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# Opportunities for using Sawmill Residues in Australia

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FWPA Level 4, 10-16 Queen Street,  
Melbourne VIC 3000, Australia

T +61 (0)3 9927 3200 F +61 (0)3 9927 3288

E [info@fwpa.com.au](mailto:info@fwpa.com.au) W [www.fwpa.com.au](http://www.fwpa.com.au)



# **Opportunities for using Sawmill Residues in Australia**

Prepared for

**Forest & Wood Products Australia**

by

**Dean Goble, Malcolm Peck**

## **Publication: Opportunities for using Sawmill Residues in Australia**

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**Researcher:**

Dean Goble, Malcolm Peck  
The Carnot Group Pty Ltd

**Forest & Wood Products Australia Limited**

Level 4, 10-16 Queen St, Melbourne, Victoria, 3000  
T +61 3 9927 3200 F +61 3 9927 3288  
E [info@fwpa.com.au](mailto:info@fwpa.com.au)  
W [www.fwpa.com.au](http://www.fwpa.com.au)

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# 1 EXECUTIVE SUMMARY

The saw mill industry in Australia generates large volumes of wood residue in the form of chip, bark and sawdust and understandably it is keen to use this to increase revenue streams. In 2007 the Carnot Group was engaged by Forest & Wood Products Australia (FWPA), on behalf of the industry, to examine options for producing revenues from sawmill residues. This report provides an update to the first edition.

The following physical/chemical attributes of wood can be used as the basis of revenue generation:

- Stored chemical energy: conversion into thermal, electrical or kinetic energy
- Source of organic polymers: conversion into useful chemicals
- Mechanical properties of the fibrous cellulosic structure
- Source of organic material for biological feed
- Use of thermal or acoustic insulation properties

There are various processes for turning these attributes into useful products that can provide revenue streams. These include:

- Combustion: using the heat, via a heat transfer medium, for power generation and heating
- Gasification: using the syngas to fuel a boiler or IC engine for power generation or to produce bio-fuels
- Pyrolysis: to produce bio-oil or char products
- Pelletising: a dense fuel for domestic heating and fuelling small scale power plant
- Hydrolysis and fermentation: production of ethanol or butanol
- Various combined thermal and chemical processes: production of chemicals

Associated with the processes are technologies that are more or less developed to commercial readiness. The capital and operating costs of processing plant in comparison with the value of the product will strongly influence any decision to take a particular route to a marketable product. The other major consideration must be the size and maturity of the relevant markets for the products. There are a limited number of state and federal government incentives schemes currently available. These are mainly related to renewable electricity generation, energy efficiency or the reuse of waste.

Perhaps the most well-known use of wood residues is in “waste to energy”, where the wood is combusted (directly or via gasification) for subsequent use in power plant producing electrical energy and often useful amounts of heat. This employs mature technologies such as boilers, steam engines and generators.

In these power plants the critical factors are ensuring that sufficient wood residue with the appropriate attributes is available to fuel the boiler or gasifier; that the electrical power can be used (possibly via an off-take agreement) and that there is a match between demand and supply. The capital cost of plant employing steam turbine or Organic Rankin Cycle (ORC) technology with capacity of 5 to 10MW<sub>e</sub> is in the range \$3 to 6million per MW<sub>e</sub>.

Economies of scale generally improve economic viability, in which case a number of mills could consider combining their residues. This action will be strongly influenced by the cost of transport between sites, for which an indicative figure of \$20 per tonne for a 200km round trip could be used. To increase the collection radius, it may help to increase the bulk density of the residue to maximise the weight of material carried per load. This can be done by processing the residues into pellets at a cost of approximately \$6 to 8 per tonne. At the

present time there is a small market for pellets in Australia however there is a potentially large export market into Korea, Japan and the EU, if economic shipping can be secured and compliance costs kept low.

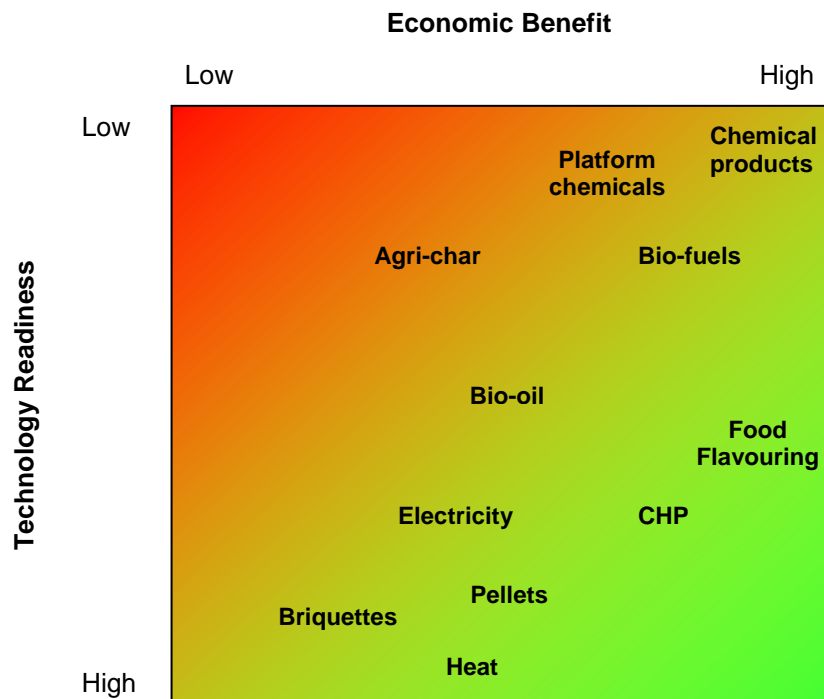
Consideration could be given to the future production of agri-char. This product is made by the pyrolysis (and possibly subsequent gasification) of wood to produce a dense carbon rich solid. There are some indications that agri-char may be effective for the enhancement of soils for agriculture. The Federal Government is encouraging R&D into agri-char use as a means of sequestering carbon. Trials to prove the effectiveness are being carried out in Australia and globally but the results to date are, in general, inconclusive.

The energy density of wood can be concentrated by converting it to a bio-fuel, such as ethanol and bio-oil. Ethanol from food crops such as corn, wheat and sugar cane is made in large volumes overseas and increasingly in Australia. There is extensive research into its production from ligno-cellulosic materials such as wood. It appears that the commercial scale production of ethanol from wood is roughly 1 to 2 years away (as of 2012) and some global companies are building plants driven by US policy and European grants. Monitoring the progress of second generation bio-ethanol commercialisation, market uptake and regulations would be worthwhile.

Bio-oil is more advanced and is currently produced from wood feedstock in commercial plants in Canada. The bio-oil is generally converted into useful chemicals, most significantly industrial resins and food flavourings, or fuels. There is no established market for bio-oil in Australia, but markets for industrial resins may be readily accessible.

The manufacture of a range of chemicals from wood via other process routes is technically feasible, but is still at research stage.

The benefits and commercial readiness of the various products that can be obtained from wood waste is summarised in the 'value matrix' shown below:



Whilst the value matrix is somewhat subjective it is apparent that the products that provide for immediate possible sources of revenue from sawmill residues are solid fuels, heat and electrical power generation. The major equipment needed, such as boilers, gasifiers and gas filters will likely be supplied by overseas companies and installed and supported by local

industry. Previously, it has been difficult to entice overseas suppliers with tried and tested equipment to supply into Australia.

As time progresses, a number of factors can impact on the viability of all these options. Important factors are the changing government position on CO<sub>2</sub> reduction, increasing prices for fossil fuels, government desire for energy security, changing attitudes to waste disposal and advancements in relevant technologies.

Datasheets have been provided in Appendix II for the options found to be most technologically ready:

- Briquetting
- Pelletising
- Electricity or CHP via steam turbine
- Electricity or CHP via reciprocating steam engine
- Electricity or CHP via gasification and internal combustion engine

These data sheets are intended to be an easy reference tool for sawmill operators to quickly assess the suitability of these options for their particular circumstances.



## 2 INTRODUCTION

The aim of this report is to identify opportunities for using residues from normal sawmill activities, predominantly focusing on hardwood mills. In Australia, hardwood mills are generally small scale and scattered around the country. The softwood mills are generally larger and more commonly integrated with other wood processing facilities.

Opportunities of interest will yield economic benefit either for a specific business or a collective. Economic benefits may involve reduction in operating costs, through the provision of cheaper heat and/or electricity, or new revenue streams, by value adding to wood residues. There is also a growing desire socially and within government and regulatory bodies to recycle, re-use and reduce waste going to landfill.

Forestry and Wood Products Australia, on behalf of the sawmill industry, has engaged The Carnot Group to examine options for producing revenue streams from sawmill residues. The Carnot Group is an engineering firm based in Melbourne, with a background in renewable energy.

### 2.1 Background

When a log is received into a saw mill only portions of its cross section are suitable for use as structural timber. The remaining streams of wood residue may consist of bulk pieces, hogged wood, sawdust, shavings, trimmings, bark and woodchips.

Estimating the volume of mill residues available for further processing is difficult. Recovery rates vary from location to location depending upon the dominant species processed, standard of processing equipment, log quality, production methods, grading, storage, drying and level of horizontal and vertical integration. The recovery rate is especially dependent on log dimensions. For logs in the range of 30 to 70 cm in diameter, recovery rates drop to about half when the log diameter is halved.<sup>1</sup>

Waste or mill by-products can then be categorized by six main attributes:

- Species
- Segregation (species mixture)
- Purity (clean or contaminated)
- Moisture content
- Storage (in silos, bins or left on the ground)
- Size

These attributes are important when considering potential uses for the waste. A wet log processed by a softwood sawmill would typically produce the following quantities by weight after de-barking<sup>2</sup>:

- Bark – 6 %
- Sawdust – 7%
- Shavings – 5%
- Woodchips – 35%

It should be noted that hardwood sawmills in Australia usually receive de-barked logs so there would be no bark residues emanating from the sawmill.

## 2.2 Current Utilisation Practices

The waste streams from sawmills are increasingly put to a wider variety of uses. Nowadays, some softwood mills are able to sell or use practically all of their residue streams, meaning almost no by-products remain unutilised.<sup>2</sup> Typical uses for sawmill residues are shown in Table 1.

**Table 1:** Typical uses of sawmill residue.<sup>3</sup>

By-product	End Use
Bark	Soil Amendment (incl. mulch)
Chips	Pulp and paper (mainly export), some soil amendment
Sawdust	Mainly kiln, some soil amendment, animal bedding
Shavings	Soil amendment, kilns and boilers, animal bedding

Wood chips are either sold for domestic pulping or exported for pulp and paper manufacturing for a price of \$35 to \$60 per tonne. Bark is primarily mulched and used as a soil amendment product or composted. The revenue for bark is generally \$10 to \$30 per tonne.<sup>3</sup>

There are still sawmills where some or all residues are either dumped or burnt for no useful purpose, particularly hardwood mills which are generally smaller in size than softwood mills.

## 2.3 Sawmill Energy Requirements

The energy usage between sawmills varies widely since no two sawmills are alike. Sawmills normally use electrical energy to drive motors for a variety of operations, many also perform kiln drying, using large quantities of heat, as shown in Table 2. It is clear that a considerable amount of energy is used when kiln drying is employed.

**Table 2:** Typical energy usage in sawmills, based on a standard well operated hardwood sawmill capacity of 100 m<sup>3</sup> per day of finished timber product.<sup>4,5</sup>

Process	Energy Requirement		
	Air drying	Kiln drying	
	(GJ/m <sup>3</sup> )	(GJ/m <sup>3</sup> )	(%) <sup>a</sup>
Electrical			
Sorting and barking	0.02	0.02	0.8
Sawing	0.07	0.07	3.5
Chipping	0.02	0.02	0.8
Materials handling	0.05	0.05	2.6
Planing	-	0.03	1.7
Kiln fans	-	0.07	3.3
Miscellaneous	0.01	0.01	0.3
Total electrical consumption	0.16 GJ/m <sup>3</sup> (44kWh/m <sup>3</sup> )	<b>0.26 GJ/m<sup>3</sup></b> (71kWh/m <sup>3</sup> )	13%
Thermal energy for Kiln Drying	-	<b>1.70 GJ/m<sup>3</sup></b>	87%
<b>TOTAL (Thermal and Electrical)</b>	-	<b>1.96 GJ/m<sup>3</sup></b>	100%

a. applicable to kiln drying and not air drying

It is pertinent to note that in Australia in 1999, timber residues from sawmills and material that was not chipped for export or used for board products was estimated to have an energy equivalency of about 120 PJ per yr (1PJ = 1 million MJ). At a conversion efficiency of 30%

that would generate about 10,000 GWh of electricity annually. In practice though, only a fraction of this resource could be economically used for electricity generation.

The use of biomass to displace fossil fuel derived energy is of growing interest and there are government incentives to increase the generation of renewable and carbon neutral energy. The CO<sub>2</sub> emissions brought about in generating sawmill electricity and drying heat have been estimated and are shown in Table 3 below; however these values are dependent on the energy source from which it was derived.

**Table 3:** Estimated CO<sub>2</sub> emissions (x1000 tonnes per year) from a typical hardwood sawmill (20,000 m<sup>3</sup> per year of finished timber product) including kiln drying. <sup>6</sup>

	Electricity	Heat	Both
NSW	1.51	2.42	3.94
VIC	1.88	2.16	4.04
QLD	1.49	2.34	3.83
SA	1.47	2.51	3.98
WA	1.33	2.06	3.39
TAS	0.09	2.38	2.47
NT	1.02	1.82	2.84
ACT	1.51	2.42	3.94
Average	1.29	2.27	3.55

*Note:* The electricity is assumed to be normal grid procured power. Heat is assumed to be derived from combustion of natural gas. Emission estimates take into account energy involved in fuel handling, generation and distribution costs.

## 3 TECHNOLOGY OPTIONS

### 3.1 Overview

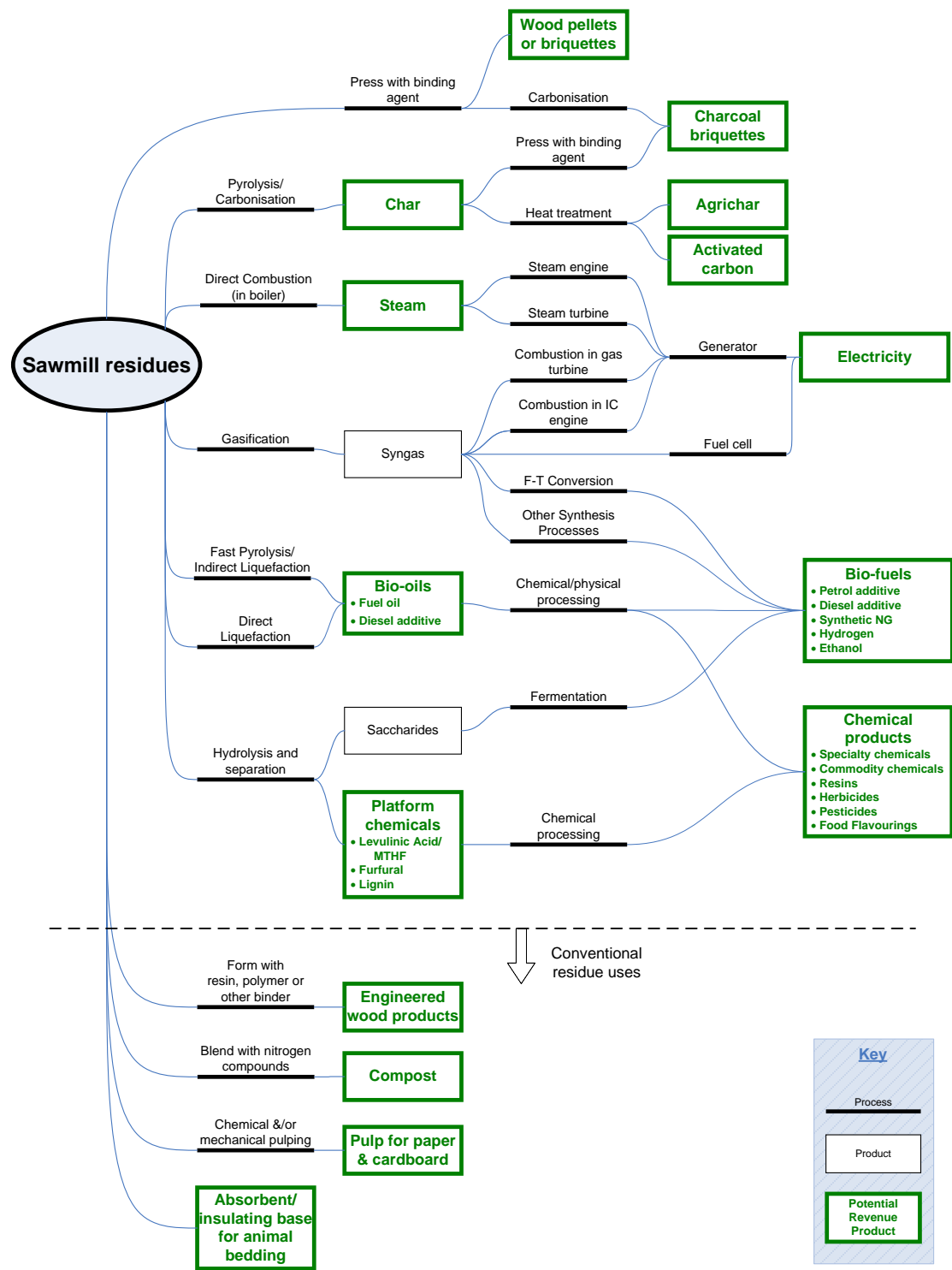
The practical uses for sawmill residues may be grouped in many ways, however most applications utilize one or more of the intrinsic material properties of wood as follows:

- Conversion of stored chemical energy into thermal, electrical or kinetic energy
- As a source of organic polymers for useful chemicals
- Employing the mechanical properties of the fibrous cellulosic structure
- As a source of organic material for biological feed
- Use of thermal or acoustic insulation properties

There is a long list of products that can be derived from sawmill residues, employing an array of different technologies. Energy products are of increasing interest to developers and regulators at present, due to mounting social and political pressure to reduce Greenhouse Gas (GHG) emissions. The combustion of biomass for energy is recognised under the Kyoto Protocol as being neutral in terms of GHG emissions. Wood combustion may be exploited to reduce GHG emissions and potentially attract economic benefits through government incentives. Energy may be derived from woody biomass in a number of different forms, including:

- Heat in hot gases or steam
- Electricity
- Bio-fuels and bio-oils
- Solid fuels - compressed wood (pellets or briquettes) or charcoal briquettes

Each of these energy products may be produced via a number of process routes or technologies, as illustrated in Figure 1 below. There are also other non-energy products such as agri-char, activated carbon and a long list of chemicals, presenting a complex set of options and opportunities. The paths and products below the dashed line are considered, for the purposes of this report, to be largely established technologies and are not discussed in detail.



**Figure 1:** Potential technologies for the conversion of sawmill residues into useful products.

*Note:* The pre-processing required for each method is not shown but may not be equivalent for each route. For example, many of these applications require the wood waste to be separated from other wastes, cleaned and processed (grinding or chipping).

The sections below provide a description of these technologies and their state of maturity, in relation to sawmill residues.

### 3.2 Pre-treatment - Size Reduction and Drying

Essentially all the technology options discussed in this report for using sawmill residues require some degree of size reduction of the wood and most require drying. Size reduction via hogging, chipping, grinding, etc, requires mechanical energy usually provided by electrical motors or internal combustion engines. Drying too requires energy, and may be provided by solar, natural convection, mechanical pressing or heating. These processes can be energy intensive and expensive.

The energy required to grind wood is dependent on many variables relating to the equipment used, the characteristics of the wood and the degree of size reduction. The energy requirements for size reduction is difficult to measure accurately, but has been reported for some different applications in Table 4 below. The consumption of energy increases exponentially with decreasing particle size.

**Table 4:** Reported energy requirements for grinding of biomass.

Product	Equipment	Max particle size after reduction (mm)	Grind energy (MJ <sub>e</sub> /tonne)
Barley straws, corn stover, switch grass <sup>7</sup>	Hammer mill	3.2	40
Barley straws, corn stover, switch grass	Hammer mill	0.8	100
Poplar chips (10-15% mc) <sup>8</sup>	Hammer mill	1.0	432
Pine chips (10-15% mc)	Hammer mill	1.0	540
Pine bark (10-15% mc)	Hammer mill	1.0	126
Aspen wood <sup>9</sup>	Hammer mill	3.0	200
Unspecified wood <sup>10</sup>	Attrition mill	0.9	940
Unspecified wood	Attrition mill	0.1	2,360

An improvement in the ability to grind biomass through torrefaction (thermal treatment in temperature range of 200 to 300°C) was observed by Bergman et al<sup>11</sup>. It was found that the energy for size reduction can be decreased by 50 to 85% and throughput increased by a factor of 2 to 6.5 after torrefaction, compared to untreated biomass. Additionally, as the fibrous structure of biomass is partly destroyed, the material is more easily fluidised assisting in pneumatic conveying and entrained air gasification. Around 83 to 97% of the original energy (LHV<sub>daf</sub>) is retained in the torrefied wood with reaction times of less than 10 min. The lost energy corresponds to 0.36 to 2.04MJ per tonne. This approach may be suitable in certain cases and basically involves trading capital and operating costs on grinding equipment with capital and operating costs on up front torrefaction.

To remove moisture from very wet biomass, mechanical drying (eg, centrifuging, pressing) may be used to reduce moisture content to about 50% w.b. (wet basis). To reduce moisture content below 50% w.b. requires thermal or forced convection drying. A modern thermal dryer uses about 5 to 10MJ of energy for the evaporation of 1 kg water. This means that decreasing the moisture content by approximately 10% consumes about 3.5% to 7% of the heating value of the dry material. When local conditions of solar availability and humidity permit, solar drying is an appealing alternative.

Forced drying of biomass using low grade waste heat from other processes such as flue gases, steam heat recovery heat exchangers, timber kiln exhaust, etc, is appealing at first glance. These approaches may be advantageous in certain circumstances, but involve additional capital and operating costs in ducting, fans, drying silos, safety systems and control systems. In general, excess heat in flue gases is much more economically used in the preheating of combustion air. Dryers are expensive to install and even more expensive to maintain, present a serious fire hazard, and increase the suspended particulate loading in the flue gas.<sup>12</sup>

### 3.3 Compressed Fuels for Burning

An option for using fine wood waste is compressing it into pellets or briquettes to be used as a dense, solid fuel source for stationary heat and power applications. Compression of fine and loose sawmill residues will create a solid fuel that is easier to convey and transport and has a higher, uniform volumetric energy density.

Pellets are small highly compressed wood slugs that can be produced on a large scale and are used widely. Briquettes are larger products that can be manufactured at smaller scales for moderate costs, but are less widely used. Pellet and briquette products can be made from both hardwoods and softwoods.

There are two grades of wood pellets, namely premium and industrial. Premium grade pellets are of the highest quality and are made from clean wood with no added starch and bark. They burn very cleanly with an ash content of typically <0.5%. On the other hand industrial grade pellets are made from recycled timber, bark and often dirt and burn less efficiently and have an ash content around 3-4%. Premium grade pellets are used in domestic appliances whilst industrial grade are normally used in larger scale boilers.

An up to date (2012) report on the use of industrial grade wood pellets worldwide is available from:

[www.enplus-pellets.eu/wp-content/uploads/2012/04/Industrial-pellets-report\\_PellCert\\_2012\\_secured.pdf](http://www.enplus-pellets.eu/wp-content/uploads/2012/04/Industrial-pellets-report_PellCert_2012_secured.pdf)

The report states that global wood pellet production in 2010 was about 13 million tonnes, with US-Canada and Scandanavia among the largest producers. Australia is an emerging producer along with South Africa and South America. Europe consumed approximately 70% of total global production in 2010, mostly for industrial power and heat applications.

