture content	Bone dry moisture content (or oven dried moisture content) is zero as wood has been dried in an over maintained at 103+/-2°C until it is at a constant weight due to all water being evaporated out (Bootle, 1996, p.90).

Energy content and moisture content

The total energy content of bone dry biomass is referred to as the gross energy or the Higher Heating Value (HHV). The total energy contained in biomass can be estimated based on the elemental composition of that biomass (Stucley *et al.* 2004, p.15). The HHV of wood varies between softwoods (21 kJ/g) and hardwoods (19 kJ/g) (Bootle, 1996, p.209) (see Table 2). Biomass net energy or Low Heating Value (LHV) is the net energy after water has been vaporized with a use (loss) of energy consumed by the process (Stucley *et al.,* 2004, p.15). Figure 3 presents a schematic of the energy release (production) from biomass combustion.

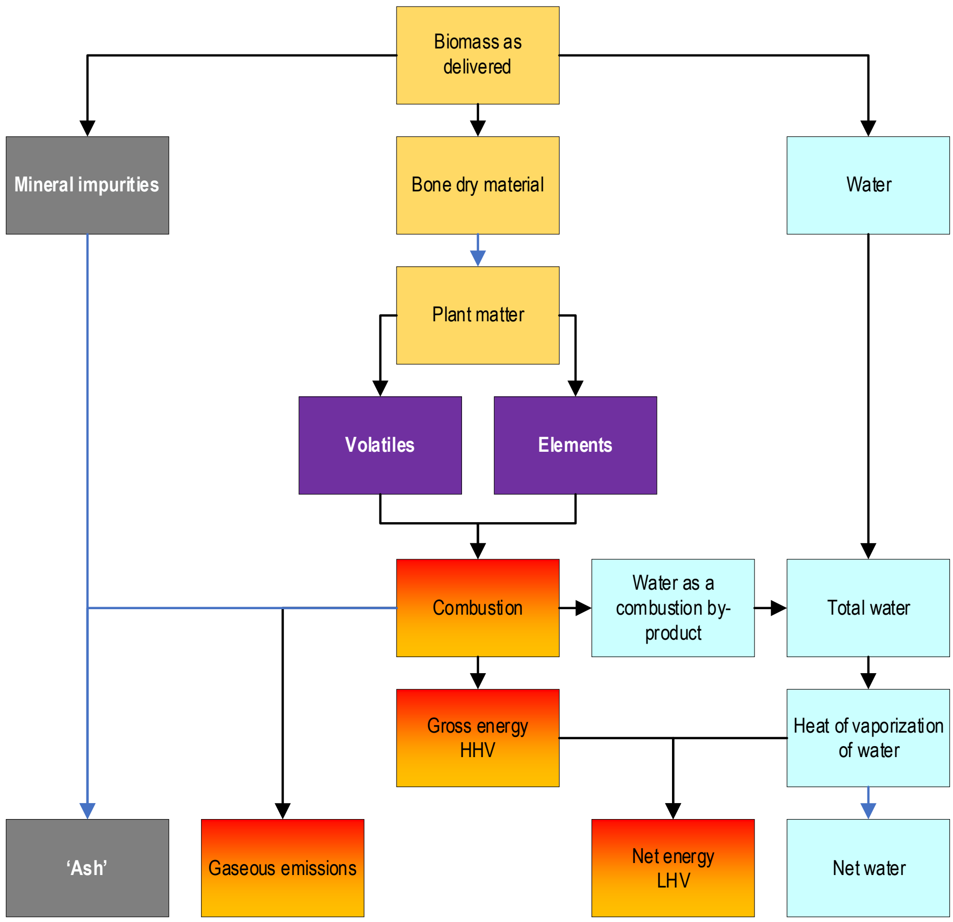

Figure 9: A schematic of combustion of lignocellulose woody biomass.

[4] Information from https://www.woodsolutions.com.au/wood-product-categories/sawn-timber accessed on 16/04/2020.

Part A: Primary and part processed products

The primary products from harvesting of trees

Overview; commencement with harvesting a tree

The first set of products result from harvesting of standing trees and recovery of components of the tree biomass through to removal of a whole tree (potentially above and below ground). In paper making terms, this is the virgin material. This section lists the basic biomass products through to minor processing of this material, but with the product still as wood in log format.

Broad classification of roundwood

Roundwood

Regardless of intended use, all trees harvested result in logs of some form and these are referred to as wood in the rough or roundwood; see Box 5 for a definition. Subsequent to this initial classification, logs are then delineated by intended use.

Box 5: The definition of wood in the rough or roundwood-based on FAO (2022, p.141).	
Wood in the rough (roundwood)	*'All roundwood felled or otherwise harvested and removed. 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. It includes all wood removed with or without bark, including wood removed in its round form, or split, roughly squared or in other form (e.g. branches, roots, stumps and burls, where these are harvested) and wood that is roughly shaped or pointed. It is an aggregate comprising wood fuel, including wood for charcoal and industrial roundwood (wood in the rough).'*

Industrial roundwood

Industrial roundwood can be utilised as wood in the rough either with or without debarking, or as an input to subsequent product manufacturing. This product specifically excludes sawlogs, veneer logs and pulpwood and Box 6 provides a specific definition. Industrial roundwood can be posts, poles, piles or used as components of bridges (e.g. girders). Specific products are listed; pitprops are using mining, logs into tanning of leather, distillation of wood to extract chemicals and match blocks for making fire-lighting matches.

Box 6: The definition of Industrial roundwood other than sawlogs, veneer logs and pulpwood provided by the FAO and industry knowledge.	
Industrial roundwood	*'Industrial roundwood (wood in the rough) other than sawlogs, veneer logs and/or pulpwood. It includes roundwood that will be used for poles, piling, posts, fencing, pitprops, tanning, distillation and match blocks, etc.'* (FAO, 2022, p.142). This can include roundwood supplied for char production as a subset or linked to distillation.

A log as an input to products other than for char production or wood distillation

As inputs to sawmill, a veneer mill or other solid wood products

Logs recovered at harvest can be provided for sawing or processing into veneer for plywood manufacturing and other solid products. The definition of a sawlog or a veneer log is linked to the intended processing and indeed a specific processing facility. That is, a sawlog or veneer log is a non-standard product and specifications are not necessarily fungible between processing sites. A definition will include specific species, dimensions (e.g. small and large end diameter, and length) and quality (e.g. sweep, straightness, branch stubs etc). It is possible that a veneer log is subsequently cross-cut into shorter sections on delivery at facility for processing and this is referred to as a billet (Leggate *et al.,* 2017, p.15). When cross-cut for shingle or stave (a bevelled edge narrow section of wood) manufacturing, a log is referred to as a bolt.

Box 7: The definition roundwood to be used as an input to the manufacture of sawn timber and veneers (FAO, 2022, p.142).	
Sawlogs and veneer logs	*'Roundwood that will be sawn (or chipped) lengthways for the manufacture of sawn wood or railway sleepers (ties) or used for the production of veneer (mainly by peeling or slicing). It includes: roundwood (whether or not it is roughly squared) that will be used for these purposes; shingle bolts and stave bolts; match billets and other special types of roundwood (e.g. burls and roots, etc.) used for veneer production.'*

As an input to a pulpmill or panel board manufacturing process

Logs can be provided as feedstock for pulp production or for the manufacturing of particleboard, oriented strand board (OSB) or fibreboard (see Box 8). Such logs would usually not meet the specifications of a sawlog or logs to be peeled (where such markets exist locally). However, the acceptance of such logs by a processor will be tested against a log specification (e.g. including but not limited to species, dimensions and quality). This resource can be provided in a range of conditions, including after infield chipping. While not indicated in the definition, an important consideration is that the logs are free of soil and other potential pollutants (e.g. oils or plastics, and in some cases, carbon resulting from wildfires).

Box 8: The definition roundwood to be used as inputs to manufacture pulp and wood-based panels (FAO, 2022, p.142).	
Pulpwood, round and split and wood for wood-based panels	*'Roundwood that will be used for the production of pulp, particleboard, oriented strand board (OSB) or fibreboard. It includes: roundwood (with or without bark) that will be used for these purposes in its round form or as splitwood or woodchips made directly (i.e. in the forest) from roundwood.'*

The other biomass of a harvested tree not regarded as the main log

Basis

This category of product is defined as any component of a tree that has been fallen at harvest. Therefore, it excludes NTFP which are addressed commencing on page 17.

Foliage of a tree

While specifically not addressed by the FAO forest products classification system (FAO, 2022, p.38), the foliage of a tree can be an important resource (see Figure 5); leaves in hardwoods and needles in conifers. For example, the leaves of eucalypts can be processed to extract essential oils (e.g. see Baker & Smith, 1902 demonstrating the early recognition of the potential for eucalypt oils). Box 9 presents a definition of foliage and the differences between softwoods and hardwoods.

Box 9: A definition foliage and the differences between softwoods and hardwoods.	
Needles	The photosynthetic structure of a softwood tree which is shaped like a needle; long and slender.
Leaves	The photosynthetic structure of a hardwood tree which is broad and thin in thickness.

Not elsewhere classified stemwood, branches and bark

While often defined by a collective description of harvest residues or biomass, the sections of a tree main stem not recovered as logs have a range of categories as presented in Box 10. This segmentation is important as it links to potential uses and markets, as well as to the requirements to recover such material. While still a part of the main stem of a tree, sections may not meet the grade requirements of the other roundwood classes (e.g. not meet sawlog or veneer log requirements). Such stemwood can be in the section of actively growing crowns with large branches present. The resulting log may not be straight, can be dominated by branch stubs and have a high degree of taper. In a similar manner, where there is excessive flaring of the stem at the butt end, this may be docked to recover a sawlog or veneer logs in the section of stem above that attribute.

Box 10: The definition roundwood that is not the main part of the tree stem (FAO, 2022, p.142).	
Wood in the rough other than from the main stem and branches	*'Includes tops, small branches, twigs, stumps, roots and bark removed in the forest that will be used in the production of other goods and services (except as a source of fuel).'*
Tops, small branches and twigs	*'Includes tops, small branches and twigs from felled trees. The lower limit of the top (the upper limit of the stem) will vary according to local logging practices.'*
Stumps and roots	*'Includes all the biomass of the tree below the separation of the harvested stem. The height of this cut will vary according to local practices and conditions.'*
Bark separated in the forest from wood in the rough	*'Includes all bark removed from the sterns or other parts of the tree during harvesting operations, as well as bark removed at the lower landing. It can be used for horticulture purposes or for other uses.'*

Non-timber forest products

The category

Muir *et al.* (2020) presents an analysis of the term non-timber forest products (NTFP) and identifies a range of elements and terms. They include any product or service other than timber that is produced in forests (the Centre for International Forestry Research - CIFOR[5]) and do not include harvesting of trees (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services - IPBES)[6]. Chamberlain and Predney (2003, Abstract) are specific and state that NTFPs *'are made from resources that grow under the forest canopy'*. The Australian government glossary[7] refers to a 'non-wood forest product' (NWFP) defined as *'a product of biological origin, other than wood, derived from forests, including game animals, seeds, berries, chemical products, mushrooms, oils, foliage, medicinal plants, flowers, fodder, and wood and non-wood Indigenous artefacts.'* For example, this would include hunting of feral deer. The inclusion of wood and non-wood indigenous artifacts is curious. The FAO provides a comprehensive and practical definition and makes use of the term NWFP (FAO, 2023, p.25); this definition is presented in Box 11. This category of products is very broad and can range from honey through to provision of select genetic materials. To be specific, this analysis adds to the FAO definition that NWFP are not the result of harvesting a tree. Any products that are the result of harvesting are treated separately for clarity and precision; for example, foliage from harvested trees is regarded as a harvesting residue.

<table>
<tr><th colspan="2">Box 11: A definition of a non-timber forest product (FAO, 2023, p.144).</th></tr>
<tr><td>Non-wood forest product</td><td>'Goods derived from forests that are tangible and physical objects of biological origin other than wood.'</td></tr>
<tr><td colspan="2">'1. Generally includes non-wood plant and animal products collected from areas defined as forest (see definition of forest).
2. Specifically includes the following regardless of whether from natural forests or plantations:
- gum arabic, rubber/latex and resin;
- Christmas trees, cork, bamboo and rattan.
3. Generally excludes products collected in tree stands in agricultural production systems, such as fruit tree plantations, oil palm plantations and agroforestry systems when crops are grown under tree cover.
4. Specifically excludes the following:
- woody raw materials and products, such as chips, charcoal, fuelwood and wood used for tools, household equipment and carvings;
- grazing in the forest;
- fish and shellfish'</td></tr>
</table>

A novel product; a fresh produce coating

A University of Queensland / Queensland Alliance for Agriculture and Food Innovation (QAAFI) research study used tree sap gum and light to extend the shelf-life of fresh fruit and vegetables. These edible coatings made from gum Arabic or acacia gum were enriched with extracts from native Australian plants to stop the growth of microorganisms. The research explored the use of light and curcumin (a compound extracted from turmeric) to deactivate fungal spores. These edible coatings prevented the growth of microorganisms in freshly cut capsicum for around 10 days under refrigeration. The active compounds

[5] Taken from https://www.cifor-icraf.org/publications/corporate/factsheet/ntfp.htm accessed on the 25/02/2025.
[6] Taken from https://www.ipbes.net/node/41585 accessed on the 25/02/2025.
[7] Taken from https://www.agriculture.gov.au/abares/forestsaustralia/glossary/search?page=5 accessed on the 26/02/2025.

were the organic acids and phenolic compounds aqueously extracted from plants; for example, extracted from Cape York Lilly pilly, boonjee tamarind, and Tasmanian pepper leaves (Timberbiz, 2025) (note: scientific names were not listed).

Next step processing of roundwood

Roughly trimmed wood

The next step in the hierarchy of products is where roundwood is simply processed into a range of products but remains effectively in the round (see Box 12). It should be noted that many of the products listed are traditional and very specific.

Box 12: The range of products classified as roughly trimmed wood (FAO, 2022, p.143).	
Roughly trimmed wood	*'It includes: Hoopwood; split poles; piles, pickets and stakes of wood, pointed but not sawn lengthwise; wooden sticks, roughly trimmed but not turned, bent or otherwise worked, suitable for the manufacture of walkingsticks, umbrellas, tool handles or the like; chipwood and the like. It includes also wood shavings, which are used in the manufacture of vinegar or for the clarification of liquids.'*
Hoopwood	*'Hoopwood cover split rods of willow, hazel, birch, etc., which are used in the manufacture of barrel hoops, hurdles, etc.'*
Split poles	*'This product incorporate stems or branches of trees split along the length. They are used as supports in horticulture, agriculture, for fencing, etc.'*
Pointed piles, pickets and stakes (including fence posts)	*'This class cover round or split poles, pointed at the ends, which can be peeled or impregnated with preservative.'*
Wooden sticks, roughly trimmed but not turned, bent or otherwise worked	*'Products of different length and thickness which serve as a raw material for the next manufacture of walkingsticks, whips, umbrellas, handles for tools, etc.'*
Chipwood	*'This product encompasses flexible, narrow, thin and even strips of wood suitable for plaiting or for making sieves, chip-boxes, match-boxes, etc. It is produced by slicing, peeling or it is sawned.'*
Others	*'These products also cover e.g. wood shavings, which are used in the manufacture of vinegar or for the clarification of liquids.'*

Preservative treated roundwood

Rough roundwood can be machined to a smooth surface and round, by peeling on a lathe. Where used in the round, products can be treated prior to use to provide added durability to protect them from weathering and in-ground contact.[8] There are a range of treated roundwood products, with the products defined by purpose and length (see Box 13).

Box 13: The different roundwood products after treatment to enhance durability and a useful life (FAO, 2022, p.143).	
Roundwood treated with preservatives	*'This group covers products which have been treated with paint, stains, creosote or other preservatives, in order to increase their resistance. It excludes: products treated with substances for the purpose of simply maintaining them during shipment or storage* [e.g.] *torrrefied pellets.'*
Poles	*'Straight pieces, usually of 5 m or more in length. They are used principally to support telephone, telegraph and electrical or transmission lines and for scaffolding.'*
Piling	*'Long straight pieces, suitable for driving into the ground under impact. They are used principally in construction of harbour works and underpinning for bridges and buildings.'*
Posts	*'Round, hewn, squared or split wood, usually less than 3 m in length, but possibly up to 5 m used for fencing, guard rails and the like.'*
For other uses not elsewhere classified	*'Roundwood treated with preservatives, other than poles, pilings and posts.'*

[8] https://www.woodsolutions.com.au/wood-species/wood-products accessed on the 02/02/2025

Part B: Secondary products

Sawn timber

Production system; sawmilling

A schematic of a generic sawmilling operation is presented in Figure 10. It presents the inputs, outputs and the by-products generated.

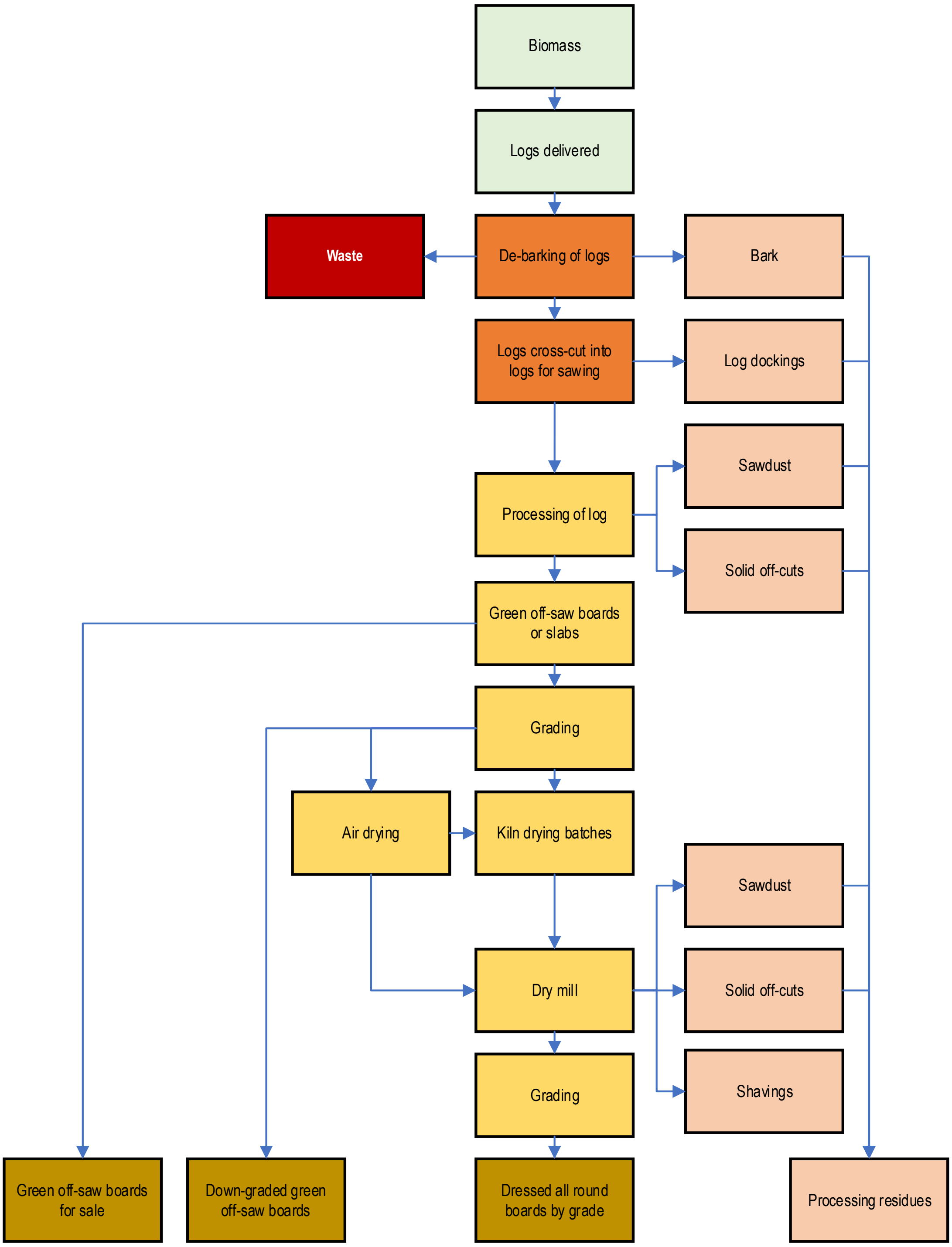

Figure 10: A generic schematic of a green mill and dry mill sawmill operation.

Routine sawn timber

The sawing of logs and the production of sawn timber is an important industry and Box 14 presents a definition of sawn wood. In the Australian context, the term sawn timber is applied rather than lumber. There are a range of grades or types of sawn timber as outputs. Such products can be specific to the type of tree processed; for example, pine sawn timber (PST)[9]. While a specific step in processing, finger jointed boards are included in multiple sub-definitions of sawn wood. A further consideration is that sawn timber can be sold in a green condition, after air drying or after a kiln drying regime down to a target moisture content (see Bootle, 1996, p.76-95). A range of biotic (e.g. decay, termites and borers) and climatic (e.g. weathering due to rain, ultraviolet exposure, and moisture) agents can reduce the service life of sawn timber (see Bootle, 1996, p.171-190). Treating sawn timber adds durability and helps to protect timber products from such hazards (see Bootle, 1996, p.191-203). The categories of sawn timber presented in Box 18 include treated or not. A simple delineation of products is presented in Box 15.

Box 14: The definition of sawn wood and sub-categories of sawn wood (FAO, 2022, p.145).	
Sawn wood	*'Wood that has been produced from both domestic and imported roundwood, either by sawing lengthways or by a profile-chipping process and that exceeds 6 mm in thickness. Both sawn and hewn sleepers are included. It includes planks, beams, joists, boards, rafters, scantlings, laths, boxboards and "lumber", etc., in the following forms: unplaned, planed, etc. It excludes wooden flooring, mouldings (sawn wood continuously shaped along any of its edges or faces, like tongued, grooved, rebated, V-jointed, beaded, moulded, rounded or the like) and sawn wood produced by resawing previously sawn pieces.'*
Sawn wood rough	*'Wood sawn or chipped lengthwise, not planed, sanded or finger-jointed. It may be green (undried) or dried. It excludes sawn and hewn railway sleepers, wood shingles and sawn veneer sheets.'*
Sawn wood rough treated or impregnated	*'Wood sawn or chipped lengthwise, not planed, sanded or finger-jointed and which was treated with insecticides or fungicides for the purpose of protection. For long-term preservation they can be impregnated with creosote or other substances.'*
Sawn wood rough other	*'Wood sawn or chipped lengthwise, not planed, sanded or finger-jointed and which was not treated for the purpose of protection.'*
Sawn wood planed	*'Wood sawn or chipped lengthwise, and planed, sanded or finger-jointed.'*
Sawn wood planed treated or impregnated	*'Wood sawn or chipped lengthwise, and planed, sanded or finger-jointed, which was not kiln- or air-dried but was treated with insecticides or fungicides for the purpose of protection. For long- term preservation they can be impregnated with creosote or other substances.'*
Sawn wood planed other	*'Wood sawn or chipped lengthwise, and planed, sanded or finger-jointed, which was kiln- or air- dried but not treated for the purpose of protection.'*

Box 15: Usual categories of sawn timber in the Australian market based on moisture content and subsequent processing.	
Green off-saw	Green off-saw (GOS) boards are the output from a green mill. They are as sawn prior to drying and any other processing or finishing. Such boards can be used by final consumers or as inputs to a next step in product development.
Dressed all round	Dressed all round (DAR) boards are the result of generally drying of GOS boards and machining to a final finish. Such boards can be used by final consumers or as inputs to a next step in product development.

Building on sawn timber; grades of sawn timber

While Box 14 presents sawn timbers based on surface conditions, the mechanical properties of a board will define the utility of a product. Structural grading is used to sort sawn timber into grades based on stress or visual grading (Box 16).

[9] https://timberupdate.com/blog/complete-guide-selling-timber-part-ii-speaking-language/

Box 16: The definition of the grades of sawn timber based on the grading system.	
Non-structural timber	*'Timber that has not been assigned a grade based on stress grading resulting in an MGP grade or by visual grading resulting in an F grade.'*
Stress graded timber[10]	*'Structural timber products are stress graded; appearance grades are not. The end product of stress grading is packages (population) of boards assigned a grade (properties) to be used for design purposes. Grade designations have been derived for in-grade tested pine (MGP grades), Australian ash (A-grades) and engineered products such as glulam (GL grades), plywood and LVL (which both have their own independent grades).'*
MGP grades[11]	*Machine graded pine (MGP) grades were introduced in 1996 by an industry body following an extensive, nation-wide in-grade testing program of Australian plantation grown pine (Radiata pine, Pinaster pine, Slash pine and Caribbean pine), undertaken by CSIRO and State Forests of NSW. As a result, some MGP structural properties reflect the performance of pine better than the properties derived using the traditional F-grade system. These properties are appropriate for higher levels of confidence in engineering design.*
Visual grading[12]	*Visual grading is the traditional method of determining a stress grade. In a visual grading process, a trained grader examines each and every piece of timber produced in accordance with either the hardwood or softwood visual grading standards; the standards define rules as to the types sizes and positions of physical characteristics that are allowed into each 'group' or structural grade of material. The highest grades allow fewer and smaller characteristics in each piece of timber. Most Australian native and imported structural hardwoods are graded using visual grading techniques. Some softwoods that are thicker than 45 mm are also visually graded. Most imported softwood is visually graded to the Australian grade rules.*
The F-grade system[13]	*An F-grade is a name for the grouping of the timber. They are a series of categories into which different grades of different species can be placed. A commercialised species will have documented basic engineering properties which determine which series of F-grades will suit that species.*

Specialist products; railway or tramway sleepers (cross-ties) of wood

Railway or tramway sleepers are a specialist sawn timber product (see Box 17). Sleepers can be treated to increase durability and resistance to decay and/or damage agents.

Box 17: The definition of sleepers used in railway systems (FAO, 2022, p.145&146).	
Sleepers	*Railway or tramway sleepers are pieces of unplaned wood, of more or less rectangular section of the kind commonly used to support railway or tramway track. There are also included switch ties, which are longer than sleepers, and bridge ties, which are wider and thicker and usually longer than sleepers. It includes sawn sleepers, hewn sleepers, untreated and treated sleepers.*
Treated or impregnated sleepers	*Sleepers may be surface treated with insecticides, fungicides or impregnated with creosote or other substances for long-term preservation.*
Other sleepers	*Sleepers which are not treated with insecticides or fungicides nor impregnated.*

[10] https://www.woodsolutions.com.au/structural-grading accessed on the 25/02/2025.
[11] https://www.woodsolutions.com.au/structural-grading accessed on the 25/02/2025.
[12] https://www.woodsolutions.com.au/visual-stress-grading accessed on the 25/02/2025.
[13] https://www.woodsolutions.com.au/structural-grading accessed on the 25/02/2025.

Veneer products

A schematic of a veneer production operation is presented in Figure 10. It presents the inputs, outputs and the by-products generated. A log can be sliced or peeled to produce thin sections of veneer sheets (see Box 18). While most veneer is produced by a rotary process, some species natural features are best displayed by slice veneering (Bootle, 1996, p.115). The resulting veneers can be used for decorative or non-decorative purposes (as reflected in Box 18). A decorative wood veneers highlight timber's inherent natural beauty.[14] Veneers can be produced as an input into a next stage of manufacturing or for sale to another party.

Box 18: A definition of veneer sheets (FAO, 2022, p.146).	
Veneer sheets	*'Thin sheets of wood of uniform thickness not exceeding 6 mm (excluding any reinforcing material), obtained by sawing, slicing or peeling (rotary cutting). Veneer sheets are used for the manufacture of plywood, laminated construction material, veneering furniture, veneer containers, etc.'*
Decorative veneer sheets	*'Veneer sheets whose face veneer has an attractive appearance due to figure, colour, grain, lustre, etc. The sheets for veneering of fine highly grained woods used in cabinet making veneers are more often obtained by sawing or slicing.'*
Decorative veneer sheets, for plywood (faces)	*'Decorative veneer sheets for the manufacture of plywood. Because of its specific decorative characteristics this material is usually used on the face of plywood.'*
Decorative veneer sheets, for other purposes	*'Decorative veneer sheets not intended for the manufacture of plywood. Possible uses are the veneering of furniture, sawn wood, or panels other than plywood, or marquetry and inlay work.'*
Non-decorative veneer sheets	*'Veneer sheets, usually peeled, without specific decorative characteristics. They are often used for the cores of plywood.'*
Non-decorative veneer sheets, for plywood	*'Non-decorative veneer sheets used for the manufacture of plywood. They may either be used in the core or for the face of those plywoods for which a face of decorative veneer sheets is not considered necessary. Woods used for the manufacture of plywood are generally cut by the peeling process.'*
Non-decorative veneer sheets, for other purposes	*'Non-decorative veneer sheets not used for the manufacture of plywood. Included in this item are veneer sheets for match boxes, violins, cigar boxes, etc. It excludes chipwood which is used for plaiting or to make chip baskets, pillboxes, etc.'*

[14] https://www.woodsolutions.com.au/wood-species/wood-products/decorative-wood-veneers

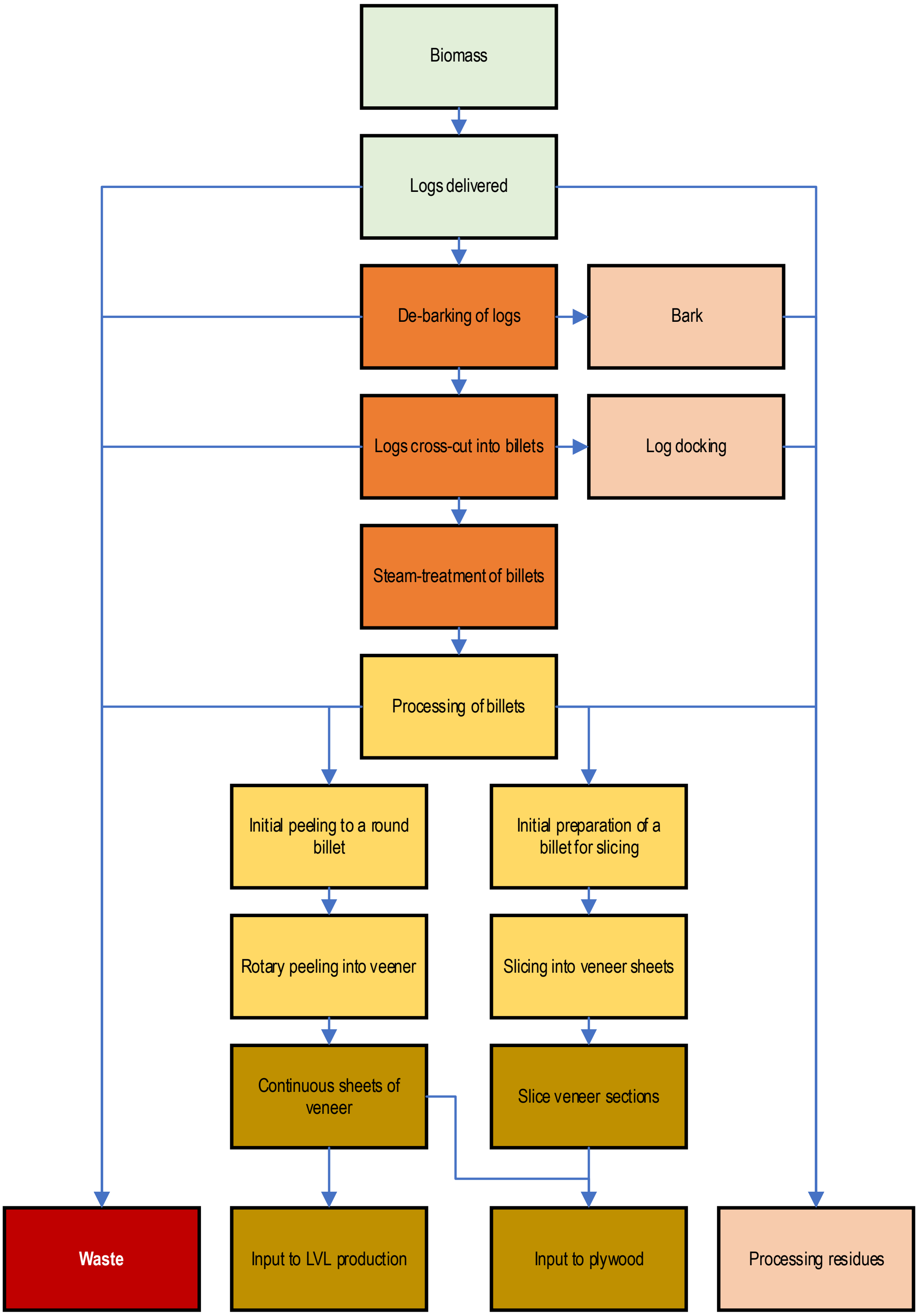

Figure 11: A generic schematic of a rotary peeling and sliced veneer operation.

Wood and non-wood-based panels

Overview

Wood-based panels are a specific group of products delineated by manufacturing processes, the nature of the constituent fibre and the intended use (see Box 19).

Box 19: A definition of wood-based panels as a product (FAO, 2022, p.147).	
Wood-based panels	*'This product category is an aggregate comprising plywood, particleboard, oriented strand board (OSB), fibreboard, densified wood, combination board and other panels based on wood or other lignocellulosic materials.'*

Plywood

Veneer plywood

Veneer plywood is a specific product manufactured from veneer sheets and there are a range of types as presented in Box 20. In plywood, the wood veneers are glue bonded together to produce a flat sheet. It is a versatile product used for a wide range of structural, interior and exterior applications; from formwork (e.g. shuttering in an overseas context) through to internal panelling[15]. Treating plywood provides added durability for a range of applications[16].

Box 20: A definition of veneer plywood as a product (FAO, 2022, p.147).	
Plywood	*'Plywood is a panel consisting of an assembly of veneer sheets bonded together with the direction of the grain in alternate plies generally at right angles. The veneer sheets are usually placed symmetrically on both sides of a central ply or core that may itself be made from a veneer sheet or another material. It includes veneer plywood, core plywood or blockboard, cellular board and composite plywood. It excludes laminated construction materials (e.g. glulam), where the grain of the veneer sheets generally runs in the same direction.'*
Veneer plywood	*'Plywood manufactured by bonding together more than two veneer sheets, where the grain of alternate veneer sheets is crossed, generally at right angles.'*
Veneer plywood, tropical non-coniferous	*'Non-coniferous (tropical) plywood is defined as having at least one face sheet of non-coniferous (tropical) wood.'*
Veneer plywood, interior grade	*'Veneer plywood suitable only for indoor applications.'*
Veneer plywood, exterior grade	*'Veneer plywood in which waterproof glue is used to bond plies. It is a resin-based glue similar to the glue used in wooden ships. It dries to a hard, crystal substance that will never yield to moisture of any kind. It is suitable for indoor and outdoor applications.'*

Core plywood

While not always manufactured from veneer, the core of a plywood board can be a range of products as noted in Box 21. The term 'core' refers to the inner layer around which plywood is built. In a three-ply panel, the core is laid at right angles to the grain of the outer layers. In plywood with more than three layers of veneer, the core is laid parallel to the surface layers with the alternate layers laid at right angles to them. This provides a balance to the panel and prevents warping as any stresses

[15] https://www.woodsolutions.com.au/wood-species/wood-products accessed on the 02/02/2025.
[16] https://www.woodsolutions.com.au/wood-species/wood-products accessed on the 02/02/2025.

through shrinkage are equalised on either side of the core. Therefore, veneered panels are nearly always made-up of an odd number of laminations (Wallis, 1970, p.86).

Box 21: A definition of core plywood as a product (FAO, 2022, p.147).	
Core plywood	*'Core plywood is a plywood with a solid core. Core can consist of MDF, particleboard, veneer or from narrow boards, blocks or strips of wood.'*
Blockboard, laminboard and battenboard	*'Plywood with a solid core (i.e. the central layer, generally thicker than the other plies) that consists of narrow boards, blocks or strips of wood placed side by side, which may or may not be glued together.'*
Other core plywood	*'Plywood in which the wooden core is replaced by other materials such as a layer or layers of particleboard, fibreboard, wood waste glued together, etc.'*

Cellular board

Cellular boards are a specific board product defined by a non-solid core structure (see Box 22).

Box 22: A definition of cellular board as a product (FAO, 2022, p.147).	
Cellular board	*'Plywood with a core of cellular construction, which are somewhat similar in appearance to the blockboard and battenboard but the battens or laths forming the core are spaced one from the other, either parallel or in lattice form. Cellular boards are used for partitions, doors and sometimes in the manufacture of furniture.'*

Other plywood

As with all categories of products, there can be other grades and types of products not captured by the main product types (see Box 23).