#### 3.3.1 Wood pellets

##### 3.3.1.1 Wood Pellets Technology Description

Wood pellets, shown in Figure 2, are made from compressed dry sawdust, with the assistance of steam or a binder such as starch. The pellets can be made in a range of sizes depending on their required final application and market. Pellet markets generally require pellets to conform to a strict standard, which stipulates that pellets should be dry (moisture content typically less than 7% w.b.), mechanically robust and have an ash content and may also define other contaminants levels such as chlorine content. Pellets should also flow freely and be able to be delivered via a pneumatic system.<sup>13</sup> The Australian and New Zealand standard for wood pellets is AS/NZS 4014.6:2007 and there are both US and European standards.





**Figure 2: Wood Pellets** (Courtesy <http://www.hotstovies.com/contact-us.html>)

Energy content is critical to many end users. For example, a high calorific value can lead to higher combustion temperatures and potentially damage furnaces. Pellets for export need to be sampled and tested to ensure conformance to standards.

Although details of the production process vary between companies, pellet production is generally applied for the processing of material which is not suitable to be made into pulp-grade wood chips. Typically the pellet production process consists of the following steps<sup>14</sup>:

1. *Milling* - Raw material is reduced to a particle size of about 3mm.
2. *Conditioning* - to the required temperature and moisture content to activate the lignin as a pellet binding agent and to obtain the necessary malleability of the product. .
3. *Pressing* - The woody material is fed into the pellet press. Pellets are formed by compressing the wood in a dye, as shown in Figure 3, to achieve compaction. The shape/design of the dye used for the press, depends on the feedstock used.



**Figure 3: Pellet Dye** (Photo: the Energy Crops Company Ltd)

4. *Cooling* - The wood pellets need to be cooled after leaving the press. Cooling the pellets ensures they harden, making them more robust during storage and handling.
5. *Screening* - Pellets are passed over a vibratory screen to separate fines.



6. *Storage* – Pellets need to be kept dry and can only be stored for a limited time.

### 3.3.1.2 *Wood Pellets Products and Markets*

Wood pellets are a renewable and GHG neutral fuel alternative for old coal fired heaters and boilers as well as being able to be used in a range of modern combustion systems. As a fuel, pellets are comparable with coal in terms of energy content, and offer potential reductions in NO<sub>x</sub> and SO<sub>x</sub> emissions with usually less ash.

Pellets have benefits over wood chips and other types of wood fuel in terms of their consistency, moisture content and energy density and as such they are easier to ignite and handle<sup>14</sup>. However they are typically more expensive to produce and excessive handling causes them to degrade and become more dusty<sup>14</sup>.

In several European countries, wood pellets have proved to be a very popular alternative to fossil fuel based domestic, district and industrial heating systems and in small to large scale Combined Heat and Power Plants<sup>13</sup>. The demand is driven by EU and regional incentive schemes making pellets competitive with fossil fuels. There is a general shortage of pellets in Europe and so pellets can attract premium prices. Market prices for pellets have been stated to be in the range of \$100 to \$350 per tonne delivered for bulk quantities.<sup>15</sup> Market spot prices for pellets can be obtained from a number of web based sources such as FOEX ([www.foex.fi](http://www.foex.fi)); Argus Media ([www.argusmedia.com](http://www.argusmedia.com)) and apx-endex ([apxendex.com](http://apxendex.com)). FOEX indicates that pellet prices at September 2012 were around €200 per tonne.

As a consequence of the shortage in Europe, pellets are currently imported from the east coast of North America into Europe, with a resulting net flow of pellets from the west coast supplying the east coast. There is also a net shortage of pellets in the US. Whilst there have been attempts to export pellets from Australia and New Zealand to Europe these have generally not been successful for a variety of reasons. The two main reasons were transport costs and the requirement in Europe that the pellets are manufactured and transported by “green” methods. The raw material for example must comply with the Forestry Stewardship Scheme (FSE).

Domestic and commercial heating needs, town structures and the regulatory environment within Australia are fundamentally different to Europe. The Australian market for pellets is presently limited to small amounts for use in wood heaters and as absorbent material. However, several companies are looking to expand their supply into the local market as a precursor to exporting into the Asian market. As with any business the viability of the operation depends in part upon the balance between the size of the market and the ready availability of the source materials (in this case for making pellets). A recently released (policy) report (October 2012) by the Victorian Government<sup>16</sup> stated that over 285,000 tonnes of wood/timber waste goes to landfill each year and the Government is very keen for this to be re-used rather than dumped.

An Australian company, Altus Renewables, based in Queensland is nearing completion of its 125,000tonne/year pelletising plant with commissioning scheduled for January 2013. The company has a supply agreement with Hyne’s Tuan wood processing facility to take residue and surplus wood as the feedstock for the pelletising plant. The sawmill processes softwood plantation trees with the plantation being FSE accredited. The pellets will be available in bags or bulk. Initial markets will be to Korea, Japan and the EU and the pellets will be transported by ship in bulk out of the port of Bundaberg. The pellets will be stored at the terminal in sheds set up for bulk sugar storage.

Australian New Energy a Geelong based company ([www.australianewenergy.com](http://www.australianewenergy.com)) has set up its business (through supply agreements) to use a range of raw materials such as wood waste, truss off cuts, sawdust & shavings from a variety of sources to ensure that it has a constant and consistent supply to its pellet plant. Its market is based upon expanding local demand and export to Korea and Japan.

A sample of wood pellet manufacturing plants that have been set up in Australia, is shown in Table 5:

**Table 5: Examples of Australian wood pellet manufacturing plants**

<b>Plant</b>	<b>Capacity</b>	<b>Main machinery supplier</b>	<b>Material</b>	<b>Status</b>
Plantation Energy Australia (Albury WA)	250,000 tonnes/year	Kahl	Plantation residues	Shut down, Jan 2012
Pellets Heaters Australia (Woodburn NSW)	3000 tonnes/year	Ace press by Andritz	Plantation softwood	Start up phase
East Coast Woodshavings (Gatton Qld)	3000 tonnes/year	Ace press by Andritz	Wood fines and sawdust	Operating making kitty litter
Scottsdale Hop Growers (Scottsdale Tas)	3000 tonnes/year	Ace press by Andritz	Plantation pine residues	Presently not operating, awaiting installation of a dryer
South Eastern Fibre Exporters (Eden, NSW)	500 kg/hour	AGICO (agent Artech, Rosedale, Qld)	Hard and softwood fines from chips	Producing pellets using hardwood & softwood
Altus Renewables	125,000tonnes/year	Andritz LM26, Folk Fabrication (US)	Softwood sawdust & shavings	Plant to be commissioned in Jan 2013
Australian New Energy	10,000tonnes/year	Chinese	Wood waste eg sawdust &shavings	Start up phase

An excellent source of information and means of meeting people working or interested in biomass use including pellets is the “Victorian Bioenergy Network” ([www.bioenergyvictoria.net.au](http://www.bioenergyvictoria.net.au)).

### 3.3.1.3 Wood Pellets Capital and Operating Cost

Prices which have been provided by some pellet manufacturing equipment suppliers are listed in Table 6 (2012 prices). Equipment prices vary significantly, mainly due to country of manufacture. Of course, a careful comparison of equipment specifications from each supplier is advisable prior to making any procurement decision.

**Table 6: Prices of Pelletising Equipment**

<b>Machinery</b>	<b>Company</b>	<b>Productivity (t/hr)<sup>c</sup></b>	<b>Energy Usage<sup>h</sup> (kW)</b>	<b>Cost (million AUD)</b>
Pellet press only	“Ace” by Andritz	4	-	0.1
Pellet Mill Equipment (Dry sawdust feed)	Andritz Pty Ltd	4	-	1.2 <sup>e</sup>
Pellet Mill <sup>a</sup>	Andritz Pty Ltd	20	-	11 <sup>f</sup>
Pellet Mill (PP300 Kompakt)	Sweden Power Chippers AB	0.25 – 0.35	-	-
Pellet Mill (PP300 Twin)	Sweden Power Chippers AB	0.5 – 0.7	-	-
Pellet Mill (PP450 Kompakt)	Sweden Power Chippers AB	0.4 – 0.5	-	-
Pellet Mill (PP450 Twin)	Sweden Power Chippers AB	0.8 – 1	-	-
Pellet Mill - including crusher & drying plant, pelletising & cooling plant, bagging, electrical equipment, fixing material & packing	Anyang General Int.	1	150	0.16 <sup>b</sup>
Pellet press, feed and receiving bin	Lawson Mills (Canada)	0.4	26	0.05
Pellet mill (turnkey)	Zhangqui Yulong Machinery	1	137	0.12

a. CAPEX including presses mill and dryer excluding installation

b. Assuming 1.00 AUD = 1.00 USD

c. Mills A, B and C represent generic sawmills of large, medium and small capacity respectively, and are defined in section 5.3

d. Prices are for an operational mill

e. CAPEX for mill only

f. \$30 million for main machinery (pellet press) and \$5 million for installation, buildings, steel, electrical and dryer

g. There are 6 off 3.5 tonnes per hour presses each requiring 240kW

h. Energy usage by electrical motors only – does not include thermal energy for drying if required. Energy for drying is discussed in section 3.2.



**Figure 4:** Pelletising Plant - Pellet Heaters Australia

It is important to note that due to the extreme pressure used in a pelletising system (1.7GPa) wear parts such as dies need replacing regularly. This can represent a significant operating cost, depending on the type of wood being processed.



**Figure 5:** BioJoule Pelletising Plant

It is possible to make use of third party equipment, whereby pelletising plant is owned and operated by an equipment supplier and sited ideally at or adjacent to the sawmill.<sup>18</sup> Sawmill residue in this case would earn a per tonne revenue, depending on the type of residue. Agreements would need to be established in relation to supply quantity and quality, energy requirements and permits, but potentially allow sawmill operators to avoid having to develop operational expertise in pelletising as well as removing sales and marketing issues.

The use of mobile pelletising plant may allow expertise to be sub-contracted or shared between nearby sawmills or other compatible biomass producers. Mobile plant is available from some suppliers, while others believe it is not a practically feasible option due to the high pressures involved.

### 3.3.2 Wood Briquettes or Synthetic Logs

#### 3.3.2.1 Briquettes Technology Description

Wood briquettes are made by compacting loose wood waste into a dense material through the application of high temperatures of approximately 300 to 350°C and moderate pressure. Sawdust, wood chips and bark are suitable for making briquettes, although sawdust is the preferred raw material. Briquettes can also be carbonized to create charcoal of very high quality (charcoal briquettes discussed in section 3.3.3).<sup>19</sup>

#### 3.3.2.2 Product Types

Wood briquettes, shown in Figure 6, are similar to wood pellets but are physically larger. Briquettes vary in diameter from around 50 to 100mm and are usually 60 to 150mm long. They are generally burnt as a cleaner and more consistent alternative to firewood logs, offering a higher energy density and steady combustion.<sup>12</sup> Wood briquettes can be used in stoves, furnaces and solid fuel burning equipment, although this is a relatively small niche market.<sup>23</sup> In the fuel industry, briquettes have to compete with other fuels, such as wood and agricultural residues, kerosene and diesel, which are often cheaper.<sup>20</sup>



**Figure 6:** Wood Briquettes<sup>21</sup>

### 3.3.2.3 Plant Capital Cost

Prices for a briquetting plant/equipment have been provided by a couple of companies and these are shown in Table 7.

**Table 7:** Prices of Briquetting Equipment

<b>Machinery</b>	<b>Company</b>	<b>Productivity (kg/hr)</b>	<b>Energy Consumption (kW)</b>	<b>Cost (AUD)<sup>a</sup></b>	<b>Comments</b>
Crusher (JXI - 1, for log)	Henan Jingxin Diamond Machinery	700	11	\$2,100	Incl packaging and freight to Shanghai
Crusher (JXI - 2, for branch)	Henan Jingxin Diamond Machinery	900	11	\$2,500	Incl packaging and freight to Shanghai
Drying Machine (JXII - 1)	Henan Jingxin Diamond Machinery	250 - 300	4	\$3,000	Incl packaging and freight to Shanghai
Drying Machine (JXII - 2)	Henan Jingxin Diamond Machinery	600 - 800	5.5	\$3,800	Incl packaging and freight to Shanghai
Drying Machine (JXII - 3)	Henan Jingxin Diamond Machinery	1000 - 1400	7.5	\$4,500	Incl packaging and freight to Shanghai
Briquette Extruder Machine (JXIII - 1)	Henan Jingxin Diamond Machinery	275	15.5	\$5,000	Incl packaging and freight to Shanghai
Briquette Extruder Machine (JXIII - 2)	Henan Jingxin Diamond Machinery	400	15.5	\$5,700	Incl packaging and freight to Shanghai
Briquette Extruder Machine (JXIII - 3)	Henan Jingxin Diamond Machinery	500	17.5	\$6,400	Incl packaging and freight to Shanghai
Wood Briquetting Equipment	Cipta	1050	-	\$313,000	Excl power supply system
Mechanical Briquetting Equipment	Woodfield Machinery	500-2000	22	\$75,000- \$160,000	Machine made by CF Nielsen in Denmark
Hydraulic Briquetting Equipment	Woodfield Machinery	60-500	6-27	<\$75,000	POR Italian produced machine

a. Assuming 1.00 AUD = 1.00 USD

### 3.3.2.4 Briquetting Technology Status

Wood briquettes are relatively common in colder countries for use in log wood fires. However in Australia with the low cost of gas heating they are not as frequently used. The best market for wood briquettes is seen to be as a heating source for residential use in small local communities where low cost gas is unavailable.

Briquettes are manufactured for example by Aussie Crates and sold at a retail price of \$5 per 10kg bag (which equates to \$500/tonne).

There are no foreseeable technological developments for this product.

### 3.3.3 Charcoal Briquettes

#### 3.3.3.1 Charcoal Briquetting Technology Description

Charcoal briquettes, shown in Figure 7 can be made from two different methods; turning the wood wastes into charcoal dust then making briquettes from the dust or carbonizing wood briquettes to charcoal briquettes.



**Figure 7:** Charcoal Briquettes (photo: <http://www.freewtc.com/products/sawdust-briquette-charcoal-266-10030.htm>)

To produce charcoal briquettes from wood briquettes, the wood briquettes are made as per usual, they are then put into a carbonizing machine and pyrolysed.

The charcoal dust used to create charcoal briquettes is made from saw mill waste which has been screened to a uniform size before being treated in an oxygen controlled vessel at temperatures of 315 to 980°C. The resulting char is mixed with other ingredients, such as a binder like starch, before it is moulded to the required briquette shape, dried and packaged.<sup>22</sup> There are alternative methods which may be used but each of them follows this same basic principle.<sup>22</sup>

#### 3.3.3.2 Charcoal Briquette Products

Charcoal briquettes are a convenient source of burning fuel which tends to burn longer and more consistently than lump charcoal, but not quite as hot. Some briquettes contain ingredients in addition to charcoal to improve aesthetics of the product during combustion; consequently they can result in a larger amount of ash.<sup>22</sup>

The majority of char briquettes produced in Australia are made from coal char rather than wood due to the abundance and low cost of coal. There is only a relatively small local market for wood char briquettes.<sup>23</sup>

#### 3.3.3.3 Charcoal Briquetting Costs

Prices have only been found for carbonising wood briquettes and not producing briquettes from char dust. The briquetting equipment listed in Table 7 is needed in order to produce charcoal briquettes. The prices of the carbonising equipment are shown in Table 8.



**Table 8: Prices of Carbonising Equipment** <sup>24, 25</sup>

<b>Machinery</b>	<b>Company</b>	<b>Productivity (kg/hr)</b>	<b>Energy Usage (kW)</b>	<b>Cost (AUD) <sup>a</sup></b>	<b>Comments</b>
Carbonising Machine (JXIV - 1)	Henan Jingxin Diamond Machinery	125	1.5	4,800	Incl packaging and freight to Shanghai
Carbonising Machine (JXIV - 2)	Henan Jingxin Diamond Machinery	187.5	1.5	5,600	Incl packaging and freight to Shanghai
Carbonising Machine (JXIV - 3)	Henan Jingxin Diamond Machinery	250	1.5	6,700	Incl packaging and freight to Shanghai

a. Assuming 1.00 AUD = 1.00 USD

Charcoal for use in barbeques is sold in Western Europe at a wholesale price of EUR 280 to 300 per tonne and bagged charcoal is sold in Moscow wholesale for around EUR 300 per tonne. <sup>15</sup> No wholesale prices have been found for selling charcoal briquettes in Australia; however they are sold in service stations in metropolitan Melbourne for a retail price of \$8 for a 10kg bag (which equates to \$800/tonne).



## 3.4 Direct Combustion

Direct combustion of woody biomass yields net energy in the form of radiation, in the visible and infrared range of the spectrum, and sensible heat within the combustion products, predominantly in the flue gas stream. Combustion chambers are designed to facilitate efficient burning and to focus the evolved heat to where it is needed. Combustion chambers vary in design depending on the quantity and characteristics of the fuel and the way in which the heat will be used.

### 3.4.1 Theory

Combustion or burning of wood involves a complex series of chemical reactions, as outlined below.

#### 3.4.1.1 Stage one - *Drying and torrefaction*

The first stage of combustion of wood is the heating and evaporation stage. The temperature of the wood surface approaches 100°C and the water in the wood evaporates. As long as water remains in the wood, the evaporation process maintains the temperature at 100°C. Moisture must be driven off before combustion can begin, so wood with high moisture content is hard to ignite. As the wood surface temperature rises beyond 100°C to about 230°C, torrefaction begins evolving gases such as carbon dioxide, carbon monoxide along with acetic and formic acids. The initial drying can take place either in the furnace (assisted by using hot combustion air) or in an external dryer.

#### 3.4.1.2 Stage two combustion - *Volatilisation*

After moisture is driven from the wood and the temperature of the wood rises above about 280°C, the second stage of combustion takes place. This is the heat-producing stage. It occurs at two different temperature levels: primary and secondary combustion.

The process by which gases are released from the wood and burned is called primary combustion. Primary combustion begins at about 280°C, continues toward 500°C and results in the release of a large amount of energy. During this stage large amounts of unburned combustible gases, including methane and methanol as well as more acid, water vapour and carbon dioxides are produced. These gases contain up to 60% of the potential heat in the wood and their combustion is important to achieve high overall combustion efficiency. These gases are not burned near the wood because of a lack of oxygen.

The conditions needed to burn secondary gases are sufficient oxygen and temperatures of at least 600°C. The air supply is critical. Too little air will not support combustion and too much will cool the temperature to a point where combustion cannot occur. Air contains approximately 80% nitrogen, an inert gas, and when introduced into the combustion chamber it will be below the 600°C needed to sustain secondary combustion. The more air that mixes with the secondary gases, the greater the quantity of heat absorbed by the nitrogen, resulting in a lower the temperature of the secondary gas-air mixture.

#### 3.4.1.3 Stage three combustion – *Charcoal burn*

After the gases are evolved from the wood, what remains is a char which is basically carbon. Carbon burns over a long time with a low rate of heat output and is reduced to ash to complete the combustion process.

### 3.4.2 Combustion in Practice

#### 3.4.2.1 Approaches

The common method of combusting solid fuel such as biomass is to burn it on a grate with excess (greater than stoichiometric) air to ensure complete combustion as described above. A more recent process (at least in power production) incorporates an intermediate step - the *gasification* of the fuel. In this case the fuel is supplied with little to no air and the material is pyrolysed then gasified (often in the presence of steam) to produce a “syngas” (mainly CO, methane and H<sub>2</sub>). The syngas can be combusted in a second stage, known as *staged*

*combustion*, where the evolved heat is then usually directed into a boiler to produce steam. Alternatively, the syngas can be collected and stored for later use or burnt in an internal combustion engine or gas turbine. This technology is discussed further in section 3.5.

#### 3.4.2.2 Staged Combustion

In staged combustion, the syngas is immediately mixed with air in a second chamber where it burns completely, the gas temperature rises and the heat is used usually in a boiler. Separating the stages of combustion provides a number of benefits, including:

- Improved control allowing oxygen levels to be optimised for each stage
- Pre-combustion (or gasification) can be performed at lower temperatures, reducing the driving force for a variety of ash related problems such as clinkering
- Gaseous phase combustion can be better controlled to ensure complete combustion and, by controlling the residence time at the desired temperature, reduce emissions of harmful halogenated organic compounds such as dioxins and furans

### 3.4.3 Biomass Furnace technologies

Modern furnace types basically fall into four categories: pile burners, stoker grate, suspension and fluidised bed. The advantages and disadvantages of each are outlined below in a qualitative sense. As mentioned in the section above combustion can be carried out by either 'conventional' means or by staged combustion or gasification. Apart from suspension burners, the other types of furnaces can be designed and used for any of the forms of combustion.

#### 3.4.3.1 Pile Burners

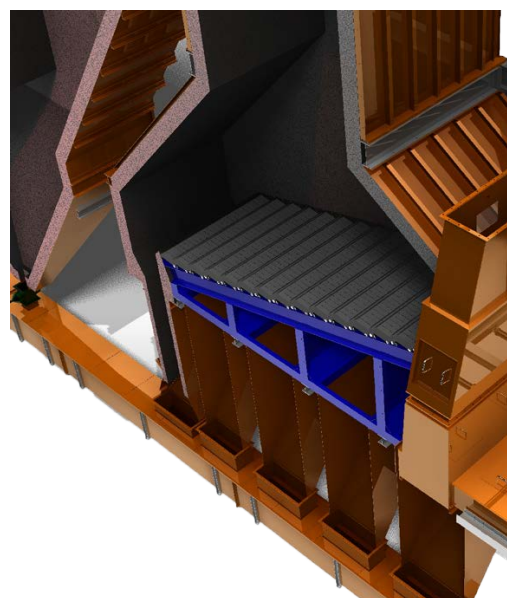
In pile burners the biomass is dumped into piles in a furnace and burned with the help of combustion air coming from under and above the grate. Advantages of this technology are the fuel flexibility and the simple design. Whilst the burner/boiler is simple the disadvantages are the generally low combustion efficiency due to poor combustion control and the need to manually remove ash. This manual operation means that the pile type furnaces are not often used in commercial plant unless the ash content is very low.

#### 3.4.3.2 Stoker Fired

Within the group of stoker fired boilers, there are three major types of grate namely stationary sloping grate, travelling grate and vibrating grate (an example is shown in Figure 8). The aim in each case is to automatically remove ash whilst helping to ensure complete combustion of the biomass. Common to these types is a fuel feeding system which 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. The disadvantages of this type of boiler are the difficulty in controlling the combustion process and the risk of avalanching of the fuel.

#### 3.4.3.3 Travelling Grate

In a travelling grate boiler 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



**Figure 8:** A reciprocating grate furnace - a type of vibrating grate with an incline. (Image courtesy of Sigma Thermal)

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. This type of grate has less moving parts than a travelling grate and therefore typically has lower maintenance requirements. 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  $\text{NO}_x$  creation.



**Figure 9:** A travelling grate type furnace. (Image courtesy of AET-Biomass)

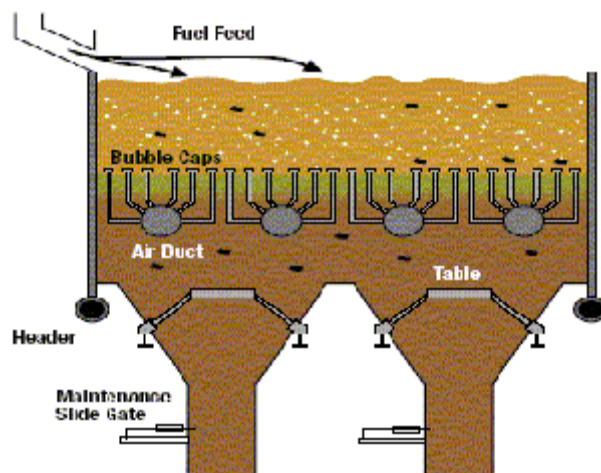
#### 3.4.3.4 Suspension Firing

In suspension fired boilers 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 and as such requires fine friable fuel. Preparation of the fuel to a suitable state often involves intensive pre-treatment. The particle size is dependent on the type of biomass and the furnace design – dictated by residence time required for efficient combustion. A particle size of 1-2mm is recommended for wood. The main advantage of suspension firing is high combustion efficiency.

#### 3.4.3.5 Fluidised Bed

In fluidised bed systems, combustion air fed from below the furnace chamber through a mass of sand at a high speed so that the fuel becomes a seething mass of particles and bubbles. A general feature of fluidised bed systems is that they are flexible in the kind of fuel that can be fired, which makes them quite suitable for co-firing different kind of fuels. Carbon burnout efficiency is very high in fluidised bed systems.

Another important advantage is the possibility of controlling  $\text{NO}_x$  creation by controlling combustion



**Figure 10:** Bubbling Fluidised Bed

(Image courtesy Babcock & Wilcox)

temperatures and to minimize SO<sub>x</sub> creation in the case of fossil fuel co-firing. A disadvantage of fluidised bed systems is the high demand for air to fluidise the bed. This requires large fans adding significantly to the plant parasitic power consumption, particularly in smaller furnaces.

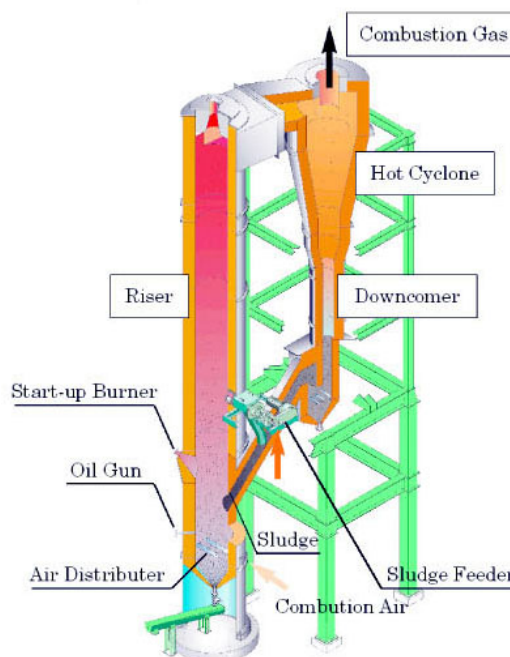
There are two types of fluidised bed boilers, a bubbling fluidised bed (BFB) and a circulating fluidised bed (CFB). Selection of the type of fluidised bed boiler depends on the fuel type, steam condition, etc. An advantage of bubbling fluidised beds over circulating fluidised beds is their lower capital requirement at modest scales, i.e., smaller than 60 MW<sub>th</sub>, which equates to approximately 90,000 tonnes per year of dry wood.

#### 3.4.3.6 Bubbling Fluidised Bed (BFB)

In a BFB, materials in the furnace are fluidised by supplying fluidising air (combustion air) from the furnace bottom. Fuels are fed into the furnace whose temperature is kept 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% w.b. moisture content fuels although they are generally designed to handle 65%. BFBs are a square design and cannot easily be scaled up in size. As a result they have traditionally been used for smaller to moderate scales.

#### 3.4.3.7 Circulating Fluidised Bed (CFB)

Due to the higher superficial velocity found in a CFB most of the particles leave from the furnace. These particles are collected by a cyclone located at the furnace exit, and then returned to the furnace for further combustion. CFB systems have better carbon burnout efficiencies and absorb acid gases more easily. The bed material, usually sand, needs to be cleaned regularly of ash and other non-combustibles and this is done automatically in a circulating fluidised bed. CFBs would be used with biomass containing high chloride levels, as would occur in agricultural residues. CFBs have very low NO<sub>x</sub> emissions; however they are limited to 60 to 63% w.b. moisture content.



**Figure 11:** Circulating Fluidised Bed  
(Image Courtesy Kubota Corporation)

#### 3.4.4 Heat and steam

The combustion of sawmill residues for useful heat is an obvious and in many cases prudent exploit. To make use of the evolved heat, it is commonly transferred to a heat transfer medium in a heat exchanger or a boiler. Saturated or superheated steam is a relatively inexpensive and efficient heat transfer medium and is widely used for process and space heating. Steam is also widely used for electricity production, which is discussed in section 3.4.5, and in co-generation, which is discussed in section 3.4.6.

Boiler types vary depending on the scale of the system and the pressures or temperatures required. There are two basic types of boiler - fire tube and water tube. Water tube boilers are more often favoured when high pressure steam is required, for example to drive a turbine. Water tube boilers are commonly either D-type or tower type and are used almost exclusively for steam pressures above 10 bar (g)<sup>27</sup>, especially to drive steam turbines. At lower pressures, fire-tube boilers offer relative simplicity and lower cost.

The thermal efficiency of a steam plant depends strongly upon the boiler pressure; the higher the boiler pressure, the higher the efficiency. Also, as the boiler pressure rises, the flow rate of the steam needed to produce a given power output falls. Conversely, lower pressures

mean that more steam is needed and hence more fuel has to be used. On the down side, increasing boiler pressure means higher temperatures and necessitates the use of higher quality materials and construction techniques thus increasing system costs.

The amount of heat energy that can be extracted from wood is dependent on the type of wood residue, but more significantly on its moisture content. Table 9 shows the effect of moisture content on its recoverable energy. Compared with most fossil fuels, even bone dry wood has a relatively low heating value at typically 19 to 21MJ per kg.<sup>28</sup> This value decreases significantly as moisture content increases. Green hardwood eucalypt typically has a moisture content of around 30% w.b., while green softwood pine typically has moisture content around 50% w.b.

**Table 9:** Heating values (wet basis) of a eucalypt hardwood at various moisture contents compared with fossil fuels.

<b>Fuel</b>	<b>HHV, Higher Heating Value (MJ/kg)</b>	<b>LHV, Lower Heating Value (MJ/kg)</b>
Hardwood at 0% m.c. <sup>a, 28</sup>	19	19
10% m.c. <sup>b</sup>	17.1	16.8
20% m.c.	15.2	14.7
30% m.c.	13.3	12.5
40% m.c.	11.4	10.4
50% m.c.	9.5	8.2
Anthracite <sup>29</sup>	31.4	26.1
Lignite	26.7	24.1
Heavy fuel oil	42.6	35.1
Light fuel oil	43.5	35.9
Butane	49.3	38.9
Propane	50	39.4

a. Eucalypt hardwood

b. Calculated, wet basis

The successful commercial operation of the plant is heavily dependent on the total amount, rate of delivery and quality of the fuel. These factors influence the technologies employed in the furnace, which can have a large impact on the capital costs (CAPEX) and operating costs (OPEX). Clearly, the amount of fuel available largely determines the upper limit on the size of the plant. The fuel size is another important factor, since the cost of purchasing hogging or chipping equipment for size reduction is significant and the operating costs are very high, especially the power consumption.

The inorganic content of some types of biomass fuel presents specific difficulties compared with fossil fuels. Some types of biomass used contain significant amounts of chlorine, sulphur and potassium. The salts, KCl and K<sub>2</sub>SO<sub>4</sub>, are quite volatile, and the release of these components may lead to heavy deposition on heat transfer surfaces, resulting in reduced heat transfer and enhanced corrosion rates. Severe deposits may interfere with operation and cause unscheduled shut downs. The release of alkali metals, chlorine and sulphur to the gas-phase may also lead to generation of significant amounts of aerosols (sub-micron particles) along with relatively high emissions of HCl and SO<sub>2</sub>.

The type of furnace for burning biomass would generally be either a variety of stoker grate or fluidised bed. In grate-fired furnaces, deposition and corrosion problems are the major concern when using dirty or high alkali fuels. Fluidised bed combustors are frequently used in these cases with circulating fluidised beds being the preferred choice in larger units. Here,



silica and other inorganics in the biomass may cause agglomeration of the bed material requiring specialised agglomerate removal systems.

Fuel consistency is also a factor, particularly with regard to homogeneity and moisture content. Variations in fuel size and feed rate will influence the type of furnace selected, with some types more able to adapt to load and fuel burning characteristics. Moisture content is particularly crucial in furnace selection. In general terms, for moisture contents less than say 35% w.b. grate boilers can be used, although at this level some pre-drying is probably required. At moisture contents above 35 to 40% w.b. fluidised bed boilers are more appropriate.

In modern furnaces a high combustion quality is achievable, yielding efficient heat recovery and low emission levels. Combustion quality mainly depends on the combustion chamber temperature, turbulence of the burning gases, residence time and the amount of excess oxygen. These parameters are governed by a series of technical variables such as:

- combustion technology (for example, combustion chamber design, process control technology)
- settings of the combustion (for example, primary and secondary air ratio, distribution of the air nozzles)
- load condition (full- or part-load)
- fuel characteristics (shape, size distribution, moisture content, ash content, ash melting behaviour)

The air borne emissions from a modern biomass furnace are a vast improvement from domestic heaters or open air uncontrolled combustion, mostly due to more complete combustion. However, even in modern furnaces combustion will need to be carefully controlled in order to meet EPA standards. It is likely that a bag house filter would be required to keep particulate emissions below the legal level, depending on location.

### 3.4.5 Electricity

As indicated in Figure 1 the combustion of wood can be employed to generate electricity either through direct combustion to produce steam then passing the steam through a steam turbine or steam engine to drive a generator, or first gasifying the wood and combusting the gas in a gas turbine or internal combustion engine to drive a generator. The steam route requires direct combustion and boiler technologies as outlined above. The gasification route requires pyrolysis and gas clean-up technologies as outlined in section 3.5.1.

#### 3.4.5.1 Steam turbine system

Steam turbine systems are an established, widely available and robust technology but are generally only economically feasible on biomass fuels above 10MWe, although may be a marginal proposition down to 5MWe. This corresponds roughly to 50,000 to 100,000 tonnes per year of dry wood waste (0% moisture content). The rule of thumb presently used by the industry for these types of biomass fuelled generation systems is \$5 to 6 million per MWe for new equipment. For a mature power generation technology, the industry rule of thumb for maintenance costs is typically 3% of capital investment per year. This can rise to 5-10% for less mature technologies. Indicative total operating costs for a 10MWe plant running 8,000 hrs per year are laid out in Table 10.

**Table 10:** Indicative breakdown of direct operating costs for a 10MWe steam turbine power generation system fuelled by sawmill residues and operating 24hrs/day with dedicated staff.

Cost element	Units	Qty	Unit Cost (\$)	Cost (\$)
Labour	man hours/yr	16,000	60 <sup>a</sup>	960,000
Fuel (displacement cost)	tonnes	100,000	16	1,600,000
Ash disposal (3%)	tonnes	3,000	6	18,000
Water make-up	ML	40	2000	80,000
Water treatment				37,000
Maintenance	3% of CAPEX (20,000,000)			600,000
Fuel preparation and transport	Assume none required			-
Total				33,295,000
Generating Cost (based on 8000hrs/yr operation)				\$41/MWh <sub>e</sub>

<sup>a</sup> Indicative labour cost including overhead costs such as leave entitlements, insurance, payroll, etc

Steam turbines normally require superheated steam, which is steam that is heated above its boiling point at a given pressure, to ensure the steam is free of droplets that would erode the turbine blades. Therefore, a boiler driving a steam turbine requires a superheater. Typical superheated boiler pressures are usually either 46 bar or 64 bar and the steam is superheated to temperatures around 450°C (these pressures and temperatures are largely driven by limitations in the material grades used). Increased efficiency and fuel economy is achieved through the use of an economiser, which is a feed-water heater where the heat from flue gases is recovered to raise the temperature of feed-water supplied to the boiler.

A plant using steam boilers needs a source of high quality water for initial filling and then for continuous make up. All steam plants need make up water for both the boiler, where water is lost through leaks, during blow down and due to bleed off for process use, and for the cooling tower, where water is lost through evaporation. A typical boiler plant may need around 10% make up water, that is 10% of the boiler capacity needs to be made available for make-up. Additional make up water is also usually required for the cooling tower, although this water can be of a lower purity than that used in the boiler. For a 30MW<sub>th</sub> boiler working at 46 bar water is evaporated at around 50 tonnes per hour. This plant may need up to 5 tonnes per hour of boiler make up water. The water will have to be of high quality and the use of a purification plant such as Reverse Osmosis may be needed along with chemical treatment.

A condensing turbine provides the most efficient cycle, whereby steam passes directly from the turbine into a condenser, operating at sub-atmospheric pressure, enabling the maximum amount of energy to be extracted in the turbine. Condensers are used to condense the steam that exits the turbine back into a liquid so that it is able to be pumped. Typically condensers use re-circulated water that is cooled either in a cooling tower or via a cooling pond.

Cooling towers are typically either wet or dry. As the name implies wet cooling towers need a source of water that is evaporated. Dry cooling towers, using forced convection of air through a heat exchanger, are typically more expensive and constitute a larger parasitic load as electricity is required to drive the fans.

A commercially available small steam turbine generator set developed by Energent ([www.energent.net](http://www.energent.net)) can produce over 250kW<sub>e</sub> from steam at the conditions shown in Table 11.

**Table 11 Operating conditions for 250kW<sub>e</sub> steam turbine from Energent**

Steam inlet pressure (kPa)	Steam exhaust pressure (kPa)	Steam flow needed (tonnes/hour)
862	103	5.0
862	207	6.3
1379	414	6.8

The unit is fully automatic and can run unattended. The company indicates that costs associated (1 USD = 1 AUD) with the system are:

- Capital \$271,000-\$300,000 (depending upon options)
- Installation \$73,000-\$145,000 (depending upon site conditions)
- Routine & preventative maintenance \$3,900 per year

#### 3.4.5.2 Organic Rankine Cycle

The Organic Rankine Cycle (ORC) is similar to a conventional steam turbine cycle, except that the fluid which drives the turbine is an organic fluid with high molecular mass. The selected working fluids efficiently exploit low temperature heat sources (80-500°C) to produce electricity in a wide range of power outputs (2kW<sub>e</sub> up to 3 MW<sub>e</sub>). Theoretically, the lower the “input” temperature the lower the system efficiency.

ORC systems can be run off waste steam, engine exhaust gas or hot water. Waste heat can be extracted from the flue of biomass boilers or from excess steam and hotoil and used to drive an Organic Rankine Cycle (ORC) engine generator set. These engines can utilise heat at 150°C (or less with a drop in efficiency). Recent developments have produced reliable units with reasonable efficiencies.

Verdicorp ([www.verdicorp.com](http://www.verdicorp.com)) produces ORC power systems with power output of 25kW<sub>e</sub> to 100kW<sub>e</sub>. Verdicorp are represented in Australia by Verdeco Energy ([www.verdecoenergy.com.au](http://www.verdecoenergy.com.au)). The hardware for 100kW<sub>e</sub> system will cost in the range \$0.5-0.6million (which equates to \$5-6million per MW<sub>e</sub>).

An Australian company gT Energy Technologies ([www.g-tet.com](http://www.g-tet.com)) manufactures ORC based systems producing electrical power with standard size units of 25kW, 170kW and 600kW although units can be combined to provide greater power.

The following provides general information on the cost of their 170kW<sub>e</sub> unit:



**Table 12 Output and costs for an ORC system from gT Energy Technologies (2012)**

Item	Value
Gross power	170kW
Net power	150kW
Capital cost	<ul style="list-style-type: none"> <li>• ORC unit \$340,000</li> <li>• Installation \$50,000*</li> <li>• Wet cooling tower \$40,000<sup>#</sup></li> <li>• Dry cooling tower \$80,000<sup>#</sup></li> </ul>
Operating cost	<ul style="list-style-type: none"> <li>• \$6800 per annum</li> </ul>

Notes: \* This figure is site dependant

# The plant will either have a wet or dry cooling tower

gT Energy Technologies estimate that a payback period of just under three years for this system operating 24 hours per day for 245 days.

The company has installed one of their systems at Reid Brothers sawmill in Yarra Junction, Victoria under an arrangement whereby the saw mill does not own the system but pays gT Energy Technologies for the electricity generated. The ORC is run off excess steam from the kiln heating circuit. The use of the ORC generating system saves Reid Brothers \$10,000 per year.<sup>32</sup>

The Gympie Timber Company ([www.gympietimber.com.au](http://www.gympietimber.com.au)) has installed a Pratt & Whitney ORC system that generates up to 240kWe of net power using thermal oil at 150°C from their drying kilns. Most of the electricity is used on site but depending upon the mill demand some is exported to the grid. The unit was delivered to site in 2010 and the company regularly examines ways of improving the system performance.

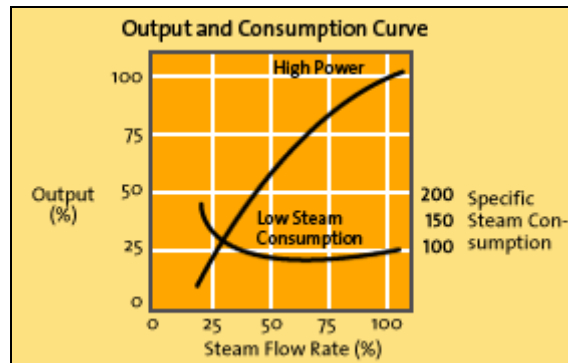
#### 3.4.5.3 Steam engine

Steam engines, like those shown in Figure 12, are a flexible electricity generation option, most suitable at scales less than a few MW<sub>e</sub>. Steam engines, being supplied with steam from an external combustion plant, can burn a wider variety of fuel cleanly and efficiently compared to internal combustion engines.



**Figure 12: Two Spilling 6 - Cylinder (3/3H12) Engine Sets.**<sup>33</sup>

In a reciprocating steam engine the steam is expanded in cylinders to provide the motive force. The steam, in expanding, causes the quality (dryness fraction) to decrease and potentially form droplets of water. These would lead to corrosion in the cylinder; therefore, it is important to ensure that the steam entering the cylinders is very dry (no entrained water droplets) or ideally slightly superheated



**Figure 13:** Relative power output and steam consumption curve for a reciprocating steam engine<sup>33</sup>

Figure 13 shows a relatively linear power output versus steam flow rate relationship from around 25 to 100% of the engine capacity; and that the specific steam consumption (steam consumed per unit of power generated) is relatively flat in this range. In other words, the efficiency of the engine remains roughly constant whether it is running at full load or turned down to a quarter of a load. In contrast, steam turbine efficiency decreases significantly as steam flow rate is reduced below its design value. The good turn down performance of the steam engine is particularly applicable when steam supply is widely variable, in contrast to steam turbines which have very poor efficiencies at high turndown.

Steam engines are commonly used as part of a co-generation system as described in section 3.4.6 below. In co-generation applications, steam engines are normally operated in back pressure mode where the exhaust heat is also used (for example in drying kilns). In this operation mode they have a better electrical efficiency than steam turbines, combined with their very good part load efficiency.

If the focus is solely on electricity production and the load is quite constant, a steam turbine would normally achieve a higher electrical efficiency because a turbine can expand the steam more fully into a vacuum.

Presently, Spilling, who are based in Europe, USA and Asia, are the only notable manufacturer of reasonably sized reciprocating engines.<sup>34</sup>



**Figure 14:** Spilling Steam Engine installed at Big River Timbers, NSW <sup>33</sup>

A Spilling steam engine used by Big River Timbers in New South Wales is shown in Figure 14. This mill has a 2-cylinder engine with a quite high inlet pressure of 3400kPa, expanding 5.5 tonnes of steam per hour to approximately 100kPa (g). The nominal electrical output is 428 kW which is used on site. The site has an existing boiler providing steam to their dryers, presses etc and the Spilling engine was integrated into the steam circuit. Other examples of (overseas) applications of Spilling engines are shown in Table 13.

**Table 13: Application of Spilling Steam Engines** <sup>35</sup>

Company & Industry	Year of Install	Location	Number of Cylinders	Electric Output (kW)	Steam Press (bar <sub>g</sub> )	Steam Temp (°C)	Outlet Press (bar <sub>g</sub> )	Flow rate (t/h)
Zemcheba Fruit growing & processing	2012	Czech Rep	6 Cylinder Set	1000	26	Saturated	0.5	12.8
Mlinotest Food industry	2012	Slovenia	2 Cylinder Set	172	23	Saturated	0.5	2.4
Elk Waste incineration	2012	Poland	6 Cylinder Set	824	16	Saturated	6	13
Komers Distillery biomass	2012	Poland	3 Cylinder Set	680	19	Saturated	3.5	16
Grajewo District heating	2012	Poland	4 Cylinder Set	628	22	Saturated	4.5	5.5
BEK-Jungingen Biomass cogen	2011	Germany	2 Cylinder Set	225	20	Saturated	0.5	3
AKZO-Nobel Chemicals	2010	Germany	2 Cylinder Set	226	4	Saturated	0.3	3
Pfleiderer Papermill	2009	Germany	4 Cylinder Set	474	11	Saturated	6/2.5	14.5
Border Timber Sawmill	2009	Zimbabwe	3Cylinder Set	470	10	Saturated	0.5	10
Buttenpapierfabrik	2009	Germany	2 Cylinder Set	353	24	250	1.8	5.5

Prices of some of the Spilling Machinery are shown below in Table 14 and more details for these engines are provided in Appendix I. <sup>32</sup>

**Table 14: Prices of Spilling Machinery**

Saw Mill	Engine Type	Steam Flow Rate (tonne/hr)	Electrical Output (kW)	Thermal Output (kW)	Price of Steam GenSet with Accessories (AUD) <sup>b</sup>
A <sup>a</sup>	6-Cylinder, type 3/3H12	14	1170	8060	862,400
B	4-Cylinder, type 2/2H12	9	760	5180	662,500
C	2-Cylinder, type 1/1H12	3.5	300	1990	438,800

a. The maximum steam flow rate through the biggest Spilling steam engine, a 6-cylinder-type, is for the inlet and outlet pressures given in Appendix I. In this case it would need to be decided either to limit it to that size or to use two 4-cylinder-engines or one 2-cylinder-engine and one 6-cylinder-engine or to use a steam turbine. With two engines (2 x 4-cylinder or 1 x 6-cylinder and 1 x 2cylinder) the total electrical output with 18 tonnes per hour of steam flow would be approximately 1520kW and the total thermal output approximately 10,350kW.

b. Assuming 1.0 AUD = 0.8 EURO

Note: These prices do not include engineering, documentation, packing, transport and commissioning.

Additional parts which are sometimes also delivered by Spilling are compensators - to be installed in the pipes to and from the steam engine to avoid a transfer of vibrations, a pressure reducing station - to be installed parallel to the steam engine, a condensate tank and condensate pumps and a heating condenser.

The electrical efficiency of the steam engines described in Table 14 is approximately 12%. There is also a thermal output (in this case at 50kPa and 110°C) which is approximately 6 to 7 times as high as the electrical output.

#### 3.4.5.4 Gas turbine

Gas turbines can be fuelled by sawmill residues by first gasifying the wood (refer to section 3.5.1) and cleaning the pyrolysis gas or syngas. The syngas is combusted within the gas turbine engine and the resulting gas expansion is used to rotate the turbine and drive a generator. At larger scales and with fossil fuels, gas turbines are often coupled with a heat recovery steam turbine system, whereby heat is recovered from the high temperature gas turbine exhaust and used to produce steam, which is used to drive a steam turbine and generator. Known as Integrated Gasification Combined Cycle (IGCC), these systems have been extensively trialled but have not been found to be commercially viable with wood fuels, primarily due to size constraints. However, IGCC systems offer the 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.

While conventional gas turbine sizes range from 500 kW to 350 MW, micro-turbines are in development with capacities from 30 to 400 kW, however, they are targeted at usage with fossil fuels. Like larger gas turbines, micro-turbines can be used in power-only generation or in combined heat and power (CHP) systems, which are explained in more detail in section 3.4.6.

Micro-turbines generally turn at a higher rotational speed than larger gas turbines to achieve the same blade tip velocity with a smaller diameter. Speeds are generally 60,000 to 100,000rpm depending on the specific turbine design characteristics.