Box 23: A definition of other plywood as a product (FAO, 2022, p.147).	
Other plywood	'*Includes any plywood not covered by definitions of other groups.*

Particleboard

Particleboard (also known as chipboard) are panels manufactured from similar sized small pieces of wood or other lignocellulosic materials (e.g. chips, flakes, splinters, strands, shreds, shives, etc.) bonded together with glue. There are a range of products as presented in Box 24. The resulting large board is then cut into the required panel sizes. This product can be manufactured with a range of finishes; for example, raw sanded, wood veneer, vinyl or melamine white papers. The product can be prone to swelling and should not be used for exterior applications (WPV, undated, p.15).

Box 24: A definition of particleboards as a product group (FAO, 2022, p.148).	
Particleboard	*'Flat-pressed or moulded panels manufactured from particles of wood or other lignocellulosic materials bonded by a suitable, usually organic, binder in the presence of heat and pressure. They may also be manufactured by extruding the materials into a mould under heat and pressure. Extruded particleboard may be solid or with hollow cavities. The density of particleboards varies with the density of raw materials used and the binder, pressures and temperatures used in manufacture. It includes special types of particleboard as waferboard and oriented particleboard. It excludes wood wool board or other boards with mineral binders.'*
Wood particleboard	*'Particleboard manufactured from particles of wood.'*
Waferboard	*'Special type of platen pressed particleboard, made up of long particles ('wafers'), which are less than twice as long as they are wide and thereby improving the strength characteristics of the board.'*
Medium density particleboard (MDP)	*'MDP panel is composed of a synthetic adhesive matrix and a reinforcing phase composed of wood particles (usually Eucalyptus). The wood particles are arranged in three layers. The particles are positioned in a differentiated manner, the largest are laid in the middle and the thinner particles are placed on the outer surfaces, creating three layers. They are glued and compressed with a synthetic resin by applying pressure and heat at the same time in a state-of-the-art continuous press.'*
Extruded particleboards	*'Particleboards made by extrusion the mixture of wood particles and resin through a die. The particles lie with their larger dimensions mainly at right angles to the direction of extrusion. They are used as cores or middle layers.'*
Other wood particleboard	*'Other wood particleboard not mentioned'* under other groups.
Particleboard of lignocellulosic material other than wood	*'Particleboard of bagasse, flax, hemp, straw or other non-wood lignocellulosic materials.'*

Fibreboard

Fibreboards are a specific group of products defined by their manufacturing process and intended use; see Box 25. It is a group of products comprising hardboard, medium / high-density fibreboard (MDF / HDF) and other fibreboard[17]. Masonite is a specific high-density board product. The Mason method (resulting in Masonite) of producing hardboards manufactured from sawmill residue and forest thinnings is by '*blasting them'* into long fibres with steam and forming them into boards using their inherent wood glues to bind them together. This product is considered environmentally friendly due to no reliance on synthetic glues or resins. The resulting boards are highly flexible and have a smooth finish on one side. Masonite applications include as a flooring underlay and for wall bracing (WPV, undated, p.15).

[17] FAOSTAT accessed on the 25/02/2025

Box 25: A definition of fibreboard group of products (FAO, 2022, p.148&49).	
Fibreboard	*'A panel manufactured from fibres of wood or other lignocellulosic materials (bamboo, bagasse) with the primary bond deriving from the felting of the fibres and their inherent adhesive properties. Additional resins or other organic bonding substances may be used to agglomerate the fibres. Fibreboard may consist of a single sheet or of several sheets bonded together. It includes fibreboard panels that are flat-pressed and moulded fibreboard products.'*
Dry process fibreboard	*'Dry process fibreboards are engineered woodbased panel materials made by bonding together wood fibres with a synthetic resin adhesive. The resinated fibres are dried and then formed into a mattress ready for pressing. The mattress is pressed between heated polished press plates to the desired thickness. Dry process fibreboards have a fibre moisture content of less than 20% at the forming stage.'*
Dry process fibreboard of a density not exceeding 0.5 g/cm³	*'Low density fibreboard is a wood-fibre insulation board produced in the dry process.'*
Dry process fibreboard of a density exceeding 0.5 g/cm³ but not exceeding 0.8 g/cm³	*'A medium density fibreboard (MDF) of a density ranges from 0.5 g/cm³ to 0.8 g/cm³. Additional thermosetting resins are added to the dried wood fibres in order to assist the bonding process in the press. It can be used in many different applications such as furniture, interior decoration and in building.'*
Dry process fibreboard of a density exceeding 0.8 g/cm³	*'A high-density fibreboard (HDF) of a density exceeding 0.8 g/cm³ produced in the dry process'*
Wet process fibreboard	*'The wet fibres are formed into a mat which is either rolled (softboards), or rolled and then pressed, at a high temperature to the desired thickness. The primary bond is generally derived from the felting together of the fibres and their inherent adhesive properties, although in some instances a synthetic adhesive may be added to the fibres. Other additives such as wax, bitumen emulsion, natural oil or fire retardant chemicals may also be added. Wet process fibreboards have a fibre moisture content of more than 20% at the forming stage.'*
Wet process fibreboard, of a density not exceeding 0.5 g/cm³	*'It is a wet-process fibreboard of a density not exceeding 0.5 g/cm³. These boards are used mainly for thermal or sound insulation in building.'*
Wet process fibreboard, of a density exceeding 0.5 g/cm³ but not exceeding 0.8 g/cm³	*'It is a wet-process fibreboard of a density exceeding 0.5 g/cm3 but not exceeding 0.8 g/cm³. It is mainly used in furniture production and for interior or exterior walls.'*
Wet process fibreboard, of a density exceeding 0.8 g/cm³	*This type of fibreboard has one smooth and one rough surface with a mesh pattern. It is mainly used for furniture, in the automotive industries, for door skins and for packaging. It excludes similar products made from pieces of wood, wood flour or other lignocellulosic material where additional binders are required to make the panel; and panels made of gypsum or other mineral material.*

Oriented strand board

Oriented strand boards are a widely used, versatile engineered wood panel group of board products defined by their mechanical properties as they relate to the intended use; see Box 26. It is a structural panel product produced by bonding thin rectangularly shaped wood strands arranged in cross-oriented layers, with waterproof heat-cured adhesives.[18] The input strands are 8 to 15 cm long and it can be made from whole-trees generally regardless of form.[19] It is similar in strength and performance to plywood, resisting deflection, warping and distortion.

[18] https://www.woodsolutions.com.au/wood-species/wood-products accessed on the 02/02/2025.
[19] https://www.naturallywood.com/products/oriented-strand-board-osb/ accessed on the 02/02/2025.

Box 26: A definition of oriented strand board products (FAO, 2022, p.148).	
Oriented strand board	*'A structural board in which layers of narrow wafers are layered alternately at right angles in order to give the board greater elastomechanical properties. The wafers, which resemble small pieces of veneer, are coated with e.g. waterproof phenolic resin glue, interleaved together in mats and then bonded together under heat and pressure. The resulting product is a solid, uniform building panel having high strength and water resistance.'*
General purpose OSB and OSB for interior fitments	*'OSB used only in dry conditions, mainly for interior fitments (including furniture), grade OSB/1.'*
Load-bearing OSB	*'Load-bearing OSB used in dry (grade OSB/2) or humid (grade OSB/3) conditions.'*
Heavy-duty load-bearing OSB	*'Heavy-duty load-bearing boards used in humid conditions (grade OSB/4).'*

Combination boards

A combination board is a product manufactured from a range of other and different board products (see Box 27).

Box 27: A definition of combination boards as products (FAO, 2022, p.149&150).	
Combination board	*'Boards which have special properties as a result of the combination of two or more wood-based panels. The latter may be identifiable in their own right under other items of the classification, but under the present item they form an integral part of the panel. It excludes panels covered with veneers that are classified as plywood.'*
Particleboard covered on one or both faces with fibreboard	*'Laminated panels consisting of particleboard covered on one or both faces with fibreboard.'*
Several particleboards whether or not covered on one or both faces with fibreboard	*'Laminated panels consisting of several particleboards whether or not covered on one or both faces with fibreboard.'*
Several particleboards and several fibreboards assembled in any order	*'Laminated panels consisting of several particleboards and several fibreboards assembled in any order.'*
Other combination board	Combination boards other than those included in other groups.

Other panels based on wood or other lignocellulosic materials

There are a range of other panels based on wood or other lignocellulosic materials as noted in Box 28.

Box 28: A definition of other panels based on wood or other lignocellulosic materials as products (FAO, 2022, p.150&151).	
Other panels based on wood or other lignocellulosic materials	*'This heading includes notably cement bonded panels, other mineral bonded panels and thermoplastic bonded panels.'*
Cement bonded panels	*'Panels manufactured from wood wool, chips, particles, flakes, etc. of wood or other lignocellulosic material bonded together with cement and chemical additives. Wood constitutes the major part of the panel, by volume.'*
Cement bonded particleboard	*'The panel is a mixture of wood particles and Portland cement together with some additives. The mat is formed in three layers, the outer layers comprising small chips. Unlike normal particleboard production in a multi-daylight press, the set of cauls in cement bonded particleboards production must be kept under pressure until the cement has set.'*
Cement bonded wood wool board	*'The panel is made of wood wool and Portland cement with addition of natural mineralizing agent. Wood strands are first impregnated, and then by pressing they are bonded with cement in the continuous technological process. In this process wood strands become resistant to expanding, insects, rotting, water absorption, and fire resistance is also significantly improved.'*
Wood strand cement board (cement OSB)	*'Panels composed of long and thin wood strands bonded with Portland cement.'*
Fibre-reinforced cement board	*'There is a combination of cement and reinforcing fibres. These fibres can be of different origin (cellulose fibres, glass fibres)'*
Other cement bonded panels	*'Includes notably wood-cement blocks wherein the wood particles are of varying type.'*
Mineral bonded panels, other than cement bonded	*'Panels manufactured from woodchips particles, flakes etc. of wood or other lignocellulosic materials, bonded together with mineral binders other than cement, and chemical additives (e.g. gypsum board).'*
Gypsum fibreboard	*'Panels manufactured from gypsum and cellulose or recycled paper fibres. These two natural raw materials are mixed with water, without any other binders being added. The mixture is then pressed into stable boards under high pressure, dried, coated with a water repellent.'*
Gypsum particleboard	*'Panels manufactured from gypsum and particles of wood, bagasse, straw or other lignocellulosic materials.'*
Other mineral bonded panels	*'Other mineral bonded panels, other than cement bonded.'*
Thermoplastic bonded panels	*'Panels manufactured from particles of wood, bagasse, straw or other lignocellulosic materials bonded with thermoplastic (polyethylene [PE], Polypropylene [PP], polyvinyl chloride [PVC] etc.)'*
Wood-plastic composite	*'Wood-plastic composite are composite materials made of wood fibre or wood flour and thermoplastic. They are produced by thoroughly mixing ground wood particles and heated thermoplastic resin. The most common method of production is to extrude the material into the desired shape.'*
Other thermoplastic bonded panels	*'These composites contain no cellulose-based fibre fillers such as pulp fibres, peanut hulls, bamboo, straw, digestate, etc.*
Other panels based on wood or other lignocellulosic materials	Includes any panels not covered by definitions in other groups.

Structural composite lumber products

The group of products

Recall the use of sawn timber rather than lumber as a descriptor in Australia. This group of products makes use of the term lumber to indicate products manufactured in the shape of a section of sawn timber. Structural composite lumber (SCL) is a family of EWP used for structural applications (see Box 29).

Box 29: A definition of structural composite lumber as a group of products[20] and the category of other EWP (FAO, 2022, p.161-163).	
Structural composite lumber	*'Structural composite lumber (SCL) is the term used to describe a family of engineered wood products used for structural applications. SCL products include laminated veneer lumber (LVL), laminated strand lumber (LSL), parallel strand lumber (PSL) and oriented strand lumber (OSL).'*
Laminated strand lumber (LSL)	*'Laminated strand lumber (LSL) resembles oriented strandboard in appearance because like OSB, LSL is made from long strands coming from fast-growing aspen or poplar. However, unlike OSB, the strands are arranged parallel to the longitudinal axis of the member.'*
Parallel strand lumber (PSL)	*'Parallel strand lumber (PSL) is a form of wood product made from clipped veneer strands laid in parallel alignment and bonded with adhesive.'*
Oriented strand lumber (OSL)	*'Oriented strand lumber (OSL) is made from flaked wood strands with a high length-to-thickness ratio. The strands are oriented and combined with an adhesive to form a large mat or billet and then pressed.'*

Laminated veneer lumber

Laminated veneer lumber is a high strength EWP that can replace larger section beams. It is manufactured from veneer sheets bonded together under heat and pressure to form a large plywood block which is then sawn into boards (see Box 30). It is used for permanent structural applications including beams and rafters.[21] The product is non-decorative; for example, in dwelling construction, LVL can be used as a replacement for sawn hardwood lintels over windows behind plaster board.

Box 30: A definition of laminated veneer lumber as a product (FAO, 2022, p.147).	
Laminated veneered lumber	*'Laminated veneer lumber is the wood product that uses multiple layers of thin wood assembled with adhesives. Laminated veneer lumber is similar in appearance to plywood without crossbands.'*

Laminated strand lumber

Laminated strand lumber is a structural product manufactured from wood veneer strands or flakes that are compressed with an adhesive to form a 'sawn timber' like board (see Box 31).

Box 31: A definition of laminated strand lumber.[22]	
Laminated strand lumber	*'Laminated strand lumber '(LSL) is part of a family of products, structural composite lumber, that are made of dried and graded wood veneers, strands or flakes that are layered upon one another and bonded together with a moisture-resistant adhesive into large blocks known as billets. LSL is similar to LVL in many ways, with the exception that it uses flakes, and not layers of veneers. The flakes are pressed together with heat—using a steam injection press—and bonded by adhesives.'*

[20] https://www.woodsolutions.com.au/wood-species/wood-products/structural-composite-lumber-scl accessed on the 12/03/2025.
[21] https://www.woodsolutions.com.au/wood-species/wood-products accessed on the 02/02/2025.
[22] https://www.naturallywood.com/products/laminated-strand-lumber-lsl/ accessed on the 02/02/2025.

Parallel strand lumber

Parallel strand lumber is a structural product manufactured from long strands of wood veneers strands or flakes that are compressed with an adhesive to form a sawn timber like board (see Box 32).

Box 32: A definition of parallel strand lumber.[23]	
Parallel strand lumber	*'Parallel strand lumber '[PSL] is part of a family of products, structural composite lumber, that are made of dried and graded wood veneers, strands or flakes that are layered upon one another and bonded together with a moisture-resistant adhesive into large blocks known as billets. In the case of PSL, long strands (longer than those used in LSL) are laid lengthwise in parallel.'*

Scrimber

Scrimber was a novel product developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the 1980s. It is interesting to note a resurgence of interest with a Swiss company promoting the product.[24] The product is manufactured from low-grade logs and other fibre into high-performance, structurally load-bearing building materials (e.g. beams). The full logs are roller-crushed to create shredded sections with the fibre strands intact; the plant is referred to as a 'scrimming mill'.[25] The process forms bundles of interconnected and aligned strands which largely maintain the original orientation of the wood fibres in a log. The materials are dried and impregnated with adhesives in a mould to the target dimensions. The Swiss group is proposing to use the product in a glue laminated timber (GLT or glulam) or cross laminated timber (CLT) type product.

[23] https://www.naturallywood.com/products/parallel-strand-lumber-psl/ accessed on the 25/02/2025.
[24] See https://www.scrimber.com/en/technologien/ accessed on the 25/02/2025.
[25] https://woodcentral.com.au/scrimber-csiro-adhesive-process-opens-structural-markets-for-small-diameter-logs/ accessed on the 25/02/2025.

Secondary wood products

Overview

The group of products resulting from the transformation of sawn timber into a product are defined as secondary wood products (see Box 33).

Box 33: A definition of secondary wood products as a group of products and the individual products (FAO, 2022, p.159).	
Secondary wood products	*'Secondary wood products include essentially wood products and furniture. This item will consider the products resulting from further transformation of sawn wood and other wood-based material. The range of operations and process is very wide, starting with the cutting to size of components and ending with the manufacture of finished and complex products such as pieces of furniture.'*

Further processed sawn wood

Sawn timber can be modified by a range of processes and the outputs are collectively referred to as further processed sawn wood (see Box 34).

Box 34: A definition of further processed sawn wood as a group of products and the individual products (FAO, 2022, p.159&160).	
Further processed sawn wood	*'Wood sawn or chipped lengthwise (including strips and friezes for parquet flooring, not assembled) and continuously shaped (tongued, grooved, rebated, V-jointed, beaded, moulded, rounded or the like) along any of its edges or faces, whether or not planed, sanded or finger jointed. It excludes bamboo-based products and sawn or chipped wood with further treatment of edges and/or faces other than planing, or sanding.'*
Boards with rounded edges or ends	*'Wood sawn or chipped lengthwise with rounded edges or ends.'*
V-jointed wood	*'It covers i.e., wood tongued and grooved with chamfered edges or ends.'*
Beaded wood	*'It covers wood tongued and grooved with a simple bead between the edge or end and the tongue.'*
Moulded wood	*'It covers strips of wood shaped to various contours, which are used for the manufacture of picture frames, decoration of walls, furniture, etc.'*
Rounded wood	*'It covers drawn woods, which are used in the manufacture of certain types of match splints, pegs for footwear, certain types of wooden sunblinds, toothpicks, cheesemaking screens, etc.'*
Thermowood and torrefied sawn wood	*'The manufacturing process of ThermoWood is based on the use of high temperature and steam. No chemicals are used in the treatment. The process improves dimensional stability and biological durability of wood. Another improvement is in the insulation properties of the final material, the process leads to a reduction in thermal conductivity. Due to the high treatment temperatures the resin is removed from the wood. The manufacture of torrefied sawn wood consists of heating the wood at a very high temperature (from 190 to 240°C), in a torrefaction kiln (autoclave) at controlled atmosphere and low in oxygen. The length of the process, as well as the temperature degree sustained during a determined period, depends on the torrefied specie and the desired colour. This technology requires a pre- drying process using conventional kiln driers, to lower the moisture level between 6% and 10%. After that, the torrefaction kiln lowers the moisture level to 0%. Finally, the wood is placed in a conditioning chamber where the temperature is gradually lowered by controlled steam injection. The moisture level of the product is increased between 3% and 6%, in order to give back to the wood its natural flexibility. This conditioning stabilizes the wood and allows better quality manufacturing.'*
Other further processed sawn wood	*'Other further processed sawn wood not mentioned in the previous items.'*

Densified wood as a product

To allow utilisation in specific circumstances, wood can be chemically (e.g. with formaldehyde resin) and/or mechanically (e.g. compression and heat) treated to increase its density and/or hardness; such products are referred to as densified wood (Bootle, 1996, p.121). Bootle (1996, p.121) noted that densified wood veneers used in panel production is *'considerably higher electrical resistance than wood, is very resistant to destruction by decay and insects, and movement due to moisture content variations is practically eliminated'*. A further point noted was that such products are *'resistant to fire and chemical attack'* (Bootle, 1996, p.121). Box 35 presents an agreed definition of densified wood.

Box 35: A definition of densified wood as a product (FAO, 2022, p.149).	
Densified wood	*'Densified wood has been chemically or physically treated to increase its density or hardness and improve its mechanical strength or resistance to chemical or electrical agencies. It may be solid or consist of several layers bonded together and have a density as great as 1.4 g/cm^3. It is generally used in the manufacture of gears, shuttles, bearings and other machine parts, propellers, insulators and other electric goods, etc.'*

Specific engineered wood products

Beams

There are a range of specific EWP in beam form as presented in Box 36.

Box 36: A definition of builder's joinery focussed on beam products (FAO, 2022, p.161-163 and as footnoted).	
Engineered structural timber products	*'Engineered structural timber products are made from sawn wood, veneers, strands of wood, or from other small wood elements that are bound together with structural resins to form structural products. They are designed for use in the same structural applications as sawn wood (e.g. girders, beams, headers, joists, studs, and columns).'*
Glue-laminated timber (GLT or GLULAM)	*'Glue-laminated timber is a type of structural timber product comprising a number of layers of dimensioned timber bonded together with durable, moisture-resistant structural adhesives. The wood laminations have their grain essentially parallel.'*
I-beams	*'I-beams are strong, lightweight, 'I' shaped engineered wood structural members that meet demanding performance standards. I-beams are comprised of top and bottom flanges, which resist bending, united with webs, which provide outstanding shear resistance. The flange material is typically laminated veneer lumber (LVL) or solid sawn lumber, and the web is made with plywood or OSB.'*
Box Beams	*'Box beams follow similar design principles to I-beams, but in this instance two web members are used, fixed to the sides of the flanges. This allows for the member to not only have a decorative face, but also enables wiring to be run through the middle of the beam and thus achieve a neater look. Box beam structures are especially ideal in areas that require a long span, such as open plan buildings like sports arenas and warehouses, as they are lightweight and can be used as a decorative feature. Box beams are designed to job-specific standards and are typically assembled off-site. There are no standard sizes to be purchased 'off-the-shelf'.'* (WPV, undated, p.12).

Large panels

There are a range of specific EWP in panel form as presented in Box 37.

Box 37: A definition of builder's joinery focussed on panel products (FAO, 2022, p.162-163 and as footnoted).	
Cross-laminated timber (CLT)	*'Cross-laminated timber [CLT or X-lam] consists of several layers of structural lumber boards stacked crosswise (typically at 90 degrees) and glued together on their wide faces and, sometimes, on the narrow faces as well. A cross-section of a CLT element has at least three glued layers of boards placed in orthogonally alternating orientation to the neighbouring layers. In special configurations, consecutive layers may be placed in the same direction, giving a double layer (e.g. double longitudinal layers at the outer faces and additional double layers at the core of the panel) to obtain specific structural capacities. CLT products are usually fabricated with three to seven layers and even more in some cases.'*
Dowel-laminated timber (DLT)	Dowel-laminated timber (DLT) is manufactured by stacking graded dimension sawn timber together on its edge or cross laminating them and fitting them together with hardwood dowels. The sawn timber can be structurally finger jointed, run through a moulder and laminated into large panels. It is prefabricated using a high-powered hydraulic press on the hardwood dowels to press them into tight-fit holes of the lamellas. The product uses the differing moisture content of the softwood and hardwood components to friction-fit the product together. This means differences in moisture of the planks, which shrink, and the dowels, which swell, help lock the panels together.[26& 27]
Nail-laminated timber (NLT)	*'Nail-laminated timber (NLT) is manufactured from dimension sawn timber stacked together on its edge and fastened together with nails or sometimes screws to form a solid structural element.' 'This can be done on-site or as factory prefabricated panels. The simplicity of NLT makes it relatively easy to assemble. While there are no industry-wide quality standards for this product, an NLT Guide provides guidance on quality control and sample specifications.'*[28] *'These are suitable for use as a floor or roof panel.'*[29]
Panel laminated timber (PLT)	Panel laminated timber (PLT) panels are made using timber boards (finger jointed or solid) that are laminated on edge into large panels with all grain running parallel to the panel span direction. They are exceptionally strong, hence can be used in from new homes to multi-story buildings, with minimal additional structural support. Utilising PLT for mid floors and roofs can help reduce the height of a building.[30&31]

Wooden wrapping and packaging material

Sawn timber can be utilised to protect goods for shipping as wooden wrapping or packaging material, and there are a range of specific products (see Box 38). To assist in handling, freight can be aggregated on pallets. Pallets provide a base for lifting (e.g. with forklift trucks) and defining the dimensions of the aggregated products for fitting in trucks and shipping containers. There is an Australian Standard for pallets (see AS4068 - 1993 Flat pallets for materials handling). For example, the CHEP Australian hardwood wooden pallet provides the basis for low cost and seamless unit load movements within and between supply chains in Australia. A CHEP pallet is a highly standard product at 1,165 x 1,165 x 150 mm with a tare weight of 38.5 kgs.[32] An alternative supplier is Loscam. Loscam supplies wooden pallets in a range of standard sizes to suit the country of operation. The Australian pallets are manufactured from Radiata pine (see Loscam, undated). Bespoke pallets are also manufactured for use in the logistics of specific products.

[26] https://www.naturallywood.com/products/dowel-laminated-timber-dlt/ accessed on the 25/02/2025.
[27] https://woodspan.co.nz/news/mass-timber-plt-clt-difference/ accessed on the 25/02/2025.
[28] https://www.naturallywood.com/products/nail-laminated-timber-nlt/ accessed on the 25/02/2025.
[29] https://woodspan.co.nz/news/mass-timber-plt-clt-difference/ accessed on the 25/02/2025.
[30] https://woodspan.co.nz/product/plt-panel/ accessed on the 25/02/2025.
[31] https://woodspan.co.nz/news/mass-timber-plt-clt-difference/ accessed on the 25/02/2025.
[32] https://www.chep.com/au/en/platforms/pallets accessed on the 25/02/2025.

Box 38: A definition of wooden wrapping and packaging materials as a group of products and the individual products (FAO, 2022, p.153).	
Wooden wrapping and packaging material	*'It includes packing cases, boxes, crates, drums and similar packings, of wood; cable-drums of wood; pallets, box pallets and other load boards, of wood; pallet collars of wood. Casks, barrels, vats, tubs and other coopers' products and parts thereof, of wood, including staves.'*
Packing cases, boxes, crates, drums and similar packings	*'It includes packing cases and boxes with solid sides, lids and bottoms; crates, fruit or vegetable boxes, egg trays and other containers with slatted sides and open tops; boxes made of sliced or peeled wood; matchboxes and conical open containers for marketing butter, fruit, etc.'*
Cable drums	*'Cable drums are large drums, used to hold and transport electric cables, telephone cables and similar cables.'*
Pallets, box pallets and other load boards	*'It encompasses products which serve as a portable platform for the assembly of a quantity of goods to form a unit load for handling, transportation and storage by mechanical appliances. It includes also platforms, post platforms, collar type box platforms, side rail platforms and end rail platforms.'*
Pallet collars	*'Pallet collars are collars made up of four pieces of wood, usually with hinges on the ends to form a frame that is placed over the pallet itself.'*
Casks, barrels, vats, tubs and other coopers' products	*'It includes containers which the bodies are composed of staves with grooves into which the heads and bottoms are fitted and the shape being maintained by hoops of wood or metal.'*
Parts of coopers' products from wood, including staves	*'It includes barrel heads, hoopwood and unfinished staves (stavewood).'*
Other wooden wrapping and packaging material	Other wooden wrapping and packaging material not mentioned in other groups.

Wood products related to dwellings

Builder's joinery and carpentry of wood; general categories of components

As a component to either assist in construction or as a component of a build, builder's joinery and carpentry of wood is defined in Box 39.

Prefabricated wooden buildings

Wood can be used to manufacture and supply prefabricated buildings to varying levels of competition as noted in Box 40.

Box 39: A definition of builder's joinery and carpentry of wood, and the individual products (FAO, 2022, p.161-163).	
Builder's joinery and carpentry of wood	*'It includes windows, doors and coverings thereof as well as cellular wood panels, assembled parquet panels, shingles and shakes. It excludes bamboo-based products.'*
Windows, French-windows and their frames	*'It includes windows, French-windows and their frames used in the construction.'*
Doors and their frames and thresholds	*'Doors and their frames and thresholds used in the construction. They can be made from of ordinary wood or of particleboard, fibreboard, laminated wood or densified wood.'*
Shuttering [form-work] for concrete constructional work	*'Shuttering for concrete constructional work, they can be made from of ordinary wood or of particleboard, fibreboard, laminated wood or densified wood.'*
Shingles and shakes	*'A shingle is a thin piece of wood having parallel sides and tapered so that one end is thicker than the other, sawn from a shingle bolt. It is primarily used to cover roofs and walls of buildings to protect them from the weather. A shake is a shingle obtained by splitting, instead of sawing the bolt or plank. Shakes may be straight split or hand split and re-sawn tapered. It is primarily used to cover roofs and walls of buildings to protect them from the weather.'*
Posts and beams	*'Posts are round, hewn, squared or split wood, usually less than 3 m in length, but possibly up to 5 m used for fencing, guard rails and the like. Beam is a piece of wood which is typically long and squared that can be used as a building material.'*
Assembled flooring panels	*'It includes solid blocks, strips, friezes, etc., assembled into flooring panels or tiles. It also includes flooring panels or tiles consisting of blocks, strips, friezes, etc., assembled on a support of one or more layers of wood, known as "multilayer" parquet flooring panels.'*

Box 40: A definition of prefabricated buildings of wood and the individual products (FAO, 2022, p.163).	
Prefabricated buildings of wood	*'It includes prefabricated buildings where the main construction material is wood.'*
Prefabricated buildings of wood complete, fully assembled	*'It includes complete buildings, fully assembled and ready for use.'*
Prefabricated buildings of wood complete, unassembled	*'It includes complete buildings but not assembled and ready for use.'*
Prefabricated buildings of wood incomplete	*'It includes incomplete buildings, whether or not assembled and having the essential character of prefabricated buildings.'*

Other wooden products not related to dwelling construction

Wood products for domestic and decorative use

Sawn timber can be used in a range of functional domestic and decorative uses as noted in Box 41. A specific product group is the Australian type of flooring known as mosaic parquetry and wood blocks, but with origins in Europe. Mosaic parquetry is a form of parquetry overlay which is manufactured to precise dimensions and pre-assembled in the form of a small square of 'tiles'; each tile is made up of c. five accurately machined blocks or 'fingers', assembled and glued together to form a tile. When laid, the tiles are arranged so the direction of the grain in each is at right angles to its neighbours. The facings or backings bind the tiles together to their setting using a mastic adhesive (Wallis, 1970, p.129).

Box 41: A definition of wood products for domestic and decorative use, and the individual products (FAO, 2022, p.160&161).	
Wood products for domestic and decorative use	*'It includes wooden frames for paintings, photographs, mirrors or similar objects; tableware and kitchenware of wood; and wood marquetry and inlaid wood, cases for jewellery or cutlery, statuettes and other ornaments of wood; hat racks. It excludes bamboo-based products.'*

Wooden frames for paintings, photographs, mirrors or similar objects	*'It includes wooden frames of all shapes and dimensions. The frames of the heading may also be of wood marquetry or inlaid wood.'*
Tableware and kitchenware	*'It includes household articles of wood, which are used as tableware or kitchenware like spoons, forks, salad servers; platters and serving dishes; jars, cups and saucers; etc.'*
Wood marquetry and inlaid wood	*'It includes panels of wood marquetry and inlaid wood, including those partly of material other than wood.'*
Caskets and cases for jewellery or cutlery	*'It includes a wide variety of articles of generally of careful manufacture and good finish, such as small articles of cabinetwork (for example, caskets and jewel cases); small furnishing goods; decorative articles, etc.'*
Statuettes and other ornaments	*'It includes statuettes, animals, figures and other ornaments.'*
Other wood products for domestic or decorative use	Other wood products for domestic and decorative use not mentioned in other groups.

Other manufactured wood products

Items can be manufactured from sawn timber by combining further inputs and activities. Such items can be as a single piece of sawn timber or by combining a number of components (see Box 42).

Box 42: A definition of other manufactured wood products and the individual products (FAO, 2022, p.153).	
Other manufactured wood products	*'It includes tools, tool handles, broom or brush bodies and handles, boot or shoe lasts or trees; clothes hangers, coffins and other articles of wood. It excludes bamboo-based products.'*
Tools, tool bodies, tool handles	*'It includes tool bodies of not fitted with their metal working parts and wooden handles for tools or implements of all kinds (e.g. handles for spades, shovels, rakes, hammers, screwdrivers, saws, etc.)'*
Broom or brush bodies and handles	*'Broom or brush bodies are pieces of wood, shaped to the actual form of broom or brush heads. They may sometimes consist of more than one piece.'*
Boot or shoe lasts and trees	*'Boot or shoe lasts of wood and boot or shoe trees, which are used for preserving the shape or for stretching footwear.'*
Clothes hangers	*'Wooden clothes hanger consists of a flat piece of wood cut into a boomerang-like shape with the edges sanded down to prevent damage to the clothing, and a hook, usually of metal, protruding from the point. Some wooden hangers have a rounded bar from tip to tip, forming a flattened triangle. This bar is designed to hang the trousers belonging to the jacket.'*
Coffins	*'A coffin is a funerary box used for burial or cremation.'*
Other manufactured wood products.	*'It includes match splints which are manufactured to the dimensions of matches; wood paving blocks; spools, cops, bobbins, sewing thread reels; ladders and steps; clothes pegs; oars, paddles, rudders; coffins, etc.'*

Wooden furniture

Sawn timber can be fashioned into wooden furniture; either as or a complete piece of furniture or components as outlined in Box 43.

Box 43: A definition of wooden furniture and the individual products (FAO, 2022, p.163).	
Wooden furniture	*'It includes seats with wooden frames, such as wooden camping and garden seats etc. and parts thereof except seats convertible into beds, swivel seats, medical seats. Wooden furniture other than seats as of a kind used in offices, in the kitchen, bedrooms and elsewhere, as well as parts of all these.'*
Wood swivel seats with variable height adjustment	No narrative
Wood seats other than garden seats or camping equipment, convertible into beds	No narrative
Other seats with wooden frames	*'It includes seats with wooden frames which can be upholstered.'*
Wood parts of seats	*'It includes identifiable parts of chairs or other seats, such as backs, bottoms and armrests made from wood.'*
Wooden furniture	*'It includes wooden furniture of a kind used in offices, in the kitchen, in the bedroom and other wooden furniture.'*
Wood parts of the furniture	*'It includes identifiable parts of furniture made from wood.'*

Manufactured fine particles

There are two products manufactured from wood by processing into fine and very fine products as presented in Box 44. Again, while traditional or indeed historic products are listed (e.g. in the manufacture of Bakelite), there has been recent use of wood flour in the manufacture of wood-plastic composites for external use decking.

Box 44: Wood small particle size products (FAO, 2022, p.143&144).	
Wood wool	*'Wood wool is a product consists of wood slivers, curled or twisted, which have regular size, thickness and length. It is cut from logs (poplar, coniferous tree species) and is mainly used in packaging, for cooling pads in home evaporative cooling systems known as swamp coolers, for erosion control mats, and as a raw material for the production of other products such as bonded wood wool boards and used as stuffing for stuffed animals.'*
Wood flour	*'Wood flour is finely pulverized wood that has a consistency fairly equal to sand or sawdust, but can vary considerably, with particles ranging in size from a fine powder to roughly the size of a grain of rice. It is commonly used as a filler in thermosetting resins such as bakelite, and in linoleum floor coverings. Wood flour is also the main ingredient in wood-plastic composite products such as decks and roofs.'*

Wood fibre combined with other materials

Wood composite products; wood and plastic

Overview

Wood materials can be combined with plastic materials to create wood-plastic composites; see Box 45. Biocomposites (e.g. wood plastic composites; WPC) are synthetic, resin / wood / additives that contain up to 80% wood which can utilise lower quality residue biomass (Ahlqvist *et al.*, 2012b, p.8&9). The input wood component can be of any shape or size, acting as a filler and/or reinforcement to the composite; for example, a wood flour (Schwarzkopf & Burnard, 2016, p.19-22). These products are used in a variety of structural and non-structural applications; from component and product prototyping to outdoor decking. Schwarzkopf & Burnard (2016, p. 20 citing La Mantia & Morreale 2011; citing Eder & Carus 2013) noted that construction and automotive applications are the most common worldwide. They can be used outdoors or indoors; for example, common applications include construction materials, garden and yard products, automotive applications (interior and engine), household items, packaging and consumer goods. A 2012 report for the Green Triangle (Ahlqvist *et al.*, 2012b, p.8&9) recommended to evaluate if an existing MDF mill could be retro-fitted using the same front-end and providing an alternative product and market stream. The supply of a suitable polymer is a crucial consideration. It was suggested that there may be an opportunity to generate composites from sawdust, pulp logs, woodchips and shavings and add value to these biomass residuals.