A schematic of a micro-turbine based CHP system running on natural gas is shown in Figure 15. In a recuperative micro-turbine, atmospheric air is compressed, heated and mixed with fuel in the combustor. Hot combustion gases expand in the turbine causing rotation. The expansion turbine turns the compressor and, in single-shaft models, turns the generator as well. Using fossil fuels, micro-turbines can achieve electrical efficiencies of 25 to 33%, although efficiencies generally decrease at elevated ambient temperatures.

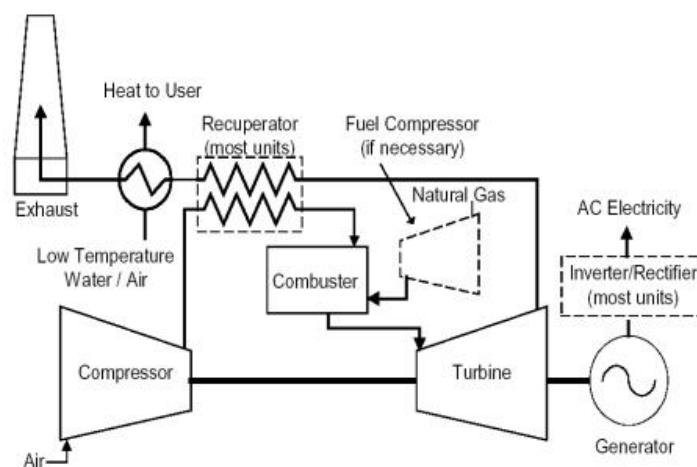


Figure 15: Schematic of a micro-turbine based CHP system <sup>36</sup>



Micro-turbines running on syngas would require a fuel gas booster compressor to ensure that fuel pressure is adequate for the gas turbine flow control and combustion systems. Booster compressors can add from \$50 to \$100 per kW (\$0.5-1 million per MW<sub>e</sub>) to a micro-turbine CHP system's total cost. As well as adding to capital cost, booster compressors lower net power and efficiency so operating cost is slightly higher. Typically, the fuel gas booster requires about 5% of the micro-turbine output.

Micro-turbine exhaust can also be used to produce heat at high temperatures that can be used directly or by means of a heat exchanger in drying or pre-heating processes. Exhaust can also be used for preheated combustion air.

Micro-turbines are currently operating on biogas from landfill and MSW operations; see for example the Italian company Turbec SpA ([www.turbec.com](http://www.turbec.com)). However, no commercial micro-turbine systems have been found that operate on pyrolysis gas.

#### 3.4.5.5 *Internal combustion engine*

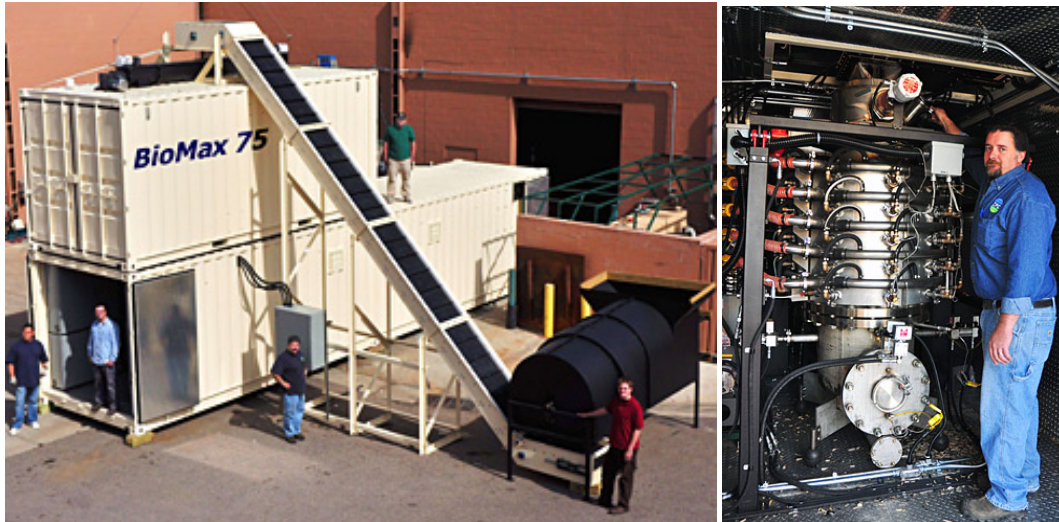
Like gas turbines, reciprocating Internal Combustion (IC) engines can also be fuelled by sawmill residues by first gasifying the wood and cleaning the syngas (refer to section 3.5.1). Cleaning the syngas adequately is technically challenging and may introduce significant commercial risks if different technology providers are used.

IC engines are generally suited to small scale electricity generation of up to a couple of MW<sub>e</sub>. There are a number of developers and suppliers of syngas fuelled IC engines, with considerable experience residing in Europe and India.

A demonstration plant in Güssing, Austria has been operated by Repotec since 2002 and engine operation now exceeds 52,000 hours. The plant consumes approximately 1.8 tonnes of wood per hour (woodchips or pellets, but not sawdust) to produce 2MW electricity and 4.5MW of district heat. The circulating fluidised bed gasifiers use steam as an oxidant, generating low nitrogen producer gas, which is scrubbed of tar, ammonia and acid components before being fed to a GE Jenbacher 620 reciprocating engine. Waste heat, recovered from gas cooling and engine cooling using thermal oil, drives an ORC system to generate additional electrical output, boosting overall electrical efficiency to 25%. A larger 5MW<sub>e</sub> CHP plant is being commissioned (as of 2012) at Senden, Germany. Based on the Gussing plant, enhanced integration of drying and ORC is anticipated to yield an electrical efficiency of 33%.

Ankur Scientific Energy Technologies is an Indian based supplier of biomass gasification systems for heat and power applications in the size range 5kW<sub>e</sub> to 500kW<sub>e</sub>. They have around 700 gasification systems installed around the world, including at 40kW<sub>e</sub> dual fuel power generation system installed at Forestry Tasmania. Sold through Alternative Energy Solutions (AES) in Australia and New Zealand, their gasification technology typically uses partial oxidation fed with air yielding a producer gas with a relatively low heating value (typically 4MJ/m<sup>3</sup>). Electrical conversion efficiency is claimed to vary from 16 to 24%.<sup>37</sup>

ANDRITZ Carbona, based in Finland, has a range of biomass gasification technologies. Their low pressure bubbling fluidized bed gasifier is installed at a commercial scale integrated gasification and reciprocating engine CHP plant at Skive Fjernvarme, Denmark. The plant was commissioned in stages during 2007 and 2008 and is fed with pellets, although it is designed to also receive woodchips. The gas is cooled (to increase density) and cleaned (to reform tars, remove particulates and scrub the gas). Gas cleaning remains an area of ongoing development and optimisation. The cleaned and cooled gas, with a heating value of around 5MJ/Nm<sup>3</sup>, is fed to 3 x 2MWe GE Jenbacher 620 gas engines. Overall efficiency is claimed to be 90% with heat recovery. Electrical efficiency is not cited..<sup>38</sup>



**Figure 16:** Community Power Corporation's BioMax75 system (left) and gasifier (right) rated at 75kWe<sup>39</sup>

A small scale integrated gasification and IC engine system, shown in Figure 16, is under development by Community Power Corporation (CPC) in the US.. Their BioMax systems come in three standard sizes - 25, 50 and 75kW<sub>e</sub> - and employ a downdraft gasifier with air as an oxidant achieving 99% carbon conversion. The gasifier can accept woodchips and pelletized sawdust, although size and moisture limitations apply. Solid ash and char residues are stored and periodically combusted and disposed in soil. With waste heat recovery overall efficiency is claimed to be up to 80%. Demonstration units have been installed in a number of sites throughout North America. CPC intend to commercialize a BM100 (100kW<sub>e</sub>) product, when its development is completed. The system presently uses reciprocating internal combustion engines, but it claimed to be adaptable to stirling engines, micro-turbines and fuel cells.<sup>39</sup>

In 2011, ZeroPoint Clean Tech commissioned an industrial scale integrated gasification IC engine power plant in Schwarze Pumpe, Germany. A downdraft gasifier was employed with air as the oxidant. A bio-char product is also produced, which is claimed to be suitable for carbon sequestration and soil conditioner (bio-char production and use is discussed in section 3.5.3). A single GE Jenbacher 320 engine (rated power ~1MW) is used, with plans to use two engines in 2012 and then to 5 or more engines.

As with all international technologies being introduced into Australia, it would need to be ensured that this equipment is compliant with Australian Standards. It would also need to be tested with Australian woods to confirm that they are suitable.

#### 3.4.5.6 Generators

Generators are generally supplied as a matched unit together with a turbine or other engine. Some generators or alternators are integrated with turbines or engines and offer a better performance and efficiency than discretely joined systems.

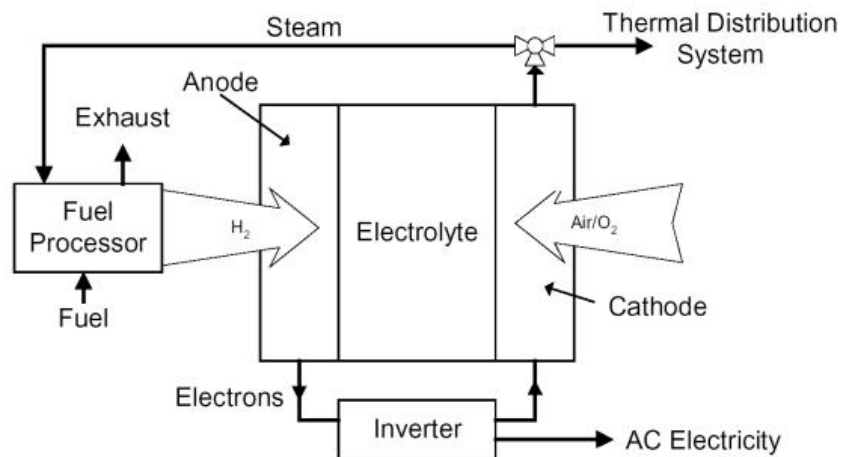
GenSets, the actual electrical generation and conditioning components of a power generation system, may comprise generators or alternators, inverters, transformers and a control system. If power is to be sold externally via the grid, then a grid interconnect system will also be required. Grid interconnection is not trivial and procurement agreements with utilities will probably include provisions for continuity and uniformity of output.

To gain assistance in connecting to the grid for a relatively large scale grid addition, that is greater than approximately 30MW<sub>e</sub>, the National Electricity Market Management Company (NEMMCO) should be contacted. Otherwise the local electricity distribution network or the dominant electricity retailer for the area should be contacted. Connecting to the grid at any scale is a complex and usually lengthy process. This should be factored into any commercial decision.

### 3.4.5.7 Fuel cells

Fuel cells are an entirely different approach to the production of electricity. Fuel cell stacks are silent, have no moving parts and have potential fuel efficiencies far beyond the most advanced reciprocating engine or turbine power generation systems. Fuel cells produce power electrochemically when hydrogen is delivered to one side of the cell (anode) and oxygen is delivered to the other side (cathode). Charged atoms or ions of either hydrogen or oxygen, depending on the fuel cell type, pass across a gas impervious membrane to react on the other side. The flow of these charged ions is a direct electric current.

Each cell produces a high current density at low voltage - usually less than 1V. To increase voltage, individual cells are connected in series to form a fuel cell stack with common fuel and air gas streams. Often, the exhaust streams contain hot gases, from which useful heat can be recovered to form a combined heat and power system. The basic elements of a fuel cell CHP system is shown in Figure 17. Like a battery, fuel cells produce direct current (DC) that must be passed through an inverter to get 50 Hz AC.



**Figure 17:** Schematic operation of a fuel cell CHP system (Image courtesy Energy Solutions Center)

There are several different liquid and solid membranes that support these electrochemical reactions - phosphoric acid (PAFC), molten carbonate (MCFC), solid oxide (SOFC) and proton exchange membrane (PEM) are the most common systems. Each of these distinct fuel cell technologies operates under different conditions and temperatures, each with its own performance characteristics.

Direct electrochemical reactions are generally more efficient than using the heat of combustion to drive a heat engine to produce electricity. Fuel cell efficiencies range from 35 to 40% for the PAFC to upwards of 60% for the higher temperature SOFC systems. If heat is recovered in a combined heat and power system then overall efficiency can be upwards of 80%.

Before a fuel cell can convert biomass to electricity, the biomass must first be converted to a suitable fuel. Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by 'internally' reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels.

The most likely process route is via gasification to syngas, followed by filtering, to remove particulates. Removal of unwanted contaminants, such as sulfurous compounds that poison catalysts or tars that foul surfaces, to a high degree is required as fuel cells are prone to rapid performance degradation from minor levels of some contaminants. A novel approach that has



been explored recently is to use a palladium-copper membrane to selectively separate hydrogen, resulting in a fuel stream that is sufficiently pure (e.g., <3ppm CO) to be used in a PEM fuel cell. An additional advantage is that CO<sub>2</sub> and other impurities are coincidentally segregated for possible sequestration. For more details refer to <http://www.xcelenergy.com/staticfiles/xcel/Corporate/RDF-DirectHydrogenProduction-Report%5B1%5D.pdf>

Where hydrogen fuel is desired, steam reforming and water-gas shift reactions can be used to boost hydrogen levels. Where methanol is desired, gas-to-liquid (GTL) processes such as Fischer-Tropsch or direct methanol synthesis can be employed. Trials of this approach have recently been reported by the EERC, University of North Dakota; the small scale system they tested is shown in Figure 18. For more details refer to <http://www.xcelenergy.com/staticfiles/xcel/Corporate/Corporate%20PDFs/RD3-66Milestone8%28final%29.pdf>



**Figure 18:** Trailer mounted research gasifier and GTL reactor that converts 100-150kg/hour of wet wood chips into 10-30litres/hour of bio-methanol, which is intended to be converted to electricity in a Direct Methanol Fuel Cell. (Photo courtesy EERC, University of North Dakota)

Thermally integrated gasifiers with high temperature SOFC stacks have been tested in the US. In this approach, the high temperature exhaust from the SOFC indirectly heats the gasifier and moisture in the biomass (up to 40%) provides necessary water for tar reforming. A low tar producer gas is fed hot into the close coupled SOFC stack, where the methane is internally reformed. Overall electrical efficiencies can theoretically approach 40% from low-grade (wet) biomass. For more details refer to

<http://www.xcelenergy.com/staticfiles/xcel/Corporate/Renewable%20Energy%20Grants/BiomassSOFC-final-report.pdf>

Coupling of a fuel cell with a micro-turbine has also been explored. The high temperature exhaust containing unspent fuel can theoretically be utilized in a micro-turbine to boost power output and overall electrical efficiency to around 43% (based on HHV). For more details refer to

[http://isigroup.org/CMS/wp-content/uploads/2010/01/Small-scale\\_Biomass\\_Fuel\\_Hybrid.pdf](http://isigroup.org/CMS/wp-content/uploads/2010/01/Small-scale_Biomass_Fuel_Hybrid.pdf)

PAFC and PEM fuel cells are the most widely deployed fuel cells with some commercial systems available. SOFC and MCFC technologies are largely in field test or demonstration stages.

As with most new technologies, fuel cell systems have several disadvantages, such as product immaturity, over-engineered system complexities and unproven product durability and reliability. These translate into high capital cost, lack of support infrastructure and technical risk for early adopters. However, the many advantages of fuel cells are driving their development and they could well become a viable product in the future.

### **3.4.6 Co-Generation**

Co-generation - also known as combined heat and power (CHP) - refers to the simultaneous production of useful heat and electricity. When the waste heat is also partially or intermittently used for cooling, via an absorption chiller, this is referred to as tri-generation or Combined Heating, Cooling and Power (CHCP). In a CHP plant, heat is usually produced in the form of steam and piped to where it is needed. The steam produced can provide a large amount of lower temperature energy for applications such as kiln drying.

The key to designing an efficient CHP plant is to balance the demand for process heat and electricity. The scale of the plant, required pressure (or temperature) and the demand over time all influence the type of CHP technology used. By using a CHP plant, considerable overall energy savings can be obtained, thus it can be a very attractive alternative with short payback periods.

In a gasification based CHP system, it is relatively straight forward to extract heat by directly combusting the gas when and where required. In this case, there would be minimal gas clean-up required. Alternatively, the heat in the flue gases from a combustion chamber (or the exhaust from the cylinders of internal combustion engine or from the engine coolant) could be used. Heat exchangers are sometimes used to avoid problems associated with noxious fumes.

Where steam is used to generate electricity it can also be a useful external source of heat. This is common in Europe where steam is piped for community heating. Steam is also a useful heat product in wood drying, where humidity levels must be controlled. Extracting steam from a steam turbine circuit for heat presents some difficulties, depending on the quantity, temperature and pressure and regularity of steam demand.

A steam turbine CHP system will generally be used when there is a steady demand for heat or only low grade heat is required. Generation of steady high grade heat may be accomplished by extracting steam from the turbine casing or by using a back pressure turbine.

If the steam is to be extracted from the turbine casing, the pressure of the steam depends on the point along the turbine at which steam is extracted, thus determining how much the steam has expanded. In these set-ups, the turbine and generator average output are somewhat below their rated capacity. This results in low utilisation and low average efficiency.

Alternatively, backpressure steam turbine systems function by regulating the exhaust from the turbine to yield steam at the desired pressure. In these turbines, condensing occurs during or after the downstream process that uses the heat. This type of system does not utilise the latter part of the steam expansion cycle and has correspondingly a lower electrical output. If the steam were not used, for example due to uneven demand for heat, this energy is lost. Steam accumulators can be used to even out demand and maintain the highest possible utilisation of the turbine and generator.

Reciprocating steam engines are generally superior when there is a widely varying steam supply, due to their flat efficiency curve as explained in section 3.4.5.3. However, steam engines are generally restricted to small scale systems, typically 10 to 2000kW<sub>e</sub>.

The use of biomass (wood) fired CHP plants at a commercial level is relatively recent and indeed there is still plenty of product development happening around the world.

Scandinavian countries such as Finland, Sweden and Denmark, with little indigenous hydrocarbon based fuel, have been at the forefront in the development and use of biomass for CHP plants. Whilst other EU countries such as Germany and Italy are keen to adopt biomass power generation plants in part to use waste streams that are presently heading to land fill and also to reduce Greenhouse Gas Emissions. There are some significant financial incentives for the installation and operation of biomass energy plants in these countries.

The USA has a long history of using wood for heating and power generation and there are a large number of suppliers of plant and equipment. In New Zealand the use of biomass boilers is about 40 years old, whilst in Australia the sugar industry has been using bagasse as a fuel in their boilers for decades. In more recent times the development and use of biomass plants in Australia has had a chequered history.

Some international examples of small scale co-generation plants are listed in Table 15.

**Table 15:** Examples of International (predominantly wood fuelled) Co-Generation Plants and Relevant Australian Co-Generation Plants

Type/Details of Plant	Location	Electrical Output (MW)	Heat Output (MW)	Technology	Cost
Wood chip CHP Vienna-Simmering <sup>40</sup>	Austria	24.5	37	Steam turbine	€52m
Biomass cogeneration plant Malchin <sup>41</sup>	Germany	10.6	U/A	Steam Turbine	U/A
Waste Wood Fired Power Plant Helbra for district heat & process steam	Germany	5.8	U/A	Steam Turbine	U/A
Biomass cogeneration plant Neubrücke	Germany	9	U/A	Steam Turbine	U/A
Waste to energy district heating plant Malmö <sup>42, 43</sup>	Sweden	16 to 19	U/A	Steam Turbine	U/A
Wood pellet/Chip CFB Gasification CHPGussing	Austria	2	4.5	IC engine + ORC	U/A
Wood waste CFB gasification CHP Senden <sup>44</sup>	Germany	5	14	IC engine + ORC	€33m
Wood chip CHP plant Danpower Schoeneck <sup>45</sup>	Germany	0.6	2.5	Thermal oil ORC	€3.8m
Waste wood CHCP BIOSTROM, Fussach <sup>46</sup>	Austria	1	6.2 (2.4 cool)	Thermal oil ORC + abs chiller	€6.1m
Biomass, BFB. Forssan Energia <sup>47</sup>	Finland	4 to 20	U/A	U/A	U/A
Biomass, BFBC, Falu Energy <sup>43</sup>	Sweden	9	30	U/A	U/A
Biomass, NUON <sup>48</sup>	Netherlands	1.5	6.5	U/A	U/A
Biomass CHP plant based on ORC cycle <sup>49</sup>	Lienz, Austria	0.001	7.5	U/A	U/A
Biomass Plant Reuthe <sup>50</sup>	Austria	U/A	U/A	U/A	U/A
Rocky Point Sugar mill. Fuelled by bagasse but has been upgraded to accept wood waste during off-season <sup>51</sup>	Australia	30	U/A	Steam Turbine	AU\$55
Ergon Energy in Wollongong using municipal green waste <sup>51</sup>	Australia	1.35	3.5	Gasification & IC engine	U/A
VISY in Tumut using bark and other wood waste in fluidised bed boiler <sup>52</sup>	Australia	20	U/A	Steam Turbine	U/A
Ergon Energy and Suncoast Gold Macadamias in Gympie fuelled by macadamia shells and food process waste <sup>53</sup>	Australia	1.5	4.5	Steam Turbine	AU\$3

Depending upon the temperature the heat in the hot water leaving a kiln heating system could be used to drive an ORC system (covered in section 3.4.5.2).

The Finish company Ekogen ([www.ekogen.fi](http://www.ekogen.fi)) has developed a micro-turbine CHP system that is fuelled by wood chips or wood pellets. The self-contained units are rated at 100kW<sub>e</sub> and 300kW<sub>th</sub> of heat and cost approximately \$920,000 (0.8 EUR = 1 AUD). Microturbines are discussed further in section 3.4.5.4.

### 3.4.7 Co-Firing

Co-firing, the simultaneous combustion of dissimilar fuels in one furnace or boiler, is a highly promising technology for using wood residue fuels in large-scale kilns and utility boilers. Co-firing of biomass production wastes in stoker-fired boilers is not new and there are a variety of techniques which are available for industrial boilers. The combustion technology most commonly used in the steam boilers of the pulp and paper industry is the traveling grate in spreader-stoker boilers. These systems readily lend themselves to co-firing. It is common for pulp mill power boilers to be fired with combinations of wood waste, 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 (those used for power generation) enables the use of the larger capacities of such boilers, the higher main steam pressures (typically 16MPa to 24MPa) and the incorporation of reheat steam into the boilers, with corresponding efficiency and availability benefits compared with smaller scale industrial boilers.<sup>51</sup> Co-firing of wood chips in other biomass fuelled systems such as cogeneration systems operated by the sugar mills can be of particular benefit when the primary biomass source (bagasse) has seasonal availability. This approach has been developed at the Rocky Point Sugar Mill, where other waste-to-energy biomass fuels have been identified and trialed to enable the plant to operate year round.

Co-firing is an effective means for Greenhouse Gas mitigation by using biomass to partially displace fossil fuel and simultaneously remove wood waste from being interred in landfills. Because biomass contains low concentrations of sulphur and nitrogen, co-firing also reduces SO<sub>2</sub> emissions and, in most cases, NO<sub>x</sub> emissions from coal power plants. Biomass co-firing also provides a low cost approach to increasing generation capacity for base load “green power” without major changes to existing equipment.

## 3.5 Pyrolysis and Gasification

Pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen or any other reagents, except possibly steam, or by partially combusting in a limited oxygen supply. The decomposition products are a mixture of gas, condensable tars/oils and char residues. Depending on the conditions (heating rate, temperature, atmosphere, particle size etc.) the product distribution can be adjusted and optimized to suit the application. Gasification is a form of pyrolysis that is generally carried out with the introduction of more air and sometimes steam and at higher temperatures, to optimise the production of gas. Typical pyrolysis conditions and product yields are shown below:

**Table 16:** Pyrolysis products and typical process yields.<sup>55</sup>

Mode	Conditions	Bio-oil	Char	Syngas
Gasification (>800°C)	high temperature, long residence times	5%	10%	85%
Fast pyrolysis/indirect liquefaction (600°C)	moderate temperature, short residence time particularly for vapours	75%	12%	13%
Pyrolysis/Carbonisation (300-550°C)	low temperature, very long residence time	30%	35%	35%

Depending on the process, some of the products are commonly combusted to provide the heat for pyrolysis.