Box 45: The definition and nature of wood-plastic composites (Schwarzkopf & Burnard, 2016, p.19-22).	
Wood-plastic composites	*'Wood-plastic composites (WPCs) are a product class that has been developing over the last 40 years resulting in increased applications and expanded market share'.* They are *'composites containing a wood component in particle form (wood particles/wood flour) and a polymer matrix'* (Schwarzkopf & Burnard, 2016, p.19&20). WPCs are comprised of two primary and distinct components. One is the matrix holding the different components together, binding them and providing load transfer between them. The other is the wood component; it can be of any shape or size and acts as a filler and/or reinforcement to the composite. A relatively small proportion of the total composite are additives to aid in processing and affect a variety properties of the final product (Schwarzkopf & Burnard, 2016, p.21). There are two types; thermosets and thermoplastics.
Thermosets	*'Thermosets are a class of polymers that upon curing cannot be remelted or reprocessed for the same type of usage. From a liquid state these polymers are cured into rigid solids that are chemically cross-linked.'*
Thermoplastics	*'Thermoplastics are a class of polymers that can be heated and softened, cooled and hardened, and then resoftened while maintaining their characteristic properties from their first usage. Thermoplastics are used for a variety of everyday products like plastic soda bottles, single use shopping bags, milk jugs, etc.'*

Thermosets

Thermosets polymers upon curing, cannot be remelted or reprocessed for the same type of usage; from a liquid state they are cured into rigid solids that are chemically cross-linked. The mechanical properties of these polymers come from the initial molecular units and the density of cross-links formed during curing (Schwarzkopf & Burnard, 2016, p.21 citing Hull & Clyne 1996). The liquid polymer penetrates the wood microstructure to varying degrees and is cured, forming a three dimensionally dispersed interphase region. Common thermosets being used are urea–formaldehyde, phenol–formaldehyde, epoxy, and polyamides. One of the first WPCs using a thermosetting polymer was a phenol–formaldehyde—wood composite which was branded 'Bakelite' by Rolls Royce in 1916 and was used for the gear shifting knob in their vehicles (Schwarzkopf & Burnard, 2016, p.21 citing Clemons, 2002).

Thermoplastics

Thermoplastics polymers are not cross-linked and rely on the properties of their monomer units, large molecular weights, and polymer chain entanglement for their mechanical performance (Schwarzkopf & Burnard, 2016, p.21&22 citing Hull & Clyne 1996). When heated, the polymer chains disentangle allowing them to slide past each other, therefore allowing reprocessing. Due to wood's thermal stability, thermoplastics are used because they can be processed at relatively low temperatures below the temperature (180–200°C) of thermal degradation of wood. These polymers are attractive WPCs as they can be cut, screwed, and nailed with tools already used for wood construction (Schwarzkopf & Burnard, 2016, p.21&22).

A specific product; Stora Enso biocomposite containers

FrostPharma and Mälarplast in collaboration with Stora Enso have developed a biocomposite hazardous waste container product. These waste containers are used to manage hazardous waste from medical, veterinary, laboratory and dental procedures. They are required to be incinerated after use to ensure safe disposal to minimise the risk of contact with the risk waste. The product is WoodSafe, with seven containers in different sizes, with the products approved according to UN3291, ISO23907 and Australian Design Rules. WoodSafe is manufactured in Sweden with renewable raw materials (Timberbiz, 2024a). The input materials to manufacture a 1 kg WoodSafe Bio80 container are presented in Table 3. The product is manufactured from softwood sawmill residue woodchips. The woodchips are mechanically processed to a target size and with a controlled size distribution. The processed fibre materials are mixed with two types of polypropylenes and the mix is pelletized into a bio composite called S-fibre. The biobased polypropylene is manufactured by Braskem based on tall oil (Lindman, 2023, p.18, 20, 21). Tall oil is a by-product of softwood kraft pulping derived from the wood extractives. It is a mixture of saponified fatty acids (30%–60%), resin acids (40%–60%, including mostly abietic and pimaric acids), and unsaponifiables (5%–10%). Crude tall oil is recovered from partially concentrated black liquor and is refined at specialist plants (Bajpai, 2018).

Table 3: The input materials to manufacture a 1 kg WoodSafe Bio80 container (Lindman, 2023, p.17).

Input	Weight (kg)	Source
Woodchips	0.408	Softwood sawmill residue chips
Polypropylene	0.204	Virgin material
Biobased polypropylene	0.408	Manufactured from kraft softwood pulping black liquor

Wood combined with metal

While connection of wood and metal components is possible, sawn timber or other wood-based materials can be combined with metals; this is referred to as a timber-steel-hybrid (see Box 46). Research has considered a *'combination of timber elements and steel beams … for mechanical performances including instabilities and fire protection'* (Jurkiewiez *et al.,* 2022, p.1,231). It was concluded that there was potential, but that further development was required (Jurkiewiez *et al.,* 2022, p.1,231). This is a similar conclusion to as noted in Box 46, that although there is potential, there are key issues to address; creeping, load distribution, safety factor, a need for additional steel plate reinforcements and assembling time.

Box 46: An overview of wood combined with steel products (Wood Solutions[33]).	
Timber-steel-hybrids	*'In engineering modern multi-storey buildings, timber-steel hybrid elements could offer new construction advantages over conventional solutions. Combining timber and steel can lead to economic and ecologic benefits as construction height can be optimised, earthquake resistance improved and assembly done more efficiently.* *Hybrid timber-steel beams have been the subject of research at the Vienna University of Technology by Wolfgang Winter and associates. The aim of the researchers is to optimise the geometry of the timber-steel hybrid beam regarding cost effectiveness and load-bearing capacity. One new approach considered was to use cold formed 'U' profiles made of thin steel plates.* *While promising, key issues for further hybrid beam research include creeping, load distribution, safety factor, need for additional steel plate reinforcements and assembling time.* *The results are promising and indicate that hybrid steel reinforced timber structures have the potential to be light, fast and clean.'*

[33] Taken from https://www.woodsolutions.com.au/blog/timber-steel-hybrid-beams-multi-storey-buildings accessed on the 14/05/2025.

The by-products of primary processing of logs

Co-products

There are a range of by or co-products generated by the production of a target or primary product and Box 47 defines such products.

Box 47: The FAO definition of other wood processing co-products (FAOSTAT, accessed on 25/02/2025).	
Other wood processing co-products.	*'It includes wood waste and scrap not useable as timber such as sawmill rejects, slabs, edgings and trimmings, veneer log cores, veneer rejects, sawdust, residues from carpentry and joinery production, and wood residues that will be used for production of pellets and other agglomerated products. It excludes woodchips, made either directly in the forest from roundwood or made in the wood processing industry (i.e. already counted as pulpwood or woodchips and particles), and agglomerated products such as logs, briquettes, pellets or similar forms as well as post-consumer wood. It is reported in cubic metres solid volume excluding bark.'*

Virgin products

Log processing residues

Processing of logs into a range of primary products will generate residues and these residues are a by or co-product rather than waste (see Box 48). The nature of these residues will depend on the primary processing inputs and processes.

Box 48: The series of co-products resulting from processing logs to generate a primary product (FAO, 2022, p.144).	
Wood residues (including wood for agglomerates)	*'Other wood processing co-products that has not been reduced to woodchips or particles and has not been agglomerated. These residues may often serve as raw material for the manufacture of certain forest products, notably pulp, particleboard and fibreboard and may always be used as a source of energy.'*
Solid wood processing residues	*'Pieces of wood arising during processing, which have not been broken down into chips, sawdust, shavings or smaller particles. These pieces are suitable as raw material for the manufacture of pulp, particleboard, fibreboard, etc. This category includes for example sawmill rejects, slabs, edgings and trimmings, veneer log cores, veneer rejects, sawdust, residues from carpentry and joinery production, etc. Excluded are bark and contaminated residues.'*
Sawdust	*'Wood dust produced in the process of sawing.'*
Shavings	*'Long, thin pieces of wood, produced in planing operations.'*
Bark removed during processing	*'Bark, separated from the wood in the wood-processing industries.'*
Other residues of wood processing, not of solid wood	*'This item includes notably sander dust and contaminated process residues.'*

Woodchips and particles

Solid roundwood can be converted into smaller and specially sized particles either as the primary intent or as a by-product of production of a target product. Box 49 presents the classification of such products.

Box 49: The range of deliberately produced wood particles (FAO, 2022, p.145).	
Woodchips and particles	*'Wood, which has been deliberately reduced to woodchips (flat, rigid and roughly squared), particles (thin and flexible), flakes, etc. from wood in the rough, processing residues or recovered wood products and has not been agglomerated. Woodchips and particles are used for producing cellulose pulp by mechanical means, by chemical means or by combining mechanical and chemical means, for the manufacture of fibreboard or particleboard, for energy or for other purposes. The specification of the woodchips and particles may vary in respect to dimensions and quality according to location and end-use. The pieces are in forms ranging from flat, rigid and roughly squared woodchips down to small, thin flexible particles.'*
Woodchips and particles from wood in the rough	*'Wood, which has been deliberately reduced to chips, particles, flakes, etc. directly from wood in the rough, not during the processing of wood.'*
Woodchips and particles from wood processing	*'Wood, which has been deliberately reduced to chips, particles, flakes, etc. during the processing of wood.'*

Pin chips and fines screened-out from woodchip production

A by-product of woodchip production are pin chips and fines (see Box 50). These are woody materials that do not meet the specifications of a woodchip and are separated out by mechanical screening. Clean woodchips as a raw material are required (FAO, 1976, p.43) as a *'too high content or uneven distribution of pin chips and fines will cause non-uniform cooking and may also cause plugging of the liquor extraction screens, particularly in continuous digesters'* (FAO, 1976, p.78). An upgrading of woodchips by screening may remove foliage, oversize chips, fines, abrasive material and bark (FAO, 1976, p.43). Acceptable woodchip sizes can be defined by width and length; Fuller (2008, slide 13) indicated that fines are materials that would pass through a less than 3 mm wide screen and that pin chips would pass through a 3 to 7 mm screen.

Box 50: The rejected material in woodchip production; fines and pin chips (based on Fuller, 2008, slide 13).	
Fines	Material that will pass through a 3 mm screen separating out acceptable woodchips and other materials.
Pin chips	Material that will pass through a 3 to 7 mm screen separating out acceptable woodchips and other materials. This is after fines have been screened out.

Recovered wood products

It is possible to recover wood products at the end of their primary service life. In regard to utility as a resource, this is defined by the intended use and the condition of the recovered material. This difference is reflected in the classification system for such material (see Box 51).

Box 51: The classification of recovered wood products (FAO, 2022, p.146&145).	
Recoverable wood products	*'Products wholly or mostly of wood or wood-based panels, which are no longer used for their original purpose and which could be used as a source of raw material or energy.'*
Woodchips and particles from recovered wood products	*'Wood, which has been deliberately reduced to chips, particles, flakes, etc. from products wholly or mostly of wood or wood-based panels, which are no longer used for their original purpose.'*
Uncontaminated recoverable wood products	*'The recoverable wood products have not been contaminated (e.g. by impregnation, gluing, coating, painting or nailing) to such an extent that they are unsuitable as raw material for pulp particleboard or fibreboard. Examples are some pallets and wood packing cases.'*
Contaminated recoverable wood products	*'The recoverable wood products have been contaminated (e.g. by impregnation, gluing, coating, painting or nailing) to such an extent that they are unsuitable as raw material for pulp particleboard or fibreboard. They are usually only suitable as energy source.'*

Garden and landscape products

Mulch

Mulch is a voluntarily regulated product under AS 4454—2003 (Composts, soil conditioners and mulches). Mulch is defined as presented in Box 52. Chalker-Scott (2007, p.239-243) noted the benefits of mulching as a ground cover or soil amendment to improve the underlying soil moisture retention, soil nutrition, binding of heavy metals and plant establishment and growth, maintaining soil temperatures, reducing soil erosion and compaction, salt and pesticide contamination, disease, weeds and pesticide use. Evidence has linked the transmission of weeds, diseases and pests from mulch to the soil and living plants, inadvertently causing harm (EPA NSW, 2016, p.1).

Box 52: A definition of mulch as applied by the NSW EPA (EPA NSW, 2016, p.13).	
Mulch	*'Plant material shredded and/or screened to a preferred particle size grading for particular applications. Mulch, by virtue of the nature and source of the plant material, must pose minimal risk of the presence of physical and chemical contaminants. Mulch may include urban wood residues and forestry and sawmill residues. Mulch does not include plant material from kerbside waste collections.'*

Compost

While similar material such as mulch may be used, compost has been through a process of composting. Definitions of composting and compost are presented in Box 53. Compost is a voluntarily regulated product under AS 4454—2003 (Composts, soil conditioners and mulches). In the State of Victoria, composting is regulated by the Environment Protection Authority Victoria (EPA Vic) who provide design guidelines (EPA Vic, 2017). The scope of the EPA Vic guideline (to the design, construction and operating of composting facilities) is restricted to thermophilic, aerobic composting processes. The National Association for Sustainable Agriculture, Australia (NASAA) citing AS 4454 (2012) (NASAA, 2017, p.1) notes the definition of composting as *'the process whereby organic materials are microbiologically transformed under controlled aerobic conditions to achieve pasteurization and a specified level of maturity'*. A mature compost *'has a high degree of stability and exhibits low levels of phytotoxicity, which simply means that when the compost is applied to the soil it will not have a negative impact on plant growth'* (NASAA, 2017, p.1).

Box 53: A definition of composting and compost.	
Composting	*'Composting is the microbiological transformation of organic materials under controlled aerobic conditions. There are two phases to the thermophilic composting process:* • *Pasteurisation which generates heat within the material to significantly reduce the number of viable pathogens and plant propagules* • *Maturation which sees the decline in microbial activity and an increase in biological stability of the organic material.'* (EPA Vic, 2017, p.1).
Compost	*'Compost is a special mixture of organic matter made up of plants and animals. The composting process rots the material and kills bad bacteria. Compost can be added to soil to increase soil organic matter'* (Gosford Primary Industries Institute, 2010, p.1).

Potting mixes

Potting mixes are a specific product and are addressed by AS3743 – Potting Mixes – 2003 as a voluntary standard. See Box 54.

Box 54: A definition of potting mix is presented.	
Potting mix	Potting mix is a combination of mineral soil, added organic matter and potentially chemical additives (e.g. wetting agent and nutrients).

Part C: Wood as a fuel in solid format

Solid biomass as biofuels

Firewood

The product

There is a delineation between firewood and fuelwood (see Box 55), however the terms are often used interchangeably. Firewood is a non-standard product that can be sold by weight (in tonnes or kilograms), volume (cubic metres) or lot (e.g. by the stack, trailer or truck load) as regulated by trade measurement laws for retail and wholesale sales (NMI, 2025). The higher heating value (HHV) energy content of wood varies between softwoods and hardwoods (see Table 2) with species-specific combustion attributes (see Figure 9). Firewood as solid wood could be produced from log offcuts, full logs or sawmill residues.

Box 55: The definitions of wood used as a simple fuel.

Term	Definition
Wood fuel simply worked	*'Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms'* (FAO, 2022, p.144).
Fuelwood	*'Wood fuel where the original composition of the wood is preserved'* (FAO, 2004, p.36).
Firewood	*'Cut and split oven-ready fuelwood used in household wood burning appliances like stoves, fireplaces and central heating systems. Firewood usually has a uniform length, typically in the range 150 mm to 500 mm'* (FAO, 2004, p.34).
Split (Firewood)	*'Split logs or billets'* (FAO, 2022, p.144).
Other wood fuel simply worked	*'Twigs, faggots, rough sticks, tree stumps and roots'* (FAO, 2022, p.144).

Firewood consumption

The 2024 State of the Forests Report indicated that nationally 2.94 million m³ of firewood was consumed in the five year period of 2017/18 to 2021/22; this equates to an average of 0.59 million m³/y (MIG&NFISC, 2024, Figure 6.1d-3b dataset). Figure 12 presents the stated firewood consumption for the State of Victoria in 5-year periods. The volume of firewood consumed can be converted to weight based on assumed moisture content and species-specific basic density.

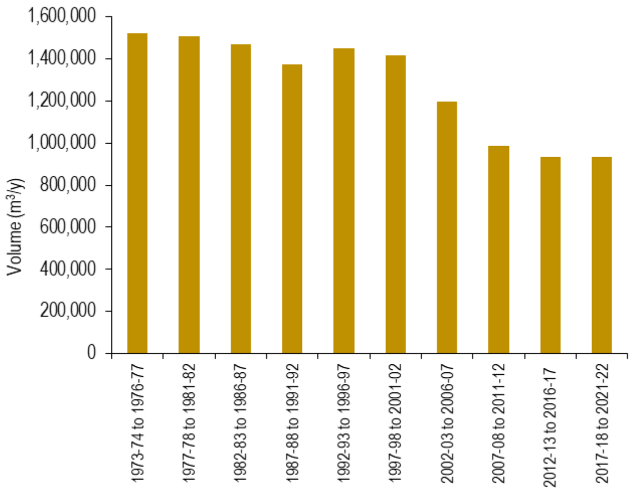

Figure 12: The historic firewood consumption for the State of Victoria based on MIG&NFISC (2024, Figure 6.1d-3b dataset). This data is in five year increments.

Reduced size solid fuels

Large sections of biomass can be processed into finer particles as a fuel and Box 56 presents the different products. Of note is that the products are defined by particle size and the process used to generate the product. Each product will have a specific use and value. The products defined in Box 56 could be produced from harvesting residues, logs or processing residues with the inputs materials defined by the quality requirements of the consuming markets.

Box 56: The definitions of other types of solid biomass biofuels.	
Term	Definition
Shredded biofuel	*'Solid biofuels which have been mechanical treated into smaller pieces by blunt tool; for example shredded straw, shredded bark or hog fuel'* (FAO, 2004, p.39).
Hog fuel	*'Fuelwood in the form of pieces of varying size and shape, produced by crushing with blunt tools such as rollers, hammers, or flails'* (FAO, 2004, p.36).
Pulverised biofuel	*'Solid biofuel in the form of dust and powder, produced by milling or grinding'* (FAO, 2004, p.39).
Fuel dust	*'Pulverised biofuel with a typical particle size of 1 to 5 mm; for example, straw dust'* (FAO, 2004, p.35)
Fuel powder or fuel flour	*'Pulverised biofuel with a typical particle size less than 1 mm; for example, wood powder, wood flour or straw powder'* (FAO, 2004, p.35).
Grinding dust	*'Dust-like wood residue formed in grinding timber and wood boards'* (FAO, 2004, p.36).

Densified wood fuels

Overview of densified products

A specific class of fuels made from biomass are densified or compressed biofuels (see Box 57). There are two forms; pellets or briquettes (Goble & Peck, 2013, p.13). They are also referred to as agglomerates (see Box 58) under the FAO statistics classification system. Densified products are created by compression of fine and loose sawmill residues to create a solid fuel that is easier to convey and transport; the products have a higher and uniform volumetric energy density than the residues from which they are made (Goble & Peck, 2013, p.13). Such products can be made from fine particulate hardwood and softwood wood residues. They can also be produced by the addition of a binder not exceeding 3% by weight (FAOSTAT, 25/02/2025). Such fuels can be used in home heating, industrial and largescale thermal power-stations with different combustion technology and product requirements (Goble & Peck, 2013, p.13).

Box 57: The FAO definition of densified fuels (FAO, 2004, p.33).	
Densified biofuel, compressed biofuel	'*Solid biofuel made by mechanically compressing biomass to increase its density and to mould the fuel into a specific size and shape such as cubes, pressed logs, biofuel pellets or biofuel briquettes.'*

Box 58: The FAO definition of agglomerates (FAOSAT, 25/02/2025).	
Agglomerates	'*Agglomerates produced either directly by compression or by the addition of a binder in a proportion not exceeding 3% by weight. Such pellets are cylindrical, with a diameter not exceeding 25 mm and a length not exceeding 100 mm. It is reported in metric tonnes'* .

Biofuel pellets

Description

Biofuel or wood pellets are a densified product (see Box 59) and can be manufactured in a range of sizes to meet application and market requirements (Goble & Peck, 2013, p.13). They are cylindrical and have a random length usually from 5 to 30 mm, and with broken ends (FAO, 2004, p.30). The total moisture content of biofuel pellets is usually less than 10%ww (FAO, 2004, p.30). From a use perspective, pellets should flow freely to allow delivery via a pneumatic system (Goble & Peck, 2013, p.13 citing www.biomassenergycentre.org.uk/portal/page?_pageid=75,18519&_dad=portal&_schem a=PORTAL).

Box 59: The FAO definitions of densified fuels.	
Biofuel pellet	*'Biofuel pellets are 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 in a die. The total moisture of biofuel pellets is usually less than 10% of mass'* (FAO, 2004, p.30).
Wood pellets	*'Agglomerates produced either directly by compression or by the addition of a binder in a proportion not exceeding 3% by weight. Such pellets are cylindrical, with a diameter not exceeding 25 mm and a length not exceeding 100 mm'* (FAO, 2022, p.145).

Quality control of the energy content of pellets is critical to many end-users; for example, too high a calorific value resulting in higher combustion temperatures can potentially damage furnaces (Goble & Peck, 2013, p.14). The quality of pellets is addressed by an Australian and New Zealand standard (AS/NZS 4014.6:2007) and there are US and European standards (Goble & Peck, 2013, p.13). Pellets for export must be sampled and tested to ensure conformance to the specific standards

(Goble & Peck, 2013, p.14). Therefore, pellet markets generally require that the product is dry (a moisture content typically < 7%wb), mechanically robust, have a set ash content and potentially may also define other contaminants (e.g. chlorine) content (Goble & Peck, 2013, p.13). Compliance with standards has implications for the input feedstock. There are two grades of wood pellets; premium and industrial. Premium grade pellets are made from clean wood with no added starch nor bark and they burn cleanly with an ash content of typically less than 0.5%ww. Such pellets are used in domestic appliances (Goble & Peck, 2013, p.13). Industrial grade pellets are made from recycled timber, bark and can include soil contaminants. They burn less efficiently with an ash content of c.3-4%ww and are normally used in larger-scale boilers (Goble & Peck, 2013, p.13).

Input feedstock

The input raw material for pellet production can be woody herbaceous, fruit biomass or biomass blends and mixtures (FAO, 2004, p.30). With woody biomass, pellet production generally uses material not suitable for pulp-grade woodchips (Goble & Peck, 2013, p.14&15); for example, sawdust (Goble & Peck, 2013, p.13). Uniform solid-wood can be used resulting in a pellet that produces little ash; however this competes with the woodchip market (Geddes 2010, p.29). In British Columbia, Canada, pellet production primarily utilises sawmill residuals, harvesting residuals and low-quality logs.[34] The form of the feedstock can vary; roundwood, woodchips, sawdust, shavings, branches and leaves (Geddes 2010, p.29). Bark contains energy, but results in a higher ash content. Sawmill residues (e.g. shavings and dry sawdust) require less drying than green biomass direct from the plantations. Softwoods have a higher lignin content and are easier to press than hardwoods (Geddes 2010, p.29).

Manufacturing and handling

Box 60 presents the steps in manufacturing biofuel pellets. The input feedstock is processed in a hammer mill into uniform size particles and then dried using a rotary drum drier to a uniform moisture content (c. < 12%) (Geddes, 2010, p.7). The particles are conditioned with super-heated steam and forced through a dye press. Lignin in the biomass is heat softened and binds the pellet as it cools. The pellets exit the press at c. 90-95 °C and are initially soft and fragile, but harden as they cool. Pellets can deteriorate if exposed to moisture (Geddes, 2010, p.7). They are handled in bulk (e.g. storage and transport) and require undercover storage at the processing facility and at the port prior to loading onto a ship.

Box 60: The steps to produce a biofuel pellet (Goble & Peck, 2013, p.14&15 citing FES, undated).	
Milling	The biomass raw material is reduced to a particle size of c.3 mm.
Conditioning	The raw materials are heated to the required temperature and moisture to activate (soften) the lignin as the pellet binding agent and to obtain the required malleability to allow shaping of the product.
Pressing	The heated raw material is fed into a pellet press and the pellets are formed by compressing the material in a dye to achieve compaction. The shape and design of the dye depends on the feedstock used.
Cooling	The pellets are cooled after leaving the press to ensures they harden to make them more robust during storage and handling.
Screening	The pellets are passed over a vibratory screen to remove any fines.
Storage	The pellets are kept dry with only a limited storage time.

[34] https://www.naturallywood.com/products/wood-pellets/ accessed on the 25/02/2025.

Wood-based biofuel briquettes

Biofuel briquettes (see Box 61) are a larger product than pellets, but can be manufactured at smaller scales with moderate costs, however they are less widely used (Goble & Peck, 2013, p.13). They are similar to wood pellets but are physically larger varying in diameter from c. 50 to 100 mm and are usually 60 to 150 mm long (Goble & Peck, 2013, p.19). Biofuel briquettes are made by compacting loose wood residues (e.g. sawdust, woodchips and bark are suitable, with sawdust as the preferred raw material) into a dense material at c.300 to 350°C and with moderate pressure (Goble & Peck, 2013, p.19 citing http://www.biofuelz.com/products/wood_briquettes.php [old page]). Biofuel briquettes are generally burnt in stoves, furnaces or solid-fuel burning equipment, which is a relatively small niche market (Goble & Peck, 2013, p.13 citing Clean Energy Council, 2010). They are a cleaner and more consistent alternative to traditional firewood, with a higher energy density and steady combustion (Goble & Peck, 2013, p.19 citing Elliot *et al.,* 1997). In emerging economies, biofuel briquettes must compete with other fuels (e.g. firewood and agricultural residues, kerosene and diesel) which are often cheaper (Enters, 2001, Chapter Availability and use of mill residues).

Box 61: The FAO definitions of biofuel and wood briquettes.	
Biofuel briquette	*'Densified biofuel made with or without pressing aids in the form of cubiform or cylindrical units, produced by compressing pulverised biomass. The raw material for briquettes can be woody biomass, herbaceous biomass, fruit biomass and biomass blends, and biomass mixtures. Biofuel briquettes are usually manufactured in a piston press. The total moisture of the biofuel briquette is usually less than 15% of mass'* (FAO, 2004, p.30).
Wood briquettes	*'Agglomerates produced either directly by compression or by the addition of a binder. Briquettes are cylindrical, with a diameter exceeding 25 mm (usually from 75 mm to 90 mm) and a length up to 300 mm'* (FAO, 2022, p.145).

Charcoal pellets and briquettes

Char then pressing into charcoal pellets

The material used to manufacture charcoal pellets can already be in a char format or prepared pellets can be carbonized. For practical application, char is usually converted into a pellet format to facilitate transport and avoid problems associated with decomposition during storage (Platt *et al.,* 2021, p.341).

Post-pressing treatment; charcoal brickettes

Charcoal briquettes are a fuel which will burn longer and more consistently than lump charcoal, but at a lesser temperature. Some products contain ingredients to improve the aesthetics on combustion which can result in increased ash (Goble & Peck, 2013, p.21). There are two options. Charcoal briquettes can be made by converting biomass into char. The char is screened to a uniform size before the resulting material is mixed with any other inputs (e.g. starch binder), placed into a mould of the required briquette shape, dried and packaged (Goble & Peck, 2013, p.21). Alternatively, prepared biofuel briquettes can be carbonized via pyrolysis at 315 to 980°C to create charcoal of very high quality (Goble & Peck, 2013, p.19 citing http://www.biofuelz.com/products/wood_briquettes.php [old page]).

Part D: Wood constituents, chemicals and non-solid wood energy

Wood pulp

Overview

Production of wood pulp can be regarded as a biorefinery process. Wood pulp is a group of products derived and recovered by breaking down a range of types of solid wood via a range of mechanisms (see Box 62). It is an aggregate of products comprising mechanical wood pulp, semi-chemical wood pulp, chemical wood pulp, and dissolving wood pulp. The process is used to recover either all or some of the constituents for subsequent use. It can be made from wood, recovered products (e.g. recycling of paper) or non-wood plant materials. A generic schematic of pulp production is presented in Figure 13. Pulp derived from wood is referred to as virgin pulp.

Box 62: The definition of wood pulp as a group of products (FAO, 2022, p.151).	
Wood pulp	*'Fibrous material prepared from pulpwood, woodchips, particles or residues by mechanical and/or chemical process for further manufacture into paper, paperboard, fibreboard or other cellulose products.'*

Mechanical wood pulp

Mechanical wood pulp results from primarily mechanical treatment of solid wood to recover the wood fibres (see Box 63). It is also called groundwood pulp or refiner pulp. This pulp includes all the chemical components of the source wood; the cellulose fibres, the lignin and any extractives not washed away during the process. The categories are defined based on process and whether the resulting fibre is bleached or unbleached. Mechanical wood pulp includes chemi-mechanical and thermo-mechanical pulp but excludes exploded and defibrillated pulps.

Semi-chemical wood pulp

A semi-chemical wood pulp is produced by a combination of mechanical and chemical processes and can be un-bleached or bleached (see Box 64). It includes chemi-groundwood pulp and chemi-mechanical wood pulp; the products are named in the order and importance of the treatment during the manufacturing process. This pulp includes all the chemical components of the source wood; the cellulose fibres, the lignin and any extractives not washed away during the process.

Box 63: A definition of mechanical wood pulp as a group of products and the individual products (FAO, 2022, p.151).	
Mechanical wood pulp	*'Wood pulp obtained by grinding or milling pulpwood or residues into fibres, or through refining woodchips or particles. It may be bleached or unbleached. It includes stone groundwood, pressurised stone groundwood, refiner mechanical pulp and thermo-mechanical pulp. It excludes exploded and defibrillated pulp.'*
Stone groundwood	*'It is produced from roundwood or blocks in stone grinders at atmospheric pressure.'*
Stone groundwood unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Stone groundwood bleached	*'Pulp treated with chemicals to increase its brightness.'*
Pressurised stone groundwood	*'It is produced from roundwood or blocks in pressurised stone grinders.'*
Pressurised stone groundwood unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Pressurised stone groundwood bleached	*'Pulp treated with chemicals to increase its brightness.'*
Refiner mechanical pulp	*'It is produced from woodchips or wafers in refiners discharging at atmospheric pressure.'*
Refiner mechanical pulp unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Refiner mechanical pulp bleached	*'Pulp treated with chemicals to increase its brightness.'*
Thermo-mechanical pulp	*'It is produced from woodchips or wafers in refiners discharging after high-pressure steaming of the wood.'*
Thermo-mechanical pulp unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Thermo-mechanical pulp bleached	*'Pulp treated with chemicals to increase its brightness.'*

Box 64: A definition of semi-chemical pulp as a group of products and the individual products (FAO, 2022, p.151&152).	
Semi-chemical wood pulp	*'Wood pulp obtained by subjecting pulpwood, woodchips, particles or residues to a series of mechanical and chemical treatments, none of which alone is sufficient to make the fibres separate readily. It may be bleached or unbleached.'*
Semi-chemical pulp	*'Semi-chemical pulp is produced in a two-part process in which the wood, is first chemically softened in digesters and then mechanically refined. It is used mainly for medium-quality papers.'*
Semi-chemical pulp unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Semi-chemical pulp bleached	*'Pulp treated with chemicals to increase its brightness.'*
Chemi-mechanical pulp	*'Chemi-mechanical pulp is produced in refiners from wood in chips, shavings, sawdust, etc. The wood is reduced to a fibrous state by the abrasive action. Small amounts of chemicals are introduced as a pre-treatment or during refining in order to facilitate fibre separation.'*
Chemi-mechanical pulp unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Chemi-mechanical pulp bleached	*'Pulp treated with chemicals to increase its brightness.'*

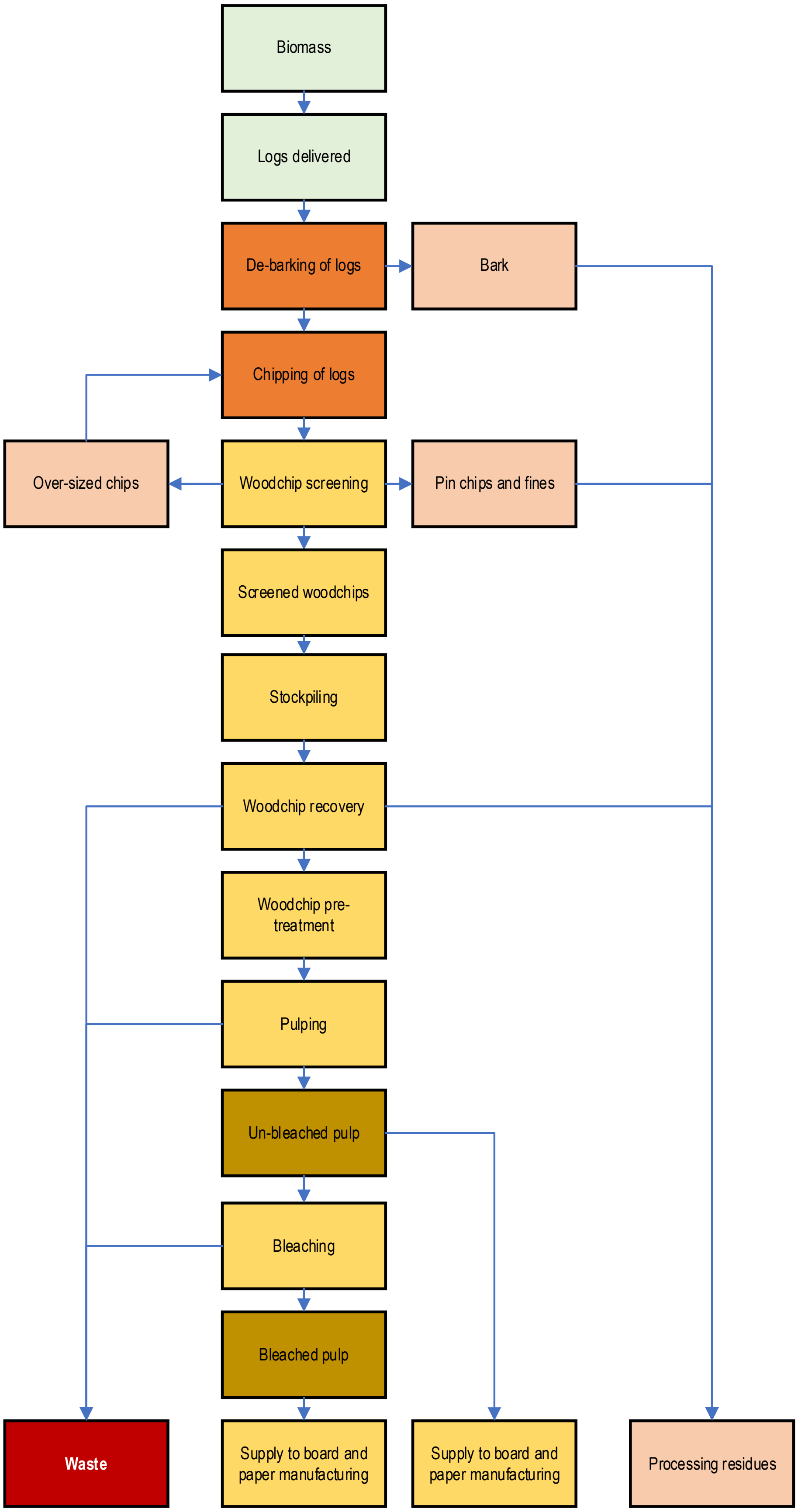

Figure 13: A generic schematic of wood pulp production.

Chemical wood pulp

The wood pulp products

A chemical wood pulp is a product resulting from chemical-based processing of wood that has been mechanical broken into units of solid wood fibre (e.g. woodchips) (see Box 65). The particles are 'cooked' in a pressure vessel in the presence of a cooking liquor (i.e. chemicals). The objective of chemical pulping is to only recover the wood fibres by dissolving and removing the lignin and other non-fibre elements (e.g. any extractives). The product types are defined based on the chemical process used and whether the pulp is un-bleached or bleached. Chemical wood pulps exclude dissolving grades of wood pulp.

Box 65: The definition of chemical pulp as a group of products and the individual products (FAO, 2022, p.152).	
Chemical wood pulp	*'Wood pulp obtained by subjecting pulpwood, woodchips, particles or residues to a series of chemical treatments. It may be bleached, semi-bleached or unbleached. It excludes dissolving grades of wood pulp.'*
Soda or sulphate chemical wood pulp	*'Wood pulp obtained by mechanically reducing pulpwood, woodchips, particles or residues to small pieces that are subsequently cooked in a pressure vessel in the presence of sodium hydroxide cooking liquor (soda pulp) or a mixture of sodium hydroxide and sodium sulphite cooking liquor (sulphate pulp). It is used in the manufacture of absorbent products as well as for papers and paperboards requiring high tearing resistance and tensile and bursting strength.'*
Soda or sulphate chemical wood pulp unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Soda or sulphate chemical wood pulp bleached or semi-bleached	*'Pulp treated with chemicals to increase its brightness.'*
Sulphite chemical wood pulp	*'Wood pulp obtained by mechanically reducing pulpwood, woodchips, particles or residues to small pieces that are subsequently cooked in a pressure vessel in the presence of a bisulphite cooking liquor. Bisulphites such as ammonium, calcium, magnesium and sodium are commonly used in this process. The process is used extensively for the treatment of spruce fibre. It is used alone or mixed with other pulps, for various writing or printing papers, etc.'*
Sulphite chemical wood pulp unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Sulphite chemical wood pulp bleached or semi-bleached	*'Pulp treated with chemicals to increase its brightness.'*

Black liquor; by-product of chemical pulping

The recovery of fibres during pulping separates the wood fibres by dissolving the lignin. Black liquor is the specific by-product from sulphate or soda pulp production (see Box 66) and is the residual chemical soup after the fibre has been recovered.

Box 66: The definition of black liquor (FAO, 2004, p.31).	
Black liquor	*'Alkaline spent liquor obtained from digesters in the production of sulphate or soda pulp during the process of paper production, in which the energy content is mainly originating from the content of lignin removed from the wood in the pulping process.'*

Dissolving wood pulp

A dissolving wood pulp is a specific quality of bleached pulp manufactured for specific end uses (see Box 67). It is used principally as a source of cellulose in the manufacture of products such as synthetic fibres, cellulose plastic materials, lacquers and explosives.

Box 67: A definition of dissolving wood pulp as a group of products (FAO, 2022, p.152) and a specific by-product from viscose production (FAO, 2004, p.41).	
Dissolving wood pulp	*'Chemical pulp (sulphate, soda or sulphite) made from wood of special quality, with a very high alpha-cellulose content (usually 90% and over). This type of pulp is always bleached and is specially refined or purified to meet requirements of its intended use. It is used for making regenerated cellulose, cellulose ethers and esters and products of these materials, such as plates, sheets, film, foil and strip, textile fibres and certain papers (filter paper, vegetable parchment, …)'*
Sulphate dissolving wood pulp	*'Dissolving grade wood pulp obtained by use of the sulphate and soda process.'* See the description in Box 62.
Sulphite dissolving wood pulp	*'Dissolving grade wood pulp obtained by use of the sulphite process.'* See the description in Box 62.
Viscose by-products, viscose residues	*'By-products from viscose production and processing in which cellulose of wood pulp is treated with high concentrations of sodium hydroxide and carbon disulfide and then dissolved in sodium hydroxide forming a thick solution called viscose.'*

Other non-wood pulp products

There are a range of the other pulp products which are not derived from wood, as presented in Box 68. This group of pulps comprises fibres other than wood and recovered fibre pulp (FAOSTAT, accessed 25/02/2025). Used paper and non-plastic packaging materials can be aggregated as an input resource. The recovered paper and other materials described as recovered paper, can be processed back into pulp for re-use and this is referred to as recovered pulp fibre (see Box 68).

Box 68: A definition of other pulp as a group of products and the individual products (FAO, 2022, p.153).	
Other pulp	*'Includes pulp, except dissolving grades, obtained by any method from fibrous lignocellulosic materials, except wood. It may be unbleached or bleached.'*
Pulp from fibres other than wood	*'Pulp manufactured from fibrous vegetable materials other than wood and used for the manufacture of paper, paperboard, fibreboard and other uses. It excludes pulp made from recovered paper. It includes pulps made from: straw; bamboo; bagasse; esparto; other reeds or grasses; cotton fibres; flax; hemp; rags; and other textile wastes.'*
Recovered fibre pulp	*'Pulp manufactured from recovered paper or paperboard and used for the manufacture of paper, paperboard and fibreboard. It excludes pulp made from straw; bamboo; bagasse; esparto; other reeds or grasses; cotton fibres; flax; hemp; rags; and other textile wastes. It may be unbleached or bleached.'*
Pulps of fibres derived from recovered (waste and scrap) paper or paperboard	*'Pulps of fibres derived from recovered (waste and scrap) paper or paperboard used for the manufacture of paper, paperboard and fibreboard.'*
Pulps of fibres derived from recovered (waste and scrap) paper or paperboard unbleached	*'Pulp not treated with chemicals to increase its brightness.'*
Pulps of fibres derived from recovered (waste and scrap) paper or paperboard bleached	*'Pulp treated with chemicals to increase its brightness.'*

Paper

Overview

Pulp regardless of source or type, can be converted into a range of paper and paperboard products (see Box 69).

Box 69: A definition of paper and paperboard as a group of products (FAO, 2022, p.153).	
Paper and paperboard	*'The paper and paperboard category is an aggregate category. In the production and trade statistics, it represents the sum of graphic papers; sanitary and household papers; packaging materials and other paper and paperboard. It excludes manufactured paper products such as boxes, cartons, books and magazines, etc.'*

Printing, writing papers and graphic papers

Printing and writing papers are a range of papers used for a range of print and graphical purposes (see Box 40). Graphic papers are a range of papers used for a range of print and graphical purposes (see Box 71). This range of products can include wood-free pulp.

Box 70: A definition of printing and writing papers as a group of products and the individual products (FAOSTAT, accessed 25/02/2025).	
Printing and writing papers; uncoated, mechanical	*'Paper suitable for printing or other graphic purposes where less than 90% of the fibre furnish consists of chemical pulp fibres. This grade is also known as groundwood or wood-containing paper and magazine paper, such as heavily filled supercalendered paper for consumer magazines printed by the rotogravure and offset methods. It excludes wallpaper base..'*
Printing and writing papers, uncoated, wood free	*'Paper suitable for printing or other graphic purposes, where at least 90% of the fibre furnish consists of chemical pulp fibres. Uncoated woodfree paper can be made from a variety or furnishes, with variable levels of mineral filler and a range of finishing processes such as sizing, calendering, machine glazing and watermarking. This grade includes most office papers, such as business forms, copier, computer, stationery and book papers. Pigmented and size press "coated" papers (coating less than 5 g per side) are covered by this heading. It excludes wallpaper base.'*
Printing and writing papers, coated	*'All paper suitable for printing or other graphic purposes and coated on one or both sides with carbon or minerals such as China clay (kaolin), calcium carbonate, etc. Coating may be by a variety of methods, both on-machine and off-machine, and may be supplemented by supercalendering. It includes raw carbon and self-copy paper in rolls or sheets. It excludes other copying and transfer papers.'*

Box 71: A definition of graphic papers as a group of products and the individual products (FAO, 2022, p.153).	
Graphic papers	*'The graphic papers category is an aggregate category. It represents the sum of newsprint; uncoated mechanical; uncoated woodfree and coated papers. Products in this category are generally manufactured in strips or rolls of a width exceeding 15 cm or in rectangular sheets with one side exceeding 36 cm and the other exceeding 15 cm in the unfolded state. It excludes manufactured paper products such as books and magazines, etc.'*
Newsprint	*'Uncoated paper mainly used for printing newspapers. It is made largely from mechanical pulp and/ or recovered paper, with or without a small amount of filler. Products in this category are generally manufactured in strips or rolls of a width exceeding 36 cm. Weights usually range from 40 to 52 g/m^2 but can be as high as 65 g/m^2. Newsprint is machine finished or slightly calendered, white or slightly coloured and is used in reels for letterpress, offset or flexo printing.'*
Uncoated graphic papers	*'Paper and paperboard, except newsprint, that may have been subjected to sizing, calendering, super-calendering, glazing, water marking or similar simple finishing processes, but not to coating.'*
Uncoated graphic papers mechanical	*'Paper and paperboard containing 10% or more fibres obtained by mechanical or thermo- mechanical process.'*
Uncoated graphic papers wood free	*'Paper and paperboard not containing 10% or more fibres obtained by mechanical or thermo-mechanical process.'*
Hand-made paper and paperboard	*'Hand-made paper and paperboard can be made from any paper-making material but mainly are used best grade linen or cotton rags. The term "hand-made" means that moulding the pulp fibres into sheet form is performed by hand.'*
Wood free uncoated graphic papers used as a base for photo-sensitive, heat-sensitive or electro-sensitive paper or paperboard	*'Paper and paperboard used as a base for photo-sensitive, heat-sensitive or electro-sensitive paper or paperboard.'*
Other wood free uncoated graphic papers	*'Other wood free paper and paperboard.'*
Coated graphic papers	*Paper and paperboard which has been coated on one or both sides by a compound or polymer to impart certain qualities to the paper, including weight, surface gloss, smoothness or reduced ink absorbency.*
Coated graphic papers, mechanical	*'Coated paper and paperboard containing 10% or more fibres obtained by mechanical or thermo-mechanical process.'*
Light-weight coated paper	*'Light-weight coated paper is a coated paper with a high mechanical pulp content. They are used for high quality magazines and advertising materials with demanding colour-printing requirements.'*
Other mechanical coated graphic papers	*'Other mechanical coated papers.'*
Coated graphic papers, wood free	*'Coated paper and paperboard not containing 10% or more fibres obtained by mechanical or thermo-mechanical process.'*
Carbon paper, self-copy paper and other copying or transfer papers	*'Papers coated on one side with a layer of a loosely bound dry ink or pigmented coating, bound with wax, used for making one or more copies simultaneously with the creation of an original document by applying pressure (using a typewriter or a ballpoint pen). These products must be in strips or rolls of a width exceeding 36 cm.'*
Other wood free coated graphic papers	*'Other wood free coated graphic papers.'*

Sanitary and household papers

The range of paper products use for sanitary and household purposes are presented in Box 72.

Box 72: A definition of sanitary and household papers as a group of products and the individual products (FAO, 2022, p.154&155).	
Sanitary and household papers	*'This covers the stock of a wide range of tissue and other hygienic papers for use in households or commercial and industrial premises. Products in this category are generally manufactured in strips or rolls of a width exceeding 36 cm. Examples are toilet paper and facial tissues, kitchen towels, hand towels and industrial wipes. Some tissue is also used in the manufacture of baby napkins, sanitary towels, etc. The parent reel stock is made from virgin pulp or recovered fibre or mixtures of these.'*
Toilet or facial tissue stock, towel or napkin stock and similar paper	*'Toilet or facial tissue stock, towel or napkin stock and similar paper of a kind used for household or sanitary purposes.'*
Cellulose wadding and webs of cellulose fibres	*'Cellulose wadding consists of creped web of cellulose fibres of open formation. Webs of cellulose fibres (tissues) consist of cellulose fibres of closed formation.'*
Other sanitary and household papers	*'Other sanitary and household papers.'*

Recovered paper

It is possible to make use of recovered paper and paperboard as a raw material from which to recover fibres and other materials (see Box 73). This is a recycling process.

Box 73: A definition of recovered paper as a group of products and the individual products (FAO, 2022, p.153).	
Recovered paper	*'Waste and scraps of paper or paperboard that have been collected for re-use or trade. It includes paper and paperboard that has been used for its original purpose and residues from paper and paperboard production.'*
	'Unbleached kraft paper or paperboard or corrugated paper or paperboard.'
	'Other paper or paperboard made mainly of bleached chemical pulp, not coloured in the mass.'
	'Paper or paperboard made mainly of mechanical pulp (newspapers, journals and similar).'
	'Other, including unsorted waste and scrap.'

Packaging materials

Overview

Products used mainly for wrapping or packaging purposes are referred to as packaging materials and Box 74 presents a definition.

Box 74: A definition of packaging materials as a group of products (FAO, 2022, p.155).	
Packaging materials	*'Paper or paperboard mainly used for wrapping and packaging purposes. Products in this category are generally manufactured in strips or rolls of a width exceeding 36 cm. It excludes unbleached kraft paper and paperboard that are not sack kraft paper or Kraftliner and weighing more than 150 g/m² but less than 225 g/m²; felt paper and paperboard; tracing papers; not further processed uncoated paper weighing 225 g/m² or more.'*

Case materials

Case materials are the components used in the manufacturing of corrugated board products (see Box 75).

Box 75: A definition of case materials as a group of products and the individual products (FAO, 2022, p.155).	
Case materials	*'Papers and boards mainly used in the manufacture of corrugated board. They are made from any combination of virgin and recovered fibres and can be bleached, unbleached or mottled. It includes kraftliner, testliner, semi-chemical fluting, and waste-based fluting (Wellenstoff).'*
Kraftliner	*'Paper or paperboard in rolls whose fibre content has no less than 80% fibers obtained by the chemical sulfate or soda processes and weighing more than 115 g/m².'*
Kraftliner unbleached	*'Kraftliner made wholly or principally of unbleached sulphate pulp.'*
Kraftliner bleached	*'Kraftliner made wholly or principally of bleached sulphate pulp.'*
Fluting paper	*'Paper or paperboard used mainly as a corrugating medium in the production of corrugated board. It may be produced wholly or principally from semi-chemical wood pulp or from other materials.'*
Semi-chemical fluting paper	*'Fluting paper made wholly or principally of semi-chemical woodpulp.'*
Straw fluting paper	*'Paper, in rolls, made mainly of straw pulp obtained by semi-chemical pulping processes and weighing 130 g/m² or more.'*
Other fluting papers	*'Fluting paper made wholly or principally from other than semi-chemical woodpulp.'*
Testliner (recycled liner board)	*'Testliner, like kraftliner, is used for the outer and intermediate plies of corrugated board. However, its strength is not quite as high as that of kraftliner, as it has a higher recycled fibre content.'*
Other case materials	Other case materials not mention in other subgroups.

Cartonboard

Cartonboard is the robust material used in the manufacture of cartons for the transport of consumer products (see Box 76).

Box 76: A definition of cartonboard as a group of products and the individual products (FAO, 2022, p.155&156).	
Cartonboard	*'Sometimes referred to as folding boxboard, it may be single- or multi-ply, coated or uncoated. It is made from virgin and/or recovered fibres, and has good folding properties, stiffness and scoring ability. It is mainly used in cartons for consumer products such as frozen food and for liquid containers. It includes paper and paperboard covered or coated with plastics (excluding adhesives) and coated multi-ply.'*
Kraftpaper paper and paperboard not used for writing weighing more than 150 g/m²	*'Kraftpaper paper or paperboard (cardboard) are produced from chemical pulp produced in the kraft process, which means that not less than 80% by weight of the total fibre content consists of fibres obtained by the chemical sulphate or soda processes.'*
Other uncoated paper and paperboard weighing more than 150 g/m² but less than 225 g/m²	*'Other uncoated paper and paperboard weighing more than 150 g/m² but less than 225 g/m² in rolls or sheets, not further worked or processed. '*
Paper and paperboard coated, impregnated or covered with plastics (excluding adhesives) weighing more than 150 g/m²	*'Paper and paperboard coated, impregnated or covered with plastics (excluding adhesives) weighing more than 150 g/m², if the layer of plastics does not constitute more than half the total thickness.''*
Other kraft paper and paperboard weighing 225 g/m² or more	*'Other kraft paper and paperboard weighing 225 g/m² or more, in rolls or sheets, can bleached or unbleached.'*
Other cartonboard	Other cartonboard not mentioned in the other subgroups.

Wrapping papers

Wrapping papers are used to wrap products or as a packaging material for products. This material can be manufactured from a range of materials (see Box 77).

Box 77: A definition of wrapping papers as a group of products and the individual products (FAO, 2022, p.156&157).	
Wrapping papers	*'Wrappings papers (up to 150 g/m^2) whose main use is wrapping or packaging made from any combination of virgin or recovered fibres, bleached or unbleached. They may be subject to various finishing and/or marking processes. It includes sack kraft, other wrapping krafts, sulphite and greaseproof papers as well as coated paper and paperboard not uniformly bleached throughout the mass, except multi-ply. It excludes: tracing papers.'*
Sack kraft paper	*'Sack kraft paper is a porous kraft paper with high elasticity and high tear resistance, designed for packaging products with high demands for strength and durability. It contains more than 80% by weight fibres obtained by chemical sulphate or soda processes.'*
Sack kraft paper unbleached	*'Sack kraft paper made wholly or principally of unbleached sulphate pulp.'*
Sack kraft paper bleached	*'Sack kraft paper made wholly or principally of bleached sulphate pulp.'*
Kraft paper and paperboard weighing 150 g/m² or less	*'Kraftpaper paper and paperboard means paper and paperboard of which not less than 80% by weight of the total fibre content consists of fibres obtained by the chemical sulphate or soda processes.'*
Kraft paper and paperboard weighing 150 g/m² or less unbleached	*'Kraftpaper paper and paperboard made wholly or principally of unbleached sulphate pulp.'*
Kraft paper and paperboard weighing 150 g/m² or less bleached	*'Kraftpaper paper and paperboard made wholly or principally of bleached sulphate pulp.'*
Sulphite wrapping paper	*'Sulphite wrapping paper means machine-glazed paper. It contains more than 40% by weight fibres obtained by chemical sulphite process.'*
Vegetable parchment	*'Vegetable parchment is made by passing sheets of paper made of pulp fibres into sulfuric acid. The sulfuric acid hydrolyses and solubilizes the main natural organic polymer, cellulose, present in the pulp wood fibres. The paper web is then washed in water, which stops the hydrolysis of the cellulose and causes a kind of cellulose coating to form on the paper. The final paper is dried and it is then resistant to grease and semi-translucent.'*
Greaseproof papers	*'Greaseproof papers are translucent papers that are impermeable to oil or grease and are normally used in cooking or food packaging. Normally greaseproof paper are produced by refining the paper stock and thus create a sheet with very low porosity.'*
Glassine and other glazed transparent or translucent papers	*'Glassine and other glazed transparent paper is made in the same manner as greaseproof paper but in the final stage they are supercalendered to further improve the density. They are mainly uncoloured and generally less impermeable than vegetable parchment and greaseproof papers.'*
Corrugated paper and paperboard	*'Corrugated paper and paperboard results from processing material through grooved rollers with the application of heat and steam. Flat surface sheet can be applied on one or both sides.'*
Kraft paper, creped or crinkled	*'Creped and crinkled papers are made by mechanical treatment of the webs of paper in the moist state or by passing the made paper between rollers with wrinkled surfaces. The product has a wrinkled appearance and the property of high elasticity.'*
Other wrapping papers	*'Other wrapping papers not mentioned in the subgroups'.*

Other papers mainly used in packaging

The other papers mainly for the packaging group of products includes packaging materials not specifically considered by the groups of products already addressed (see Box 78).

Box 78: A definition of other papers mainly for packaging as a group of products and the individual products (FAO, 2022, p.153).	
Other papers mainly for packaging	*'This category embraces all papers and boards mainly for packaging purposes other than those listed above. Most are produced from recovered fibres, e.g. greyboards, and go for conversion, which in some cases may be for end-uses other than packaging.'*
Other uncoated paper and paperboard weighing 225 g/m² or more	*'Other uncoated paper and paperboards weighing 225 g/m² or more, in rolls or sheets, and not further worked or processed.'*
Other papers mainly for packaging	*'Other papers mainly for packaging.'*

Other paper and paperboard

The group of paper and paperboard products used in very specific situations is defined as part of the other paper and paperboard category as presented in Box 79.

Box 79: A definition of other paper and paperboard as a group of products and the individual products (FAO, 2022, p.157&158).	
Other paper and paperboard	*'Other papers and paperboards for industrial and special purposes. It includes cigarette papers and stock of filter papers, as well as gypsum liners and special papers for insulating, roofing, and other specific applications or treatments; wallpaper base; unbleached kraft paper and paperboard that are not sack kraft paper or Kraftliner and weighing more than 150 g/m² but less than 225 g/m²; felt paper and paperboard; tracing papers; not further processed uncoated paper weighing 225 g/m² or more; and raw copying and transfer papers, in rolls or sheets except carbon or self-copy paper. It excludes all composite, not coated, paper and paper board of flat layers stuck together; coated paper and paperboard not uniformly bleached throughout the mass; and paper and paperboard covered or coated with plastics (excluding adhesives).'*
Wallpaper base	*'Uncoated paper of a kind used for further converting into acrylic or vinyl wallpapers.'*
Filter paper and paperboard	*'Filter paper and paperboard are porous products, devoid of wood fibres obtained by mechanical or semi-chemical process. They are designed to remove solid particles from liquids or gases. They are produced from rag or chemical pulp or a mixture of. It includes filter paper and paperboard not further worked or processed.'*
Felt paper and paperboard	*'Felt paper and paperboard are products made from a fibrous mass of varying degrees of absorbency. Waste and scrap of paper or paperboard and wood pulp or textile waste in the form of fibres are used in their manufacture. They are mainly used in the manufacture of paperboard for roofing.'*
Tracing papers	*'A form of tracing paper is similar to greaseproof paper. Tracing paper is usually made from sulphite pulp by reducing the fibres to a state of fine subdivision and hydrolysing them by very prolonged beating in water. Tracing paper is named as such for its ability for an image to be traced onto it.'*
Filter blocks, slabs and plates, of paper pulp	*'Filter blocks, slabs and plates, of paper pulp are manufactured by using vegetable fibres (cotton, flax, wood, etc.) with a high cellulose content, which are compressed together in the form of blocks, slabs or plates without the aid of any binding material. Filter blocks are used in filters for clarifying liquids (e.g. wine, spirits, beer, vinegar, etc.)'*
Cigarette paper	*'This item covers all cigarette paper regardless of its size or presentation. This paper is of good quality (frequently of hemp or linen rag pulp), but very thin and relatively strong.'*
Other paper and paperboard	Other paper and paperboards not mentioned in the other divisions.

Example of specific novel products

Metsä Group; Muoto products as wood-based alternatives to plastic packaging

A fibre-based packaging product trial has been undertaken by the Metsä Group; the product line is referred to as Muoto packaging. These products can be used as a plastic replacement for takeaway containers, berry trays, trays in general, and combination packaging (Timberbiz, 2024b). The product is made of wet wood-fibre pulp shaped by pressing into their final form using three dimension (3D) printing technology that enables production of rounded, complex shapes as made by the plastics industry (CEPI, 2023).

Fibres for fabric; viscose rayon

Dissolving pulp can be used to manufacture viscose fibres which are then made into viscose rayon. Specific product names include sabra silk or cactus silk. These products have the same molecular structure as cellulose.[35] The product is used for textile and personal hygiene product manufacturing (APR, 2025, p.2). A specific product is rayon-based carbon fibres (see Box 80).

Box 80: The recommended terminology for carbon as a solid; Rayon-based carbon fibres (Fitzer *et al.*, 1995, p.503).	
Rayon-based carbon fibres	*'Rayon-based carbon fibres are carbon fibres made from rayon (cellulose) precursor fibres. Rayon-based carbon fibres have a more isotropic structure than similarly heat treated polyacrylonitrile (PAN)- or mesophase pitch (MPP)-based carbon fibres. Their Youngs's modulus values are therefore drastically lower (E^a .< 100 GPa, σ^b > 100 MPa). Rayon-based carbon fibres can be transformed into anisotropic CARBON FIRBRES with high strength and Young's modulus values by hot-stretching treatment at temperatures of approximately 2,800 K.'*

[35] https://en.wikipedia.org/wiki/Rayon accessed on the 25/02/2025.

Chemical extraction and biorefineries; an overview and classification

A definition of biorefineries

'The objective of a wood-based biorefinery is to upgrade biomass to valuable products such as pulp, biofuels, and chemicals' (Wilke *et al.,* 2021, p.ii). The underlying concept of a biorefinery is the conversion of biomass into product streams via an integration of different technologies and processes (Parratt & Associates, 2013, p.5). Examples of bio-based chemicals include non-food starch, cellulose fibres and cellulose derivatives, tall oils, fatty acids and fermentation products such as ethanol and citric acid (de Jong, *et al.*, 2012, p.3). Bio-based products are used in construction and insulation, packaging, automotive and consumer goods (see Raschka & Carus, 2012, p.14, figure 3).

The World Economic Forum (2010, p.8) segments *'bio-based products'* into three product categories: biofuels (e.g. biodiesel and bioethanol), bio-energy (heat and power) and bio-based chemicals and materials (e.g. succinic acid and polylactic acid). These products are produced in biorefineries. The International Energy Agency (IEA) Bioenergy Task 42 applies the following definition; a *'biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)'* (de Jong *et al.*, 2012, p.4). Historically, the initial stage of biorefinering focused on energy production and extended to bioproduct production, including chemicals (Yogalaskmi *et al.,* 2023, p.18).

Historic biorefineries; wood distillation

A significant contribution

Biomass is the oldest source of energy with fuelwood as the main source of bioenergy but now liquid biofuel production is experiencing rapid growth (Eisentraut, 2010, p.17). However, the use of biorefineries is not a new technology. Historic extraction of chemicals from wood can be regarded as 'intangible cultural heritage'. For example, Tintner *et al.* (2021, Abstract) describes pitch oil production by heating of resinous Scots pine (*Pinus sylvestris* L.) wood in small kilns (also fuelled by wood) to produce liquid for collection in Central Europe (e.g. the Czech Republic, Northern Austria and South Eastern Germany, Finland and Southern France). Syngas from coal gasification has been influential in the development of human society since its first commercial use by the London Gas, Light and Coke Company in 1812 (Ephraim 2016, p.1 citing Knoef, 2012). In another example in 1860, Nikolaus August Otto invented the Otto engine using ethanol as an automotive fuel; during the early 20th century, Rudolf Diesel invented the diesel engine to run on peanut oil and Henry Ford designed his Model T car to run on hemp-derived ethanol (The World Economic Forum, 2010, p.15).

A historic product

Eucalypt oil and the qualities of that oil have been recognised since the early years of Australia's European settlement, and subsequently an industry developed from the mid-nineteenth century reaching maturity by the turn of the 1900s (Pearson, 1993, p.99). In 1789, a First Fleet assistant surgeon (Denis Considen), is credited as 'the first to send a sample (14 gallons)' of eucalyptus oil to Britain for testing. Considen, together with Surgeon-General John White, took a strong interest in testing the commercial potential of the flora of the new colony. The oil was claimed to be better for 'collicky complaints' than the English peppermint, and the source tree was therefore named 'Sydney peppermint' (*E. piperita*) (Pearson, 1993, p.99 citing Penfold & Willis 1961; citing Boland *et al.,* 1991). No industry stemmed from this early discovery. This was despite development of a still in Hobart by Robert Officer in the 1830s, and a report by the Colonial Botanist Mr Fazer in the Sydney Gazette in 1839 stated that he had extracted oil from *E. globifera* and had *'treated rheumatism with it'* (Pearson, 1993, p.100

citing Shiel, 1985; citing Jervis 1949). The eucalypt oil industry commenced due to Baron Ferdinand von Mueller (the Victorian government botanist) with Joseph Bosisto (a Melbourne pharmacist). Von Mueller experimented with eucalypt oils, and Bosisto established a distillery on Dandenong Creek in 1854, to extract *E. radiata* oil (Pearson, 1993, p.100 citing Boland *et al.*, 1991; citing Penfold & Willis 1961). Bosisto exhibited his eucalypt oil product at seventeen exhibitions between 1854 and 1891 and disseminated information about the potential of the industry (Pearson, 1993, p.100).

The products

Eucalypts contain many chemical compounds with specific roles; defence against insect and vertebrate herbivores, protection against ultra violet (UV) radiation and against cold stress (Foley & Lassak, 2004, p.1). Differing with species, eucalypt volatile oils (referred to as 'essential oils') can occur in many parts of the plant, with the leaves as the dominant source. These oils are produced and stored in small glands in the leaves of different species at 0.1 up to 7.0%ww of the fresh weight (Pearson, 1993, p.99 citing Boland *et al.,* 1991). Terpenoids are the best-known compounds forming most of the essential oil and generating the characteristic smell of eucalypt foliage (Foley & Lassak, 2004, p.1). These essential oils are readily volatilised, and this produces the blue haze of the Australian forests in summer and allows heat based distillation (Pearson, 1993, p.99). There are three broad categories of uses for eucalypt oil: medicinal, industrial and perfumery/flavouring (Pearson, 1993, p.99). Eucalypts are also a rich source of phenolic constituents (e.g. tannins and simpler phenolics) and some have been the basis of past industries; for example, tannins were extracted from *E. astringens* and rutin from *E. macrorhyncha* (Foley & Lassak, 2004, p.1 citing Lassak & McCarthy, 1992).

A pulpmill as a biorefinery

For clarity, pulping of wood for paper product has been treated as separate to the discussion on biorefineries. It is possible for a conventional kraft pulp mill to be transformed into an integrated biorefinery by addition of a number of new processes (Wilke *et al.*, 2021, p.ii) as presented in Box 83. However, using pulping byproducts other than as fuels will affect a site’s energy balance with reduced organic materials incinerated in the recovery boiler impacting the recovery of chemicals (Wilke *et al.*, 2021, p.ii). Black liquor gasification is not currently implemented in pulp mills despite its positive effects (e.g. high production of electric power or production of biofuels). The analysis conducted by Wilke *et al.* (2021, p.ii) concluded that the proposed best available technology for a kraft pulp mill of 2040 would include a conventional recovery boiler combined with new processes reducing the load to the recovery boiler potentially leading to an increased production rate. An on-site production of sulfuric acid by an internal recycling of sulphur would reduce the impact on the sodium/sulphur balance and the need for sodium make-up.

Box 81: The potential additional processes that could be attached to a kraft pulpmill (Wilke, *et al.,* 2021, p.ii).
‘Black liquor gasification to produce electric power and heat to the pulp mill, and/or biofuel for the transport sector.’
‘Lignin extraction with the LignoBoost process to produce biofuel or other chemicals and products based on lignin.’
‘On-site production of sulfuric acid from non-condensable gases.’
‘CleanFlow membrane filter, resulting in cleaner green liquor.’
‘Tall oil diesel production from fatty acids.’
‘Extraction of hemicellulose from woodchips to produce ethanol.’

Classification of biorefineries

Classification of biorefineries based on complexity

Calvo-Flores and Martin-Martinez (2022) provide a framework to assist in understanding biorefineries (see Box 82). The complexity of a biorefinery can be defined based on the number of input feedstocks and the number of out-put products. Biorefineries can be phase I to III with a phase III biorefinery processing multiple feedstocks to generate multiple products.

Box 82: The types of biorefineries based on the number of feedstocks processed and the number of products produced (Calvo-Flores & Martin-Martinez, 2022, p.3).

Type of biorefinery	Sub-type	Type of feedstock	Final product	Comments
Phase I		Single feedstock	Primary products	
Phase II		Single feedstock	Several products	
Phase III		Multiple feedstocks	Multiple products	
	Whole-crop biorefinery			Raw crops such as wheat or corn are used as a unique feedstock material to produce value-added products such as chemical building blocks, pharmaceutical products, textiles, plastics, lubricants, and biofuels
	Green biorefinery			Natural-wet biomass such as cereals or grass are processed and transformed into marketable chemicals and fuels.
	Lignocellulosic biorefinery			Lignocellulosic biomass is converted into value-added products such as bio-oil, biochar, or other bio-based chemicals.
	Two-platform concept biorefinery			Both thermochemical and biochemical conversions take place in an integrated design to produce valuable products and fuels.

Classification based on feedstock, conversion process, platforms and products

In general, biorefining commences with a mechanical process to prepare biomass for the conversion processes (e.g. pressing, fractionation, and/or size reduction) (Calvo-Flores & Martin-Martinez, 2022, p.2). While bio-based products (e.g. chemicals and materials) can be produced in single product processes, de Jong *et al*. (2012, p.3) citing Kamm *et al*. (2006) and the World Economic Forum (2010) noted that *'the production in integrated biorefinery processes producing both bio-based products and secondary energy carriers (fuels, power, heat), in analogy with oil refineries, probably is a more efficient approach for the sustainable valorisation of biomass resources in a future biobased economy'*. Therefore, a biorefinery classification covers a range of industrial activities and is potentially applied differently by different industry participants. Cherubini *et al.* (2009, p.2&4) provided insights towards a common classification system of biorefineries based on platforms, products, feedstock and processes. Three conversion processes for biomass into products are noted by FAO (2004, p.11) and Calvo-Flores and Martin-Martinez, (2022, p.2); biochemical conversion is conversion using biological processes (e.g. fermentation), physico-chemical conversion process provides a liquid fuel based on physical and chemical processes (e.g. acid hydrolysis, oxidations, and esterification) and thermo-chemical conversion as a conversion process of biomass based on thermal energy; (e.g. hydrothermal processing, pyrolysis, and gasification). Subsequent presentation of a classification system (see de Jong *et al.*, 2012, p.4; Platt *et al.*, 2021, p.4) changed the order of the defining elements to follow the logical flow in a process; feedstock, process, platforms and products. The Platt *et al.* (2021) classification system is presented in Table 4.

Table 4: A biorefinery classification system as presented by Platt *et al.* (2021, p.6, Table 1).

1. Feedstocks	2. Conversion Processes	3. Platforms	4. Products
1.1. Primary biomass†: • Aquatic biomass • Lignocellulosic from croplands and grasslands • Lignocellulosic wood/forestry • Oil crops • Starch crops • Sugar crops • Other primary biomass* 1.2. Secondary Biomass†: • Microbial biomass • Residues from agriculture • Residues from aquatic biomass • Residues from forestry and forest-based industry. • Residues from nature and landscape management • Residues from recycled bio-based products • Other organic residues*	2.1. Biochemical: • Aerobic conversion • Anaerobic digestion • Enzymatic process • Fermentation • Insect-based bioconversion • Other biochemical conversion* 2.2. Chemical: • Catalytic • Esterification • Hydrogenation • Hydrolysis • Methanation • Chemical pulping • Steam reforming • Water electrolysis • Water gas shift • Other chemical conversion* 2.3. Mechanical and thermomechanical: • Blending • Extraction • Mechanical & thermomechanical disruption & fractionation • Mechanical pulping • Separation processes • Other mechanical and thermomechanical conversion 2.4. Thermochemical: • Combustion • Gasification • Hydrothermal liquefaction • Pyrolysis • Supercritical conversion • Torrefaction & Carbonization • Other thermochemical conversion*	• Biochar • Bio-coal • Bio-crude • Biogas • Bio-oils • Bio-hydrogen • Bio-naphtha • C5/C6 sugars • Carbon dioxide • Lignin • Oils • Organic Fibres • Organic Juice • Protein • Pyrolytic Liquid • Starch • Syngas • Other platform*	4.1. Chemicals: • Additives • Agrochemicals • Building blocks • Catalysts & enzymes • Colorants • Cosmeceuticals • Flavours & fragrances • Lubricants • Nutraceuticals • Paints & coatings • Pharmaceuticals • Solvents • Surfactants • Other chemical product* 4.2. Materials: • Composites • Fibres** • Organic Fertilizers • Polymers • Resins • Other material product* 4.3. Food 4.4. Animal Feed 4.5. Energy: • Cooling agents • Fuels • Heat • Power • Other energy product*

† Primary biomass is a biomass originated via artificial or natural photosynthesis. Secondary biomass is produced during the processing, conversion or decomposition of primary biomass and organic material.

* 'Other' is included to enable new concepts, technologies or product categories to be included.

** 'Fibres' potentially can be further subdivided according to their application: textile fibres, paper and board fibres, carbon/specialty fibres and other fibres.

The thermomechanical conversion processes

The thermomechanical conversion processes as listed in Table 4 can be expanded on based on the technology applied (see Box 83). To assist in an understanding of the differences between the similar processes of pyrolysis, gasification and combustion, Figure 14 presents the combination of temperature and oxygen required by each process.

Box 83: The definitions of the key processes paraphrased from Platt *et al.* (2022, p.340).		
Method	Description	Reference
Combustion	A chemical reaction of a fuel in presence of an oxidizer (commonly oxygen) and heat. The fuel and the oxidizer react together to form new chemical substances, often gaseous products.	Bastidas-Oyanedel, *et al.* (2019)
Gasification	Gasification converts carbon-based raw material into fuel gas (i.e. syngas). The process occurs, generally at high temperature/pressure in presence of controlled amount of oxygen (or air) and steam. Syngas is composed of carbon monoxide and hydrogen and can be burned directly or be used as a starting point to manufacture fertilizers, pure hydrogen, methane or liquid transportation fuels such gasoline and diesel.	NETL (____)
Hydrothermal liquefaction	Hydrothermal liquefaction (HTL) is a process to increase the energy content of wet organic materials. Biomass can be converted into a heavy oil (biocrude) product without drying. Black liquor, lignin, sawdust sludge or other organic containing feedstock can be converted. Via hydrogenation, of this heavy fuel-oil, diesel, kerosene, or other (chemical) end-products are made.	Rutz, *et al.* (2020)
Pyrolysis	Under pyrolysis in the absence of oxygen (dried) organic material is thermally cracked at temperatures from 400 °C to 600 °C to produce a combustible gas, pyrolysis oil and char. There are roughly three different types of pyrolysis with a different ratio of the three products: slow (mainly char), medium (both char and pyrolysis oil) and fast (mainly pyrolysis oil); slow pyrolysis also called carbonization.	Annevelink, *et al.* (2016)
Torrefaction & carbonization	Torrefaction and carbonization are thermal process to convert biomass into a coallike material, with higher energy density compare the original biomass and hydrophobic characteristics. These are slow pyrolysis.	BTG (____)
Supercritical conversion	The supercritical conversion processes occurs at temperatures and pressures above the critical point of water. Main super critical conversion processes of biomass are: supercritical water gasification (SCWG) and supercritical water oxidation. Supercritical water oxidation is used particularly for degradation of harmful and toxic materials. SCWG of biomass shows promise as a conversion route for wet biomass and waste streams into hydrogen and/or methane.	Akgül (2014)

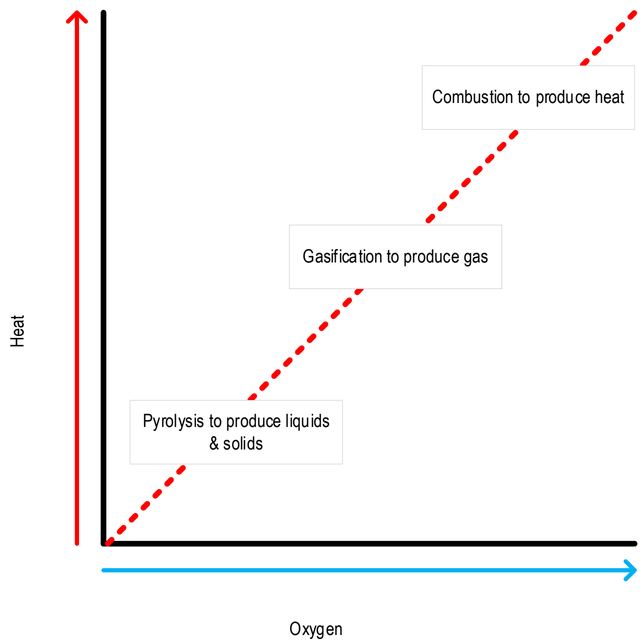

Figure 14: A schematic of the different processes using biomass (based on Goble & Peck, 2013, p.5).