### 3.5.1 Gasification

The gas produced by gasification is commonly called synthesis gas or *syngas*, and is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen. As mentioned above, the process generally produces a fraction of solid char and tar that will condense to liquids at ambient temperature. These are normally separated in a subsequent clean-up step (described below).

The ultimate composition of the syngas and its energy content will depend upon the specific wood variety and residue mix used and the operating conditions for conversion, significantly the approach used to supply heat. Most gasifier designs use oxygen as an oxidizing agent, either in air or in a concentrated form, partially combusting the wood and generating heat. In air-blown gasification, nitrogen in the air dilutes the syngas product, so that a low-energy producer gas results, containing perhaps 45 to 60% nitrogen, 10 to 20% hydrogen and 15 to 30% carbon monoxide. This low-energy syngas can be used where the heat content of the gas is not critical.

A medium-energy syngas can be produced by blowing concentrated or pure oxygen into the gasifier for partial combustion. This avoids nitrogen dilution in the syngas and increases the energy content. Alternatively, heat can be provided to the gasifier by an external source reducing dilutant gases to those entering with the fuel. The key differences between partial oxidation and indirect heating gasification are shown in Table 17.

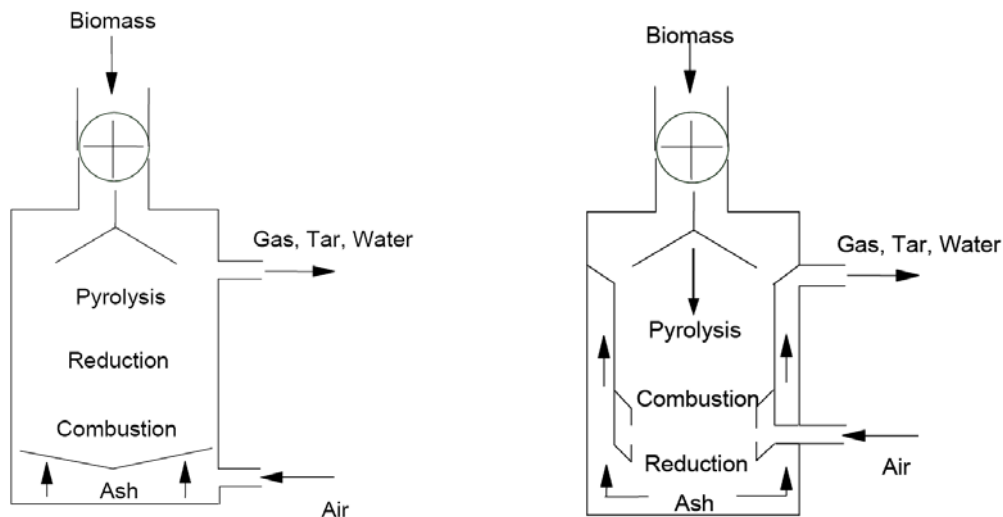
**Table 17:** Gasification product routes and energy values <sup>56</sup>

Gasifier	Inlet gas	Product Gas Type	Typical Product Gas HHV	
			MJ/Nm <sup>3</sup>	MJ/kg
Partial Oxidation	Air	Producer gas	7-9	5-7
Partial Oxidation	Oxygen	Syngas	10-12	9-11
Indirect	Steam	Syngas	15-18	14-17
-	-	Natural Gas	36	40
-	-	Methane	41	53

Conceptually, a biomass gasifier is a fairly simple device consisting generally of a cylindrical container with internal space for reaction and ports for fuel inlet, gas inlet and gas exit. The cylinder can be made of masonry or metal. In practice, gasifiers have been designed in numerous configurations. Fixed bed gasifiers are most common and are best suited to small scale gasification. Fluidised bed gasifiers are also used widely, particularly at larger scales, being either Bubbling Fluidised Bed (BFB), Entrained Flow or Circulating Fluidised Bed (CFB) type. Various types of travelling grate beds have been used as well as molten salt reactors.<sup>54</sup>

Fixed bed gasifiers are characterised by a stationary reaction zone that is normally supported on a grate. They are usually in up-draft (counter current) or down-draft (co-current) configuration, as illustrated in Figure 19, with down-draft generally producing a cleaner gas in terms of particulates and tars.





**Figure 19:** Fixed bed gasifiers in down-draft (left) and updraft (right) configurations <sup>53</sup>

The core gasification vessel is usually part of an integrated system also comprising a fuel pre-treatment and feed system and a gas cleaning unit.

The evolved syngas may be burnt in either a gas engine or gas turbine, which are usually coupled to generators to produce electricity, as discussed in section 3.4.5. The syngas may also be used in a fuel cell with conversion directly to electricity, as discussed in section 3.4.5.7. Alternatively, the syngas may be processed into liquid fuels using Fischer-Tropsch or other synthesis processes, as discussed in sections 3.5.1.2 and 3.5.1.3. Each application will demand a tailored gas specification, for example in terms of energy content, contaminant level, composition, temperature, etc.

Austrian company CLEANSTGAS ([www.cleanstgas.com](http://www.cleanstgas.com)) manufactures small scale gasifier based power generation systems. The units are modular in construction, run on relatively high moisture content (35%) wood chips and can produce an output of 250kW<sub>e</sub> and 430kW<sub>th</sub> of heat.

### 3.5.1.1 Gas Cleanup and Conditioning

The product gases from the gasifier generally require treatment before they can be used for their final application - except in a close-coupled gasifier-combustor system where there is no cleanup of the gases at all.

For gas turbine applications in a power system the gas has to be free of particulates, tars, sulfur and chlorine compounds and alkali metals to ensure the integrity of the hot section of the turbine. Particulate removal to protect the turbine blades from erosion requires filtration technology, while the removal of tars ensures an even and less luminous combustion process - to avoid radiant heat transfer problems at the turbine. Alkali metal removal is to avoid deposition and corrosion of the turbine blade materials and has to be carried out down to levels of potassium and sodium less than 1 ppm (part per million) to ensure long turbine blade and hot section lifetimes. The tolerance to alkali metals is a function of the temperature of operation of the turbine inlet section, at very high temperatures (greater than 1350°C) the level has to be about 25 ppb (parts per billion). The deposition and corrosion problems can also be addressed by means of turbine blade coatings. It is likely that both coating components and making them more robust will be required as well as enhanced gas cleanup developments.

For internal combustion applications it is necessary to cool the gas to ensure that a sufficient charge of energy can be put into each cylinder – the lower temperature gas has a higher

density and therefore higher volumetric energy density. Particular attention has to be given to both tar and particulate contents to ensure that the valves and cylinders are protected.

Fuel cell applications would require the gas to be mainly hydrogen or methane without any significant sulphur or chloride contamination to protect the electrodes.

For synthesis operations such as methanol and hydrogen production removal of particulates and contaminants such as hydrogen sulphide is required to prevent poisoning of downstream catalysts.<sup>55</sup>

There are different processes to remove these unwanted components, the selection of which depends on the application. The following is a list of possible processes:

- Tar Removal
- Cyclone Separator for Dust
- Bag Filter
- COS Hydrolysis in Scrubber
- HCl scrubbing with NaOH or reaction in bag filter
- Tar condensation
- $\text{NH}_3 + \text{HCN}$ , scrubbing with  $\text{H}_2\text{SO}_4$  or Sulphinol D
- $\text{H}_2\text{S} + \text{COS}$ , scrubber with COS hydrolysis or Sulphinol D, traces removed with ZnO filter
- S-Oxidation followed by desulphurization system with lime or limestone

In practice, the 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.

The processes that rely on contaminant separation rather than conversion present a further issue of disposal, which can become a significant cost and environmental problem, particularly if dirty or high ash input streams are used.

It is important to recognise that gas cleanup is a highly important step in rendering syngas suitable for the applications explored in this report. This operation is technically challenging to perform efficiently and consistently and represents a major challenge for most biomass gasification based technologies.

### 3.5.1.2 Fischer-Tropsch Process

A purified and high energy syngas may be put through the Fischer-Tropsch (F-T) process to synthesise liquid hydrocarbons. This process has been used for decades, most notably by Germany during the Second World War and by South Africa (SASOL) in the 1970s and 80s, to produce synthetic liquid fuels from coal or natural gas. In the F-T process, the carbon monoxide and hydrogen in the syngas are reacted in the presence of heat and a catalyst (typically iron and cobalt) to produce a liquid comprising of various hydrocarbon fractions. The various fractions may be separated by distillation or other separation processes into synthetic equivalents of automotive fuels. The F-T diesel can be created with a higher yield if first F-T wax is produced, followed by hydro-cracking (a process that employs elevated temperature and pressure essentially to crack carbon double bonds and rings). Heat is evolved during these synthesis processes and this heat is frequently used to dry the fuel, aid distillation and similar.

Fischer-Tropsch diesel is similar to fossil diesel with regard to its energy content, density and viscosity and it can theoretically be blended with fossil diesel in any proportion without the need for engine or infrastructure modifications. Fischer-Tropsch diesel has some favourable attributes, i.e. a higher cetane number (better auto-ignition qualities) and lower aromatic content, which results in lower NO<sub>x</sub> and particle emissions.

While F-T conversion of coal is well established, there are technical issues still being resolved in adapting this technology to biomass. During gasification, biomass reacts at a lower temperature than coal and has different ash characteristics, requiring a different reactor design.

In Germany, a pilot facility is currently in operation for the production of F-T liquids from biomass.

The F-T Process is used by Zero Point Clean Tech in the production of ethanol via the multi-stage gasification process. The syngas from the gasification is passed through an F-T reactor initially and then the refined finished ethanol is put through a final stage distillation process. As a consequence the economics start to make sense using multiple gasifier lines. Zero Point has investigated 20, 40 and 60 million litres per year configurations, each of which they believe makes commercial sense. These typically have 4, 8 and 10 gasifier lines. Zero Point has said that the system could scaled up to 80 to 100 million litres per year, however beyond which the multi-gasifier approach probably makes less sense economically.

### 3.5.1.3 Other Synthesis Processes

The conversion of syngas into a variety of other fuels is also possible and like F-T conversion, they “piggy-back” on available and established technologies. The development work involves controlling the gasification and clean-up stages, then adapting the synthesis processes to a different feed gas. Bio-fuels under development include:<sup>59, 60, 62, 63</sup>

- Bio-SNG – Synthetic Natural Gas is produced from the syngas via a process called methanation, which uses a nickel based catalyst to produce a methane (CH<sub>4</sub>) rich fuel stream. Compared to other synthesis fuels including F-T, a lower gasification temperature can be used prior to methanation – at lower temperatures some methane is produced in the syngas which subsequently helps control the methanation process by reducing the energy released from this highly exothermic reaction. The lower gasification temperatures can help reduce technical difficulties with biomass gasification. Bio-SNG can be used for transport fuel as well as stationary heat and power potentially using existing infrastructure. A technology demonstration plant of approximately 1MW capacity is under development by Repotec in Güssing, Austria using solid biomass fuels.
- Bio-hydrogen – Gasification employs a water gas shift reaction to increase the hydrogen yield and fully oxidise the carbon to carbon dioxide. Carbon dioxide is usually separated by pressure swing absorption and the hydrogen is then typically compressed. Hydrogen may be used as a fuel in internal combustion engines or fuel cells.
- Bio-methanol – Unlike F-T conversion, methanol synthesis preferably takes place in the liquid phase, which results in a higher yield. Bio-methanol can be used as a petrol substitute in spark ignition engines due to its high octane number, although like bio-ethanol, it has a lower energy density, lower vapour pressure and may be incompatible with certain engine materials (rubbers and plastics). It can alternatively be used in fuel cells being directly converted to electricity. Methanol must be treated with particular caution as it is poisonous and burns with an invisible flame.
- Bio-DME (Di Methyl Ether) – In the chemical industry, DME is usually produced from pure methanol via a process called catalytic dehydration, which chemically separates water from methanol. Often methanol and DME are produced together in one process. Bio-DME can be produced directly from synthesis gas, but this is still under development.

### 3.5.2 Carbonisation

The conversion of woody biomass into charcoal (char) is an ancient process which continues today. The early process was carried out by piling up wood, setting it alight and covering it with earth. Holes poked in the earth cover allowed air in to control the charring process. The

char is produced by driving off the volatile compounds in the wood leaving a carbon rich solid. This 'direct' method is still used today but indirect heating is also used. In this case the wood is placed in a container which is heated externally, often by burning the volatile gases driven off the wood during charring. The first method is a batch process whilst the second method can be made continuous.

Modern pyrolysis plants employ indirect heating in typically continuous processes achieving high efficiency and low emissions, although with significantly high capital and operating cost than traditional earth pits.

The char produced is used as:

- A reductant in metallurgical processes
- An absorbent for odour and chemicals
- Fuel for cooking (e.g., BBQ)
- Fuel for heating (often in the form of briquettes)
- Soil improver
- A carbon sequestration material

Generally all species of wood can be carbonised to produce useable charcoal. There is a variation in the ash content of different woods but this is generally not significant. Bark, however, has unacceptably high ash content and the structure of bark charcoal is too friable to be useful for most purposes. Therefore, where possible, bark should not be used or the amount of bark charred with the wood should be minimized. Softwoods generally produce a softer, more friable charcoal than hardwoods but they are a good raw material and can produce all types of charcoal. Eucalypt species produce good dense charcoal and are often the preferred species for the purpose.

The rate of carbonisation is closely related to wood size. Large wood pieces carbonise slowly since the transfer of heat to the interior of the wood is a relatively slow process. Whereas sawdust can be flash carbonised very rapidly but the powdered charcoal produced has a low market value. On the other hand, large diameter trunks of dense species may shatter when carbonised, making the charcoal more friable. Studies have shown that charcoal with optimum properties for use as a reductant in the iron industry is produced with wood pieces measuring about 25 to 80 mm across the grain. Length along the grain has little influence.

A tonne of wood with a moisture content of say 25% w.b. can be expected to produce approximately 200-250kg of char. The rest of the mass is volatilized – into water and other compounds, some of which contain carbon. In this case, the yield is approximately 20-25% (wood to char).

The cost of production is dependent upon the type of plant used, the process (batch versus continuous) and cost of the wood feed stock. Some cost estimates are shown in Table 18.

**Table 18:** Approximate costs of charring.

<b>Manufacturing Method</b>	<b>CAPEX (A\$/t, approx)</b>	<b>OPEX (A\$/t, approx)</b>	<b>Total (A\$/t, approx)</b>
Brick kilns (using wood) <sup>64</sup>	20	115	135
Brick kilns (forest residues) <sup>64</sup>	20	70	90
Continuous retort (using wood) <sup>64</sup>	60	140	200
Continuous retort (forest residues) <sup>64</sup>	60	100	160
Retort <sup>64</sup>	-	-	240

*Note:* These figures based upon a tonne of char do not include transport of the char to market and are based upon an exchange rate of 1 AUD = 1 USD

Simcoa Operations Pty Ltd <sup>66</sup> are the largest producer of charcoal for commercial use in Australia that have been identified, albeit from coal feedstock. Their charcoal product is used in their own silicon manufacturing plant. Other than this use no market in Australia for the sale of charcoal in commercial quantities has been identified.

Another type of char which is produced is called agri-char. Agri-char is made from biomass, usually by pyrolysis and often subsequent gasification (to further activate the char) and used as a soil enhancer. The carbon in the char can be viewed as a form a sequestration of CO<sub>2</sub> from the atmosphere into the soil thus reducing the CO<sub>2</sub> foot print. The char is a far more stable form of carbon than that in the original biomass and thus its effects will last much longer. While studies of charcoal from fires are stable for thousands of years, the stability of modern biochar products is uncertain. The limited data available suggests stability in the range tens to hundreds of years, depending on the biochar.

The char can be mixed with manures and fertilisers and has been shown to improve the structure and fertility of the soil thus improving biomass production. There is some evidence that the char helps retain the fertiliser and decreases its run off. The Australian and New Zealand biochar network ([www.anzbiochar.org](http://www.anzbiochar.org)) set up in 2008 is a collaborative group of scientist interested in advancing the understanding and application of biochar. They indicate that some likely benefits of adding biochar to soil are:

- increase water holding capacity of the soil
- increase biomass (crop) production
- increase soil carbon levels
- increase soil pH
- decrease Aluminium toxicity
- decrease tensile strength
- change microbiology of the soil
- decrease emissions from soil of the greenhouse gases CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>
- improve soil conditions for earthworm populations
- increase CEC, especially over the long-term
- improve fertiliser use efficiency

The organisation states that *“It should be noted that the wide variety of biochar feedstock materials, process conditions and applications leads to a huge and diverse range of responses that are often contradictory. Some biochars have been shown to have no influence on some of the factors noted above; some biochars have been shown to have adverse effects on crop productivity. More research is required to verify the observed effects and to distinguish beneficial from detrimental biochar products”*.

Similarly, a 2011 technical report by the Australian Department of Agriculture, Fisheries and Forestry (ABARES) titled ‘Biochar: implications for agricultural productivity’ stated that *“there are significant potential productivity and other benefits from adding appropriate biochars to Australian agricultural soils”*. However, *“...current knowledge about the effects of adding biochar to Australian agricultural soils is not sufficient to support recommending its use.”* The full report is available here:

[http://adl.brs.gov.au/data/warehouse/biochar9abcm001/biochar9abcm00101/TR.2011.06\\_Biochar\\_v1.0.0.pdf](http://adl.brs.gov.au/data/warehouse/biochar9abcm001/biochar9abcm00101/TR.2011.06_Biochar_v1.0.0.pdf)

Never the less the Federal Government is keen to continue funding research into the use of biochar and have recently (April 2012) awarded a number of grants through its Biochar Capacity Building Program. These went to:

1. Direct quantification of biochar that is stable on centennial timescales-James Cook University
2. The National Biochar Initiative II-A country wide approach to biocar systems-CSIRO
3. Understanding and observing the benefits of biochar in the carbon cycle-North East Catchment Authority
4. The contribution of biochar in increasing soil carbon in native woody bioenergy crops and on-farm revegetation-Monash University
5. Integrated riverine land management using biochar-South Australian No Till Farmers Association Inc.

The CSIRO Sustainable Agriculture Flagship and its partners are quantifying the properties of biochar from a wide range of materials including wood chips and sawdust and assessing their benefits when added to various soil types.

Biochar is being provided to CSIRO (as well as the University of Queensland and Melbourne University) by Pacific Pyrolysis ([www.pacificpyrolysis.com](http://www.pacificpyrolysis.com)). The company and its predecessors have been involved in R&D of pyrolysis for many years. They use an externally heated paddle pyrolyser to produce the char which can then be activated by subsequent gasification. The char so produced has a very large surface area per unit volume

Biochar is available from a range of companies, including:

**Table 19 - Selection of Biochar suppliers and indicative prices**

<b>Company</b>	<b>Base material</b>	<b>Price</b>	<b>Contact</b>
<b>Black Earth Products</b>	Chicken litter & manure	\$1500/tonne	(07) 3886 6712
<b>O'Grady Rural</b>	Bamboo	\$1960/tonne	(02) 6621 6088
<b>Geomite</b>	Bamboo	\$825/tonne	(08) 8341 9896

An excellent up to date (October 2012) source of information on all aspects of biochar production and use entitled "*Biochar in horticulture. Prospects for the use of biochar in Australian horticulture*" has been produced by Horticulture Australia (HAL) and NSW DPI. The report is available from HAL. It is available for download here:

<http://www.dpi.nsw.gov.au/agriculture/resources/soils/soil-carbon/biochar-in-horticulture>

### 3.5.3 Fast Pyrolysis

Fast pyrolysis of biomass is one of the most recent renewable energy processes to have been introduced. The process can be carried out at medium to large scales and produces a liquid oil-like product that can be readily stored and transported. Bio-oil is a renewable liquid fuel and can also be used for production of chemicals.



### 3.5.3.1 Fast Pyrolysis Technology Description

Fast pyrolysis, used to yield a high fraction of bio-oil, employs a short residence time of 0.5 to 2 seconds and moderate temperatures - 400 to 500°C, in the pyrolysis chamber. The biomass particles and the evolved oil mist must be rapidly heated and cooled at approximately 500°C per second. Consequently, these processing conditions demand a fine feedstock of less than 3mm particle size that is relatively dry, with moisture content of less than 10% w.b. The key steps of the process are described below.

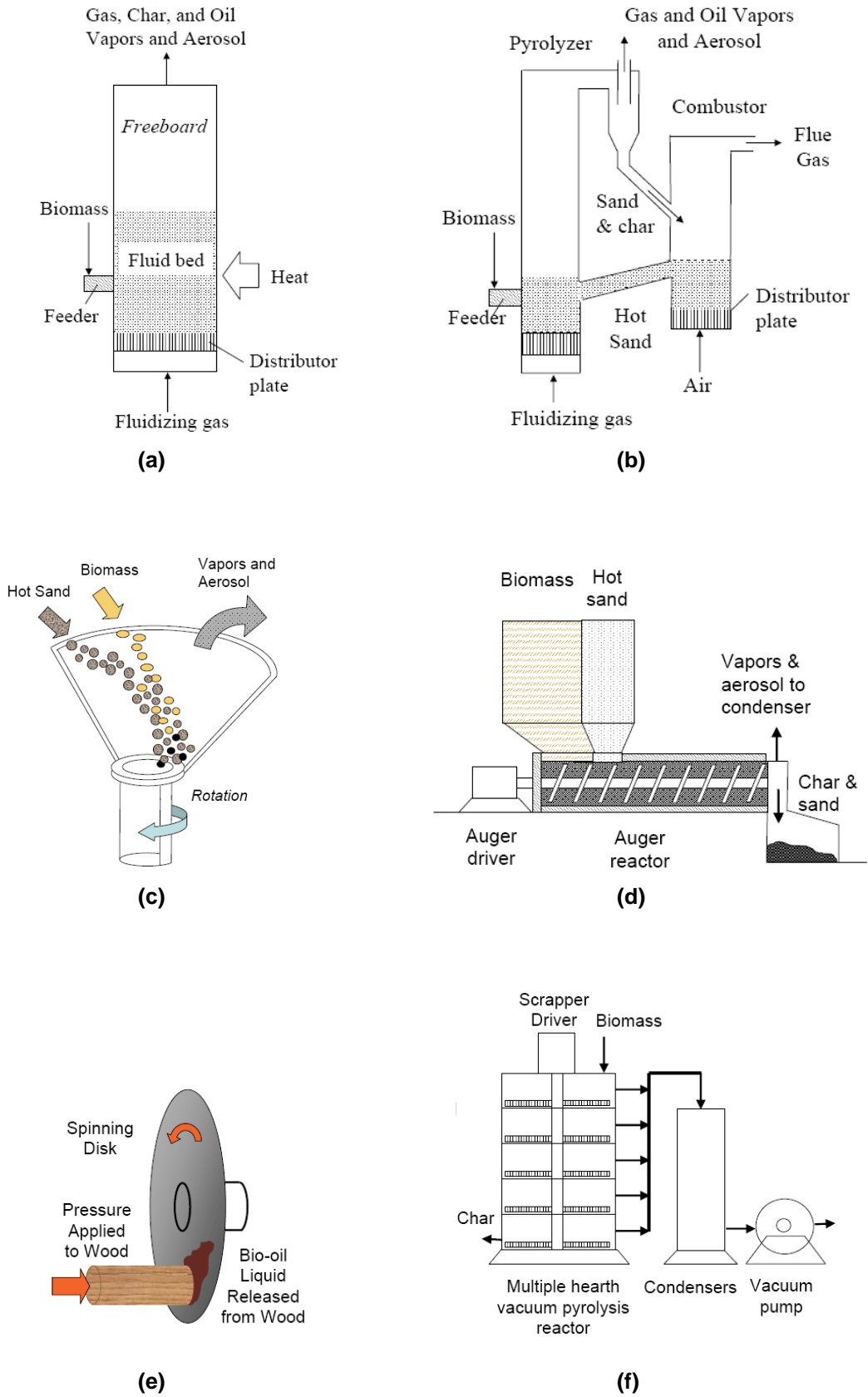
Feed drying	Typically a 10% moisture content in the wood is required. Waste low grade process heat would usually be employed, for example from the combustion of char and/or syngas.
Comminution	For most reactor types, wood particles have to be very small (typically <1-5mm) to enable the rapid heating required to achieve high liquid yields.
Pyrolysis vessel	The fine dry feed material is rapidly volatilised then condensed in a low oxygen atmosphere. There are six main types of fast pyrolysis vessels under development. These are illustrated in Figure 20 and the relative merits of each reactor type are shown in Table 19.
Char & ash separation	Almost all of the ash in the biomass is retained in the char so successful char removal gives successful ash removal. The char may be separated and sold as a separate product or combusted to provide process heat.
Liquids collection	Condensable gases must be cooled to collect the liquids. At large scales, quenching with an immiscible liquid such as a hydrocarbon or cooled liquid product is usually employed. The use of electrostatic precipitators is also under development. Careful process design and control is required to capture a full range of molecular weights.
Storage and transport	The bio-oil will require some local storage prior to local or remote use. Storage of bio-oil will usually require agitation to prevent settling and possibly some heating, depending on local environment.