Pyrolysis

The process

Overview

Pyrolysis is the heat treatment of biomass with incomplete combustion; more precisely, it is the *'thermal depolymerization of biomass at modest temperatures in the absence of added oxygen'* (Huber, 2008, p.31); the biomass components are cellulose, hemicellulose, and lignin (Mathew, S. & Zakaria, Z.A., 2015, p.611). During the process, the main matrix polymers (i.e. cellulose, hemicellulose and lignin) decompose in a non-oxidizing atmosphere (Moya *et al*., 2024, p.1). This results in a solid product (char), two types of liquid (which can be separated in pyrolysis-oil or pyroligneous acid commonly known as wood vinegar), and non-condensable gases (Moya *et al.*, 2024, p.1 citing Kan *et al.*, 2016); see Figure 15. To be precise, the aqueous liquid fraction is obtained by the condensation of the condensable pyrolysis vapours (Mathew, S. & Zakaria, Z.A., 2015, p.611; Pyrotech Energy, undated, p.1). A key point is that the chemical additives (catalysts) will determine the output chemicals. Out-puts can be inputs to a biorefining process to generate subsequent products. As an example, Box 84 presents an industry definition of carbonization and coalification to assist.

Box 84: The definition of carbonisation (Fitzer *et al.,* 1995, p.484) and coalification (Fitzer *et al.,* 1995, p.485).	
Carbonization	*'Carbonization is a process by which solid residues with increasing content of the element carbon are formed from organic material usually by pyrolysis in an inert atmosphere. As with all pyrolytic reactions, carbonization is a complex process in which many reactions take place concurrently such as dehydrogenation, condensation, hydrogen transfer and isomerization. It differs from coaliflcatlon in that its reaction rate is faster by many orders of magnitude. The final pyrolysis temperature applied controls the degree of carbonization and the residual content of foreign elements, e.g. at temperature – 1,200 K the carbon content of the residue exceeds a mass fraction of 90%wt, whereas at temperature 1,600 K, more than 99%wt carbon is found.'*
Coaliflcatlon	*'Coaliflcatlon is a geological process of formation of materials with increasing content of the element carbon from organic materials that occurs in a first, biological stage into peats, followed by a gradual transformation into coal by action of moderate temperature (about 500 K) and high pressure in a geochemical stage. Coalification is a dehydrogenation process with a reaction rate slower by many orders of magnitude than that of carbonization. Some specific reactions approach completion before others have started. The dehydrogenation remains incomplete.'*

The process outputs

The three primary products of pyrolysis are: gas (mainly hydrogen [H_2], methane [CH_4], carbon monoxide [CO], carbon dioxide [CO_2], hydrocarbons CxHy (x = 2 or 3), condensed liquids (wood vinegar, bio-oils and tars), and char (Ephraim, 2016, p.11 citing Bridgwater, 2003). Wood vinegar forms the top of bio-oil, and with tar as the heavy fraction at the bottom (Zhou *et al.,* 2025, p.1 citing Chen *et al.,* 2021, Abstract). The relative yields of these products depend mainly on the heating rate, pyrolysis temperature and residence time in the reaction zone, as well as the initial biomass composition. These are addressed in detail in this section.

Feedstock types and impacts

Lignocellulosic biomass materials with high lignin content tend to increase char yield, while high cellulose and hemicellulose content increases gas and oil (tar) yields (Ephraim, 2016, p.11 citing Blasi, *et al.,* 2001 & Couhert, *et al.,* 2009). To encourage rapid heating requires a fine feedstock of less than 3 mm particle size that is relatively dry, with moisture content of less than 10%wb (Goble & Peck, 2013, p.50&51). See Box 85 for an example.

Box 85: An example of fast pyrolysis of sawdust and the outcome materials.
As an example of the use of processing residues, Soni and Karmee (2020 Abstract) reported on the pyrolysis of sawdust. The sawdust was pyrolyzed in a fixed bed batch scale reactor at 400 °C - 600 °C; it was found that the optimum temperature was 500°C to produce pyrolysis-oil (34.9%ww), biochar (38.6%ww) and pyrogas (26.5%ww). A vertical moving bed type continuous reactor with a capacity 15 kg/h and operating at 500°C obtained yields of 41.05%ww of pyrolysis -oil, 27.59%ww of biochar and 31.36%ww of pyro-gas (a mixture of non-condensable gases).

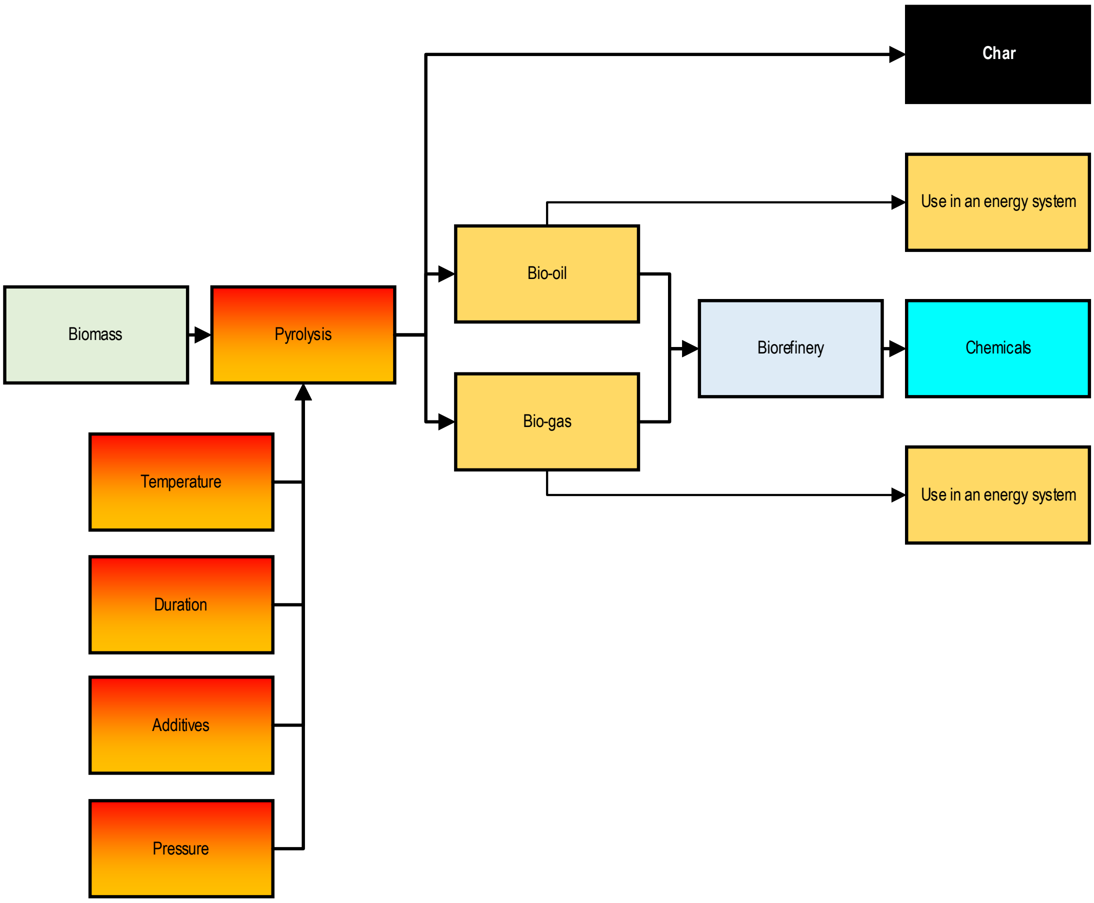

Figure 15: A simple schematic of biomass pyrolysis based on Huber (2008).

The production process

Pyrolysis or devolatilization, is a thermal decomposition or thermal cracking process that occurs in the absence of oxygen at temperatures between 300 °C and 800 °C (Jenkins & Jenkinson, 2009; Ephraim, 2016, p.11; Hagemann *et al.*, 2018, p.2 citing Lehmann & Joseph 2015; Allohverdi, *et al.*, 2021, p.2, citing Brunn *et al.*, 2012). The output characteristics of pyrolysis depend on the feedstock properties, process temperature, pressure, and residence time of the liberated pyrolysis vapours (Huber, 2008, p.31,32&35; Allohverdi, *et al.*, 2021, p.2, citing Brunn *et al.*, 2012). Importantly, it is incomplete combustion. A low pyrolysis temperature, slow heating rate and long residence time increases biomass conversion to char (Ephraim, 2016, p.11 citing Antal & Grønli 2003). A high temperature, slow heating rate and longer residence time favours conversion to gas (Ephraim, 2016, p. 11 citing Vasile, & Brebu, 2006). Pyrolysis oil yield is maximised by operating at a moderate temperature, fast heating rate and short vapour residence time (Ephraim, 2016, p. 11 citing Abnisa & Daud, 2014). Therefore, pyrolysis is segmented based on the duration of the process which impacts the proportions of the three outputs as presented in Table 5.

Table 5: A segmentation of the types of pyrolysis and the resulting products (based on Goble & Peck, 2013, p.43 citing Moulton, 2009; Goble & Peck, 2013, p.50&51; Cremers *et al.,* 2015,; Annevelink *et al.*, 2016; Soni & Karmee, 2020, Abstract, Greco, *et al.,* 2020, Abstract; Greco, *et al.,* 2021, Abstract).

Process	Slow pyrolysis	Medium pyrolysis	Fast pyrolysis
Alternative nomenclature	Carbonization or torrification		
Outputs			
Char	Mainly char	35%	12%
Liquids	Wood vinegar	Mixture	Pyrolysis-oil
Syngas		35%	14%
Time	Very long residence times		Short residence times; 0.5 to 2.0 seconds
Oxygen levels	Very low to none		
Temperature	300 - 550ºC		400 to 600ºC
Pressure	e.g. 0.2–0.9 MPa	e.g. 0.1-0.5 MPa	e.g. 0.2–0.9 MPa Determines the resulting compounds

Slow pyrolysis; torrefaction as a specific process

A specific named process is torrefaction which is a slow pyrolysis conversion of biomass into a coallike (biocoal) material, with a higher energy density and hydrophobic characteristics compare the original biomass (Platt *et al.,* 2021, p.340). The degree of torrefaction depends typically on the time that a (dry) biomass material resides in the torrefaction reactor and on the temperature inside the reactor. The higher the temperature or the longer the residence time the higher the torrefaction degree. Torrefaction temperature has more impact than residence time (Strandberg *et al.*, 2015 abstract).

Cremers *et al.* (2015) provides an account of torrefaction including the production technology and the following is based on their account. During the process, solid biomass is heated to a temperature of c. 250-320°C in the absence of (or drastically reduced) oxygen, resulting in a loss of moisture and a partial loss of the volatile matter component (c.20%). Defined by processing conditions, the attributes of the biomass used and torrefaction degree, the energy content of the volatiles released is of the same order of magnitude as the heat required to drive-off moisture contained in the feedstock. The volatile gases released during torrefaction are combusted to dry the input biomass, supplemented with combustion of additional biomass fuel. The partial removal of the volatile matter significantly changes the characteristics of the original biomass. The tenacious (e.g. the ability to resist breaking or stretching) fibre structure is largely destroyed by the breakdown of hemicellulose and to a lesser degree, of cellulose molecules; the material becomes brittle and easy to grind. The material changes from being hydrophilic to becoming hydrophobic. The removal of the light volatile fraction (that contains most of the oxygen), increases the heating value from 19 MJ/kg (of bone dry wood) to 21 or 23 MJ/kg for torrefied wood through to 30 MJ/kg for complete devolatization into charcoal.

A historic process

In Victoria, there was a wood distillation plant located in Britannia Creek Block (Upper Yarra Forest District) (see Figure 16). Wood distillation commenced in 1907 at the integrated sawmill and distillation plant processing Mountain ash (*E. regnans*) logs and billets, ceasing in c.1934 (Rae, 1987, p.469&472). Wood distillation was via a pyrolysis process. The site produced crude wood spirit, charcoal, tars, crude creosote oils, acetate of lime, acetone and formalin (Rae, 1987, p.474). Some products were in response to specific needs. For example, acetone was produced for supply to the Government and reduced at the end of World War 1 (Rae, 1987, p.472&473). The acetone was mostly used in gelling a mixture of nitro-glycerine and nitrocellulose to form the explosive, cordite (Rae, 1987, p.472).

Figure 16: The historic Wood distillation Works Britannia Creek. Creswick Campus Historical Collection, accessed April 26, 2025, https://omeka.cloud.unimelb.edu.au/cchc/items/show/5400.

The primary products

Pyrogenic carbonaceous materials

Pyrogenic carbonaceous materials (PCM) are all materials produced by thermochemical conversion and contain some organic carbon (Hagemann *et al*., 2018, p.2 citing Lehmann & Joseph 2015). There are a variety of uses; for example, charcoal as fuel (a more traditional use) and biochar as a soil amelioration (Moya *et al*., 2024, p.1 citing Patal *et al.,* 2020). Other products include environmental 'black carbon' (e.g. fossil fuel soot, biomass char), engineered carbons (e.g. activated carbon), and related materials such as graphene and nanotubes (Pignatello *et al.,* 2017, Abstract).

Char; charcoal and biochar

An output of pyrolysis is char; the products are referred to as biochar or charcoal. The FAO (2004, p.31) defines char as *'solid partially or non-agglomerated carbonaceous material produced by pyrolysis of solid biofuels'*. Char has a porous structure with a large specific surface area (Bhattacharya *et al.* 2024, Introduction). Soni and Karmee (2020 Abstract) characterised char produced by fast pyrolysis of sawdust and found it to be porous in nature with negligible amounts of volatiles. Biochar and charcoal are the same material and the intended use is the basis of delineation (Hagemann *et al.,* 2018, p.1; Allohverdi, *et al.,* 2021, p.1; Moya *et al.,* 2024, p.1&2). See Box 86. If char is used as a fuel (i.e., burned and the carbon transformed by oxidization into CO_2), it is classified as charcoal. If char is used for agricultural purposes (see Allohverdi, *et al.,* 2021) or the application as a multifunctional material to address pollution (Bhattacharya *et al.* 2024, Introduction) it is referred to as biochar. Charcoal and biochar are highly carbonaceous products (Bhattacharya *et al*., 2024, Introduction) and an extremely complex stable form of carbon (Jenkins & Jenkinson, 2009, p.1). This makes a precise definition of the resulting products problematic (Huber, 2008, p.35).

Box 86: The recommended terminology for carbon as a solid; char and charcoal (Fitzer *et al.,* 1995, p.484).	
Char	*'Char is a solid decomposition product of a natural or synthetic organic material. If the precursor has not passed through a fluid stage, char will retain the characteristic shape of the precursor (although becoming of smaller size). For such materials the term "pseudomorphous" has been used. Some simple organic compounds, e.g. sugar, melt at an early stage of decomposition and then polymerize during carbonization to produce chars.'*
Charcoal	*'Charcoal is a traditional term for a char obtained from wood, peat, coal or some related natural organic materials. Charcoal has highly reactive inner surfaces and a low sulfur content. It has or has had, therefore, a variety of uses, e.g. in ferrous metallurgy and for gun-powder (minor uses: medical purpose and paint materials).'*

Due to cost-effectiveness, physical attributes and good stability, biochar is a suitable material compared to other carbon materials (e.g. graphene, activated carbon, and single or multiple carbon nanotubes) for use in the food packaging and food processing industries (Bhattacharya *et al.,* 2024, Introduction). It is a nutrient rich material which can be used in agriculture (Hagemann *et al.,* 2018, p.1), gaining attention for soil amelioration, improving crop yields as well as for carbon sequestration (Allohverdi, *et al.,* 2021, p.1) (see Table 6). Research has shown that biochar can be used in biosensors, supercapacitors, and fuel-cell applications (Bhattacharya *et al.,* 2024, Introduction). Activating biochar at the nanoscale is regarded as a new research direction to create reliable and simple biosensors and nanocomposites for sustainable food safety purposes (Bhattacharya *et al.,* 2024, Introduction).

Table 6: An example of the elemental content of biochar (from Moragues-Saitua *et al*., 2023, Table 1, p.3).

Element	Name	Units	Content
P	Phosphorous	(g/kg)	1.6
Ca	Calcium	(g/kg)	18.8
Mg	Magnesium	(g/kg)	1.9
Na	Sodium	(g/kg)	0.8
K	Potassium	(g/kg)	12.2
Al	Aluminium	(g/kg)	2.1
C	Carbon	(g/kg)	858.0
N	Nitrogen	(g/kg)	5.1
Cu	Copper	(mg/kg)	13.5
Zn	Zinc	(mg/kg)	67.8
Fe	Iron	(mg/kg)	2,531.5
Mn	Manganese	(mg/kg)	196.1
Cd	Cadmium	(mg/kg)	0.2
Pb	Lead	(mg/kg)	0.01
Cr	Chromium	(mg/kg)	79.9
Ni	Nickle	(mg/kg)	32.6

Char as a replacement for coke and coke products

A source of carbon is required in the manufacturing of steel. Box 82 presents a breakdown of coke products. Pandit *et al.* (2020, p.5, Figure 1) presents the four production methods (blast furnace, smelting reduction, direct reduction and scrap recycling) and indicates the introduction of coke and coal. They reported that 71.6% of the world steel is produced by using blast furnace technology. In a blast furnace, iron ore (iron oxide) is fed into the furnace as 'lump', as sintered or pelletised fines and is reduced to iron. Carbon is introduced to the furnace; as coke in a top-feed or as pulverised coal as a tuyere (a nozzle through which air is forced) injectant. The carbon reacts with the oxygen in the 'blast' air to produce carbon monoxide (the major reductant) and to provide energy for the reduction reaction (Pandit *et al.,* 2020, p.5). Char can replace coal and coke for metal production, however the main barrier is cost, as existing pyrolysis processes are limited in scale and often require feedstocks in a particular form.[36]

Box 87: The recommended terminology for carbon as a solid; Coke (Fitzer *et al*., 1995, p.485&486), Coke breeze (Fitzer *et al*., 1995, p. 486), Delayed coke (Fitzer *et al*., 1995, p.486) and Metallurgical coke (Fitzer *et al*., 1995, p.497).	
Coke	*'Coke is a solid high in content of the element carbon and structurally in the nongraphitic state. It is produced by pyrolysis of organic material which has passed, at least in part, through a liquid or liquid-crystalline state during the carbonization process. Coke can contain mineral matter. As some parts, at least, of the carbonization product have passed through a liquid or liquid-crystalline state, the resulting non-graphitic carbon is of the graphitizable variety. From a structural viewpoint, the term coke characterizes the state of graphitizable carbon before the beginning of graphitization.'*
Metallurgical coke	*'Metallurgical coke is produced by carbonization of coals or coal blends at temperatures up to 1,400 K to produce a macroporous carbon material of high strength and relatively large lump size. Metallurgical cokes must have a high strength to support heavy loads in the blast furnace without disintegration. Metallurgical coke is also used as filler coke for polygranular carbon products.'*
Delayed coke	*'Delayed coke is a commonly used term for a primary carbonization product (green or raw coke) from high-boiling hydrocarbon fractions (heavy residues of petroleum or coal processing) produced by the delayed coking. Delayed coke is a commonly used term for a primary carbonization product (green or raw coke) from high-boiling hydrocarbon fractions (heavy residues of petroleum or coal processing) produced by the delayed coking. Delayed coke has, with only a few exceptions, a better graphitizability than cokes produced by other coking processes even if the same feedstock is used. Delayed coke contains a mass fraction of volatile matter between 4 and 15%wt which can be released during heat treatment.'*
Coke breeze	*'Coke breeze is a by-product of coke manufacture; it is the residue from the screening of heat-treated coke; the particle size is less than 10 mm. Generally, coke breeze has a volatile matter content of c. 3%wt.'*

Technology using woody biomass as a of raw materials for producing metallurgical coke was examined by adding it to coal and then carbonizing. It was shown that compressively formed woody biomass as a raw material for coke manufacturing was possible (Matsumura, *et al.,* 2008, p.572). A research project found that the addition of 2% eucalypt sawdust in coal blends for the production of metallurgical coke, achieved the required quality while lowering the cost (Carvalho, *et al.,* 2021, Abstract). A research project investigated torrefied woodchips as a substitute for industrial coke. They found that the surface area of the resulting substituted coke was 30 times larger and the reactivity was six times greater than industrial coke with lower sulphur content and lower ash yield. These properties would increase blast furnace production and decrease environmental problems associated with the use of industrial coke. It was concluded that a 50% biomass replacement in coke production would reduce the cost of liquid iron production (Uwaoma, *et al.,* 2022, Abstract).

Wood vinegar as a product of slow pyrolysis

An output of slow pyrolysis is pyroligneous acid or wood vinegar. Mathew & Zakaria (2015, p.611) noted that wood vinegar *'is a source for valuable chemicals'* and that it adds a smoky flavour for food. Wood vinegar has a smoky aroma and sour taste, with a pH between 1.5 to 3.7, and a specific gravity generally greater than 1.005 (Zhou *et al.,* 2025, p.1 citing Mathew & Zakaria, 2015; citing Yatagai, *et al.,* 2002). It is described variably as a light brownish liquid (Pyrotech Energy, undated, p.1) or a red-brown liquid (Zhou *et al.,* 2025, p.1 citing Mathew & Zakaria, 2015; citing Yatagai, *et al*., 2002); indeed, a figure in Pyrotech Energy (undated, p.1) presents wood vinegar as varying from pale yellow to deep dark brown. Wood vinegar contains more than 200 organic compounds, including water, methanol, ester, acetic acid and ketone (Pyrotech Energy, undated, p.1). Further, Mathew & Zakaria (2015 abstract) indicates that it contains 'a complex mixture of guaiacols, catechols, syringols,

[36] https://www.csiro.au/en/work-with-us/ip-commercialisation/marketplace/low-cost-charcoal-production

phenols, vanillins, furans, pyrans, carboxaldehydes, hydroxyketones, sugars, alkyl aryl ethers, nitrogenated derivatives, alcohols, acetic acid, and other carboxylic acids'. Acetic acid is reported as the largest component of wood vinegar (Yatagai *et al.,* 2002, p.338). Acetic acid is in common vinegar. Wood vinegar is used in agriculture and forestry (e.g. as a fungicide) (Zhou *et al.,* 2025, p.1). Table 7 presents a statement of the claimed uses of wood vinegar. Other applications noted include as an antioxidant, antimicrobial, anti-inflammatory, plant growth stimulator, coagulant for natural rubber, and termiticidal and pesticidal agent (Mathew & Zakaria, 2015, p.611). In support of use, wood vinegar has been tested for efficacy as a termiticidal efficacy (Yatagai *et al.,* 2002, p.338), as a biofungicide (Zhou *et al.,* 2025, p.1) and as an antioxidant (Chen *et al.,* 2021, Abstract).

Table 7: A summary of the claimed use and benefits of wood vinegar (see Pyrotech Energy, undated, p.2).

As a fertilizer	As a pesticide	Other benefits
Stimulates plant and vegetable growth Strengthens roots and leaves Improved absorption within the roots Quantity of microbes Increased soil microbial weight Improves flavour, colour, firmness, and preservation of fruit Crop resistance to adverse conditions Thicker and stronger steams Higher growth rates More resistant to disease Stimulate development of crops	Repels pests and insects Prevents plant infection from fungal, bacterial diseases and viruses Reduce odour Preservative for corn	Enriches soil fertility Facilitates composting Accelerates seed germination

Pyrolysis oil or bio-oil

Pyrolysis oil or bio-oil is a liquid fuel for boilers, furnaces and gas turbines. Pyrolysis oil can be upgraded to hydrocarbon fuel by adding hydrogen and releasing oxygen to obtain a deoxygenated product (Geddes 2010, p.15) and this is discussed later. Pyrolysis oil is a liquid blend of hundreds of chemicals and can be almost black through to dark red-brown in colour, depending on its chemical composition. Table 8 presents an example of the outputs from a fast pyrolysis process. Soni and Karmee (2020, Abstract) characterised an example of pyrolysis oil produced by fast pyrolysis of sawdust which indicated that 71 chemical compounds were present. An analysis of the co-produced pyro-gas content found; hydrogen [H_2] (1.59%$_{vol}$), nitrogen [N_2] (13.61%$_{vol}$), oxygen [O_2] (2.48%$_{vol}$), CO (54.23%$_{vol}$), CH_4 (8.02%$_{vol}$) and CO_2 (24.72%$_{vol}$). It has a density of c.1,200 kg/m^3, and is mildly acidic (pH 2.5 to 4.0). The viscosity varies from 25 cP to 1,000 cP depending on water content, the amount of light-ends, and the age of the oil. While chemically stable, pyrolysis -oil will physically separate if left to settle (a timeframe of months is claimed) (Goble & Peck, 2013, p.53 citing http://www.dynamotive.com/fuels/#industrialfuels accessed Sept 2012 [Old site]). Stirring (with or without heat) will mix the pyrolysis oil into a homogeneous fluid. Pyrolysis oil contains a high level of oxygenated compounds, resulting in its poor miscibility (e.g. the ability to mix completely) with hydrocarbons which can be overcome with surfactants, enabling a stable emulsion to be formed with hydrocarbon fuels (e.g. diesel). Pyrolysis oil contains less nitrogen than petroleum products, almost no metal nor sulfur components, which is attractive from an emissions perspective. A high oxygen and water content makes them generally inferior to hydrocarbon fuels (Goble & Peck, 2013, p.53).

Table 8: A general breakdown of the components in fast pyrolysis pyrolysis-oil (Huber, 2008, p.35 citing Bridgwater *et al.,* 2001).

Product	Content (%ww)
Water	20-30
Lignin fragments: Insoluble pyrolytic lignin.	15-20
Aldehydes: Formaldehyde, acetaldehyde, hydroxyacetaldehyde & glyoxal.	10-20
Carboxylic acids: Formic, acetic, propionic, butyric, pentanoic & hexanoic.	10-15
Carbohydrates: Cellobiosan, levoglucosan & oligosaccharides.	5-10
Phenols: Phenol, cresol, guaiacols & syringols.	2-5
Furfurals: a naturally occurring organic compound, an aldehyde, with a furan ring structure	1-4
Alcohols: Methanol & ethanol	2-5
Ketones: Acetol (1-hydroxy-2-propanone) & cyclopentanone	1-5

Secondary processing and products

Subsequent processing of pyrolysis oil

A biorefinery designed similarly to a traditional petroleum refinery, can process pyrolysis oil; de Jong *et al.* (2012, p.6) provides the following description. Biomass conversion into pyrolysis oil can be a de-centralized process close to the biomass source. This is a major advantage of a pyrolysis biorefinery; an ability to decentralize production to regions with a biomass resource and retain the minerals (char) at the origin with cost-effective transport of the resulting liquids. The pyrolysis oil is transported to a biorefinery to be divided into different fractions. The fractions are of variable quality requiring upgrading into fine chemicals, petrochemicals, automotive fuels and energy. Each fraction can be upgraded with appropriate technology to derive the optimal combination of high-value and low-value products.

Conversion of char to activated carbon

The output char from pyrolysis can be converted to activated carbon by subsequent treatment and processing. An industry definition for activated carbon is presented in Box 88. Activated carbon is produced from any carbon source (i.e. fossil fuels, waste or residues) and is engineered to be used as a sorbent to remove contaminants from gases and liquids (Hagemann *et al.,* 2018, p.1 citing Smisek *et al.,* 1970; citing and Marsh & Reinoso, 2006). The properties of activated carbon are influenced by the source biomass materials (Gęca *et al.,* 2022, Table 1). It commences with char and is activated physically or chemically depending on the desired surface properties; physical activation utilises steam or carbon dioxide and chemical activation is undertaken with zinc chloride, phosphoric acid, potassium or sodium hydroxide and potassium or sodium carbonate (Gęca *et al.,* 2022, p.1 citing Angin *et al.,* 2013). Fitzer *et al.* (1995, p.476) notes that the adsorptive properties of char to activated carbon are enhanced by treatment, where char is subjected to reaction with gases, including the potential addition of chemicals (e.g. ZnCl), before, during or after carbonization. The material is defined by its properties linked to the intended uses; as noted in Box 88, there is a fibrous form of the material. While there are a range of product names, there are inherit differences between some products as presented in Box 89.

Box 88: The recommended terminology for carbon as a solid product; Activated carbon (Fitzer *et al.,* 1995, p.476) and fibrous activated carbon (Fitzer *et al.,* 1995, p.488).

Activated carbon	*'Activated carbon is a porous carbon material, a char which has been subjected to reaction with gases, sometimes with the addition of chemicals, e.g. ZnCl, before, during or after carbonization in order to increase its adsorptive properties. Activated charcoal is a traditional term for activated carbon.'*
Fibrous activated carbon	*'Fibrous activated carbon is an activated carbon in the form of fibres, filaments, yarns or rovings and fabrics or felts. Such fibres differ from carbon fibres used for reinforcement purposes in composites by their high surface area, high porosity and low mechanical strength. Sometimes fabrics of fibrous activated carbon are named charcoal cloths; a more precise term is "activated carbon cloth".'*

Box 89: A comparison of the key differences between the four types of PCM listed based on a range of sources.[37]

Product	Char		Activated charcoal	Activated carbon
	Charcoal	Biochar		
Key differences	Energy source; combusted	Used in non-combustion situations	Less porosity than activated carbon; greater than the other two forms	A maximum porosity
Source material	Biomass	Biomass	Biomass	Carbon rich material
Temperature processed	300 – 500 °C			High temperatures
Aeration	Low oxygen	Low oxygen	An absence of oxygen	
Modification (activation)	None	None	Includes physical and /or chemical treatment to maximise porosity	
Form	As input materials or ground		As input materials	Ground to size
Porosity	Less than activated charcoal		Less than activated carbon; greater than the other two forms	Greater than the other forms
Purity			Less than activated carbon; greater than the other two forms	Maximum

Graphite

A definition of the process of graphitization is presented in Box 90 and the range of products is presented in Box 91. Graphite is essential for making lithium-ion batteries; CarbonScape indicates that there is 60 kg of graphite in an electric vehicle and the battery has 42% graphite by volume (CarbonScape, 2024, slide 2). It was reported that China is estimated to produce 60% of the world's natural mineral graphite and 69% of all synthetic graphite which it refines to supply nearly all of the very pure graphite used in lithium-ion batteries (Timberbiz, 2023).

Box 90: The recommended terminology for production of carbon as a solid; graphitization (Fitzer *et al.*, 1995, p.493) and high-pressure graphitization (Fitzer *et al.*, 1995, p.495).

Graphitization	*'Graphitization is a solid-state transformation of thermydynamically unstable nongraphitic carbon into graphite by means of heat treatment. Graphitization is also used for the transformation of metastable diamond into graphite by*

[37] https://www.westerncarbon.com/activated-carbon-vs-activated-charcoal.html accessed on 25/02/2025; Gęca *et al.*, 2022, p.1 citing Angin *et al.*, 2013; Fitzer *et al.*, 1995, p.476

	heat treatment, as well as in metallurgy for the formation of graphite from thermodynamically unstable carbides by thermal decomposition at high temperatures. Such uses of the term graphitization are in line with the above definition. The use of the term graphitization to indicate a process of thermal treatment of carbon materials at T [temperature] > *2,500 K regardless of any resultant crystallinity is incorrect.'*
High-pressure graphitization	*'High-pressure graphitization refers to a solid-state transformation of nongraphitic carbon into graphite by heat treatment under elevated pressure (e.g. 100 to 1000 MPa) so that a definitely higher degree of graphitization is achieved at lower temperature and/or for a shorter heat treatment time than in heat treatment of the same NON-graphitic material at atmospheric pressure.'*

Box 91: The recommended terminology for carbon as a solid; Graphitic carbons (Fitzer *et al*., 1995, p.493), Graphite (Fitzer *et al*., 1995, p.491&2), Graphite fibres (Fitzer *et al*., 1995, p.492) and Carbon fibres (Fitzer *et al*., 1995, p.481).	
Graphitic carbons	*'Graphitic carbons are all varieties of substances consisting of the element carbon in the allotropic form of GRAPHITE irrespective of the presence of structural defects.'*
Graphite	*'Graphite is an allotropic form of the element carbon consisting of layers of hexagonally arranged carbon atoms in a planar condensed ring system (graphene layers). The layers are stacked parallel to each other in a three-dimensional crystalline long-range order. There are two allotropic forms with different stacking arrangements, hexagonal and rhombohedral. The chemical bonds within the layers are covalent with* sp^2 *hybridization and with a C-C-distance of 141.7 pm. The weak bonds between the layers are metallic with a strength comparable to van Der Waals bonding only. The term GRAPHITE is also used often but incorrectly to describe graphite materials, i.e. materials consisting of graphitic carbon made from carbon materials by processing to temperatures greater than 2,500 K, even though no perfect graphite structure is present.'*
Graphite fibres	*'Graphite fibres are carbon fibres consisting mostly of synthetic graphite for which three-dimensional crystalline order is confirmed by X-ray diffraction. Graphite fibres can be obtained by graphitization heat treatment of carbon fibres if these consist mostly of graphitizable carbon. If the h, k , l diffraction lines are difficult to recognize because they are of minor intensity, the mean interlayer spacing c/2 can be used as indication for the presence of a graphitic structure. The c/2 value of 0.34 nm is generally considered as an upper limit for synthetic graphite.'*
Carbon fibres	*'Carbon fibres are fibres (filaments, tows, yarns, rovings) consisting of at least 92% (mass fraction) CARBON, usually in the non-graphitic state. Carbon fibres are fabricated by pyrolysis of organic precursor fibres or by growth from gaseous hydrocarbons. The use of the term graphite fibres instead of carbon fibres as often observed in the literature is incorrect and should be avoided. The term graphite fibres is justified only if three-dimensional crystalline order is confirmed, e.g. by X-ray diffraction measurements.'*

Graphite can be manufactured from woody biomass. Nakayasu *et al.* (2022, abstract) reported success in preparation of highly crystalline graphite-like carbon from woody sawdust at 850ºC. The physical properties were similar to artificial and natural graphite. Application of a hydrothermal pre-treatment process resulted in higher crystallinity compared with a conventional pre-treatment process. CarbonScape manufactures biographite by recovering carbon from woodchips and conversion through a low temperature process into a biographite for use in Lithium-ion Batteries (CarbonScape, 2024, slide 7). A Massachusetts Institute of Technology (MIT) research project explored the graphitization of wood via a high temperature (at 2,400◦C) and a low-temperature (1,400◦C) approach using a catalyst. The incorporation of a catalyst was crucial in lower-temperature synthesis of high-quality graphite from woody biomass (Kim *et al.,* 2024, p.1&12).

Nano products

Nanotechnology is the technology used in developing products on a nanometer scale. The resulting materials are available in a wide variety of forms; for example, nanoparticles, nanocomposites, nanotubes, nanocatalysts and nanocrystals (Ahlqvist *et al.,* 2012c, p.51).

Demonstration and pilot scale plants; Norske Skog Tasmania; a pyrolysis system

A joint venture between Norske Skog and the Circa Group established a commercial demonstration plant at the Boyer Mill (Tasmania) to produce the biosolvent Cyrene™ (Timberbiz, 2017). The Boyer Mill processes plantation grown softwood fibre[38]. The production process uses the proprietary 'Furacell™' process applied to lignocellulose biomass feedstock to produce levoglucosenone (LGE) (CIRCA Group, 2021). Levoglucosenone is a versatile chiral molecule (e.g. a molecule that is not superimposable on its mirror image) uniquely obtained from the pyrolysis of lignocellulosic feedstocks (e.g. sawdust) (De Bruyn *et al.*, 2021, section 3.3). Cyrene™ is a novel renewable non-toxic biobased solvent that can replace existing, toxic and fossil-based solvents; for example, N-methyl-2-pyrrolidone (NMP), Dimethylformamide (DMF), Dimethyl sulfoxide (DMSO) and Dichloromethane (DCM) (Richardson & Raverty, 2016, p.344; Circa Group, 2021). At that time there were no viable environmental alternatives available at large scale to replace these solvents (Circa Group, 2021). The LGE is a platform molecule to produce multiple biochemicals; for example trial results producing agrochemicals, flavours, fragrances, electronics, batteries, paints, graphene, polymers and more (CIRCA Group, 2021). Richardson and Raverty (2016, p.344) describe the process as follows. *'The Furacell™ process takes lignocellulosic material and uses a combination of catalysts and heat to form LGE, biochar and water. The vapours formed during the process are separated from the biochar, distilled and purified before subsequent catalytic hydrogenation to form (Cyrene™).* Richardson and Raverty (2016, p.345) indicate that the Furacell™ process is applied to Radiata pine sawdust. The joint venture demonstration plant was to process 1,500 t/y of wood to produce 50 t of Cyrene™ (a ratio of 30:1) to be shipped overseas for use in the pharmaceutical and other biochemical industries (Timberbiz, 2017). In 2019 it was announced that 99% pure Cyrene™ had been produced (Bioenergy International, 2019).

[38] https://www.norskeskog.com/About-Norske-Skog/Press-room/Articles/Boyer-conversion accessed on the 24/04/2025.

Gasification and supercritical conversion; syngas production

The process

Overview

The gas produced by gasification is referred to as synthesis gas or *syngas* (Goble & Peck, 2013, p.44) or producer gas when from solid biofuel gasified or manufactured in a gasifier (FAO, 2004, p.31). It is a mature technology (a thermochemical process) pathway via a controlled process involving heat, steam, and oxygen[39]. Typically, a gasification system is made up of three elements (Ephraim, 2016, p.29 citing Belgiorno *et al.,* 2003).

- A gasifier: To produce syngas.
- A cleaner: A syngas cleaning system to remove contaminants.
- An energy recovery system: An energy recovery system (e.g. burning the syngas to produce energy) including suitable components for controlling environmental impacts (e.g. air pollution, solid waste production, and/or wastewater).

The syngas production system

The syngas production system is two-stage; the first stage produces char by pyrolysis at temperatures above 550 °C (Ephraim 2016, p.11) or greater that 700°C[40] without combustion. It was noted that the process of torrefaction can be used as pre-treatment for gasification (Platt *et al.,* 2021, p.114). While pyrolysis and gasification are thermal decomposition processes, pyrolysis occurs in the full absence or near absence of oxygen, sublimating organic matter into solid, liquid, and gaseous products. In the second stage, the char reacts with gasification oxidants (i.e. with controlled oxygen levels, steam and/or carbon dioxide) to produce syngas which includes carbon monoxide [CO] and hydrogen [H_2] (Ephraim, 2016, p.11). The carbon monoxide then reacts with water to form carbon dioxide and more hydrogen via a water-gas shift reaction (Ephraim, 2016, p.11). To provide the heat required for drying the biomass, pyrolysis and char gasification, exothermic combustion is facilitated in the gasifier vessel, by injecting air or pure oxygen (Ephraim, 2016, p.12).

Feedstock type and condition

Most pyro-gasification systems use biomass with a moisture content of 10 to 20%ww (Ephraim, 2016, p.11). The nature of the feedstock contributes to the composition and behaviour of the syngas. Adverse contaminants can result from waste-derived syngas including; particulate matter, tars, sulphur compounds (hydrogen sulfide [H_2S], Carbonyl sulfide [COS]), nitrogen compounds (ammonia [NH_3], hydrogen cyanide [HCN]) alkali metals (K, Na), hydrogen chloride (HCl) and trace heavy metals (mercury [Hg], Pb, Cd, Zn) (Ephraim 2016, p.29&30 citing Devi, *et al.,* 2003; Khan, *et al.,* 2009; Yung, *et al.,* 2009; Woolcock & Brown, 2013). Furthermore, alkali salts in the bio-waste ash tends to catalyse pyrolysis reactions to favour CO_2 over CO production (Ephraim, 2016, p.11 citing Varhegyi, *et al.,*1989 & Couhert, *et al.*, 2009).

[39] From https://www.energy.gov/eere/fuelcells/hydrogen-production-biomass-gasification on 05/02/2025.
[40] From https://www.energy.gov/eere/fuelcells/hydrogen-production-biomass-gasification on 05/02/2025.

The output syngas

Syngas attributes

The composition of syngas and the energy content depends on the wood and residues used and the operating conditions for conversion, particularly the approach used to supply heat (Goble & Peck, 2013, p.44). Most gasifiers use oxygen as an oxidizing agent (in air or a concentrated form) partially combusting the wood and generating heat. With air used, nitrogen dilutes the syngas resulting in a low-energy producer gas; c. 45 to 60% N, 10 to 20% H_2 and 15 to 30% CO. Such low-energy syngas is used where the heat content is not critical (Goble & Peck, 2013, p.44). For example, the characteristics of syngas from the pyrolysis and gasification of food waste was assessed by syngas flow rate, hydrogen flow rate, output power, total syngas yield, total hydrogen yield, total energy yield, and apparent thermal efficiency (Ahmed & Gupta, 2010, Abstract). The analysis tested operating temperatures of 800 - 900°C and determined that gasification was more beneficial than pyrolysis, but with a longer cycle time required to complete the process. The longer time was attributed to slow reactions between the char and gasifying agent. Char reactivity increased with increased degree of conversion. The char gasification kinetics were investigated and determined that inorganic constituents of food waste derived char had a catalytic effect.

If the intent is a medium-energy syngas, blowing concentrated or pure oxygen into the gasifier for partial combustion is required to avoid nitrogen dilution and to increases the energy content. An alternative is that external heat is provided to the gasifier reducing dilutant gases to those entering with the fuel (Goble & Peck, 2013, p.44). Adsorbers or special membranes are required to separate the hydrogen from this gas stream.[41]

Syngas contaminants and quality requirements

Ephraim (2016, p.29, citing Arena, 2011) noted that the greatest technical challenges to be overcome to achieve wider market penetration of gasification technologies appears to be associated with *'improved and cheaper cleaning of syngas in order to meet defined specifications'*. Contaminants in syngas can cause serious problems in gasification systems; for example, fouling, clogging, corrosion, and catalyst poisoning which in turn can cause efficiency and safety concerns if not removed from the syngas (Ephraim, 2016, p.29&30). As noted, it is the nature of the biomass processed that contributes to the contaminant. For example, Goble and Peck (2013, p.46 citing Moulton, 2009) noted that for use of syngas to produce methanol and hydrogen required removal of particulates and contaminants (e.g. hydrogen sulphide) to prevent poisoning of downstream catalysts.

Cleaning of syngas

The level of cleaning required for syngas is determined by the quality requirements of the end-use applications and environmental emissions regulations in the location of use (Ephraim, 2016, p.30 citing Arena, 2011). The exception is in a close-coupled gasifier-combustor systems with no clean-up (Goble & Peck, 2013, p.46). The technologies to clean syngas are presented in Box 92, segmented by the condensation temperatures of various compounds (Ephraim, 2016, p.30 citing Woolcock & Brown, 2013 & Asadullah, 2014). Details are presented in Table 9. The syngas exit temperature is usually from 800 to 900°C, which is beyond the temperature required for many syngas using devices, hence it must be cooled prior to use. This makes use of cold gas clean-up technologies (e.g. wet scrubbing), appropriate. Wet-scrubber technologies generate wastewater with dissolved tars which must be removed, adding to costs and can be energy inefficient (Ephraim, 2016, p.32,

[41] From https://www.energy.gov/eere/fuelcells/hydrogen-production-biomass-gasification on 05/02/2025.

including citing Arena, 2011). If a hot gas clean-up technology is used, pre-removal of particulates and aerosols is required to prevent catalyst fouling, poisoning or deactivation. To address these shortcomings, warm gas clean-up is becoming increasingly important with respect to tar, particulate and HCl removal (Ephraim, 2016, p.32). In practice, tars are normally broken-down at high temperature before they pass through a filter to prevent contamination of the filter elements. This is usually carried out in a 'tar cracker' where high temperatures and a catalyst break down the tar into lighter fractions (Goble & Peck, 2013, p.46).

Box 92: A segmentation of the technologies used to clean syngas of contaminants (Ephraim 2016, p.30 citing Woolcock & Brown, 2013 & Asadullah, 2014).	
Cold	*'Cold gas cleanup technologies, which often use water sprays, have exit temperatures near ambient conditions (<100°C) to enable water condensation.'*
Warm	*'Warm gas cleanup typically occurs at temperatures higher than the boiling point of water up to temperatures of around 300°C which allows for ammonium chloride condensation.'*
Hot	*'Hot gas cleanup usually occurs in the temperature range of 400 to 700°C. This results in the condensation of several alkali compounds. Higher temperatures are not usually employed in order to avoid using expensive piping material.'*

Table 9: An overview of the different syngas cleaning techniques presented by Ephram (2016, p.32, Table 1).

Contaminant	Hot gas cleanup	Warm gas cleanup	Cold gas cleanup
Particulate matter	Cyclones	Cyclones	Wet scrubbing
	Barrier filtration	Barrier filtration	
	Electrostatic separation	Electrostatic separation	
	Turbulent flow precipitator (TFP)		
Tars	Thermal cracking	Oil based gas washer	Wet scrubbing
	Catalytic cracking		Biological gas treatment
	Non-thermal plasma		
	Physical separation		
Sulphur (H_2S, COS)	Hot adsorption using metal oxides based on Zn, Fe, Cu, Mn, molybdenum [Mo], cobalt [Co] & vanadium [V]. etc	Semi-wet scrubbing	Chemical / physical solvents
			Chemical redox
			Biological processes
			Physical absorption
Nitrogen (NH_3, HCN)	Catalytic selective oxidation	Semi-wet scrubbing	Wet scrubbing
	Thermal catalytic		Adsorption
			Biological processing
Alkali	Hot adsorption using natural minerals, e.g. clays and kaolinite	Semi-wet scrubbing	Condensation
			Wet scrubbing
Chlorine	Hot adsorption using Na, Ca and magnesium [Mg] based minerals, etc	Semi-wet scrubbing using lime slurry	Wet scrubbing
Mercury	Hot adsorption using silica, bauxite kaolinite, zeolite, etc.		

Next step processing properties, products and uses

Syngas has illuminated cities, provided heat and power, and fuelled vehicles through both direct use and conversion to liquid fuels (Ephraim, 2016, p.1). The potential benefits of gasification is realised where the syngas produced is adequately cleaned prior to use in various end-use systems (Ephraim, 2016, p.29 citing Milne, *et al.*, 1998; citing Boerrigter & Rauch, 2005); see Figure 17. The following endues are noted.

- Electricity and/or heat: Electricity and/or heat production in steam cycles, gas engines, turbines (combined cycle), as well as fuel-cells.
- Hydrogen production: Synthesis of hydrogen (as used in refineries), synthetic natural gas and ammonia (mainly for fertiliser production).
- Transport fuels: Transportation fuel synthesis from gas-to-liquids processes including *Fischer-Tropsch* diesel and methanol / dimethyl ether.

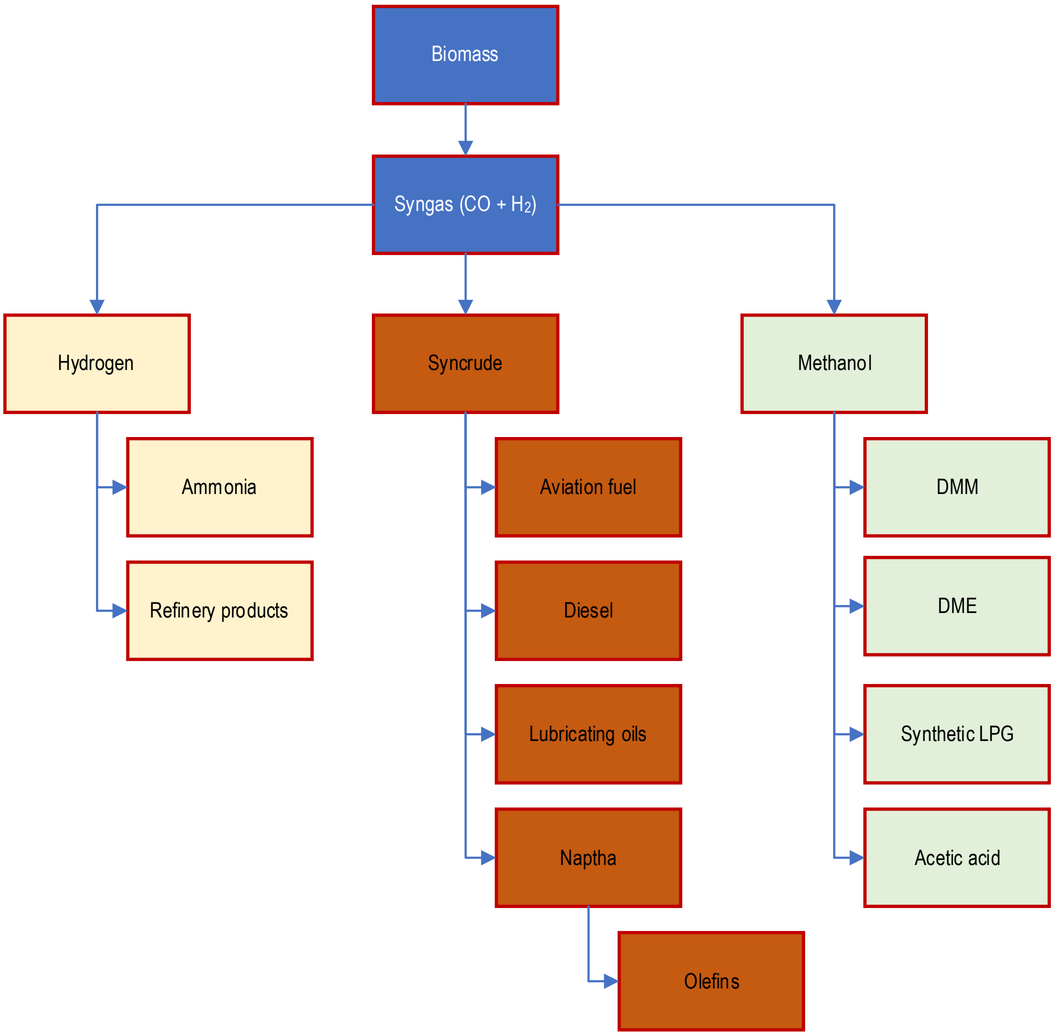

Figure 17: A summary of the range of products manufactured after an initial conversion of biomass into syngas (based on Sims *et al.*, 2008, p.55). DME = dimethyl ether; DMM = Dimethoxymethane; LPG = liquid petroleum gas.

After cleaning, the syngas can be used to produce power or can be converted into lower alcohols, fuel (e.g. Fischer-Tropsch diesel) and chemical products (de Jong *et al.*, 2012, p.6 citing Vlachos, *et al.*, 2010). Syngas can also be fermented to produce methanol [CH_3OH], ethanol [C_2H_6OH], ammonia [NH_4] and potentially other chemical building blocks (de Jong *et al.*, 2012, p.6, citing Ineosbia, 2011). The conversion of syngas into a variety of fuels is based on available and established technologies. Production involves controlling the gasification and clean-up stages, then adapting the synthesis processes to a different feed gas. Bio-fuels under development include Bio-SNG, Bio-hydrogen, Bio-methanol and Bio-DME (Di Methyl Ether) (see Box 93).

Box 93: A snap-shot of four liquid fuels produced from syngas (based on Goble & Peck, 2013, p.46&47 citing a range of material; see below[42]).	
Product / process	Overview
The Fischer-Tropsch process	*'Purified and high energy syngas can be synthesised to liquid hydrocarbons via the Fischer-Tropsch (F-T); a process used for decades, most notably by Germany during the Second World War to produce synthetic liquid fuels from coal or natural gas. Carbon monoxide and hydrogen are reacted in the presence of heat and a catalyst (typically iron and cobalt) to produce a liquid composed of hydrocarbon fractions. These can be separated by distillation (or other processes) into synthetic automotive fuels. Heat is evolved during synthesis and frequently used to dry the fuel, aid distillation and similar.'*
Bio-SNG	*'A synthetic natural gas produced from syngas via a process called methanation, which uses a nickel based catalyst to produce a methane (CH_4) rich fuel stream. A lower gasification temperature to produce syngas prior to methanation produces some methane in the syngas which helps control the methanation process by reducing the energy released from this highly exothermic reaction. A lower gasification temperature helps address technical difficulties with biomass gasification. Bio-SNG can be used for transport fuel and as stationary heat and power, potentially in existing infrastructure.'*
Bio-hydrogen	*'Gasification employs the water gas shift reaction to increase hydrogen yield and fully oxidise carbon to carbon dioxide. Carbon dioxide is usually separated and hydrogen is then typically compressed. Hydrogen may be used as a fuel in internal combustion engines or fuel cells.'*
Bio-methanol	*'Methanol synthesis preferably takes place in the liquid phase, resulting in higher yields. It can be a petrol substitute due to its high-octane number. Bi-methanol, like bio-ethanol has a lower energy density, lower vapour pressure and may be incompatible with certain engine materials (e.g. rubbers and plastics). It can be used in fuel cells with direct conversion to electricity.'*
Bio-DME (di methyl ether)	*'Bio-di methyl ether) is usually produced from pure methanol via catalytic dehydration, which chemically separates water from methanol. Often methanol and DME are produced together in one process. Bio-DME produced directly from synthesis gas is still under development.'*

[42] US Department of Energy Bioenergy Technologies Office http://www1.eere.energy.gov/biomass/thermochemical_processes.html (accessed Sept, 2012) Good for other bio products; Deurwaarder, E.P., .Boerrigter, H., .Mozaffarian, H., Rabou, L. P.L.M. & van der Drift, B. (2005). Methanation of Milena product gas for the production of bio-SNG. Published at 14th European Biomass Conference & Exhibition, Paris, France, 17-21 October 2005.
http://www.biofuelstp.eu/bioethanol.html No access
http://www.repotec.at/index.php/research-development.html old link

Thermo-chemical conversion (direct or hydrothermal liquefaction)

The technology and intent

There are three titles applied to this technology to produce liquid fuels; thermo-chemical conversion, direct liquefaction or hydrothermal liquefaction. For simplicity it will be referred to as hydrothermal liquefaction (HTL). The purpose of liquefaction is to increase the H:C ratio of the oil product and to decrease the O:C ratio of the input feedstock to achieve hydrocarbon-like products. Addition of a reducing gas (e.g. H_2 or CO) increases the H:C ratio and oxygen removal occurs via internal dehydration and decarboxylation reactions occurring during the initial pyrolytic stages (Goble & Peck, 2013, p.59 citing http://www.webpages.uidaho.edu/~bhe/biorefinery/4.pdf [an old link]). Overall, HTL is still considered as an emerging technology, however some companies are active in its commercialization.

The process

Overview

Hydrothermal liquefaction is a direct liquefaction to convert biomass into liquid oil and is different to indirect liquefaction which produces a liquid fuel by gasifying organic materials to syngas and then synthesis to ethanol, methanol or other chemical compounds (Goble & Peck, 2013, p.59). The process replicates the natural process of conversion of a liquid slurry of biomass into organic materials and then to hydrocarbon oils and by-products under high pressure and temperature over millions of years, but in c. 30 minutes (Goble & Peck, 2013, p.59). It involves the reaction of the input feedstock in the presence of water under super critical conditions (high temperature and pressure) where the pressure maintains the water primarily in the liquid phase (Goble & Peck, 2013, p.59 citing http://www1.eere.energy.gov/biomass/printable_versions/pyrolysis.html US Department of Energy, Bioenergies Technologies Office and http://www.webpages.uidaho.edu/~bhe/biorefinery/4.pdf [old link]). Supercritical water conditions occur at temperatures above 374°C and pressures above 22.1 MPa and Table 10 presents hydrothermal conditions reported. A series of separation processes remove the solids and water rich streams from the bio-derived oil (Goble & Peck, 2013, p.59).

Table 10: Reported examples of the operating conditions under which HTL is achieved.

Attribute	Units	System A	System B
Temperature	(°C)	250 to 370	300 to 350
Pressure	(MPa)	4 to 22	12.2 to 20.3
Reference		Platt *et al.* (2021, p.119)	Goble & Peck (2013, p.59 citing http://www1.eere.energy.gov/biomass/printable_versions/pyrolysis.html US Department of Energy, Bioenergies Technologies Office and http://www.webpages.uidaho.edu/~bhe/biorefinery/4.pdf [old link]).)

A gas production system

A subset of biomass HTL is the catalytic reforming of biomass in sub and supercritical water to produce gas; H_2 and/or methane (Huber, 2008, p.38, citing Matsumura, *et al.* 2005). Catalytic reforming is a process in which hydrocarbon molecules are structurally rearranged to higher octane forms. It was shown that supercritical reforming of wood sawdust produces gaseous products while avoiding coke formation (Huber, 2008, p.38 citing Modell, 1977 & Modell, *et al.*, 1978). For example, the Battelle single-step subcritical gasification reactor produces gas with high methane levels at temperatures of around 350°C and pressures of 21 MPa with ruthenium [Ru] and nickel [Ni] catalysts supported on titanium oxide [TiO_2], zirconium oxide (ZrO_2) or carbon (Huber, 2008, p.38, citing Elliott, *et al.,* 2004 & Elliott, *et al.*, 2006). Higher reaction temperatures and pressure (600°C and 34.5 MPa) have produced H_2 from supercritical reforming of glucose (Huber, 2008, p.38, citing Matsumura, *et al.,* 2005) with activated carbon as an efficient catalyst (Huber, 2008, p.38, citing Xu *et al.*, 1996). At a weight hour space velocity (e.g. a measure of mass flow feeds of fluids through a reactor per unit of catalyst) of c.20 h, close to 100% of the glucose feed was gasified resulting in a molar gas composition of 22% H_2, 34% CO, 21% CO_2, 15% CH_4, 6% ethane [C_2H_6], and 2% propane [C_3H_8].

Huber (2008, p.38) notes the following advantages of supercritical reforming; high reaction rates, impure feedstocks can be used, wet feedstocks can be processed (with high thermal efficiencies), the product gas is produced in a single reactor, and is available at high pressure. The disadvantages noted are the high capital cost of a high-pressure reactor and that H_2 can be selectively produced only at high temperatures where large amounts of CO are also produced. A concluding comment was that supercritical reforming is an excellent way to produce product gases from aqueous biomass mixtures (Huber, 2008, p.38).

Feedstock; type, condition and preparation

Feedstock inputs to HTL can include lignocellulosic materials (e.g. residues) from forestry and agriculture (Platt *et al.,* 2021, p.119). The biomass feedstock is formed into a water-based slurry (typically with 20% to 30% solids) with a uniform particle size (typically <1mm) (Goble & Peck, 2013, p.59 based on http://age-web.age.uiuc.edu/bee/research/IntroHTL.pdf [an old link]). As noted, a key difference with this technology is an ability to use wet biomass (Castello *et al.,* 2018, Abstract) which allows aquatic biomass and organic residues to be considered as potential feedstock. As well, low or negative-cost low-quality feedstocks (e.g. sludge and manure) can potentially be processed. Depending on feedstock and process, yields of oil can range by from 26 to 80%mw of the mass of the biomass feedstock (Goble & Peck, 2013, p.59).

Products

The output of HTL is a biocrude product; a liquid with high viscosity (free flowing) and is a combustible mixture of oxygenated hydrocarbons with a considerably lower oxygen content. It can be burned for fuel or converted (upgraded) to hydrocarbon fuels and commodity chemicals similar to those produced from petroleum (Goble & Peck, 2013, p.59). To produce a finished hydrocarbon product, HTL (without a first stabilization step), gives an important economic advantage, compared with fast pyrolysis. Compared to fast pyrolysis oil, HTL oil has lower oxygen content and is more thermally stable. These desirable properties are the result of the more severe processing conditions involved with HTL (i.e., longer residence time at high pressure). Subsequent hydrodeoxygenation can be accomplished through a catalytic hydrotreatment under conventional conditions resulting in high yields of hydrocarbon products (Huber, 2007, p.56). The primary by-product is water containing soluble organic compounds; the other by-products include steam, solid minerals and metals (i.e. as present in the feedstock), carbon char and inert and combustible gases. Derived from the feedstock, the solid minerals can include nitrogen, phosphorus, potassium and calcium which may be used as fertiliser. The inert and combustible gases vary by feedstock and process, but mainly are CO_2, CO and H_2. The combustible fuel gases (CO and H_2) produced may be recycled back into the process as a heating source, as process catalysts, or potentially as fuel for power generation. Steam can also be reused for process heat (Goble & Peck, 2013, p.59&60).

Hydrolysis and fermentation

Second generation biofuels

The definitions of first and second-generation biofuels are presented in Box 94. Current commercial-scale fuel ethanol production plants ferment readily available starch or sugars (e.g. corn, wheat or sugar cane) and the output is referred to as first generation bio-ethanol (Goble & Peck, 2013, p.60). A challenge was the fuel versus food dilemma with first generation biofuels, which stimulated the search for sustainable non-edible (second generation) feedstocks for production of biofuels (Eisentraut, 2010, p.7; Derman, *et al.,* 2018, p.285). Second-generation biofuels can be manufactured from a range of non-food bioresources; for example, energy crops, crop and forest residues and, construction and municipal waste (Naveed *et al.,* 2023, p.163). Indeed, the use of lignocellulose is an attractive feedstock due to the scale of material available combined with a reduction of food crop diversion to ethanol production (Goble & Peck, 2013, p.60). This material comprises a mixture of carbohydrate polymers from plant cell walls; cellulose and hemicellulose, plus lignin, and smaller amounts of extractives which include proteins, lipids and ash (Goble & Peck, 2013, p.60&61). It was reported in 2010 that there was no experience with commercial production of second-generation biofuels (Eisentraut, 2010, p.11).

Box 94: A delineation between first- and second-generation biofuels (based on GHD, 2019, p.6).	
First generation biofuels (aka conventional biofuels)	Second generation biofuels (aka advanced biofuels)
'Conventional biofuels are usually considered to be biodiesel produced from vegetable oils or ethanol produced from sugarcane, corn or wheat. Due to their high oxygen and moisture content, sedimentation and cold flow issues, there is a limit to how well these fuels can blend with petroleum.'	*'Advanced biofuels include renewable diesel, green diesel, Fischer–Tropsch (FT)-diesel, bio-jet fuel, and bio-gasoline. They are compatible with the existing infrastructure that was designed around petroleum. These and other advanced fuels like cellulosic ethanol, bio-CNG and bio-LNG also have a much greater potential to reduce carbon emissions than conventional biofuels.'*
'Conventional biofuels are: • *Produced almost exclusively from the human food chain.* • *Includes ethanol from sugar (for example, from cane) or starch (from corn).* • *Also includes biodiesel from oils and fats.* • *Not typically 100% compatible with existing fuel infrastructure or with existing vehicles, ships and planes.'*	*'Advanced biofuels are:* • *Referred to as second-, third- and even fourth-generation biofuels, depending on the type of feedstock used* • *Produced from non-food feedstocks* • *Includes residue from the forestry and agricultural sectors, including straw, cotton trash, sawdust and vegetation removed by agricultural thinning* • *Also includes purpose-grown crops such as high-yield grass, woody biomass or algae, typically grown on semi-arable land* • *Draws on eligible urban waste streams such as municipal solid waste (MSW) or household rubbish, and food waste streams such as corn stover (stalks, leaves and cobs left over after harvest)* • *Compatible with existing fuel infrastructure, these biofuels are widely seen as 'drop-in' biofuels.'*

Products

Feed stock trade

Trade (exports) in second-generation feedstock is an option for some countries to profit from growing biomass as a simpler and less capital-intensive venture. However, it is suggested that constraints (e.g. infrastructure) might make domestic use (e.g. for electricity production) more beneficial than exporting (Eisentraut, 2010, p.8).

Fuel ethanol

Second-generation bioethanol has potential as a valuable substitute or as a complement to petrol (Xiros *et al.*, 2013, p.633). Fuel ethanol is at least 99.5% pure before it is denatured with petroleum (regardless of feedstock; corn, sugar cane or biomass) to render it unfit for human consumption (Goble & Peck, 2013, p.61 combined with US Energy Information Administration glossary[43]). The ethanol product could have an energy content (lower heating value - LHV) of 26.7 GJ/t and density of 0.79 t/m^3 (21.2 MJ/l) (Goble & Peck, 2013, p.61).

Manufacturing process

The production of ethanol from lignocellulose has two general pathways; 1) the sugar route which employs hydrolysis to break down cellulose and hemicellulose into sugars, followed by fermentation into ethanol; and 2) the gasification route. Hydrolysis is undertaken by one of three methods; dilute acid hydrolysis, concentrated acid hydrolysis or enzymatic hydrolysis. Dilute acid hydrolysis occurs in two stages; the first hydrolyses the hemicellulose, exposing the cellulose for hydrolysis in the second stage. With concentrated acid hydrolysis, the feedstock is 'cooked' in sulfuric acid creating a mash, which is compressed to collect the excess fluid which is separated into ethanol and other by-products. Enzymatic hydrolysis uses enzymes to hydrolyse the feedstock into sugars. Enzymatic hydrolysis is sometimes carried out simultaneously with fermentation (Goble & Peck, 2013, p.60&61). A reported challenges is the pre-treatment of the biomass as the initial steps in most processes, is the recalcitrance of the lignocellulosic materials to biological degradation. One suggested process has been an *'integrated overall bioconversion process in which fermentation technology and genetic engineering of ethanologenic microorganisms aim not only at maximizing yields and productivities, but also at widening the range of fermentation products and applications'* (Xiros *et al.,* 2913, p.633).

Commercial production; UPM mono-ethylene glycol and mono-propylene glycol production

The UPM biorefinery in Leuna, Germany produces three broad chemicals (see Table 11). The site processes native hardwood (*Fagus sylvatica* - beech) thinnings and industrial roundwood sourced in compliance with Forest Stewardship Council (FSC™) or the Programme for Endorsement of Forest Certification (PEFC) and avoiding any deforestation. The site was to produce 220,000 t/y of output chemicals via a hydrolysis (and other processes) (BiLFINGER, 2025, p.1&2). The logs are debarked and chipped after delivery (UPM, 2024, p.9&11). The biorefinery processes extracts cellulose, lignin, and hemicellulose for subsequent refining into high-value base and performance chemicals (Table 11). A pre-treatment process separates out the hemicellulose and converts it into industrial sugars. These industrial sugars can be processed into other products; for example, fuel, food, and polymers for diverse applications (UPM, 2024, p.12). The next stage is a separation of the cellulose from lignin by an enzymatic process. This process breaks-down the cellulose into simple sugars which are converted into bio-monoethylene glycol and bio-monopropylene glycol. The lignin is converted into an entirely new category of biochemicals; renewable functional fillers (RFF), produced as a sustainable alternative to *carbon black* and precipitated silica in a broad range of rubber and plastic applications (UPM, 2024, p.12). Carbon black is finely divided graphitic carbon which is usually obtained as soot from incomplete combustion of petroleum products (e.g. diesel and fuel-oil), from firewood combustion, and other combustion processes (Klinkova, & Thérien-Aubin, 2024, Section 4.2).

[43] https://www.eia.gov/tools/glossary/index.php?id=Fuel%20ethanol accessed on the 10/02/2025.

Table 11: A summary of the UPM biorefinery outputs and subsequent products (based on UPM, 2024, p.4&11).

Chemical	Product	Product group	Specific products
Mono-ethylene glycol	UPM BioPura™ BioMEG	Base material for various industrial products and consumer goods	PET bottles, Packaging materials Polyester textiles Engine & battery coolants
Mono-propylene glycol	UPM BioPura™ BioMPG		Cleaning agents De-icing fluids Fragrances Cosmetics
Lignin based	UPM BioMotion™	Renewable Functional Fillers	Alternative to carbon black and silica in a variety of rubber and plastics applications. 100% electrically insulating.

Biochemical production based on specific examples

Lignin as a potential source subject to solving of technical issues

de Jong *et al.* (2012, p.8; citing Hatakeyama & Hatakeyama, 2010; citing Holladay *et al.,* 2007) noted that *'the structure of lignin suggests that it could play a central role as a new chemical feedstock, particularly in the formation of supramolecular materials and aromatic chemicals'.* They provide a list of products as presented in Box 95. This potential should be considered based on the point of caution presented. While noted as cost competitive for some products, there are specific challenges to be addressed, particularly in regard to lignin (see Box 96). A review presented an insight on currently available pre-treatment technologies (physical, chemical, physicochemical and biological methods) for deconstruction and fractionation of lignocellulosic biomass for development of a lignocellulosic feedstock based biorefinery (Kumar *et al.,* 2020, abstract). The current status of each pretreatment technology on sugar and biofuel yield along with their limitations was presented. Research to overcome the challenges with lignocellulose to achieving full-scale commercial outcomes has been conducted with pretreatment and enzymatic hydrolysis. This fractionation of biomass *'is one such specific development of accessible, eco-friendly and profitable pretreatment which qualitatively extracts and separates lignocellulose constituents, thus making the products marketable'* (Yogalakshmi *et al.,* 2023, p.18).

Box 95: A summary of the potential products derived from lignin (de Jong *et al.,* 2012, p.8).

Syngas products	Hydrocarbons	Phenols	Oxidised products	Macromolecules
Methanol	Benzene	Phenols	Vanilin	Carbon fibre filler
Dimethylether	Toluene	Substituted phenols	Vanilic acid	Polymer extenders
Ethanol	Cyclohexane	Catechols	Dimethul sulfoxide	Substitute lignins
Mixed alcohols	Styrenes	Cresols	Aroinatic acid	Thermoset resins
Fischer Tropsch liquids	Biphenyls	Resorcinals	Allphatic acid	Comosites
C1-C7 gases		Eugenol	Syringaldyde	Adhesives
		Syringols	Aldehydes	Binders
		Coniferols	Quinones	Preservatives
		Guaiacols	Cyclohexanol	Pharmaceuticals
			B-keto adipate	Polyols

Box 96: The main pre-processing and processing technologies used in biorefinery are as follows (Calvo-Flores & Martin-Martinez, 2022, p.2).

'State-of-the-art biorefineries already produce cost-competitive chemicals and materials, but other products remain challenging from the economic point of view, or their scaled-up production processes are still not sufficiently developed. In particular, lignin's depolymerization is a required milestone for the success of integrated biorefineries, and better catalysts and processes must be improved to prepare bio-based aromatic simple molecules.'

Experimental stage; biomass extracts and paracetamol production

Research has developed a cost-effective and environmentally sustainable way to produce paracetamol from biomass and this potential new revenue stream could make cellulosic biofuels cost competitive with fossil fuels. The chemical of interest is in the lignin of the Family Salicaceae (e.g. Salix and Populus), the Family *Arecaceae* (e.g. coconut, carnauba, date and oil palms which are not trees) and in *Aralia cordata,* and in the seagrass *Posidonia oceanica* (of the monocot Family *Posidoniaceae*) (Karlen *et al.,* 2024, p.2). Paracetamol is one of the most widely used pharmaceuticals and since introduction in the early 1900s, it has been traditionally manufactured from derivatives of coal tar or petroleum (Timberbiz, 2024c). Karlen *et al.* (2024

Abstract) reported on research into a biomass-based paracetamol. The process utilised p-hydroxybenzoate in biomass feedstocks (e. g. poplar and palm trees) and converted this into a range of commodity chemicals (see Figure 18). The first step generates *p*-hydroxybenzamide produced from p-hydroxybenzoate esters found in the plants. The second stage is a continuous reaction process converting the p-hydroxybenzamide to p-aminophenol via the Hofmann rearrangement and recovers the unreacted *p*-hydroxybenzamide. In the third stage, the p-aminophenol is acetylated to form paracetamol.

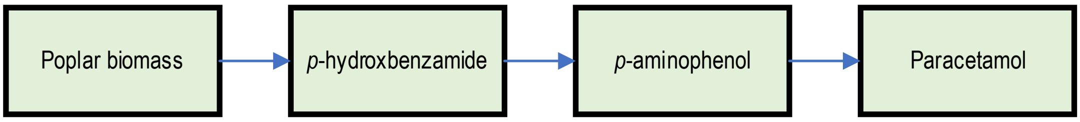

Figure 18: The production of paracetamol from chemicals in Poplar spp. lignin (based on Karlen *et al.,* 2024, p.1).

Demonstration and pilot scale plants; Metsä Group lignin refining

A Metsä Group project was to commence in mid-2024 in connection with its Äänekoski (Finland) bioproduct mill, to develop a demonstration plant for lignin refining to develop a production process. The objective is to make use of lignin as a by-product. The intent is to determine the various product properties suitable for a range of end-uses. This plant will integrate the LigniOx process (Timberbiz, 2024d). The demonstration plant is intended to produce 2 t/day of lignin products[44]. The LigniOx process is an alkali-O_2 oxidation technology for the conversion of several lignin-rich side-streams into versatile dispersants; for example high-performance concrete and mortar plasticizers (CBE, 2025). A plasticiser is added to concrete to make it softer, improve workability and strength, and to reduce water requirements (Bisley Company, 2023).