**Table 20:** Fast pyrolysis vessel types and relative merits <sup>70</sup>

Type	Status <sup>a</sup>	Bio-oil yield wt%	Complexity	Feed size specification (High = fine particles)	Inert gas need	Specific reactor size	Scale up	Gas quality
Fluid	Commercial	75	Medium	High	High	Medium	Easy	Low
CFB	Commercial	75	High	High	High	Medium	Easy	Low
Rotating	Demonstration	70	High	High	Low	Low	Medium	High
Auger	Pilot	60	Medium	Low	Low	Low	Medium	High
Ablative	Lab	75	High	Large	Low	Low	Hard	High
Vacuum	None	60	High	Low	Low	Large	Hard	Medium

a. Lab: 1-20 kg/hr      Pilot: 20-200 kg/hr      Demonstration: 200-2000kg/hr      Commercial 2t/hr-20t/hr

Favourable feature
Moderate feature
Unfavourable feature



**Figure 20:** Some different types of fast pyrolysis vessels (a) BFB - Bubbling Fluidised Bed, (b) CFB - Circulating Fluidised Bed, (c) Rotating, (d) Auger, (e) Ablative and (f) Vacuum

### 3.5.3.2 Bio-oil

Bio-oil is a liquid blend of hundreds of chemical species, which may be almost black through dark red-brown in colour, depending on its chemical composition. The density of the liquid is about 1200 kg per m<sup>3</sup> and is mildly acidic, with a pH of typically 2.5 to 4. The viscosity of the oil varies from as low as 25 cP up to 1000 cP depending on the water content, the amount of light ends, and the age of the oil. As a reference, water has a viscosity of approximately 1cP and fuel oils have viscosities in the range 800 to 12,000cP. While bio-oil is chemically stable, it will physically separate if left to settle (a timeframe of months is claimed).<sup>71</sup> Upon stirring, with or without heat, the bio-oil will mix again into a homogeneous fluid.

Bio-oil contains a high level of oxygenated compounds, giving it a polar nature resulting in its poor miscibility with hydrocarbons. This can be overcome by using surfactants, enabling a stable emulsion to be formed with hydrocarbon fuels such as diesel. Bio-oil contains less nitrogen than petroleum products, and almost no metal and sulfur components, making them attractive from an emissions perspective. However, the high oxygen and water content of bio-oils makes them generally inferior to hydrocarbon fuels. A higher energy product, known as Bio-Oil Plus, can be produced by adding back the separated char into the bio-oil, in a finely ground form of about 8 microns in size.

The development and adoption of bio-oil as a blended transport fuel alternative has been hampered by a number of factors that are still to be overcome<sup>72</sup>:

- Availability - limited supplies for testing
- Standards - lack of standards and inconsistent quality inhibits wider usage
- Incompatibility with conventional fuels
- Unfamiliarity of user
- Dedicated fuel handling needed due to settling
- Poor image

In Canada, bio-oil is partially or completely substituted for fossil fuels in some utility boilers. Immediate opportunities for industrial heating applications are also being explored. In primary industry, these include kilns and boilers in pulp and paper (see Figure 21), process heat in boilers in sawmills, metallurgy, oil and gas industries, and in secondary industries applications such as greenhouses and district heating.



**Figure 21:** Canadian paper mill firing bio-oil in a lime kiln.

Bio-oil developers have successfully tested bio-oil as liquid fuels in internal combustion engines and gas turbines, and bio-oil has been used commercially in boilers and other industrial combustors. As well as being emulsified with diesel, bio-oils have also been converted to synthetic hydrocarbon fuels via gasification and Fischer-Tropsch synthesis, although at a presently unacceptable energetic and financial cost <sup>73</sup>. In the future, these bio-refining processes will probably be viable at large scales only.

Bio-oils have also yielded useful chemicals, mainly by extraction of resins using separation processes. Thermo-chemical conversion into higher value chemicals has also been performed although only at laboratory scale to date.

### 3.5.3.3 Fast Pyrolysis costs

Due to the small number and limited scale of existing pyrolysis oil production units, the economics of a commercial scale unit can only be estimated. Costs of bio-oil production depend on feedstock (pre-treatment) costs, plant scale, type of technology etc. Below are a number of different claims for the cost of production (2012):

- \$5-6/GJ (\$85-94/tonne) – Ensyn <sup>74</sup>
- \$3-4/GJ (\$51-68/tonne) - BTG (2012) <sup>75</sup>
- \$7-30/GJ (\$125-500/tonne), assuming feedstock costs \$0-3.20/GJ (\$0-165/t) <sup>76</sup> (1999)
- \$6.90/GJ - IEA study (Europe) in December 2006; see Table 21 for details.

**Table 21:** Production costs for bio-oil and char co-products compared with fuel oil prices. (Published in December 2006 IEA study in Europe <sup>77</sup>)

	<b>Weight/Volume basis<sup>a</sup></b>	<b>Energy Basis<sup>a</sup></b>
<b>Bio-Oil Production Costs</b>		
Feedstock	13.30 \$/tonne	0.76 \$/GJ
Manufacturing <sup>b</sup>	76.65 \$/tonne	4.38 \$/GJ
Transport (rail transport to nearest port)	19.25 \$/tonne	1.10 \$/GJ
Total	<b>109.20 \$/tonne</b> <b>0.13 \$/litre</b>	<b>6.24 \$/GJ</b>
<b>Fuel oil Prices</b>		
Spot price for gas-oil in Singapore	<b>0.82 \$/litre</b>	<b>17.00 \$/GJ</b>
Spot price for No. 2 diesel in Singapore	<b>0.80 \$/litre</b>	<b>25.00 \$/GJ</b>
<b>Char Production Costs</b>		
Feedstock	2.63 \$/tonne	0.15 \$/GJ
Manufacturing	4.90 \$/tonne	0.28 \$/GJ
Transport	11.20 \$/tonne	0.64 \$/GJ
Total	<b>18.73 \$/tonne</b>	<b>1.07 \$/GJ</b>

a. Calculation assumptions

Gas-oil heating value	40	GJ/tonne
Bio-Oil heating value	17.5	GJ/tonne
Bio-Oil density	1.20	kg/litre
CAD/AUD	1.00	\$/
EUR/AUD	0.80	€/
USD/AUD	1.00	\$/
Litres/gallon	3.88	litres/gallon

b. Based on **200 tonne per day** (oil) plant with capital cost CA\$16.5million, 90% of mfg cost apportioned to bio-oil, 10% to char

### 3.5.3.4 Fast Pyrolysis Technology Status

A number of organic materials have successfully been utilised in the fast pyrolysis process, including bagasse, palm residues, rice husks, straw, dried sludges, pine wood, olive husks, beech wood, oak wood, switch grass and poplar.

A variety of different fast pyrolysis vessel types are under development by proponents, as illustrated in Table 21.

**Table 22:** Fast pyrolysis technologies and present development scale.

<b>Pyrolysis Vessel Type</b>	<b>Capacity</b>	<b>Operator</b>
<i>BFB</i>	<i>130 &amp; 200 tonne/day</i>	<i>DynaMotive</i> <sup>78</sup>
	<i>5000 tonne/year</i>	<i>USTC (China)</i> <sup>79</sup> <i>2009 Demo plant, Binzhou</i>
	<i>20 kg/hr</i>	<i>RTI</i> <sup>78</sup>
<i>CFB</i>	<i>1000 kg/hr</i>	<i>Ensyn (Red Arrow)</i> <sup>78</sup>
	<i>20 kg/hr</i>	<i>Ensyn (VTT)</i> <sup>78</sup>
	<i>50,000tonne/year</i>	<i>Fortum, Finland</i> <sup>78</sup> <i>2012 plant in Joensuu</i>
<i>Rotating Cone</i>	<i>2tonne/hour</i>	<i>BTG (Netherlands)</i> <sup>78</sup> <i>Malaysian plant</i>
<i>Vacuum</i>	<i>3tonne/hour</i>	<i>Pyrovac</i> <sup>78</sup>
<i>Auger</i>	<i>200 kg/hr</i>	<i>ROI</i> <sup>78</sup>

Canada is regarded as a leader in pyrolysis oil technology and development, with two systems at the commercialization stage and two near commercialization. Current developments, as well as non-Canadian examples, include:

- DynaMotive Energy Systems (Canada) - Has a patented fast-pyrolysis process using a fluidized bed that converts forest and agricultural residues into pyrolysis oil. It is now expanding its 100 tonne per day (input) pyrolysis oil plant, already the world's largest, and constructed and commissioned a 200 tonnes per day plant at Guelph in 2007, (see Figure 22). Dynamotive is part of a consortium that also includes Virgin Australia and Renewable Oil Corporation ([www.renoil.com.au](http://www.renoil.com.au)) who are considering the development of aviation biofuels from mallee trees in WA.
- Ensyn Corp (Ottawa) - Uses its high efficiency (around 75% by weight) core technology (Rapid Thermal Processing - RTP™) to transform a wide range of biomass feedstocks into more valuable chemical and fuel products. Ensyn first remove valuable chemicals from the bio-oil such as natural resins and other resin ingredients, leaving a clean residual bio-fuel that has been used commercially for industrial heat since the early 1990s. Ensyn's bio-fuel (after refining) can be blended with diesel and other petroleum fuels, although this has not been commercially implemented in transport fuels. Ensyn has teamed with Fibria in Brazil (2012) to develop bio oil from pulp waste, Fibria paying US\$20million for a 6% stake in the company. More information can be found at [www.ensyn.com](http://www.ensyn.com)
- Agri-Therm (Dorchester) – has developed a 10tonnes/day mobile pilot plant, which uses primarily agricultural residues in farm applications. The unit produces

5.5tonnes/day of oil and 2tonnes/day of bio-char. More information can be found at [agri-therm.com](http://agri-therm.com)

- Biomass Technology Group, BTG (The Netherlands) – Has commissioned (2005) a 2tonne/hour pyrolysis plant into Malaysia where it has been installed alongside a palm oil processing plant. The waste Empty Fruit Bunch (EFB) is converted in oil via pyrolysis in the BTG plant. The company is presently (2012) engaged in a project to build a plant in Hengelo, Netherlands with commissioning scheduled for 2013. The plant will produce 5tonne/hour of pyrolysis oil along with electricity and process steam. More information can be found at [www.btgworld.com/en](http://www.btgworld.com/en)



**Figure 22:** DynaMotive's 200 tonne per day Plant in Guelph, Ontario, has an input of approximately 65,000 dry tonnes per year of biomass from waste construction and demolition wood and produces an energy output equivalent to 130,000 barrels of oil. (Image courtesy DynaMotive)

- KiOR (Mississippi, USA) – Is in late stages of construction of US\$222 million initial scale commercial facility, designed to process 500 bone dry tons of Southern Yellow Pine woody biomass per day. The plant includes hydrotreating to upgrade the oil into gasoline, diesel, and fuel oil blendstocks (over 11 million gallons or 42 million litres annually). Production is scheduled to commence in the second half of 2012. More information can be found at [www.kior.com](http://www.kior.com)





**Figure 23** KiOR Mississippi plant 500 bone dry tons of biomass, to be completed in late 2012. (www.kior.com)

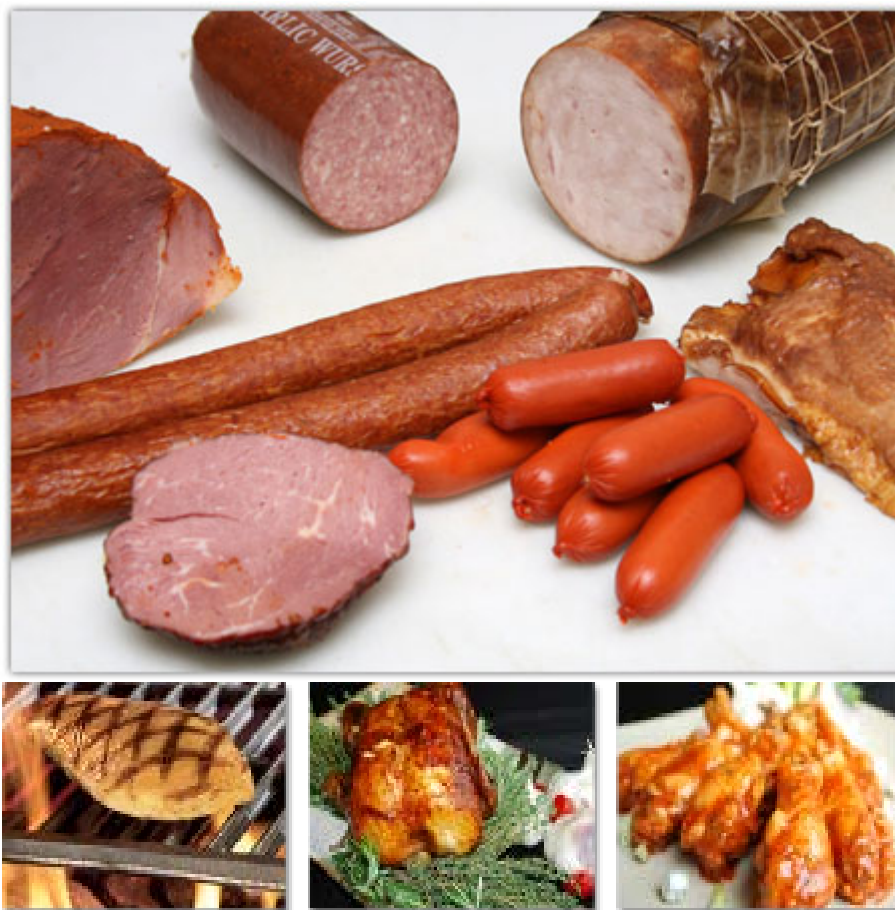
#### **3.5.4 Food flavouring**

Liquid smoke solutions are used to impart flavour, colour, texture and in certain cases provide enhanced shelf life for food products. The constituents of liquid smoke are obtained from thermal degradation reactions of cellulose, hemicellulose and lignin, typically from hardwoods.<sup>80</sup>

The production process firstly involves smoke generation by heating the wood (usually dried sawdust) in a low oxygen pyrolysis chamber.<sup>81</sup> The evolved gases are condensed with water. Char and a range of harmful compounds such as Poly-cyclic Aromatic Hydrocarbons (PAHs), are insoluble and are separated by settling and filtration to ppm levels. The tar, char and non-condensable gases are combusted to provide heat for drying and pyrolysis. The resulting liquid solution is claimed to be safer than conventional food smoking and is cheaper and more controlled.

The important product characteristics are acidity (typically acetic acid) and phenol content, which impact the flavour strength, as well as the reactivity of carbonyl compounds (defined by a stain index), which impact the propensity for non-enzymatic Maillard type browning reactions with amino acids when applied on protein substrates. Cellulose and hemicellulose degradation are the primary sources of carbonyls and carboxylic acids, while phenols are obtained from lignin pyrolysis.

The main variables that control liquid smoke product yield and characteristics are temperature, rate of heat transfer, particle size, atmosphere of pyrolysis, vapour and particle residence times, and composition of biomass. Higher liquid and lower char yields are obtained from fast pyrolysis type processes, similar to bio-oils.



**Figure 24:** A range of food flavourings (Photos courtesy Red Arrow International)

There is considerable regulation of food products and additives. Various assessments of the suitability of smoke flavourings for consumption have been made by international regulatory bodies. While some genotoxic compounds exist in these products, generally the level of harmful constituents is below acceptable levels and safety is not of concern at normal levels of use.<sup>82</sup>

Smoke flavourings are typically added to ready-to-eat savouries, soups and broths as well as meat and meat products. Smoke flavouring is normally added at levels ranging from 0.1 to 10 g/kg. Liquid smoke is a relatively high value product. There appears to be a small cottage industry within Australia although most demand is met by imports. The market size is limited, for example the largest US manufacturer (Red Arrow) consumes less than 90 green tonnes per day.<sup>83</sup>

## 3.6 Direct Liquefaction

A wide range of process approaches initially developed in the 1970's for coal, peat and wood sludge liquefaction have been researched and patented. Recent developments and commercialisation have targeted waste biomass. Direct liquefaction, the heat and pressure conversion process of producing liquid oil, is sometimes referred to as thermo-chemical conversion, thermal depolymerisation or simply liquefaction. By contrast, indirect liquefaction produces a liquid fuel by gasifying organic materials to syngas, followed by synthesis to ethanol, methanol, or other chemical compounds.

Direct liquefaction replicates nature's conversion of biomass materials into petroleum under high pressure and temperature over millions of years. The thermo-chemical direct liquefaction process converts liquid slurry of biomass and organic materials to hydrocarbon oils and by-products, using high pressure (generally up to 200 atm) and temperature (generally up to 350°C), reducing processing times to minutes.<sup>84, 85</sup>

### 3.6.1 Direct Liquefaction Technology Description

The main purpose of liquefaction is to increase the H:C ratio of the oil product relative to that present in the feedstock. A decrease of the O:C ratio is also necessary to achieve hydrocarbon-like products. Addition of a reducing gas, such as H<sub>2</sub> or CO, is thus needed to increase the H:C ratio. In biomass materials, oxygen removal occurs via internal dehydration and decarboxylation reactions occurring during the initial pyrolytic stages. Another necessity of successful liquefaction is using uniform feedstock slurry in a liquid carrier, that is, a specific solvent or an aqueous system.<sup>85</sup>

In the case of sawmill residue, the woody biomass feed stock would be formed into a water based slurry with a uniform particle size (<1mm typically) and typically 20 to 30% solids.<sup>88</sup> The slurry is then heated at elevated temperatures of 300 to 350°C with sufficient pressure to maintain the water primarily in the liquid phase (120 to 200 atm) for residence times up to 30 minutes. Carbon monoxide, hydrogen and other catalysts may be added to increase the hydrogen to carbon ratio, and reduce the oxygen to carbon ratio, thereby improving the hydrocarbon yields.

A series of separation processes remove the solids and water rich streams from the bio-derived oil.

### 3.6.2 Direct Liquefaction Products

The primary product is liquefaction oil, a free-flowing liquid that is a combustible mixture of oxygenated hydrocarbons. This organic liquid with reduced oxygen content (about 10%), can be converted to hydrocarbon fuels and commodity chemicals for products similar to those produced from petroleum.

Depending on feedstock and process details, yields of oil can range by mass weight from 26 to 80% of the mass of the biomass. Estimated yields from processing 180 tonnes per day of turkey offal and grease waste at the Changing Worlds Technology bio-refinery based in Carthage, Missouri show approximately 63 tonnes per day (about 500 barrels) of bio-derived oil.<sup>86</sup>

For their Carthage, Missouri plant, Changing World Technologies has calculated an energy efficiency of 85% as measured by the energy in the combustible products that leave the plant divided by the total energy input (a sum of the energy in the dry feed and the electric power used).

At research level, liquefaction of ligno-cellulosic biomass (crop residues) yielded 60 to 80% bio-liquids.<sup>79</sup> Research has shown that biomass feedstock with more lignin means more energy content resulting in higher oil yield.<sup>88</sup>

The primary by-product is water containing soluble organic compounds. Other by-products include steam, solid minerals and metals (as present in the feedstock), carbon char and inert

and combustible gases. Depending on the feedstock, the solid minerals can include elements such as nitrogen, phosphorus, potassium and calcium. These products may be sold as soil amendments. Inert and combustible gases vary by feedstock and process, but mainly include CO<sub>2</sub>, CO and H<sub>2</sub>. When the combustible fuel gases CO and H<sub>2</sub> are produced, they 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.

### **3.6.3 Direct Liquefaction Costs**

Commissioned in 2003, a \$20 million facility in Carthage, Missouri processes 180 tonnes per day of fats, bones, feathers, grease and oils from a ConAgra Foods turkey processing operation.

### **3.6.4 Direct Liquefaction Technology Status**

Development of biomass direct liquefaction has focused on slurried wastes such as sewerage, Municipal Solid Waste, sludge and animal manure. A commercial scale plant was commissioned in 2003 and operational in 2004 in Carthage, Missouri to process 180 tonnes per day of animal waste material from a ConAgra Foods turkey processing operation. In 2002, Biomass Transformation Industries LLC (BTI) was seeking support for its extruder feeder liquefaction technology. Further development has not been identified and BTI was deregistered as a company in 2009.

Liquefaction of ligno-cellulosic biomass (crop residues) has been successfully performed at research level. Using an ethylene carbonate catalyst, it has been found that hardwood lignin is more easily processed than softwood.

Licella, a subsidiary of Australian based Ignite Energy, are developing Catalytic Hydrothermal Reaction (CAT-HTR) technology for the conversion of multiple biomass feedstocks, including forestry residues, into bio-crude oil. The bio-crude oil generated in their catalysed supercritical process can be refined into fuels such as diesel and jet fuel alternatives using existing refinery infrastructure. Licella has generated bio-crude from Radiata Pine sawdust in their Pilot Plant and opened a partly Government Funded Commercial Demonstration Plant in Somersby, NSW, in December 2011.

Research and commercialisation efforts for new reactor designs and processing are ongoing worldwide.

## **3.7 Hydrolysis**

Currently, commercial scale production plants for fuel ethanol ferment readily available starch or sugars. Commonly, this is from corn, wheat and sugar cane (the main feedstock used in Australia) and is now commonly referred to as first generation bio-ethanol. First generation ethanol consumption reached 280 million litres in 2010 in Australia, representing a market share of 1.5%. In the US, first generation ethanol consumption was 45 billion litres (8.4% market share). In Brazil, market share was around 66% in 2010.<sup>89</sup>

Ethanol can also be produced from ligno-cellulosic biomass and is often referred to as second generation, next generation or advanced bio-ethanol. The use of the cellulose part of plants (ligno-cellulose) is an attractive alternative feedstock as there is a greater mass of material available and this shall result in the reduction of food crop diversion to ethanol production. However the production of ethanol from wood waste is a far more complicated process.

### **3.7.1 Hydrolysis Technology Description**

Ligno-cellulosic biomass, which forms the bulk of the stem parts of trees, shrubs and grasses, comprises a complex mixture of carbohydrate polymers from plant cell walls known as cellulose and hemi-cellulose, plus lignin and smaller amounts of other compounds generally known as extractives which include proteins, lipids and ash.



In the production of ethanol from ligno-cellulose there are two general paths which may be taken 1) the sugar route which employs hydrolysis to break down cellulose and hemi-cellulose into sugars, followed by fermentation into ethanol and 2) the gasification route.

Hydrolysis is done using one of three methods – dilute acid hydrolysis, concentrated acid hydrolysis and enzymatic hydrolysis. Dilute acid hydrolysis occurs in two stages, the first hydrolyses the hemi-cellulose, exposing the cellulose for hydrolysis in the second stage. During concentrated acid hydrolysis the feedstock is cooked in sulfuric acid creating a mash, which is then squeezed to collect the excess fluid and separated into ethanol and other by-products using simulated moving bed chromatography. Enzymatic hydrolysis uses enzymes to hydrolyse the feedstock into sugars. This enzymatic hydrolysis step (saccharification) is sometimes carried out simultaneously with fermentation.

The gasification process is quite different to hydrolysis. The feedstock is input into a gasifier, where it is heated in a low oxygen atmosphere to produce a syngas which is purified and conditioned. Conventional Fischer-Tropsch Processing (described in section 3.5.1.2) may then be used to generate ethanol. Alternative approaches are also being developed that use microorganisms to convert the syngas into ethanol.

The choice of process is affected by many things including potential ethanol yield and feedstock type. It must be understood that at this point in time there is no clear winner with regards to technology options. Acid hydrolysis - both concentrated and dilute - of woods is old technology. A few of these types of plants were shut down after WWI because they weren't economical. Once enzymes were discovered and developed, they offered the opportunity for higher yields and potentially lower costs.

If the feedstock for the process is "clean" - like hardwood - any of these pathways has the potential to work well. However, according to the NREL, gasification and concentrated acid hydrolysis both have the potential to work well for feedstocks that are heterogeneous, such as mixed wood wastes, urban green wastes and MSW. A dilute acid or enzyme hydrolysis route does not work as well at these greater levels of heterogeneity.

### 3.7.2 Hydrolysis Products

Fuel ethanol is always at least 99.5% pure before it is denatured whether it comes from corn, sugar cane or biomass. The final ethanol product could be expected to have energy content (LHV) of 26.7GJ per tonne and density of 0.79 tonnes per cubic metre (21.2MJ per litre).

**Table 23** Comparison of typical yields per bone dry tonne of wood feedstock for various products using gasification process<sup>90</sup>

Electricity	6.3 GJ (1.75 MWh)
Diesel	400L
Methanol	800L
Ethanol	300-400L

The data shown in Table 22 is based on a feedstock with a calorific value of 19.7 GJ per tonne using the gasification process described earlier. However, there is a significant difference in the expected yield of the feedstock depending on the process and the company producing the ethanol. TECNIA expect to produce around 400L of ethanol per tonne of dry wood, using the FERMATEC continuous fermentation process, whereas the NREL are currently targeting 280L per tonne of dry wood using their gasification method.

In order to produce liquids, a minimum carbon content of 50% and ash content of less than 6% is needed. Hence it is necessary to know the chemical composition of the sawdust before using it in this process; however, according to NREL, saw dust from a saw mill is expected to be suitable.

In most of the processes described earlier, lignin (a phenol polymer) remains as residual material after the sugars in biomass have been fermented to ethanol. It has energy content similar to coal and may be employed to power the operation, thereby reducing production costs. The lignin may also be used as an adhesive or binding agent, dispersant, emulsifier or sequestrant.

The energy density of the lignin residue is subject to a significant variation which depends greatly on factors such as process used, moisture content and what else is in the residue. The properties of lignin also depend on whether it is produced from hard or soft wood; some these properties are shown in Table 23.

**Table 24** Properties of Lignin Residues <sup>91</sup>

Parameter	Hardwood Lignin Mean Value	Softwood Lignin Mean Value
Volatile Matter (% db)	76	73
Fixed Carbon (%db)	22	26
HHV (MJ/kg) (db)	21	24

There are also a wide range of products which are made from lignin and/or sugars, including furfural, furans, glycols, MEK, adipic acid, ethylene, methanol, propylene, phenols, aromatics, dibasic acids and olefins.

A study was completed in 2005-06 on the development of new chemical products which could be produced from lignin. This study found a selection of small molecules that can be derived from waste lignin streams. A large library of microorganisms that produce chemicals from small molecules derived from lignin was generated and uses for some of the microbial products were identified. <sup>91</sup>

There are also a variety of products which can be made from sugars such as the obvious ethanol, lipids, n-butanol, glycerol, acetone, acetylaldehyde, methanol, citric acid, itatonic acid, butanediol, fumaric acid, single cell protein, isopropanol, lactic acid, butanediol, acetic acid, lactic acid, butyric acid, acetylaldehyde, propionic acid, succinic acid, food grade sweeteners and other oxychemicals.

Bio-butanol is being developed as an alternative to ethanol for transport fuel. It has a higher energy density (25%) than ethanol, closer to that of petrol, and can be blended at ratios of up to 16% compared with 10% for ethanol, without requiring specially adapted vehicles. <sup>92</sup>

### 3.7.3 Hydrolysis Capital and Operating Costs

A number of commercial scale bio-refineries are presently under construction or in advanced planning, as shown in Table 25. CAPEX and projected operating costs for some of these plants is available. For comparison purposes the capital cost for each plant has been normalised to a capital cost (\$) for a unit capacity (L/y), which has been shortened to \$/L/y. A currency conversion of AUD1 = USD1 has been used.

A 2012 industry report indicated that the CAPEX for a 100 million litre per annum plant would be in the range US\$135-200million. This equates to a normalised cost of US\$1.35-2.00 per litre per annum (\$/L/y), for a commercial scale plant using enzymatic hydrolysis. <sup>89</sup>

BP Biofuels had plans to construct a 136 million litre per year enzyme plant in Florida with a budget of US\$350 million (US\$2.57/L/y). <sup>93</sup> This project was cancelled in October 2012.

DuPont Cellulosic Ethanol (DCE) claimed a CAPEX in 2009 of US\$1.32-1.85/L/y for their enzyme based process, although this process appears to produce a low purity ethanol. They have a commercial CAPEX target of \$0.80-1.30/L/y. <sup>94</sup> The capital cost for their commercial plant under construction in Iowa has not been disclosed.



Mascoma is presently constructing a US\$232million cellulosic ethanol plant in Michigan with a nameplate capacity 76 million litres per year. This equates to US\$3.05/L/y. In their IPO, they estimate an operating cost at the plant of US\$1.77 per gallon (US\$0.47 per litre). They claim that US\$1 per gallon is achievable with increased scale and by selling co-products like electricity. Their cost projections are based on hardwood feedstock at US\$73 per tonne and a conversion yield of 345 litres per bone dry tonne of hardwood.<sup>95</sup>

Some other groups (e.g., Coskata) have projected their total costs for producing cellulosic ethanol as low as US\$1 per gallon (US\$0.26 per litre), however these low cost projections are based on very early stage development and theoretical calculations.<sup>96</sup> DDCE estimated their cellulosic ethanol cost at around US\$2 per gallon in 2012 with a commercial goal of approximately US\$1.50 per gallon (\$0.40 per litre).<sup>94</sup> They expect that cellulosic ethanol will be cost competitive with oil derived fuel without subsidies on energy parity at approximately \$80 per barrel oil. Their process, based on enzyme hydrolysis, is low in capital but is also relatively low yielding in terms of ethanol. Feedstock price is a key cost driver.

POET, a global leader in bio-ethanol who is the largest producer of first generation ethanol, has claimed a cost for producing cellulosic ethanol from corn cobs of US\$2.35 per gallon (US\$0.62 per litre). This cost is based on real data from their pilot plant using enzyme technology and includes items such as interest, depreciation, wages, benefits, repairs, maintenance and insurance. POET hopes to get costs below US\$2 per gallon (US\$0.52 per litre).<sup>97</sup>

Fuel ethanol futures prices in 2012 are approximately \$0.60 per litre<sup>98</sup>, with production costs (non-cellulose base) varying from \$0.27 to \$0.87 per litre. Most governments throughout the world subsidise the cost of production of fuel non-cellulosic ethanol and frequently impose tariffs to protect local production. The fuel, unlike petroleum fuels, is not traded freely which it will ultimately need to be.

### 3.7.4 Hydrolysis Technology Status

Driven by US energy policy (in place at the time of writing) targeting 60 billion litres per year of cellulosic ethanol in the fuel supply by 2022 and funding support in Europe, a number of multinational companies have increased investment in recent years.

The following companies are recognised as global leaders in cellulosic ethanol at the time of writing:

- BP Biofuels – Acquired enzyme technology and a demonstration plant through acquisition of Verenium (previously formed via merger between Celunol and Diversa). Recently cancelled plans to build commercial scale plant in Florida. Will now focus on licensing its technologies.<sup>99</sup>
- DuPont Cellulosic Ethanol (DCE) – Has operated a 1 million litre per year demonstration plant in Tennessee since 2009. In 2011, DuPont acquired Danisco and its Genecor Enzymes unit. DCE has appointed Fagen to build their first commercial scale plant in Iowa using corn stover. They plan to extend feed to switchgrass and sorghum.<sup>100</sup>
- Abengoa Bioenergy – Has 4500 hours of operational experience at their 5 million litres per year demonstration plant in Salamanca, Spain. Their enzymatic hydrolysis technology will be deployed at a 95 million litre per year commercial hybrid plant in Kansas, USA. They also provide technology licensing as well as project development, operations management, biomass supply, marketing and hedging services.<sup>101</sup>
- Poet-DSM – POET, a giant first generation bio-ethanol producer, recently formed a joint venture with DSM, who has cellulosic enzyme and yeast fermentation technologies. They plan to complete their first commercial facility in 2013.<sup>102</sup>

- Mascoma – Employs Consolidated Bioprocessing (CBP) by using a “magic bug” to simultaneously carry out hydrolysis and fermentation. CBP requires better pre-treatment but overall costs are ultimately lower than separate hydrolysis and fermentation, as endorsed by the US DOE. Mascoma is relatively unique amongst the leading developers in pursuing wood waste from the outset.<sup>103</sup>
- Novozymes – Develops and supplies enzymes to numerous partner organisations, most of the major players, that are suited to specific process technologies and feedstocks.<sup>104, 105</sup>
- ZeaChem – while ZeaChem’s commercialisation has progressed less than the majors (construction of 1 million litre per year demonstration plant completed in October 2012), its hybrid process is of note as it produces high ethanol yields by utilising the carbon in lignin. Ethanol yields of approximately 560 litres per bone dry tonne of feedstock is claimed. Combustion of remaining lignin compounds almost meets plant energy requirements. Acetogens are used in place of yeasts for simultaneous conversion of both xylose (C5) and glucose (C6) sugars into ethanol. Other carbon based chemicals and fuels can also be produced or co-produced within the same plant. ZeaChem is partially funded by Australia’s Macquarie Group.<sup>96</sup>

**Table 25 Large scale cellulosic ethanol plants**

<i>Owner</i>	<i>Capacity Million litres per year</i>	<i>Feedstock</i>	<i>Hydrolysis Technology</i>	<i>Launch</i>
Fiberight, USA (Iowa)	23	MSW	Enzyme	2013
Mascoma, USA (Michigan)	76	Woody Biomass	CBP	2013
BP Biofuels, USA (Florida)	136	Sugarcane Bagasse	Enzyme	2013
Poet-DSM, USA (Iowa)	95	Corn stover	Enzyme	2013
DuPont, USA (Iowa)	95	Corn stover	Enzyme	2013
Abengoa, USA (Kansas)	95	Corn stover		2013
Petrobras, Brazil	15	Sugarcane Bagasse	Enzyme	2013
Abengoa, France	49	Agricultural residue		2013
Inbicon, Denmark	5	Wheat straw	Enzyme	2009
M&G – Chemtex, Italy	49	Energy crops	Enzyme	2012
Cofco/Sinopec, China	57	Corn stover	Enzyme	2013
American Process, USA (Michigan)	3.4	Wood hydrozylate (hemicellulose) residue from panel board process	Enzyme	2012
INEOS Bio, USA (Florida)	30	MSW and Agricultural waste	Gasification	2012
ZeaChem, USA (Oregon)	1	Wood and wheat straw	Biochemical & Thermochemical	2012

References: 92 to 116

Second generation bio-ethanol is moving rapidly towards commercialisation, with 23 million litres per year of cellulosic capacity in North America at nine demonstration plants and around 400 million litres per year of capacity under construction.<sup>107</sup> The race to commercialisation has had its casualties, such as former leader Range Fuels along with Terrabon, Qteros, Iogen and Codexis all failing or stalling. A big blow recently was BP deciding not to proceed with their first commercial plant. In another sign of the times, a technology leader, Coskata, has decided to focus development of its fermentation process which produces liquid fuels to use natural gas rather than syngas from biomass gasification.

More positively, a commercial milestone was reached recently when Blue Sugars Corp. attained the first cellulosic renewable identification number (RIN) issued by the US EPA – a requirement for subsidies and regulatory approval. Chemtex and Ineos Bio recently started commissioning their commercial scale plants, with others not far behind.

It is noteworthy that most second generation plants are being designed for agricultural residue feedstock, probably due to feedstock availability and lower pre-treatment costs. Exceptions include Mascoma in the US, whose pre-treatment process is complex regardless, and American Process, whose Michigan plant uses a by-product from a panel board process.

While the technology has previously been described as being five years away, it is now more like one to two years from commercialisation.<sup>107</sup>

### 3.8 Mulching and composting

Composting is an aerobic biological treatment process which converts solid organic material into a stable humus at elevated temperatures (40 to 60°C). Composting wood waste reduces the waste volume, detoxifies it and transforms the waste into a product that can be used as a soil amendment. Composting increases the organic matter content and improves the water-holding capacity, structure, texture and aeration of the soil. Compost also loosens clay soils, improves soil fertility and stimulates healthy root development in plants.<sup>118</sup> A composting operation can be implemented at a plant site and requires limited knowledge, equipment and space; alternatively wood waste can be sold to mulching companies.<sup>119</sup> The cycles of markets for residuals, mulch and sawdust, also are complementary; sales of sawdust increase in the winter, and sales of mulch increase in the summer.

Compost is used in many households throughout Australia as a method of recycling food scraps to nourish soil. However, composting can also be used at a commercial scale provided it is stored in a well-drained area and is kept hot and dry. The Australian standard for composts, soil conditioners and mulches is AS4454.

The ideal carbon-to-nitrogen (C:N) ratio in a compost is around 30:1. At lower ratios, nitrogen is supplied in excess and lost as ammonia gas, causing undesirable odours. Higher ratios mean that there is not enough nitrogen for optimal growth of the microbial populations, so the compost remains relatively cool and degradation proceeds slowly. Since wood chips or sawdust have a C:N of approximately 125:1 and bark 115:1<sup>120</sup>, wood wastes from saw mills need to be combined with other organic waste streams to produce high quality compost.<sup>121</sup> One option for achieving this mix is by first using the wood waste as animal bedding, this will add the required nitrogen hence creating high quality mulch.

Heat can also be extracted from compost piles (thermopiles) and used for other processes, by running pex tubing within the pile. Large piles of compost can reach 60 to 70°C. This operation is done commercially, but from this investigation a practical size of the pile and the amount the mulch needs turning to create a mature mix has not been found.<sup>122</sup>

Composting is a method which has already been recognised by saw mills across Australia as a use for saw mill wood waste. Hence it has only been discussed briefly in this report.

### 3.9 Engineered Wood Products

Engineered or composite wood products are made by using adhesives to bind together wood strands, particles, fibres or veneers. These engineered products must be carefully designed in order to meet the standards for which they are to be used.

Waste wood from sawmills such as wood particles and fibers can be used to produce engineered wood products including:

- Oriented Strand Board
- Wafer Board
- Particle or Chip Board
- Masonite
- Medium Density Fiber Board
- Hard Board
- Mineral Bonded Particle Board and Fiber Board
- Wood Plastic/Polymer Composites – Monomers are “impregnated” in the wood and polymerised increasing the wood’s dimensional stability, hardness and abrasion resistance and making the material less moisture absorbent.<sup>123, 124</sup>

Engineered wood products is recognised and well understood by saw mills across Australia as a use for saw mill wood waste. Hence it has not been discussed in detail in this report.

## 4 GOVERNMENT INCENTIVE SCHEMES

In order to decrease the effects of Greenhouse Gas (GHG) emissions the federal and state governments and some private companies have set up funding or incentive schemes to entice the use and production of renewable energy and resources. These schemes are constantly changing, with some expiring or running out of funds or new schemes being developed. The following list is all such schemes which were identified during a 2012 search. Before applying for these schemes the administering department should be contacted to find out if any changes have been made to the scheme, if it has expired or if it has exhausted all of its funding. Investment decisions that rely on government incentive schemes should consider the risks associated with these schemes being changed or abolished.

Generally, the states have or are reducing their grants and other incentive schemes so as not to duplicate federal government offerings. Also, grants are not available for potential projects that use residues from old growth forests.

### 4.1 Federal Initiatives

The Australian Renewable Energy Agency (ARENA) is a new independent statutory authority with \$3.2 billion in funding that is guaranteed in legislation out until 2020, as a part of the Australian Government's Clean Energy Future package. On 1 July 2012, ARENA became responsible for the administration of committed projects and measures from initiatives administered by the Australian Centre for Renewable Energy and the Department of Resources, Energy and Tourism. A number of existing funds and projects have rolled under ARENA's umbrella. Around \$1.7 billion of ARENA's funding is presently uncommitted (as of August 2012) and may be made available to fund activities including the research, development, demonstration, deployment and commercialisation of renewable energy and related technologies.

ARENA's funding is being guided by an interim funding strategy until its general funding strategy is fully developed, anticipated to be released by October 2012. The interim strategy will continue to progress the Emerging Renewables Program, select eligible applicants under the Advanced Biofuels Investment Readiness program and oversee the Renewable Energy Venture Capital fund. These programs will be included in the general funding strategy and may be extended or modified, along with any new programs instigated in accordance with ARENA's functions and powers.

As a general rule co-firing – of non-native forest wood - is applicable under the federal schemes; however this should be confirmed when approaching the government departments for information or when applying for the initiatives.

Some initiatives they may be relevant have been omitted because they are no longer accepting applicants.

#### 4.1.1 Emerging Renewables Program (ERP)

The \$126 million ERP provides grants for the development of renewable energy technologies as well as developing and building renewable energy capacity.

More information is available at <http://www.arena.gov.au/programs/initiatives/erp/erp.html>

#### 4.1.2 Advanced Biofuels Investment Readiness (ABIR) program

ABIR is a competitive one-stage, merit-based program offering grant funding to selected projects undertaking activities that build the investment case for significant and scalable pre-commercial demonstration projects for the production of high energy, drop-in (fossil fuel replacement) advanced biofuels in Australia.



Projects under the ABIR program include, but are not limited to, pre-feasibility, feasibility and front-end engineering design studies or extensions to the operational demonstration of pilot-scale facilities with a clear pathway to commercialisation.

More information is available at <http://www.arena.gov.au/programs/initiatives/abir.html>

#### **4.1.3 Renewable Energy Venture Capital (REVC) fund**

The Southern Cross Renewable Energy Fund is a 13-year venture capital fund that was established in January 2012 under the REVC Fund Program.

Southern Cross Venture Partners (SXVP) are licenced to manage the fund, which comprises The Australian Government's \$100 million investment matched dollar for dollar by Softbank China Venture Capital (SBCVC), a leading venture capital firm in Asia, creating a \$200 million fund dedicated to renewable energy.

The objective of the Program is to provide venture capital and active investment management to encourage the development of Australian companies that are commercialising Renewable Energy Technologies.

More information is available at <http://www.arena.gov.au/programs/initiatives/revc.html>

#### **4.1.4 Clean Technology Investment Program**

The Clean Technology Investment Program is an \$800 million competitive, merit-based grants program to support Australian manufacturers to maintain competitiveness in a carbon constrained economy. This program will provide grants for investments in energy efficient capital equipment and low emission technologies, processes and products.

Only high energy users are eligible, specifically those who in the 12 month period before submitting an application:

- used at least 300 MWh of electricity; or
- used at least five Tera-joules of natural gas; or
- used a mix of fuels and/or electricity that results in the emissions of at least 0.27 kilotonnes of carbon dioxide equivalent; or
- be directly liable under the carbon pricing mechanism.

Projects that can be supported include switching to less carbon intensive energy sources or installing new manufacturing equipment, processes and facilities to reduce energy consumption and carbon emissions.

Eligible Project expenditure can include costs for plant and equipment that is acquired through the project through purchase, lease or build. Associated freight and installation costs (where capitalised) and commissioning costs can also be eligible expenditure.

For all other grants under \$10 million, applicants will be required to contribute \$2 for every \$1 from the Government.

For grants of \$10 million or more, applicants will be expected to make a co-contribution of at least \$3 for each \$1 of Government support.

More information is available at <http://www.ausindustry.gov.au/programs/cleantechnology/cleantechnologyinvestment/Pages/default.aspx>

#### **4.1.5 Clean Technology Innovation Program**

This program is directed at *new* clean technologies and associated services that create new, or improve existing, products, processes or services to deliver greater energy efficiency or reduced greenhouse gas emissions. Funding is available for applied research and development, proof of concept and early stage commercialisation activities.

Grants in the range \$50,000 to \$5 million are available on a merits basis to any non-tax-exempt company that can provide an equivalent or greater amount of funding for an eligible project. Projects are judged on the extent of greenhouse gas emission reduction, the commercial potential of the project, the technical strength of the project and the management capability of the applicant. Advice is available from Innovation Australia on these merit criteria and indicators.

More information is available at

<http://www.ausindustry.gov.au/programs/cleantechnology/cleantechnologyinnovation/Pages/default.aspx>

#### **4.1.6 Clean Energy Finance Corporation**

The \$10 billion CEFC will provide a new source of finance to renewable energy, energy efficiency and low-emissions technologies. The \$10 billion CEFC will provide a new source of finance to renewable energy, energy efficiency and low-emissions technologies. Investment operations are scheduled to begin from July 2013.

More information is available at

<http://www.cefcexpertreview.gov.au/content/Content.aspx?doc=home.htm>

#### **4.1.7 Low Carbon Australia**

Low Carbon Australia provides financial solutions and advice to Australian business to encourage action on energy efficiency, cost-effective carbon reductions, and accreditation for carbon neutral products and organisations.

More information is available at <http://www.lowcarbonaustralia.com.au/>

#### **4.1.8 Renewable Energy Target (RET)**

The RET provides a financial incentives for investment in renewable energy sources through the creation and sale of certificates. The RET is split into two parts: The Large-Scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). The SRES does not apply to bioenergy systems but wood waste is an eligible energy source for electricity generation under the LRET. Large-scale Generation Certificates (LGC) are generated and sold under the LRET scheme, presently for around \$30/MWh.

Information on how to participate in this measure can be found on the website of the Clean Energy Regulator, which is responsible for administering the scheme.

<http://ret.cleanenergyregulator.gov.au/>

#### **4.1.9 Ethanol Production Grants**

The Ethanol Production Grants (EPG) program is an eligibility-based program administered by the Federal Department of Resources, Energy and Tourism. EPGs are paid to ethanol producers at a rate of 38.143 cents per litre. To claim the grant, the ethanol must be produced entirely in Australia by the grant recipient from biomass feedstock, which is to be used in, or as, a transport fuel in Australia. For more information see

[http://www.ret.gov.au/energy/energy\\_security/fuels/alt-trans-fuels/alt-fuels/epg/Pages/epg.aspx](http://www.ret.gov.au/energy/energy_security/fuels/alt-trans-fuels/alt-fuels/epg/Pages/epg.aspx)

#### **4.1.10 Venture Capital Limited Partnership (VCLP) and Early Stage Venture Capital Limited Partnership (ESVCLP)**

Australian sawmills with assets of less than \$50 million may be able to access venture capital from funds registered under this program. Registered fund managers that invest at least \$10 million (and not more than \$100 million for ESVCLP) are entitled to flow-through tax treatment and its investors (whether resident or non-resident) receive a complete tax exemption on their share of the fund's income (both revenue and capital). The program is managed by AusIndustry. For more details refer to

<http://www.ausindustry.gov.au/programs/venture-capital/Pages/default.aspx>

#### **4.1.11 Cleaner Fuels Grant Scheme**

The Cleaner Fuels Grant Scheme applies to the manufacture and importation of fuels that have a reduced impact on the environment. Eligible cleaner fuels include renewable fuels. The scheme offers a grant for 100% of the excise or customs duty on biodiesel and renewable diesel or a production grant equal to the excise duty rate, currently 38.143cents per litre, for fuel ethanol. This scheme is administered by the Australian Taxation office. For more information on the scheme refer to

<http://www.ato.gov.au/businesses/content.aspx?doc=/content/00128216.htm&pc=001/003/044/008/006&mnu=0&mfp=&st=&cy=>

#### **4.1.12 GreenPower**

GreenPower is the only national renewable energy accreditation program endorsed by the Government. This program allows a company to be affiliated with the name "Green", which may be desirable for some mills.