[44] See https://www.metsagroup.com/news-and-publications/news/2024/metsa-group-and-andritz-to-construct-a-demo-plant-for-developing-new-lignin-products/ accessed on the 24/04/2025.

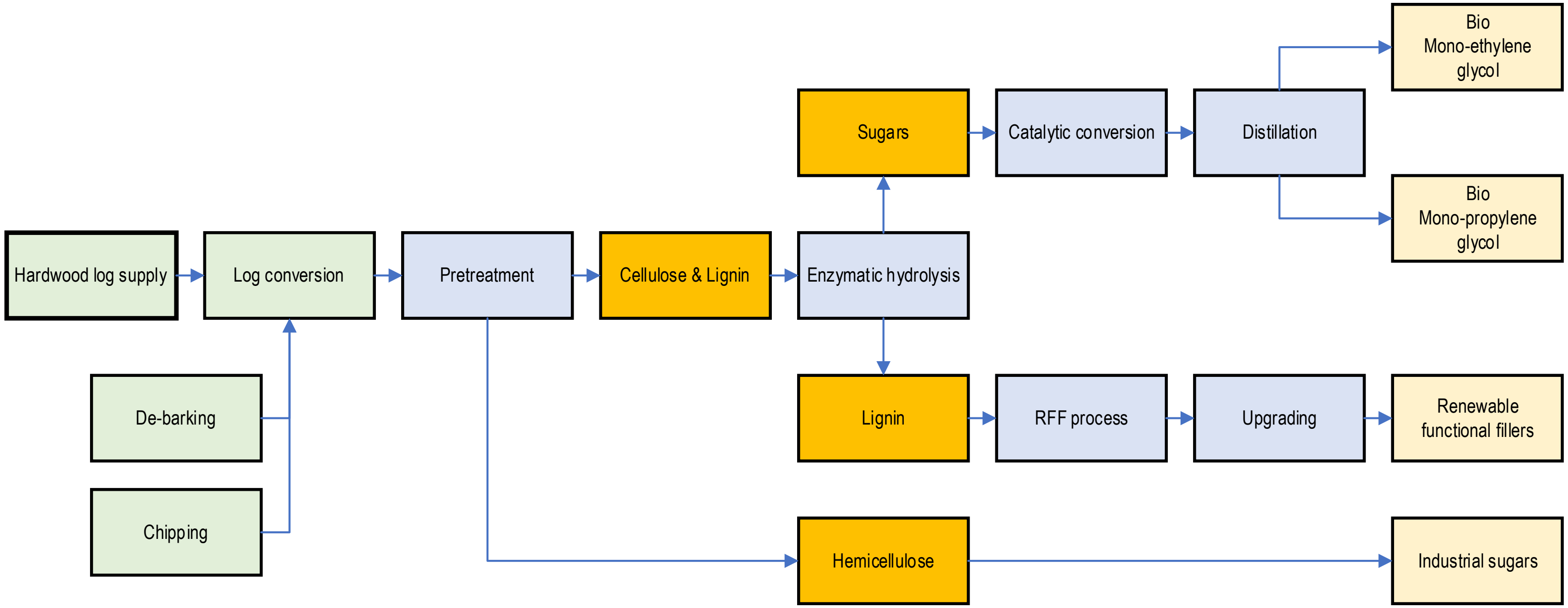

Figure 19: The steps in the UPM biorefinery located at Leuna, Germany (based on UPM, 2024, p.12).

Heat and electricity generations

Overview

The combustion of biomass generates heat and to use this energy, the heat needs to be transferred to a heat transfer medium in a heat exchanger or boiler. The medium can be saturated or superheated steam (e.g. steam that is heated above its boiling point at a given pressure). It is relatively inexpensive and an efficient heat transfer medium widely used for process and space heating. Steam is also widely used for electricity production and in co-generation (Goble & Peck, 2013, p.26&30). Biomass can supply the energy required to generate electricity; via direct combustion to produce steam then passing that steam through a steam turbine or steam engine to drive a generator, or by first gasifying the wood and combusting the gas in a gas turbine or internal combustion engine to drive a generator (Goble & Peck, 2013, p.29). Generators are usually supplied as a combined unit with a turbine or other engine. Integration with turbines or engines offers better performance and efficiency than discretely joined systems. The electrical generation and conditioning component is the GenSet. This may include generators with continuous output (or alternators with as required output), inverters, transformers and a control system (Goble & Peck, 2013, p.37).

It is important to consider the difference between electrical capacity (MW_e) and thermal capacity (MW_T). There is an electrical efficiency factor between the heat energy generated by biomass combustion and the conversion of that energy into electricity. For example, at an efficiency of 25%, a 10 MW_T system would have an electrical capacity of 2.5 MW_e. An efficiency rate of 25% is the lower-end of the range presented by the International Renewable Energy Agency (Lako *et al.,* 2015, p.12, Figure 6). The electricity output (e.g. KWh) depends on the electricity generation capacity (the MW_e) and the time an individual generator operates at a specific capacity. For example, a single generator that has an electricity generation capacity of 1 megawatt (MW_e) operating at that capacity continuously for 24 hours, it will generate 24 megawatthours (MWh) of electricity. If it operates at that capacity continuously for 365 days, it will generate 8,760 MWh (based on USEIA, 2024). At a conversion rate of one megawatt equals 3,600 megajoules (MJ), a 1 MW_e capacity generator operating non-stop for a year would generate 31.4 million MJ of energy.

Direct combustion steam-based systems

Combustion

Combustion is a chemical reaction of a fuel in the presence of an oxidizer (commonly oxygen) and heat (see Figure 9). There are three stages of combustion (see Box 97). The fuel and the oxidizer react together to form new chemical substances, often gaseous products (Bastidas-Oyanedel, *et al.,* 2019). Direct combustion of woody biomass yields net energy as visible and infrared radiation, and as sensible heat within the combustion products, predominantly in the flue gas stream. The design of a combustion chamber facilitates efficient burning and focusses the evolved heat to where it is required. They are designed to suit the fuel quantity and characteristics, and the intended use of the heat (Goble & Peck, 2013, p.23). There are four categories of modern furnace types; pile burners, stoker grate, suspension and fluidised beds (see Box 98). Combustion can be carried-out by ‘conventional’ means or by using a staged combustion or gasification. An important consideration is the by-products of combustion; any emissions and the management of the resulting ash.

Box 97: The three stages of combustion based on Goble & Peck (2013, p.23).	
Stage	Narrative
Drying and torrefaction	*'The first stage of combustion is the heating and evaporation stage. Moisture must be driven-off before combustion can begin, hence wood with a high moisture content is difficult to ignite. The initial drying can take place in the furnace (using hot combustion air) or in an external dryer. When the temperature of the wood surface approaches 100°C, the water evaporates. While water remains, evaporation maintains the temperature at 100°C. As the surface temperature increases beyond 100°C to about 230°C, torrefaction begins evolving gases (carbon dioxide and carbon monoxide) and with acetic and formic acids.'*
Combustion - Volatilisation	*'Once dry and the temperature of the wood increases above about 280°C, the second stage of combustion takes place. This is the heat-producing stage. Primary combustion is the process by which gases are released from the wood and burned. It begins at c. 280°C, continues toward 500°C releasing of energy. During this stage unburned combustible gases (e.g. methane and methanol), acids, water vapour and carbon dioxides are produced. The gases contain up to 60% of the potential heat in the wood; their combustion achieves high overall combustion efficiency. They are not burned near the wood due to a lack of oxygen. Secondary gases burn with sufficient oxygen and temperatures of at least 600°C. A balance is required; too little air will not support combustion and too much will cool the temperature below where combustion cannot occur. The more air that mixes with the secondary gases, the greater the quantity of heat absorbed, reducing below the temperature of the secondary gas-air mixture.'*
Combustion – Charcoal burn	*'The final stage is the combustion of the char which remains once the gases have been released and consumed. It burns over a long time with a low rate of heat output and is reduced to ash to complete the combustion process.'*

Biomass consumption rate

A 2018 study of the use of plantation residues to provide energy on combustion in the Green Triangle suggested an annual combustion rate of 4,000 t_{GREEN} per MW_T of capacity (Enecon, 2018, p.12). This highlights the importance of understanding the biomass moisture content and the nature of the capacity considered; in this case, biomass at 50% moisture content was used to generate thermal heat alone. Goble & Peck (2013, p.24&25) noted an advantage of bubbling fluidised beds over circulating fluidised beds was the smaller scales; smaller than 60 MW_T, which equates to approximately 90,000 t/y of 'dry wood'. This equates to 1,500 $t/MW_T/y$ for 'dry wood'.

Steam turbine system

Driving a steam turbine normally require superheated steam to ensure it is free of water droplets that would erode the turbine blades. Steam is generated in a boiler system and introduced to a steam turbine; an established, widely available and robust technology. Biomass based systems are possibly marginal at 5 MW_e (electrical capacity) and generally economically feasible above 10 MW_e (Goble & Peck, 2013, p.30). At 10,000 tonnes of bone-dry biomass per MW_e per year, the required inputs would be 50,000 to 100,000 $t_{BONE\ DRY}/y$ for the 5 MW_e and 10 MW_e capacity units respectively. Such plants require a source of high-quality water for initial filling and for continuous make-up (top-ups). A condensing turbine can be used to increase water-use efficiency. The steam passes directly from the turbine into a condenser, operating at sub-atmospheric pressure which enables the maximum energy to be recovered by the turbine. Condensers condense the steam in the turbine into liquid to allow pumping. They use re-circulated cooled water via a cooling tower or via a cooling pond (Goble & Peck, 2013, p.30).

Box 98: A summary of the different biomass combustion technologies (based on Goble & Peck, 2013, p.24&25).				
Technology			Advantages	Disadvantages
Pile burners		The biomass is placed into piles in a furnace and burned with the help of combustion air coming from under and above the grate.	It has fuel flexibility and a simple design.	Generally low combustion efficiency due to poor combustion control. Manually removal of ash. Not often used in commercial plant unless the ash content is very low.
Stoker fired		Within the group of stoker-fired boilers, there are three major types of grates, namely stationary sloping grate, travelling grate and vibrating grate.	The aim is to automatically remove ash whilst helping to ensure complete combustion of the biomass. The fuel feeding system puts a layer of fuel on the grate that is relatively small and more evenly distributed than in the case of pile burners. In a stationary sloping grate boiler, the grate does not move, but the fuel burns as it slides down the slope.	Difficult in controlling the combustion process and the risk of avalanching of the fuel.
Travelling grate		The fuel is fed on one side of the grate and has to be burned by the time the grate has transported it to the ash dumping site of the furnace.	Combustion control is improved over a stationary (or fixed grate). As there is only a small layer of fuel on the grate, carbon burnout efficiency is also better in comparison with the stationary sloping grate boiler. In a vibrating grate boiler, the fuel is fed evenly onto the whole grate. The grate has a shaking movement which spreads the fuel evenly with fewer moving parts than a travelling grate with typically lower maintenance. The degree to which carbon is fully combusted is further improved and in the case of water-cooled grates, it is possible to increase the amount of over-fire air, which has the advantage of less thermal NOx creation.	
Suspension firing		The fuel is fired as small particles which combust as they are fed into the boiler. This system can be compared with the pulverised coal firing technology.	A high combustion efficiency.	Requires fine friable fuel. Preparation to a suitable state can include intensive pre-treatment. The particle size depends on the biomass and the furnace design; the residence time required for efficient combustion. For wood; a particle size of 1-2 mm.
Fluidised bed		Combustion air fed from below the furnace chamber through sand at a high speed so that the fuel becomes a mass of particles and bubbles.	They are flexible in fuel used and are suitable for co-firing different kind of fuels. Carbon burnout efficiency is very high in fluidised bed systems. A potential to control NOx creation by controlling the combustion temperatures and to minimise SOx creation.	A disadvantage is the high demand for air to fluidise the bed which requires large fans adding to the plant parasitic power consumption, particularly in smaller furnaces.
	Bubbling fluidised bed (BFB)	Materials are fluidised by supplying fluidising air (combustion air) from the furnace bottom. Fuels are fed into the furnace at a temperature within an optimum range for combustion or gasification.	BFBs have a lower height of fluidised bed sand than CFBs and can burn up to $75\%_{wb}$ moisture content fuels although generally designed for $65\%_{wb}$. An advantage of bubbling fluidised beds over circulating fluidised beds is their lower capital requirement at modest scales, i.e., smaller than 60 MW_T, which equates to approximately 90,000 t/y of dry wood.	A square design and cannot easily be scaled up in size; traditionally been used for small to moderate scales.
	Circulating fluidised bed (CFB)	Most of the particles leave from the furnace and are collected by a cyclone located at the exit, and then returned to the furnace for further combustion.	Have better carbon burnout efficiencies and absorb acid gases more easily. The bed material (usually sand) requires regular cleaning of ash and other non-combustibles; done automatically. CFBs would be used with biomass containing high chloride levels, as would occur in agricultural residues.	Very low NOx emissions; however they are limited to 60 to $63\%_{wb}$ moisture content.

Organic Rankine Cycle

An Organic Rankine Cycle (ORC) unit does not use water for steam; they use an organic high-molecular mass fluid to drive the turbine in units with electricity outputs of 2kW$_e$ up to 3 MW$_e$. The working fluids efficiently exploits heat at 80^{o}C to 500^{o}C to produce electricity; in theory, the lower the 'input' temperature the lower the system efficiency. Such units can be run off waste steam, engine exhaust gas or hot water; for example, waste heat extracted from biomass boilers flues or from excess steam at 150^{o}C (or less with a drop in efficiency) (Bini & Manciana 1998, p.219; Goble & Peck, 2013, p.30). Bini and Manciana (1998, p.219) noted the following advantages of such systems.

- High cycle efficiency; that is the conversion of input heat into electricity.
- Very high turbine efficiency (up to 85%).
- Low mechanical stress of the turbine, due to the low peripheral speed.
- Low revolutions per minute (RPM) of the turbine allowing a direct drive of an electric generator without a reduction gear.
- No erosion of blades, due to the absence of moisture in the vapour nozzles.
- A long life.

Steam engines

Steam engines are a flexible electricity generation option, particularly at capacity of less than 'a few' MW$_e$. Steam engines that are supplied with steam from an external combustion plant, can cleanly and efficiently burn a wider variety of fuels compared to internal combustion engines (Goble & Peck, 2013, p.31). They are commonly integrated within a co-generation system where the steam engine is operated in back-pressure mode where the exhaust heat is used (e.g. in drying kilns). Under such conditions, they have better electrical efficiency than a steam turbine, combined with a capacity to operate at less than maximum requirements. Where the intent is solely electricity generation with a constant load, a steam turbine would normally achieve a higher electrical efficiency, as a turbine can expand the steam more fully into a vacuum (Goble & Peck, 2013, p.32).

Generation strategies

Co-generation of heat and electricity

Co-generation or combined heat and power (CHP) is a simultaneous production of useful heat and electricity. If waste heat is partially or intermittently used for cooling, it is referred to as tri-generation or combined heating, cooling and power (CHCP) (Goble & Peck, 2013, p.40). Combined heat and power systems suit industrial situations where there is available biomass feedstock and a need for electricity production and heating or cooling (Geddes, 2010, p.34). A specific case is a district heating plant using woodchips or wood fibres as a heating source to produce heat and electricity generation and such plants have been operating in Europe since the early 1990's (Geddes 2010, p.13). In a CHP plant, heat is usually produced in the form of steam and piped to where it is needed. The steam can provide significant quantities of lower temperature energy (e.g. for kiln drying). A CHP plant must balance demand for process heat and electricity, influencing the type of technology used. A gasification-based CHP system allows extraction of heat by directly combusting the syngas when and where required. Such systems require minimal syngas clean-up. Alternatively, heat in the flue gases from a combustion chamber (or the exhaust from an internal combustion engine or from the engine coolant) can be used. It is possible to use heat exchangers to address noxious fumes (Goble & Peck, 2013, p.40).

Co-firing of biomass

Co-firing is the simultaneous combustion of multiple different fuels in one furnace or boiler; for example, using wood residue fuels in large-scale kilns and utility boilers. Co-firing of biomass processing residues in stoker-fired boilers (i.e. where fuel is introduced into a combustion vessel) is an old technology. For example, steam boilers in the pulp and paper industry can use a traveling grate in spreader-stoker boilers suitable for co-firing. The boilers are fired with wood residues, coal, pulp mill sludge, and other fossil fuels and wastes. Such firing maximizes responsiveness to changing load conditions, while minimizing fuel costs. Co-firing of biomass in large-scale utility boilers used for power generation enables the use of the larger capacity boilers, higher main steam pressures and incorporation of reheat steam into the boilers, with corresponding efficiency and availability of benefits compared with smaller scale industrial boilers (Goble & Peck, 2013, p.42).

Biomass converted into an intermediary energy source

Gas turbine

A gas turbine is a system where syngas is combusted in a gas turbine engine and the resulting gas expansion is used to rotate a turbine and drive a generator. It can be fuelled by gasified biomass where the syngas is cleaned of contaminants. An Integrated Gasification Combined Cycle (IGCC) can be used with fossil fuels at large scale (from 500 kW_e to 350 MW_e). The gas turbines are combined with a heat recovery steam turbine system in which the heat is recovered from the high-temperature exhaust and used to produce steam. This steam is then used to drive a turbine and generator. Such systems have not been found to be commercially viable with wood fuels, primarily due to size constraints. It is considered that IGCC systems offer potential to achieve higher overall electrical efficiencies of 22% to 37% compared with 15% to 18% typical for steam turbine-based biomass fuelled generation systems. Micro-turbines (30 to 400 kW_e) are under development, but are targeted at use with fossil fuels. Like larger gas turbines, micro-turbines can be used in power-only generation or in combined heat and power (CHP) systems (Goble & Peck, 2013, p.35).

Internal combustion engine

Reciprocating (piston) internal combustion (IC) engines can be fuelled by syngas cleaned of contaminants. Cleaning of syngas to an adequate quality is technically challenging and may introduce significant commercial risks. Such systems are generally suited to small scale electricity generation (c. 2 MW_e) (Goble & Peck, 2013, p.37).

Fuel-cells

Fuel-cells generate electricity electrochemically. Hydrogen is delivered to the anode (positive side) and oxygen is delivered to cathode (negative side). Charged atoms or ions of either hydrogen or oxygen pass across a gas-impervious membrane to react on the other side. This flow of charged ions is a direct electric current. Fuel cell stacks are silent without moving parts and have potential fuel efficiencies in excess of most advanced reciprocating engine or turbine power generation systems (Goble & Peck, 2013, p.38).

Examples of biomass energy systems

Geddes (2010, p.7) reported on CHP systems in the Limestone Coast Region of South Australia noting potential in softwood sawmills, the Kimberly Clark Australia pulp mill or other factories with a need for continuous base-load heat and power. There was previous experience in the region. In the 1980s, two sawmills used cogeneration systems to provide steam to dry sawn timber and used turbines to generate electricity with surplus electricity sold into the grid at a fraction of the commercial electricity price.

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Appendix A: A detailed table of contents

Appendix B: Terms and units used in this report

Acronyms used in this report

Acronym	In full
3D	Three dimensions
AS	Australian Standard
BFB	Bubbling fluidised bed
bio-CNG	Bio compressed natural gas
bio-DME	Bio di methyl ether
bio-LNG	Bio liquid natural gas
bio-SNG	Bio syngas
BTG	Biomass Technology Group
CBE	Circular bio-based Europe
CFB	Circulating fluidised bed
CFB	Circulating fluidise bed
CHCP	Combined heat and cooling plant
CHP	Combined heat and power
CIFOR	Centre for International Forestry Research
CLT	Cross laminated timber
CNG	Compressed natural gas
CO_2-e	Carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAR	Dressed all round
DCC	Department of Climate Change
DCM	Dichloromethane
DLT	Dowel laminated timber
DMF	Dimethylflormamide
DMSO	Dimethyl sulfoxide
EPA	Environment Protection Agency
EPA NSW	Environment Protection Agency, NSW
EPA Vic	Environment Protection Agency, Victoria
EWP	Engineered wood product
FAO	The Food and Agricultural Organization of the United Nations
FAOSTAT	The statistics service of the FAO
FES	Foundation for the Economics of Sustainability
FSC™	Forest Stewardship Council
FSP	Fibre saturation point
FT	Fischer Tropsch
GL grades	Grades of glue laminated timber
GLT	Glue laminated timber
Glulam	Glue laminated timber
GOS	Green off-saw
HDF	High-density fibreboard
HHV	Higher heating value
HS Convention	Harmonized Commodity Description and Coding System
HTL	Hydrothermal liquefaction
IC	Internal combustion
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPBES	International Science-Policy Platform on Biodiversity and Ecosystem Services
LGE	Levoglucosenone
LHV	Lower heat value
LPG	Liquid petroleum gas
LSL	Laminated strand lumber
LVL	Laminated veneer lumber
MC	Moisture content
MDF	Medium density fibreboard
MDP	Medium density particleboard
MGP	Machine graded pine
MIG	Montreal Process Implementation Group for Australia
MIT	Massachusetts Institute of Technology
MPP	Mesophase pitch

Acronym		In full
MSW		Municipal solid waste
NASAA		National Association for Sustainable Agriculture, Australia
NETL		National Energy Technology Laboratory
NFISC		National Forest Inventory Steering Committee
NLT		Nail laminated timber
NMP		N-methyl-2-pyrrolidone
NSW		New South Wales
NTFP		Non-timber forest products
NWFP		Non-wood forest products
NZS		New Zealand Standard
ORC		Organic Rankin Cycle
OSB		Oriented strand board
OSL		Oriented strand lumber
PAN		Polyacrylonite
PCM		Pyrogenic carbonaceous material
PE		Polyethylene
PEFC		Progamme for Endorsement of Forest Certification
PLT		Panel laminated timber
PP		Polypropylene
PSL		Parallel strand lumber
PST		Pine sawn timber
PVC		Polyvinyl chloride
QAFFI		Queensland Alliance for Agriculture and Food Innovations
RFF		Renewable functional fillers
SCL		Structural composite lumber
SCWG		Supercritical water gasification
SITC		Standard Industry Trade Classification
TFP		Turbulent flow precipitator
UN		United Nations
US		United States of America
USEIA		US Energy Information Administration
UV		Ultra violate
WCO		World Custom Organization
WPC		Wood-plastic composites
WPV		Wood Products Victoria
X-lam		Cross laminated timber (alternative acronym)

Species mentioned in this report

Major group	Scientific name		Common name
Hardwoods	*Acacia spp.*		Acacias - wattles
	Diploglottis bracteata		Boon jee tamarind
	Eucalyptus astringens		Brown mallet
	E. globifera		
	E. macrorhyncha		Red stringybark
	E. piperita		Sydney peppermint
	E. radiata		Narrow-leaved peppermint
	E. regnans		Mountain ash
	Fagus sylvatica		Beech
	Salix spp.		Willow species
	Poplus spp.		Poplar species
	Family Salicaceae		Willows and poplars
			Cape York lilly pilly
			Gum Arabic
Softwoods	*Pinus radiata*		Radiata pine
	P. sylvestris		Scott's Pine
	Picea abies		Norway pruce
Non-trees	*Aralia cordata*		Japanese spikenard
	Family Arecaceae		Coconuts, carndauba, date palms and oil palms
	Family Posidoniaceae		Seagrass
	Posidonia oceanica		Seagrass
			Tasmanian pepper leaves

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Chemical mentioned in this report

Symbol		Name
Cr		Chromium
NO_x		Nitrous oxides
SO_x		Sulphur oxides
Al		Aluminium
NH_3		Ammonia
NH_4		Ammonium ion
Cd		Cadmium
Ca		Calcium
C		Carbon
CO_2		Carbon dioxide
CO		Carbon monoxide
COS		Carbonyl sulfide
Co		Cobalt
Cu		Copper
C_2H_6		Ethane
C_2H_6OH		Ethanol
H_2		Dihydrogen
H		Hydrogen
HCl		Hydrogen chloride
HCN		Hydrogen cyanide
H_2		Hydrogen gas
H_2S		hydrogen sulfide
Fe		Iron
Pb		Lead
Mg		Magnesium
Mn		Manganese
Hg		Mercury
CH_4		Methane
CH_3OH		methanol
Mo		Molybdenum
Ni		Nickel
N		Nitrogen
N_2		Nitrogen gas
H_3PO_4		Phosphoric acid
P		Phosphorous
K		Potassium
K_2CO_3		Potassium carbonate
KOH		Potassium hydroxide
C_3H_8		Propane
Ru		Ruthenium
Na		Sodium
Na_2CO_3		Sodium carbonate
NaOH		Sodium hydroxide
TiO_2		Titanium oxide
V		Vanadium
Zn		Zinc
ZnCl		Zinc chloride
ZrO_2		Zirconium oxide

Specific chemical compounds mentioned by name in this report

1-hydroxy-2-propanone	Formaldehyde
Abietic acids	Formic
Acetaldehyde	Glyoxal
Acetic	Guaiacols
Adhesives	Hexanoic
Aldehyde, with a furan ring structure	Hydroxyacetaldehyde
Aldehydes	Insoluble pyrolytic lignin
Allphatic acid	Levoglucosan
Aroinatic acid	Levoglucosenone
Benzene	Methanol
Binders	Mixed alcohols
bio-CNG and bio-LNG	N-methyl-2-pyrrolidone
bio-monopropylene glycol	Oligosaccharides
Biphenyls	p-aminophenol
B-keto adipate	Paracetamol
Butyric	Pentanoic
C1-C7 gases	Phenols
Carbon fibre filler	p-hydroxybenzamide
Catechols	Pimaric acids
Cellobiosan	Polyacrylonite
Comosites	Polymer extenders
Coniferols	Polyols
Cresols	Polypropylene
Cyclohexane	Preservatives
Cyclohexanol	Propionic
Cyclopentanone	Quinones
Di Methyl Ether	Resorcinals
Dichloromethane	Styrenes
Dimethoxymethane	Substitute lignins
Dimethul sulfoxide	Substituted phenols
Dimethyl ether	Syringaldyde
Dimethyl sulfoxide	Syringols
Dimethylether	Thermoset resins
Dimethylformamide	Toluene
Ethanol	Unsaponifiables
Eugenol	Vanilic acid
Fischer Tropsch liquids	Vanilin

Units used in this report

Unit		In full	
cP		Centipoise	Viscosity
kg/ha		Kilograms per hectare	Application rate
t/ha		Tonnes per hectare	Application rate
CO_2-e		Carbon dioxide equivalent	Carbon units
g/kg		Grams per kilogram	Concentration
mg/hg		Micrograms per kilogram	Concentration
kg/h		Kilograms per hour	Consumption rate
t/day		Tonnes per day	Consumption rate
g/cm^2		Grams per square centimetre	Density
g/cm^3		Grams per cubic centimetre	Density
kg/m^3		Kilograms per metre cubed	Density
t/m^3		Tonnes per metre cubed	Density
kW		Kilowatt	Electricity output
KWh		Kilowatt hour	Electricity output
MW		Megawatt	Electricity output
MWh		Megawatt hour	Electricity output
GJ/t		Giga joules per tonne	Energy
MJ		Mega joule	Energy
MJ/l		Mega joules per litre	Energy
MJ/kg		Megajoules per kilogram	Energy density
MJ/kg		Mega joules per kilogram	Energy density
MJ/l		Mega joules per litre	Energy density
kW_e		Kilowatt of electricity generation	Generating capacity
MW_e		Mega watt electricity	Generating capacity
MW_T		Mega watt thermal	Generating capacity
t/MW_e		Tonnes per megawatt of electricity generating capacity	Inputs
t/MW_T		Tonnes per megawatt of thermal capacity	Inputs
cm		Centimetre	Length
mm		Millimetre	Length
nm		Nano metre	Length
pm		Picometres	Length
%		Percentage	Percentage
%mv		Percentage mass per volume	Percentage
%solids		Percentage solids	Percentage
%vol		Percentage by volume	Percentage
%wb		Percentage wet basis	Percentage
%wt		Percentage weight for weight	Percentage
%ww		Percentage weight for weight	Percentage
GPa		Giga pascal	Pressure
MPa		Mega pascal	Pressure
K		Degrees Kelvin; 0^o K = -273.15 ^{o}C	Temperature
^{o}C		Degrees Celsius	Temperature
m^3		Cubic metre	Volume
kg		Kilogram	Weight
t		Tonne	Weight
$t_{BONE\ DRY}$		Tonne of bone-dry material	Weight
t_{GREEN}		Tonne of green material	Weight

Appendix C: Internation wood product coding

The International Convention on the Harmonized Commodity Description and Coding System

The following description of the International Convention on the Harmonized Commodity Description and Coding System (the HS Convention) is based on information presented by the World Customs Organization (WCO)[45]. The HS Convention system is a basis for national Customs Tariffs, to underpin collection of international trade statistics, for rules of origin, for the collection of internal taxes, to underpin trade negotiations, in transport tariffs and statistics and for monitoring of controlled goods (e.g. wastes, narcotics, chemical weapons, ozone layer depleting substances and endangered species). Table 12 presents the relevant forest products codes to the second level of category. The HS Convention entered into force on 1 January 1988 with an objective *'(i) to facilitate international trade and the collection, comparison and analysis of statistics by harmonizing the description, classification and coding of goods in international trade; (ii) to reduce the expenses related to international trade and (iii) to facilitate the standardization of trade documentation and the transmission of data.'* The HS Convention preamble defines why the international community supported the adoption of the HS and its 20 Articles included provisions for obligations of Contracting Parties, the role of the Council and the Harmonized System Committee, settlement of disputes between Contracting Parties, and the amendment procedure (see WCO, 1983). The HS nomenclature is defined in an Annex to the convention. All Contracting Parties must ensure that their Customs tariffs and statistical nomenclatures for both imports and exports conform with the HS Convention. Publicly available import and export trade statistics must conform with the HS six-digit codes.

The Standard international trade classification

The Standard International Trade Classification (SITC) is the United Nations (UN) product classification used for external trade statistics (export and import values and volumes of goods)[46]. It allows for international comparisons of commodities and manufactured goods. The structure of SITC reflects the production materials, the processing stage, market practices and uses of the products, the importance of the goods in world trade and technological changes. The main categories of the SITC are; food (including live animals), drinks and tobacco, raw materials, energy products, chemicals (including pharmaceuticals) and plastics), machinery and transport equipment, other manufactured goods and other goods. The scope of SITC covers all goods classifiable in HS 2007 (excluding monetary gold, gold coin and current coin). All basic headings are defined in terms of the HS 2007 subheadings (FAO, 2022, p.42).

[45] See https://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs_convention.aspx accessed on 25/02/2025.

[46] See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Standard_international_trade_classification_(SITC) accessed on 25/02/2025.

Table 12: The internation trade Harmonized System codes (to the second level) based on WCO (2022).

Section	Chapter		Heading	Description
9	**44**	**Wood and articles of wood; wood charcoal**		
			4401	Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms; wood in woodchips or particles; sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms
			4402	Wood charcoal (including shell or nut charcoal), whether or not agglomerated
			4403	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared
			4404	Hoopwood; split poles; piles, pickets and stakes of wood, pointed but not sawn lengthwise; wooden sticks, roughly trimmed but not turned, bent or otherwise worked, suitable for the manufacture of walking-sticks, umbrellas, tool handles or the like; chipwood and the like
			4405	Wood wool; wood flour
			4406	Railway or tramway sleepers (cross-ties) of wood
			4407	Wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end-jointed, of a thickness exceeding 6 mm
			4409	Wood (including strips and friezes for parquet flooring, not assembled) continuously shaped (tongued, grooved, rebated, chamfered, v-jointed, beaded, moulded, rounded or the like) along any of its edges, ends or faces, whether or not planed, sanded or end-jointed
			4410	Particleboard, oriented strand board (osb) and similar board (for example waferboard) of wood or other ligneous materials, whether or not agglomerated with resins or other organic binding substances
			4411	Fibreboard of wood or other ligneous materials, whether or not bonded with resins or other organic substances
			4412	Plywood, veneered panels and similar laminated wood
			4413	Densified wood, in blocks, plates, strips or profile shapes
			4414	Wooden frames for paintings, photographs, mirrors or similar objects
			4415	Packing cases, boxes, crates, drums and similar packings, of wood; cable-drums of wood; pallets, box pallets and other load boards, of wood; pallet collars of wood
			4416	Casks, barrels, vats, tubs and other coopers' products and parts thereof, of wood, including staves
			4417	Tools, tool bodies, tool handles, broom or brush bodies and handles, of wood; boot or shoe lasts and trees, of wood

Section	Chapter		Heading	Description
			4418	Builders' joinery and carpentry of wood, including cellular wood panels, assembled flooring panels, shingles and shakes
			4419	Tableware and kitchenware, of wood
			4420	Wood marquetry and inlaid wood; caskets and cases for jewellery or cutlery, and similar articles, of wood; statuettes and other ornaments, of wood; wooden articles of furniture not falling in chapter 94
			4421	Other articles of wood
9	**45**	**Cork and articles of cork**		
			4501	Natural cork, raw or simply prepared; waste cork; crushed, granulated or ground cork
			4502	Natural cork, debacked or roughly squared, or in rectangular (including square) blocks, plates, sheets or strip, (including sharp-edged blanks for corks or stoppers)
			4503	Articles of natural cork
			4504	Agglomerated cork (with or without a binding substance) and articles of agglomerated cork
9	**46**	**Manufactures of straw, of esparto or of other plaiting materials; basketware and wickerwork.**		
10	**47**	**Pulp of wood or of other fibrous cellulosic material; recovered (waste and scrap) paper or paperboard**		
			4701	Mechanical wood pulp
			4702	Chemical wood pulp, dissolving grades
			4703	Chemical wood pulp, soda or sulphate, other than dissolving grades:
			4704	Chemical wood pulp, sulphite, other than dissolving grades:
			4705	Wood pulp obtained by a combination of mechanical and chemical pulping processes
			4706	Pulps of fibres derived from recovered (waste and scrap) paper or paperboard or of other fibrous cellulosic material
			4707	Recovered (waste and scrap) paper or paperboard
10	**48**	**Paper and paperboard; articles of paper pulp, of paper or of paperboard**		
			4801	Newsprint, in rolls or sheets

Section	Chapter	Heading	Description
		4802	Uncoated paper and paperboard, of a kind used for writing, printing or other graphic purposes, and non perforated punch-cards and punch tape paper, in rolls or rectangular (including square) sheets, of any size, other than paper of 4801 or 4803; hand-made paper and paperboard
		4803	Toilet or facial tissue stock, towel or napkin stock and similar paper of a kind used for household or sanitary purposes, cellulose wadding and webs of cellulose fibres, whether or not creped, crinkled, embossed, perforated, surface-coloured, surface-decorated or printed, in rolls or sheets
		4804	Uncoated kraft paper and paperboard, in rolls or sheets, other than that of 4802 or 4803
		4805	Other uncoated paper and paperboard, in rolls or sheets, not further worked or processed than as specified in note 3 to this chapter
		4806	Vegetable parchment, greaseproof papers, tracing papers and glassine and other glazed transparent or translucent papers, in rolls or sheets
		4807	Composite paper and paperboard (made by sticking flat layers of paper or paperboard together with an adhesive), not surface-coated or impregnated, whether or not internally reinforced, in rolls or sheets
		4808	Paper and paperboard, corrugated (with or without glued flat surface sheets), creped, crinkled, embossed or perforated, in rolls or sheets, other than paper of the kind described in 4803
		4809	Carbon paper, self-copy paper and other copying or transfer papers (including coated or impregnated paper for duplicator stencils or offset plates), whether or not printed, in rolls or sheets
		4810	Paper and paperboard, coated on one or both sides with kaolin (china clay) or other inorganic substances, with or without a binder, and with no other coating, whether or not surface-coloured, surface-decorated or printed, in rolls or rectangular (including square) sheets, of any size
		4811	Paper, paperboard, cellulose wadding and webs of cellulose fibres, coated, impregnated, covered, surface-coloured, surface-decorated or printed, in rolls or rectangular (including square) sheets, of any size, other than goods of the kind described in 4803, 4809 or 4810
		4812	Filter blocks, slabs and plates, of paper pulp
		4813	Cigarette paper, whether or not cut to size or in the form of booklets or tubes
		4814	Wallpaper and similar wall coverings; window transparencies of paper

Section	Chapter	Heading	Description
		4816	Carbon paper, self-copy paper and other copying or transfer papers (other than those of 4809), duplicator stencils and offset plates, of paper, whether or not put up in boxes
		4817	Envelopes, letter cards, plain postcards and correspondence cards, of paper or paperboard; boxes, pouches, wallets and writing compendiums, of paper or paperboard, containing an assortment of paper stationery
		4818	Toilet paper and similar paper, cellulose wadding or webs of cellulose fibres of a kind used for household or sanitary purposes, in rolls of a width not exceeding 36 cm, or cut to size or shape; handkerchiefs, cleansing tissues, towels, tablecloths, serviettes, bed sheets and similar household, sanitary or hospital articles, articles or apparel and clothing accessories, of paper pulp, paper, cellulose wadding or webs of cellulose fibres
		4819	Cartons, boxes, cases, bags and other packing containers, of paper, paperboard, cellulose wadding or webs of cellulose fibres; box files, letter trays, and similar articles, of paper or paperboard of a kind used in offices, shops or the like
		4820	Registers, account books, note books, order books, receipt books, letter pads, memorandum pads, diaries and similar articles, exercise books, blotting-pads, binders (loose-leaf or other), folders, file covers, manifold business forms, interleaved carbon sets and other articles of stationery, of paper or paperboard; albums for samples or for collections and book covers, of paper or paperboard
		4821	Paper or paperboard labels of all kinds, whether or not printed
		4822	Bobbins, spools, cops and similar supports of paper pulp, paper or paperboard (whether or not perforated or hardened)
		4823	Other paper, paperboard, cellulose wadding and webs of cellulose fibres, cut to size or shape, other articles of paper pulp, paper, paperboard, cellulose wadding or webs of cellulose fibres

Appendix D: The FAO applied classification structure of forest products

The Food and Agricultural Organization of the United Nations (FAO) presents a periodic updated classification of forest products (see FAO, 2022 for the current version). The publication covers all wood and paper products and provides a complete product classification. This can be used for international comparisons and promotes the harmonization of various types of statistics related to forest products. It can serve as a reference for ensuring consistency among existing international statistical systems related to forest products (FAO, 2022, p.v). The system includes an up to seven digit code reflecting a six-tier classification system. The classification system is practical as a basis of segmenting potential products, as it considers wood origin (for primary wood products), tree species, stage of manufacture, chief component material, technology applied in the production process and importantly the purpose or intended use (FAO, 2022, p.9&10). As such, there is a degree of cumulative nature in the system in that products are classified at the point of trade and reflect the conversion of proceeding or input products. The language of FAO definitions is consistent with HS Convention definitions to facilitate user understanding. The 2022 edition expanded the classification of forest products to include those items that are included or excluded (FAO, 2022, p.45).

Table 13: The wood product categories as defined by the Food and Agricultural Organisation of the United Nations (FAO, 2022).

Code	Major category	Code	Sub-category
1	WOOD IN THE ROUGH (ROUNDWOOD)		
		11	Wood fuel (including wood for charcoal)
		12	Wood in the rough other than wood fuel
2	WOOD SIMPLY WORKED OR PROCESSED		
		21	Wood charcoal
		22	Torrefied wood
		23	Roundwood treated with preservatives
		24	Roughly trimmed wood
		25	Wood wool
		26	Wood flour
		27	Wood fuel simply worked
3	WOODCHIPS AND PARTICLES, RESIDUES AND RECOVERABLE WOOD PRODUCTS		
		31	Wood residues (including wood for agglomerates)
		32	Woodchips and particles
		33	Recoverable wood products
4	WOOD PELLETS AND OTHER AGGLOMERATES	41	Wood pellets
		42	Wood briquettes
		43	Other agglomerates
5	SAWN WOOD		
		51	Coniferous
		52	Tropical non-coniferous
		53	Other non-coniferous
6	VENEER SHEETS		
		61	Decorative veneer sheets
		62	Non-decorative veneer sheets
7	WOOD-BASED PANELS		
		71	Plywood
		72	Particleboard
		73	Oriented strand board
		74	Fibreboard
		75	Densified wood
		76	Combination board

Code	Major category	Code	Sub-category
		77	Other panels based on wood or other lignocellulosic materials
8	WOOD PULP		
		81	Mechanical wood pulp
		82	Semi-chemical wood pulp
		83	Chemical wood pulp
		84	Dissolving wood pulp
9	OTHER PULP		
		91	Pulp from fibres other than wood
		92	Recovered fibre pulp
10	RECOVERED PAPER		
		101	Unbleached kraft paper or paperboard or corrugated paper or paperboard
		102	Other paper or paperboard made mainly of bleached chemical pulp, not coloured in the mass
		103	Paper or paperboard made mainly of mechanical pulp (newspapers, journals and similar)
		109	Other, including unsorted waste and scrap
11	PAPER AND PAPERBOARD		
		111	Graphic papers
		112	Sanitary and household papers
		113	Packaging materials
		114	Other paper and paperboard
12	CORK		
		121	Natural cork
		122	Agglomerated cork and articles of agglomerated cork
13	SECONDARY WOOD PRODUCTS		
		131	Further-processed sawn wood
		132	Wooden wrapping and packaging material
		133	Wood products for domestic or decorative use
		134	Other manufactured wood products
		135	Builders' joinery and carpentry of wood
		136	Wooden furniture
		137	Prefabricated buildings of wood
14	SECONDARY PAPER PRODUCTS		
		141	Composite paper and paperboard
		142	Special coated paper and pulp products
		143	Carbon paper and copying paper ready for use

Code	Major category	Code	Sub-category
		144	Household and sanitary paper ready for use
		145	Packaging cartons, boxes, etc.
		146	Other articles of paper and paperboard ready for use

Appendix E: Classification of biorefineries

A summary of the production of bio-products as defined by the European Technology and Innovation Platform.[47]

Group	Process	Process	Feedstock	Outputs
PVC1: Transport fuels via gasification		Thermal gasification produces a syngas, which can be used for the production of power and heat, or further processed into transport fuels. Gasification is a thermochemical conversion process at 800-1300°C using a sub-stoichiometric amount of oxygen. Under these conditions the biomass is fragmented into raw gas consisting of simple molecules; hydrogen, carbon monoxide, carbon dioxide, water, methane, H_2S, NH_3, HCl. Solid by-products are: tar, char, and inorganic matter. After a clean-up, the gaseous molecules are chemically re-synthesized to transport fuels.	Thermal gasification is very fuel-flexible; it can use any reasonably low moisture content (<15%) combustible carbon-containing material as a feedstock. Possible feedstocks include forest and forest industry residues, short rotation coppice, lignocellulosic energy crops such as energy grasses and reeds, agricultural and agro-industrial residues as well as sorted municipal and industrial wastes, plastic wastes, digested sewage sludge.	Catalytic chemical reactions convert the syngas to methane, methanol, DME or Fischer-Tropsch hydrocarbons, respectively, at 200 up to 400 °C. The syngas can be converted to ethanol by micro-organisms at ambient temperature. In addition, hydrogen as a product can be extracted directly from the gas.
PVC2: Power and heat via gasification		As above	Any lignocellulosic material is suitable.	
PVC3: Transport fuels via pyrolytic and thermolytic conversion	Pyrolysis to bioliquid intermediates	Pyrolysis is the chemical decomposition of organic matter by heating in the absence of oxygen. The feedstock decomposes into organic vapours, steam, non-condensable gases and char.	In principle any low moisture content (<15%) organic material as a feedstock. For example, forest and forest industry residues, as well as agricultural and agro-industrial residues.	On cooling, the organic vapours and steam condense to a dark brown viscous liquid; fast pyrolysis bio oil (FPBO). The char and gas are used internally to provide the process heat required, and additionally also energy for export.
	Hydrothermal liquefaction (HTL) to bioliquid intermediates	HTL is a thermochemical conversion process of biomass into a liquid intermediate by processing in a hot, pressurized water environment, (e.g. 250 to 370 °C; 4 to 20 MPa - water sub-critical conditions), for sufficient time (10-60 mins) to break-down biopolymeric structure to liquid and gaseous components. The feed is turned into a pumpable slurry and processed without drying.	The HTL process can treat lignocellulosic, other biomasses and waste fractions. Lignocellulosic and other solid feeds are pre-treated to allow the formation of a slurry at a reasonably high solid content by mechanical or thermomechanical pre-processing.	It produces fractions; a gas phase, a solid residue, a liquid aqueous phase and a liquid oily phase (the bio-crude). The bio-crude separates from water but still has 10 – 20% oxygen and a relatively high acidity.

[47] Produced based on https://www.etipbioenergy.eu/value-chains/#value-chains-06 accessed on the 05/02/2025.

Group	Process	Process	Feedstock	Outputs
PVC4: Intermediate bioenergy carriers for power and heat	Torrefaction	Torrefaction is a partial carbonisation or slow pyrolysis process (a thermochemical process) at 200 to 350 °C in the absence of oxygen, at atmospheric pressure with low particle heating rates and a reactor time of one hour. The process causes biomass to partly decompose, creating torrefied biomass or char; referred to as 'biocoal'. It is stable, brittle and water resistant, and is easier to grind than the original biomass material with reduced biodegradation.	Biomass	Torrefaction significantly improves the suitability of biomass for co-firing in coal fired power plants and has the potential to enable higher co-firing percentages at reduced cost. Combined with pelletisation, biomass is converted into an intermediate bioenergy carrier that is easier to transport, handle and store and has superior properties in many major end-use applications.
	Pyrolysis	Pyrolysis is the chemical decomposition of organic matter by heating in the absence of oxygen. The technology can in principle use any low moisture content (preferable below 15%) organic material as a feedstock.	The feedstock includes forest and forest industry residues, and agricultural and agro-industrial residues. Plastic wastes can be used as feedstock, but the resulting fuel will not be a biofuel.	The feedstock decomposes into organic vapours, steam, non-condensable gases and char.
PVC5: Liquid transport fuels via fermentation	Fermentation of cellulosic sugars to ethanol	The first part is a pre-treatment physicochemical and enzymatic liquefaction steps, to fractionate the feedstock into cellulose, hemicellulose and lignin. After hydrothermal treatment, additional water is added to the mixture resulting from the pre-treatment after which hydrolysis and saccharification of the cellulose and hemicelluloses oligomers take place. This step uses specifically developed enzyme mixture.	Produced from agricultural residues (e.g. straw, corn stover), other lignocellulosic raw materials (e.g. woodchips) or energy crops (miscanthus, switchgrass, etc.).	Cellulosic ethanol is chemically identical to first generation ethanol (i.e. CH_3CH_2OH). However, it is produced from different raw materials via a more complex process (cellulose hydrolysis).
	Fermentation of isolated sugars to higher alcohols	Fermentation of isolated sugars to higher alcohols.	Currently crop or starch sources; in the future possibly from lignocellulosic sources,	Some bacteria produce butanol; yeast can be engineered to produce butanol instead of ethanol. To produce n-butanol and isobutanol (a high value as a chemical building block).
PVC6: Gaseous transport fuels via fermentation	Production of biogas	Production of biogas via anaerobic digestion of biomass is already widely deployed; thousands of small, farm-based biogas plants across Europe produce heat and electricity. Recently, biogas facilities have grown larger, and separating	Anaerobic digestion of biomass	Production of biogas in small, farm-based biogas plants produce heat and electricity. Recently, biogas facilities have grown larger, and separating CO_2

Group	Process	Process	Feedstock	Outputs
		CO_2 from the biogas as to upgrade it to biomethane has come into focus.		from the biogas as to upgrade it to biomethane has come into focus.

INVESTIGATING FUTURE MARKETS FOR FOREST PRODUCTS FOR GIPPSLAND

Report 2: Product option assessment

Prepared by Sylva Systems Pty Ltd

Investigating future markets for forest products for Gippsland.

Report 2: Product option assessment

Prepared for the Gippsland Forestry Hub Inc.

Prepared by

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Version dated 28/07/2025 12:25 PM

[1] Greenwood Strategy
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A disclaimer.

This report is a guide to the use of a database of a collection of information collated to present a comprehensive list of products based on wood fibre for consideration in Gippsland. That report is a high-level statement of options and it should not be relied on for any investment decisions. The intent is to assist in a journey to generate product options. It has been prepared in good faith for the Gippsland Forestry Hub Inc. as per the terms and conditions of the engagement, on a fee for service basis by Sylva Systems Pty Limited. Sylva Systems has no pecuniary interest in any of the outcomes. This report is provided solely for the use of the Gippsland Forestry Hub and for its purposes. The sources of the data and information relied on have been specifically quoted in this report. To the extent permitted by law, Sylva Systems disclaims any responsibility or liability whatsoever (in negligence, contract or otherwise) in respect of any errors, misstatements or omissions in this report and in respect of any claims which may arise out of any reliance on the contents of it or its use for any purpose.

Table of Contents

Summary

A comprehensive list of potential products for Gippsland has been prepared and a companion database created. This report presents a guide to the use of that database to explore potential product options. The database includes categorisation of products based on a range of attributes and these categories are presented in this report. For example, the state of commercialisation is a consideration. A product may be conceptual (blue sky) or routine with current markets. A product while commercial, may be redundant due to changes in technology. A key understanding is that there is no one best-fit product, hence a deliberation is required.

Introduction

There is no one best-fit forest product that could be manufactured in Gippsland. However, given the nature of the resource, the characteristics of the existing industry and developments in processing capability and technology, there are likely to be opportunities that are specifically suited to particular investor and wood processing type. To assist the industry and potential investors in understanding forest product options, Appendix 1 presents a high-level summary of the terms in regard to product production and Appendix 2 a series of definitions in regard to products. An assessment of the potential of a product for manufacturing in Gippsland requires an understanding of the current status of that product. A risk management consideration is the next best option for a product. A fall-down product is a next-best or alternative use for a product, should the intended use no longer be in demand. For example, the logs harvested from a plantation managed for sawlogs could be chipped to generate woodchips as a next best option. As products become more specialised, the options for alternative use and markets reduce. This can increase the risk associated with a product. There are two supporting considerations; the value and supply chains (see Box 1). The value chain is focused on the product creation, whereas the supply chain has a focus on the movement of products to the finished product end-users. To understand and assess a product, it is important to understand the nature of the product, as this links to enabling factors (e.g. the previous steps in production) and the drivers of demand.

Box 1:The definition of a value chain (Tardi, 2024) and a supply chain (Hayes, 2024a).	
A value chain	*'A value chain is a series of consecutive steps that go into the creation of a finished product, from its initial design to its arrival at a customer's door. The chain identifies each step in the process at which value is added, including the sourcing, manufacturing, and marketing stages of its production.'*
A supply chain	*'A supply chain is a network of individuals and companies that are involved in creating a product and delivering it to the consumer. Links on the chain begin with the producers of the raw materials and they end when the van delivers the finished product to the user.'*

A comprehensive guide to product options based on wood fibre has been prepared (see Jenkin, *et al.,* 2025) and the products included have been entered into a database to assist with option selection. This report provides background to the database as a tool for industry and potential investors to explore product options.

The manufacturing and product options matched to need

Processing and manufacturing capacity

The production of intermediary or consumer goods occurs in some form of facility where the transformation of raw materials as outputs of primary production occurs. Alternatively, manufacturing can occur as a next step on the same site. For example, sawn timber can be a consumer good used to build a house or as an intermediary good to the manufacture of glue laminated timber (GLT) as an add-on line in a sawmill. A new processing or manufacturing facility can be at an existing site (e.g. a brownfield site) as an add-on, or a new site requiring development (e.g. a greenfield site). In regard to processing or manufacturing strategy, it is possible to generate more of the same, an evolution of a product or a revolutionary new product. As a first step in understanding product options, Table 1 presents a matrix of site development type and the nature of the development.

Table 1: A matrix of the nature of the development of a processing or manufacturing site.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Site</td></tr>
<tr><td>Brownfield</td><td>Greenfield</td></tr>
<tr><td rowspan="2">Nature of the development</td><td>Stand-alone</td><td>No change.</td><td>A new site to be developed with a specific intent of a stand-alone outputs.

This could be to produce more of the same, an evolution of products or a revolution of products.</td></tr>
<tr><td>Add-on</td><td>An existing site with current capacity to produce an intermediary or consumer good.

Add-on (bolt-on) capacity could be developed to change the nature of the site outputs.</td><td></td></tr>
</table>

Documentation and databases

A wide range of products and, by proxy, processing systems have been documented and are presented in Jenkin *et al.* (2025) as part of this project. This document provides details of published and recognised definitions of products. To assist in a rapid assessment of options, the structure of the report has been replicated in a database. Table 2 provides the structure of the product categories and pre-cursor materials. As an example of how to utilise it, consider the broad pre-cursor materials. A party with materials for sale (e.g. a plantation owner) can consider this list and the type of processing that requires materials recovered from the harvest of a stand. These can be explored by reference to the database and the full report (see Jenkin, *et al.,* 2025). Another party may seek a product for a specific type of project or have a need for that product. The broad categories of products can be used to explore the database and the complete product report (see Jenkin, *et al.,* 2025).

Table 2: The clustering of product types and the associated input materials.

Division	The broad pre-cursor material	The broad product category
Part A: Primary and part processed products	Selling outputs of plantations and forests	The primary products from the harvesting of trees
		Next step processing of roundwood
Part B: Secondary products	Use of roundwood and other primary outputs	Sawn timber
		Veneer products
	Made from outputs of log processing	Panels
		Structural composite lumber products
	Generally made from sawn timber	Secondary wood products
		Wood fibre combined with other materials
	All processing residues	The by-products of the primary processing of logs
	Made from residues	Garden and landscape products
Part C: Wood as a fuel in solid format	A range of materials	Solid biomass as biofuels
		Densified wood fuels
Part D: Non-wood products chemicals and energy	Use of roundwood and other primary outputs	Wood pulp
		Paper & paper board
		Pyrolysis
		Biorefineries
		Heat and electricity generation

Self-assessment to determine needs and requirements

Available resources in Gippsland

When exploring a product option or need that can be addressed by utilising forest products, a self-assessment tool is necessary. Gippsland has a natural forest estate on public and private land and a plantation estate. As at June 2023, the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) indicated that the plantation estate of Central Gippsland was 86,300 ha and the East Gippsland / Bombala estate was 50,500 ha; a total of 136,800 ha (ABARES, 2024 dataset worksheet NPI region). Depending on future conditions, in particular plantation expansion, a realistic post-2030 fibre supply will be around c.1.5 million m^3/year, dominated by softwood plantation supply (Greenwood Strategy Solutions, 2022, p.13&14). This future estimate represents close to doubling of the total softwood fibre available compared to historic levels. Natural forests on public land are no longer available for log production, since the Victorian Government's decision to cease harvesting at the beginning of 2024. This represents a decrease in total available fibre from a peak of 2.3 million m^3/year in 2021. Any consideration of a new product should consider this dominant wood type, and the alternative uses in Gippsland.

Differences in site type

A specific need for a brownfield site

The specific needs of a site can be categorised as addressing a range of issues as follows.

- A product for sale and inputs: A party may have a specific product to sell and seeks to understand the options; it can be defined and the categories in the database considered. Alternatively, a party can have a specific need for a physical input to a site and the database can be considered to seek source options.
- Energy: Product manufacturing can require energy inputs in the form of heat and/or electricity. Considerations include energy costs, reliability, occupational health and safety, and/or sustainability. A site can consider alternative energy supply by onsite production.
- Residue disposal: As a by-product of processing, a site may generate a range of residues. These can be treated as waste to landfill, sold to an external party or consumed onsite as a strategy. Diversion from a waste stream (as a cost) to supply the material to an external processor (as a revenue stream) can be assisted by considering the pre-cursor inputs for each product. An alternative is the use of such materials onsite by considering bolt-on manufacturing capacity on a site or use in energy production.
- Higher value products: A site may produce a simple product and may seek to take a next step in manufacturing as a bolt-on to an existing site with the intent to increase the market vaue of the out-put. By considering the pre-cursor products, it is possible to determine potential options.

A specific need for a greenfield site

Development of a greenfield processing and/or manufacturing site is a specific investment decision. In making such a decision there are a range of considerations and each party will have an internal process to undertake such an assessment. The following is a high-level set of items to consider.

- The product: A proposed development can be driven by a perceived opportunity or need. A specific product need can be driven by a company's internal requirements (e.g. for an intermediary good) as part of a vertical integration. An opportunity can be defined by identifying a gap in a market or a process to replace an alternative supply.
- Input resources: Consideration of a development must consider the required type (e.g. softwood or hardwoods) and attributes of the input resources (e.g. log specifications). A simple test is to consider the availability of fit-for-purpose resources. This assessment should address logistics (e.g. cost and capacity) and the infrastructure required to support a development (e.g. energy availability).
- Sites and regulations: Development will require a suitable site, as defined by the intended process. This will require consideration of Local and State Government regulations (e.g. planning).
- Labour: While development of a greenfield site is likely to deploy capital to reduce labour demand, specific skills will still be required to be accessed.

Considerations in the options database

The attributes assigned in the dataset

Pre-cursor input materials

Raw materials can be the product traded or a pre-cursor requirement for a manufacturing system. For example, logs are the output product sold by a plantation company to a processor. Such products are primary products. The nature of the log sold is important to an assessment. A first consideration is the wood type (e.g. softwood or hardwood), the species (i.e. scientific name, not the common name, to provide clarity) and the source forest type (e.g. natural forests or plantations). The second consideration is the log specifications which will be specific to a processor. Where some degree of transformation has occurred, the product is no longer a raw material but rather is an intermediary good. For clarity and classification, the by-product of a process is an intermediary good. For example, sawdust generated by sawing a log is a processing residue and an intermediary good when it is provided as an input to another manufacturing site or a consumer good if used as is (e.g. as garden mulch). To place a product into perspective, it is important to consider the inputs to the process that generates that product. The categories included are presented in Table 5. This can be used to assess a product in a regional context. For example and practically, is that pre-cursor available in the local area?

The purpose of an item

To assist in understanding the potential of a product, the status in regard to whether it is an input to a subsequent step in manufacturing (e.g. an intermediary good), or a consumer product consumed directly. Where a point in a value chain generates an input into the next stage in a transformation prior to final consumption as a consumer good, it is an intermediary good (e.g. a woodchip destined for pulping and paper making). It is possible that an intermediary good can also be a consumer good (e.g. woodchips supplied as garden mulch). As part of the assessment, each product will be classified as either 'intermediary' or 'consumer goods'. Demand for intermediary goods is driven by the output of the process consuming such goods. While the intermediary good input scale can be limited, the overall scale of production could be significant; that is, the intermediary good is a minor input to a processing or manufacturing site. The development of such capacity can require significant investment in plant and equipment, along with securing the other main inputs. Demand for the intermediary good is driven by production of the overall output. For each product in the database, the last transformation has been noted. For example, woodchips can result from infield chipping of trees, harvest and recovery of logs to a static chipmill or as by-products of another process (e.g. sawmilling). By understanding the pre-cursor stage, it is possible to apply a degree of reality check on potential for production. For example, paper manufacturing requires access to pulp which can be imported or made domestically. Where manufactured domestically, significant capital and input resources are required. The categories included in the database and applied to each product are presented in Table 4.

Table 3: The pre-cursor materials inputs to a point in the supply chain as presented in Jenkin *et al.* (2025).

Cluster of sources	Pre-cursor input
From the forest	Standing tree
	Food grade biomass
	Biomass
	Roundwood
	Roundwood short billets
	Roundwood or solid wood
	Roundwood, solid wood or processing residues
	Any material / other panels
	Roundwood to peel or slice veneer sheets
	Roundwood / processing residues
	Roundwood or machined roundwood
From processing a log	Sawn timber
	Green off-saw
	Dressed all round kiln dry timber
	Sleepers
	Input veneer sheets
Processing residues	Wood flower
	Woodchips
	Woodchips, sawdust and shavings
	Un-screened woodchips
	Used wood products
	Bark, sawdust, shavings, solid wood
	Compost
	White pellets
	White briquettes
From pyrolysis	Char
	Syngas
	Pyrolysis vapours
	Graphite
From chemical processes	Lignin
	Cellulose
	Hemicellulose
	Pulping process
	Pulp
From combustion	Steam
	Heat

Table 4: The nature of an item; it is an input to a process; or it is the consumer product or has a dule purpose of both.

Classification	Narrative	An example
An intermediary good	The item is an input as 'raw material' or a component of a subsequent product.	A log.
A consumer product	The item is a product ready for use by the ultimate consumers rather than as an input to a subsequent product.	Sawn timber.
A product or input	Depending on the processor, an item can be both an input and a product.	A post; used 'as is' or as an input to a treatment plant.

Development status

A current product will have a current and active market with sales and consumption. This market can be local, outside the region, interstate or international. It is possible that while consumption of a product occurs internationally, it may not have a domestic market due to a range of factors; for example, regulatory restrictions through to local trends. Where a product is an intermediary product, for it to be in demand will require the next stage in manufacturing to be available locally. In the absence of that next step, markets in other regions (including as exports) would be required. Where a product is a complementary good, the linked good must be consumed to stimulate a domestic market. If not an export market will be required. Where export of a product is required, this will require materials handling and port infrastructure. While domestic markets exist for a product, this demand could be satisfied by imports. Where a product is imported, there is the potential for local production and import replacement.

While product options are available into active markets, others are at the various steps in a pre-commercial phase. The following are the three broad stages of product development.

- Current production: An objective test of current status is whether or not the product is being made; locally in the same region, in other parts of the state, inter-state or internationally. Evidence is a current production facility generating a current product supplied into current markets.
- Feasibility stage: After a process of research and development, a product will require a feasibility stage of assessment, testing of commercial potential and addressing regulatory requirements.
- Research and development: A product remains in the research and development phase where while showing potential, it has not yet been subject to a commercial assessment of feasibility.

To allow an assessment of immediacy of potential of a product, each product in the database has been assessed as to its current development status. The categories included are presented in Table 5. This assessment allows consideration of whether a product is an immediate option or requires further investment to reach commerciality.

Table 5: The stage of development of a product and supply into an active market.

Category	Narrative	An example
Blue sky	A product is conceptual and has not commenced development.	Hydrogen from cellulose
Emerging technology	A product is regarded as in the early stages of development and trials.	Ethanol from cellulose
Pre-commercial	A product has been developed and is ready for commercial production.	Plantation hardwood cross laminated timber (CLT)
Commercial	A product is readily available in the market place.	Softwood timber trusses

Relevance status

While a product may be fully commercial, due to change in technology, it may no longer be relevant. It is possible that there is an interest to develop capacity to produce a historic product (e.g. wooden spokes for a horse drawn carriage) where there is demand, but this would require a careful assessment. Other products may no longer be relevant or have reduced relevance due to a change in technology; for example, disposable lighters replacing matches. There are examples where a process and products that had historic significance see a renaissance of interest; for example, wood distillation and char production. The categories included in the database are presented in Table 6.

Table 6: The current status of a product; while some may have a long history and be commercial, some are not current nor relevant.

Category	Narrative	An example
Unknown	The current status is unknown.	
Historic	A product is well understood and accepted, but lacks current relevance beyond niche markets.	Wooden spokes for a carriage.
Not relevant	A product is not relevant due to technical and/or market redundancy.	Matches
Potential future	A product, that while developed, has a potential to be relevant.	A range of chemicals.
Current	A current product with active markets.	Treated softwood timber for fencing

Output scale and units

The scale of output of a site is a critical consideration with implications for the input resource through to the capital required to develop capacity. The scale of inputs to a manufacturing site (e.g. process) to generate a product will be a driver of the feasibility of that product. Where capacity exists, the scale will determine any ongoing challenges with input supply. For a brownfield site, to expand production or add a new process, it will be important to understand the input resources required. Where a new (greenfield) site is required, a new supply of input resources will be needed, either by taking resources from another consumer, importing them, or growing additional volume.

The growing of additional volume can be achieved by increasing the area of plantations or a change of management (e.g. silviculture) to increase the volume produced per hectare. Any intent to grow more wood will have timing issues for the planned change in product capacity. That is, the time required for trees to grow with a new planting or to change in attributes due to mid-rotation interventions. The categories of scale of output are presented in Table 7; rather than specific capacity, a range is provided for each input scale. This reflects that a processor could be at a micro scale; a sawmill could be a single portable sawmill through to processing over 0.5 million m^3/yr. These scales are indicative to provide a guide. Given the diversity of the products and processes, there are a range of units involved which can be specific to a system. These are presented in Table 8.

Table 7: The scale or magnitude of output from a single site allocated to a process and product.

A range of out-puts	Magnitude of output
Unknown	<1
1-10	<100
10-100	< 1,000
100 - 1,000	>1,000
1,000 - 10,000	>10,000
10,000 - 20,000	>50,000
20,000 - 100,000	>100,000
100,000 - 500,000	>500,000
	>1,000,000

Table 8: The units of the output of a single site which can be specific to the process and/or products.

Units	Description	Example
Unknown	The units of output are unknown.	
Truck loads	A non-standard unit.	Firewood
n/y	A whole number ‘n’ of units per year.	Poles
m^2/y	Cubic metres squared per year of output.	Veneer sheets
m^3/y	Cubic metres cubed per year of output.	Logs
ADt/y	Air dry tonnes per year of output.	Pulp
GMt/y	Green metric tonnes per year of output.	Bark
BDMt/y	Bone dry metric tonnes per year of output.	Woodchips
L/y	Litres per year of output.	Chemical production
MW_t	Mega watt thermal; heat generation capacity.	Boiler capacity
MW_e	Mega watt electricity; electricity generation capacity.	Generation capacity

Options for Gippsland

A high-level recommendation

The complete products report (Jenkin *et al.,* 2025) presents products with different levels of information. Products with a lower level of general familiarity include a more detailed account to assist in understanding the potential in Gippsland. For several reasons, it is difficult to make a definitive statement of a best product option. These reasons include diversity within the region, commercial drivers for existing and potential industry players, current and emerging technologies and products, and current and emerging markets. Investment decisions, in practice, depend on a wide range of factors commencing with whether the site will be a brownfield or greenfield site.

A brownfield site can have the advantage of a bolt-on strategy at a smaller scale to leverage-off existing infrastructure. Such a strategy can address a specific site issue (e.g. residue management) or seek to capture a specific opportunity (e.g. energy pellet production). A greenfield site is a more significant challenge proportional to the scale of investment and expected production. A site could be very small (e.g. a firewood merchant) through to consuming significant resources and capital (e.g. a biorefinery). Of the product and processing groups, pyrolysis offers an interesting opportunity and indeed Gippsland had a significant wood distillation plant from 1907 to the end of the First World War (Rae, 1987). Plants can be in a range of sizes and generate a broad range of products; some products are current with active markets (e.g. charcoal for BBQs) and others are emerging (e.g. liquid hydrocarbon fuels). Plants can be as a bolt-on to an existing site (e.g. the recently installed pyrolysis and 75 kW_e electrical generation capacity Rankin Cycle Engine unit at the Radial Timber Sales Yarram plant[3]). In regard to products in support of the building sector, production of GLT is a relatively simple bolt-on to a sawmill to generate a product with current active markets.

An example of a high-level assessment of an option

As an example of application of the database and information, Table 9 presents a snap-shot of the situation at the AKD Yarram processing centre. The site is a brownfield site, processing softwood sawlogs to generate green-off-saw and kiln dry sawn timber. The site generates a range of processing residues sold to external parties. Based on consideration of the site needs, production of heat and electricity is an option that could be explored.

Table 9: A snap-shot of a consideration of the needs of the AKD processing centre located near Yarram, Gippsland.

<table>
<tr><th>Consideration</th><th>Narrative</th><th>Implication</th><th>Use of the database</th></tr>
<tr><td>Energy</td><td>The location experiences electricity reliability issues.
The site generates heat to kiln-dry some of the sawn timber outputs.</td><td>With changes to electricity and aging transmission infrastructure there is a risk of such disruptions increasing.</td><td rowspan="2">Consider the ‘heat and energy’ section of the document and the database to look for options. The pre-cursor inputs to generate heat and electricity are presented.
Consider the ‘By products’ section of the document and the database to gain an insight to the range of residues.
A solution is the combustion of the processing residues to produce heat for the kilns and to generate electricity for the site.</td></tr>
<tr><td>Residues</td><td>A range of processing residues are generated and these are current sold to external parties.</td><td>This is a reliance on the continuance of independent businesses.
Alternative strategies for residue management are required for consideration.</td></tr>
</table>

[3] See https://radialtimbers.com.au/how-radials-pilot-plant-uses-pyrolysis-for-biochar/ accessed on the 27/05/2025).

Conclusion

As stated in the introduction, there is no one best-fit product that could be manufactured in Gippsland. This analysis and system demonstrate the process and steps to find a best-fit process and product matching the needs of an investor. Considerations include input fibre and intermediary goods, the nature of a planned investment (e.g. brownfield or greenfield site) and the scale required. This report forms part of three tools to assist in this process; a full report of the unfiltered product options (Jenkin *et al.*, 2025) and a database of products arranged into four broad groups.

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Appendix 1: The activities undertaken in creating a product

A range of activities are required to generate a product and such activities can be classified by the sector in which they occur, and the manufacturing process and strategy. These are presented in Box 2.

Box 2:The definition of the sectors of production (Kenton, 2025), manufacturing (Kenton, 2024d), manufacturing production (Kenton, 2021) and an assembly line (Banton, 2022).	
Primary sector	*'Primary sector companies are directly engaged in activities utilizing natural resources, such as mining and agriculture.'*
Secondary sector	*'Secondary sector companies produce goods derived from the products within the primary sector and include manufacturing.'*
Tertiary and quaternary sectors	*'Tertiary and quaternary sectors represent the services and knowledge-based economy and include retail and information technology.'*
Manufacturing	*'Manufacturing is the creation of finished goods through the use of tools, human labour, machinery, and chemical processing.'* *'Manufacturing allows businesses to sell finished products at a higher cost than the value of the raw materials used. Large-scale manufacturing allows for goods to be mass-produced using assembly line processes and advanced technologies as core assets. Efficient manufacturing techniques enable manufacturers to take advantage of economies of scale, producing more units at a lower cost.'*
Manufacturing production	*'Manufacturing production refers to the methodology of how to most efficiently manufacture and produce goods for sale, beyond just a bill of materials. Three common types of manufacturing production processes are:* • *Make to stock (MTS),* • *Make to order (MTO), and* • *Make to assemble (MTA).* *Such strategies have advantages and disadvantages in labour costs, inventory control, overhead, customization, and the speed of production and filling orders.'*
An assembly line	*'An assembly line is a production process that breaks the manufacture of a good into steps that are completed in a pre-defined sequence. Assembly lines are the most commonly used method in the mass production of products. They reduce labour costs because unskilled workers are trained to perform specific tasks. Rather than hire a skilled craftsperson to put together an entire piece of furniture or vehicle engine, companies hire workers only to add a leg to a stool or a bolt to a machine.'*

Appendix 2: The stages of a physical product

Given the potential for a product to be either input to a next step or a good ready for consumption, it is important to understand the various types of products and inputs. Box 3 presents definitions of products at various stages in a value or supply chain.

Box 3:The definition of a raw material (Banton, 2023), intermediate good (Kenton, 2024a), consumer goods (Investopedia team, 2024), a normal good (Kenton, 2024b), a luxury item (Kenton, 2024c) and the principle of cross elasticity of demand (Hayes, 2024b).	
Raw materials	*'Raw materials are materials or substances used in the primary production or manufacturing of goods. Raw materials are commodities that are bought and sold on commodities exchanges worldwide.'*
An intermediate good	*'An intermediate good is a product used to produce a final good or finished product—also referred to as a consumer good. Intermediate goods - like salt - can also be finished products, since it is consumed directly by consumers and used by producers to manufacture other food products.'* *'Intermediate goods are sold between industries for resale or the production of other goods. These goods are also called semi-finished products because they are used as inputs to become part of the finished product.'*
Consumer goods	*'Consumer goods are finished products bought by individual buyers for their use. Also called final goods or retail goods, consumer goods are the end result of production and manufacturing. Clothing, food products, and appliances are all common consumer goods.'* *'Consumer goods are broadly categorized as durable, non-durable, and service goods. Non-durable goods include such essentials as food and clothing.'*
A normal good	*'Normal goods are consumer products such as food and clothing that exhibit a direct relationship between demand and income. As a consumer's income rises, the demand for normal goods also increases.'*
A luxury item	*'A luxury item is not necessary to live, but it is deemed highly desirable within a culture or society. Demand for luxury goods increases when a person's wealth or income increases. Typically, the greater the percentage increase in income, the greater the percentage increase in luxury item purchases.* *Since luxury goods are expensive, wealthy people are disproportionate consumers of luxury goods. Those who are not wealthy don't usually buy luxury goods since a greater percentage of their income goes to need-based expenses in order to live. Luxury goods can be considered conspicuous consumption, which is the purchase of goods mainly or solely to show off one's wealth.'*
Cross elasticity of demand	*'The cross elasticity of demand is an economic concept that measures the responsiveness in the quantity demanded of one good when the price for another good changes. It's also referred to as cross price elasticity of demand.'* *'The cross elasticity of demand for substitute goods is always positive because the demand for one good increases when the price for the substitute good increases.'* *'The cross elasticity of demand for* ***complementary goods*** *is negative.'*

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