GreenPower is a voluntary program which may be applied for by filling in the application form found online at <http://www.greenpower.gov.au/Business-Centre/Rules-and-Accreditation> and providing the required information, such as EPA and council approvals and Environmental Impact Statement (EIS). A new applicant plant may need to arrange a power purchase agreement with an energy provider, such as Origin, prior to plant construction to ensure they will receive financial benefits.

## **4.2 Australian Capital Territory Initiatives**

The ACT Greenhouse Gas Abatement Scheme closed on 30 June 2012 with the introduction of the Commonwealth Carbon Trading Scheme.

## **4.3 New South Wales Initiatives**

A NSW Renewable Energy Action Plan is being developed to support the achievement of the national 20% Renewable Energy Target by 2020. The Plan positions NSW to increase the use of energy from renewable sources at least cost to the energy customer and with maximum benefits to NSW. The draft plan mentions the need to reduce barriers to investment in energy from waste and co-firing projects.

## **4.4 Northern Territory Initiatives**

The Northern Territory has no commercial 'standing' timber mills<sup>125</sup> and only a very few portable mills in commercial operation, and thus there is no incentive schemes in place by any Northern Territory Government agency to encourage better use of wood waste.

## 4.5 Queensland Initiatives

The Queensland Government recently released *Climate Smart 2050*. This document outlines schemes which the state Government shall be implementing in order to reduce the effects of global warming. A “\$50 million Queensland Renewable Energy Fund” and the “Queensland renewable and low-emission energy target of 10% by 2010” are examples of these schemes. This document can be found online at

[http://www.thepremier.qld.gov.au/library/pdf/climate/ClimateSmart\\_2050.pdf](http://www.thepremier.qld.gov.au/library/pdf/climate/ClimateSmart_2050.pdf).

The Queensland Department of State Development may be able to offer assistance, however at this time they do not offer any specific schemes for renewable energy.

## 4.6 South Australian Initiatives

South Australia has a target of 20% of the State's power coming from renewable sources by 2014. The following programs are run through the Government of South Australia Department of Manufacturing, Innovation, Trade, Resources and Energy

### 4.6.1 Cleantech Partnering Program

The Cleantech Partnering Program is a \$2.15 million grant program to help small and medium enterprises take new cleantech products, processes and services from conception and early development stage through to market. This fund runs until June 2013.

### 4.6.2 Clever Green Eco Innovation Program

The CleverGreen™ Eco-Innovation program helps companies develop innovative solutions that promote resource efficiency and re-use to facilitate the 'greening' of South Australia's manufacturing industry. This program closes in June 2013

## 4.7 Tasmanian Initiatives

### 4.7.1 Tasmanian Government Innovation and Investment Fund (TGIIF)

The TGIIF provides one-off grants of up to \$250,000 for business innovation that provides significant improvement to their sustainability, efficiency, performance, growth and productivity and may include projects that enable the creation of new, or retention of existing jobs, within Tasmania. Forestry and related industries will receive funding preference as a key sector. Projects that can be finalised by June 2013 are also preferred.

The second and final funding round will open 7<sup>th</sup> January 2013 and close 22 February 2013. For more information refer to:

<http://www.development.tas.gov.au/?a=61528>

### 4.7.2 Renewable Energy Loan Scheme (RELS)

This \$30 million scheme provides low interest loans to eligible businesses that wish to purchase and install renewable energy generation facilities. Loans of up to 70 per cent of the renewable energy project value plus a grant contribution of up to 10% (capped at \$100,000 per applicant) are available. The loan should be repaid within five years.

For the purpose of this program, genuine wood waste is defined as wood pieces or particles which are generated as a by-product from the manufacturing or processing of wood products that excludes wood chips, pellets and fire wood. Furthermore, biomass fuel from native forests is only eligible if generation is embedded (that is, energy is generated and used at the same site) and installed capacity less than 200kW electrical or equivalent.

[http://www.development.tas.gov.au/economic/funding/loans/Industry\\_funding\\_programs/renewable\\_energy\\_loan\\_scheme](http://www.development.tas.gov.au/economic/funding/loans/Industry_funding_programs/renewable_energy_loan_scheme)

## **4.8 Victorian Initiatives**

### **4.8.1 Technology Voucher Program**

The Technology Voucher Program provides a voucher that is exchanged for access to facilities, services or expertise provided by other companies or publicly funded organisations. The program targets industrial biotechnology, which is defined as the development, adaptation and/or integration of a bio-based product or process for industrial applications (manufacturing, waste or water remediation, production of energy) that will deliver greater efficiency and/or improve firm competitiveness.

The Technology Development Voucher worth up to \$50,000 can be used for technology development and/or absorption activities such as pilot scale product prototyping, laboratory verification, field testing. The Technology Implementation Voucher of up to \$250,000 in value can be used to implement existing technology based innovations which can improve firm competitiveness. For small Victorian businesses, up to 199 employees, a company co-contribution of 25% of the voucher value is required, while for large and non-Victorian businesses, a matching co-contribution is required. More information can be found at

<http://www.business.vic.gov.au/industries/science-technology-and-innovation/programs/technology-voucher-program>

### **4.8.2 The Technology Trade and International Partnering (TRIP)**

TRIP provides grant assistance to small Victorian companies to attend any overseas conference or trade event so long as the event is relevant to biotechnology, including industrial biotechnology. A maximum of \$2,500 is recoverable for participants at events or up to \$10,000 for exhibitors. Claimable expenses include airfares and accommodation.

### **4.8.3 First Step Exporter**

A grant of up to \$10,000 for 50% of expenses related to researching and exploring opportunities in their first export markets, where export turnover is presently less than 10% of total annual dollar turnover.

## **4.9 Western Australian Initiatives**

The Department of Industry and Resources is available to companies in Western Australia in providing advice and guidance for setting up or expanding their capabilities; however at this stage they do not offer any funding.

### **4.9.1 Strategic Waste Initiatives Schemes**

The Strategic Waste Initiatives Scheme (SWIS) is aimed at providing support and encouragement to business and industry, local government, community groups and

individuals in tackling priority waste issues. If a mill was to be using wood waste which would otherwise go to landfill or be used in other inefficient manners then it would be eligible to apply for this scheme.

This scheme is administered by the Department of Environment and Conservation. For more information see <http://www.wasteauthority.wa.gov.au/programs/grants/strategic-waste-initiatives-scheme/>



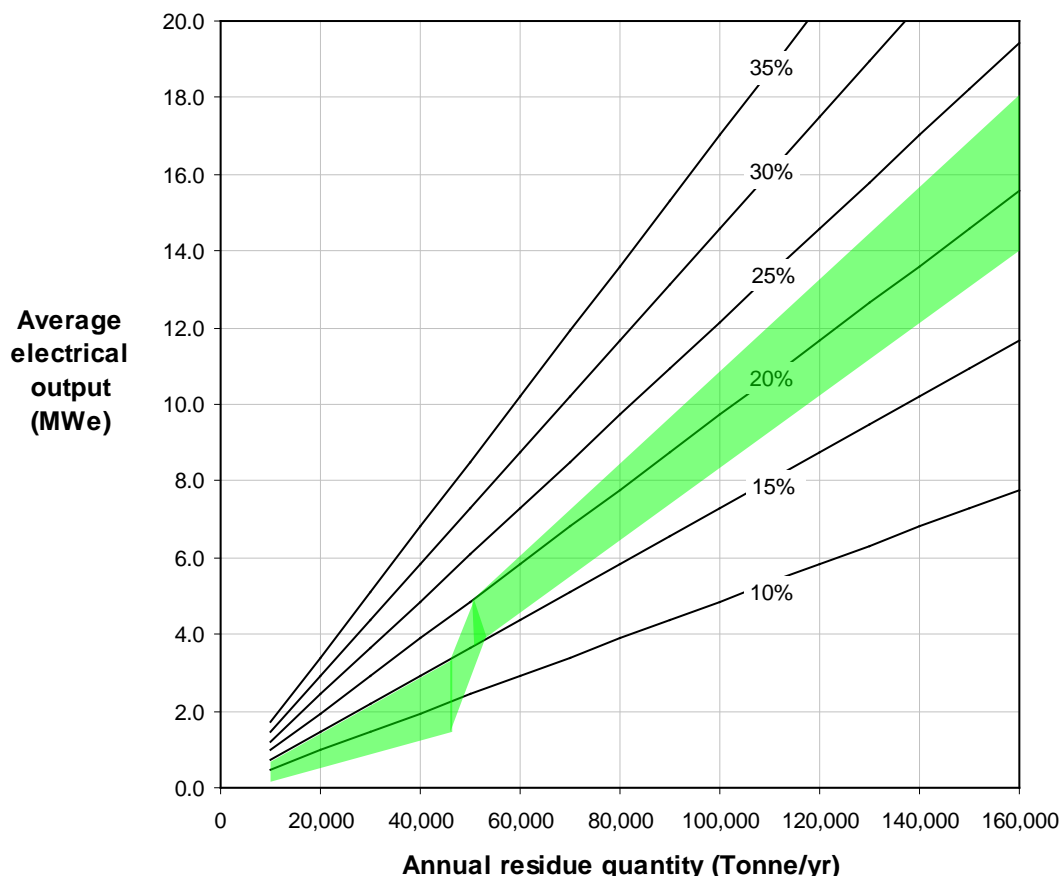
## 5 OPPORTUNITY ANALYSIS

### 5.1 Energy products

Sawmill wood residues may be used for their energy value in a variety of ways. Conversion to solely electricity is possible from scales of tens of kW upwards. Electricity generated in small scale systems at sawmills may be used for plant power and the excess electricity may be sold to the grid or to nearby neighbours. The best value will be gained by displacing purchased electricity, which will effectively yield retail prices, compared to surplus electricity sold to the grid, which will only yield considerably lower wholesale prices.

Generally, conversion efficiencies (i.e., efficiency with which energy in residues is converted into useable form) will increase and the cost per kW or MW of generation capacity will decrease with increasing scale. At larger scales, parasitic losses are proportionally smaller and heat recovery systems are more efficient and cost effective. Overall electrical efficiencies at scales less than 1MW<sub>e</sub> are likely to be less than 15%. Systems greater than about 5MW<sub>e</sub> can utilise steam turbines and will likely have electrical efficiencies of 15% to 25%. Large scale power stations typically have electrical efficiencies of 30 to 40%.

Figure 25 shows the effect of system conversion efficiency on electrical output from annual quantities of sawmill residue. A 10MW<sub>e</sub> steam turbine system may be expected to have an overall conversion efficiency of 20% and would require around 100,000 tonne per year of hardwood residue.



**Figure 25:** Average electrical output for various conversion efficiencies from hardwood residue with gross heating value of 14MJ/kg (~25% moisture content wet basis). The green band represents the likely conversion efficiency for a given system capacity.

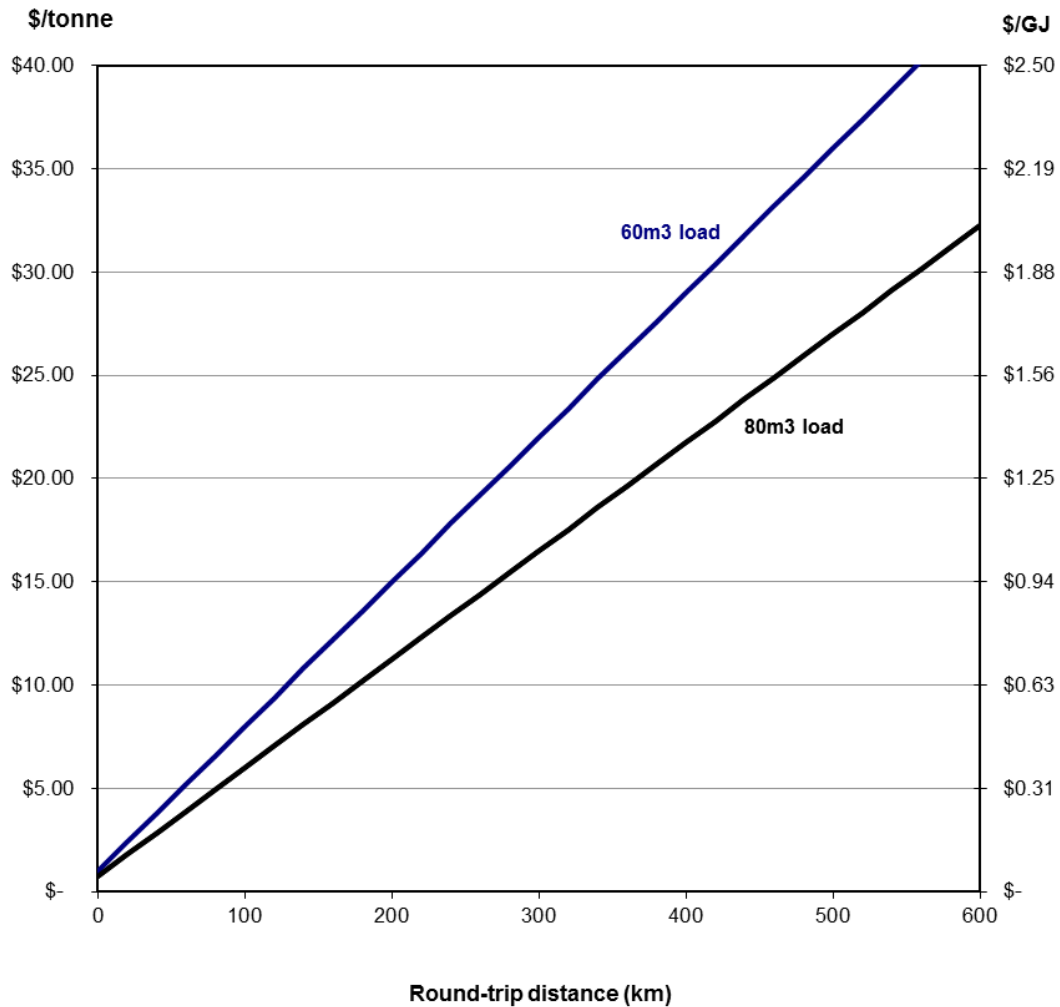
Electricity generation at small scales - up to a couple of MW<sub>e</sub> – is most suited to technologies such as reciprocating steam engines or Internal Combustion (IC) engines, micro-turbines and fuel cells. However, at present gasified wood fuelled micro-turbines and fuel cells are not commercially available, leaving either reciprocating steam or IC engines. These systems are commercially available, although there are a limited number of suppliers, particularly in Australia.

Electricity generation via steam turbines is feasible above about 5MW<sub>e</sub>, although it is marginal below about 10MW<sub>e</sub>. These systems will achieve higher conversion efficiencies than the small scale systems and improve as they get larger.

To utilise larger scale systems and thus increase electricity conversion efficiency the following approaches may be employed:

1. Collect larger quantities of biomass into a single power generation system. Most sawmills in Australia have between 10,000 and 100,000 green tonnes per year input and will individually produce around 5,000 to 50,000 green tonnes per year of residue. Stand-alone biomass fuelled electricity generation systems are not likely to be economically viable below 5 to 10MW<sub>e</sub> scale which means that collection of up to or over 100,000 green tonnes per year of residue would improve viability. This may be achieved through cooperative effort by two or more mills.
2. Co-fire biomass with fossil fuels – co-firing of solid wood in large scale utility boilers replaces and therefore competes with fossil fuels such as coal, natural gas or diesel. Coal is dominant in Australia with around 29GW<sub>e</sub> installed capacity. Natural gas is also significant with around 11GW<sub>e</sub> installed capacity. Coal is relatively cheap and difficult to compete with, particularly since co-firing sawmill residue would only fractionally displace coal meaning that savings in coal mining infrastructure and operating costs will be marginal. The co-firing of gasified wood will compete with mostly natural gas, which is also cheap and abundant in most parts of Australia. Economic viability of biomass co-firing will rely on identifying power generation sites where fossil fuels costs are high (for example, in remote areas) and/or exploiting government subsidies to fund the cost differential.

Both of these options will usually involve transporting biomass over relatively larger distances, incurring significant cost due to the low heat value and bulk density of wood biomass. Additionally, transport vehicles burn fossil fuels and generate net GHG emissions, negating the environmental benefits gained from bio-electricity. Figure 26 shows the typical costs for transporting woodchips by road using 60m<sup>3</sup> and 80m<sup>3</sup> capacity B-doubles. As an example, transporting hardwood chips 200kms is likely to add approximately \$18 to \$23 per tonne or \$1.10 to \$1.50 per GJ to the material cost. Of course, using back-loads or long-term contracts may reduce these costs.



**Figure 26:** Typical round-trip transport costs for 80m<sup>3</sup> B-double carrying woodchips. Transport costs assumed to be \$2.10 per km with no back-load ([www.freightmetrics.com.au](http://www.freightmetrics.com.au)). Wood chip bulk density is assumed to be 0.50 tonne per cubic metre and a bulk energy density of 8GJ per m<sup>3</sup>.

Technologies that increase the energy density of the wood residues can significantly reduce transport costs and improve the viability of transporting biomass large distances. Table 25 shows the volumetric energy density for a range of potential energy products from sawmill residues. When compared to most fossil fuels, the volumetric energy density of wood chips, shavings and sawdust is very low at typically 3 to 9 GJ per m<sup>3</sup>. Even brown coal, which has a relatively low energy density on a wet basis, due to its high moisture content, is typically around 8GJ per m<sup>3</sup> equivalent to a relatively dry woodchip source. Coal is made viable because it is abundant and concentrated enabling stationary power generation to utilise relatively inexpensive conveyor based transport.

Pelletising or briquetting are probably the simplest and least expensive methods of increasing bulk density and thereby volume energy density. Pelletising or briquetting will increase the energy density to approximately 12 or 13GJ per m<sup>3</sup>.

**Table 26** – Analysis of energy density for a selection of wood energy products and fossil fuels

Biomass product	Typical moisture content (wet basis)	Net Calorific Value, wet basis (LHV)	Typical bulk density	Gross Energy density (bulk volume basis, HHV)
	%	MJ/kg	kg/m <sup>3</sup>	GJ/m <sup>3</sup>
<b>Hardwood (Eucalypt)</b>				
Kiln dried shavings	12	17.6	120	2
Sawdust – green <sup>a, 127</sup>	30	14	180-200	3
Woodchips – air dried <sup>128</sup>	30	16	300	4
Solid wood – green <sup>129</sup>	50	8	1150	15
<b>Softwood (P. radiata)</b>				
Kiln dried shavings	10	18	135	3
Solid wood – green <sup>129</sup>	50	8	1000	9
<b>Compressed wood</b>				
Wood pellets <sup>130</sup>	8-10	18	650	12
Charcoal briquettes <sup>131</sup>	5	28-30	1100	31-33
Wood Briquettes	6	19	600-700	12-13
<b>Char</b>	-	30	200-250	6-8
<b>Bio-oil</b>	20	17	1200	20
<b>Bio-fuels</b>				
Syngas	-	5.7	-	(12-18MJ/Nm <sup>3</sup> )
Hydrogen <sup>132</sup>	-	142	-	(14MJ/Nm <sup>3</sup> )
Ethanol	-	30	790	24
<b>Fossil fuels</b>				
Brown coal (VIC) <sup>133</sup>	65	9	860	8
Black coal (NSW) <sup>133</sup>	8	25	940	23
Fuel Oil <sup>134</sup>	-	43	845	36
Diesel <sup>134</sup>	-	-	850	40
Petrol <sup>128, 134</sup>	-	-	737	35
Natural gas <sup>132</sup>	-	-	-	(36MJ/Nm <sup>3</sup> )

a. Sample ID 71 Residue from Timber mill: Eucalypt sawdust. The main species used at the timber mill is spotted gum.

Energy conversion efficiency may be increased by recovering both heat and electricity. This strategy allows 70 to 80% of the energy to be used where there is a need for low grade heat. Heat applications include:

- Process heat (for example, kiln drying)
- Space heating for residential, office, factory, etc
- Heat source for absorption chillers

At many sawmills, kiln drying is a high energy consumption process, accounting for approximately 70 to 90% of the mill's total energy needs. Kiln heating may either be by indirect means, transmitted by steam, hot water or thermic oil or by direct firing, whereby the combustion gases or hot air from a source exterior to the kiln are directed into the kiln. Although direct firing has been proven to give greater heat efficiency compared to the indirect method, the need to vent the combustion gases does constitute a heat loss.<sup>4</sup>

Cogeneration of heat and electricity often improves economics but the technology must be selected carefully. ORC systems, which maintain reasonable conversion efficiencies even at low source temperatures, have been employed in sawmills to utilise the waste heat from kilns and generate electricity.<sup>32</sup>

The cyclic demand for heat, particularly steam, in wood drying kilns places constraints on the electricity generation portion of the plant. As outlined in section 3.4.6 a reciprocating steam engine maintain reasonable average efficiencies where there is a varying supply of steam. Conversion efficiencies can be maintained throughout the drying cycle due to their good turn-down performance. They are generally economically competitive at scales less than 2MW<sub>e</sub>. Alternatively, a combined gasification and internal combustion engine unit may be used to generate electricity and useful waste heat. These systems are being widely tested although very few commercial units are available. Combusting wood pyrolysis gas in micro-turbines is even less mature with trials in their infancy. Fuel cell based CHP systems, even with fossil fuels, are still largely at the technology demonstration stage and commercial units are scarce.

Conversion of cellulosic biomass to liquid fuels (Biomass-to-Liquid or BTL) is an emerging set of technology options. BTL technologies include hydrolysis and fermentation, gasification and F-T conversion, fast pyrolysis or direct liquefaction and other variants, as outlined in section 3. These products potentially represent significantly higher value than solid fuels, particularly in Australia, because they can be used for transport fuels rather than being limited to stationary power. Solid fuels are largely limited to applications for stationary heat and power generation, where it competes directly with cheap coal or natural gas. Importantly, BTL fuels have higher volumetric energy densities than the solid fuel variants, at 20 to 24GJ per m<sup>3</sup>. The higher heating value and higher energy density makes the transport of these fuels over large distances more economically viable.

The technologies for the conversion of sawmill residues to ethanol via hydrolysis are nearing commercial viability at present and are probably 1 to 2 years away. There are few technical challenges to solve with biomass gasification routes however there are economic barriers, which are shown in Table 27.

**Table 27:** Capital Costs of Fuel Production (AUD<sup>a</sup>)<sup>135</sup>

Fuel	Capital Cost per Installed Unit of Capacity		
	Barrel (x \$1000)	Litre (\$)	GJ (x \$1000)
Conventional Oil	15 - 20	0.09 - 0.12	2.6 - 3.5
Ethanol	20 - 30	0.12 - 0.18	5.2 - 7.9
Gas-to-Liquid	~ 40	0.25	U/A
Coal-to-Liquid	~ 60	0.37	U/A
Biomass-to-Liquid	120 - 140	0.75 - 0.88	38 - 44

<sup>a</sup> 1.00 AUD = 1.00 USD

Fast pyrolysis of sawmill residues into bio-oil is technically feasible, and has been commercialized by a small number of companies. In Canada, the world's largest producer of bio-oil, pyrolysis oil was used for food and chemical industries and for heating buildings, mostly within the US (as of 2011).<sup>136</sup> The cost projections for bio-oil production at moderate scales (200 tonnes per day) are competitive with fossil fuels for heating applications in Europe, however for heating in Australia with natural gas costs as low as \$4-5 per GJ (for

large industry users), there is a limited market. The blending of bio-oil with diesel for use in stationary power applications has been successfully but not widely trialed. The conversion and refinement of bio-oils to synthetic transport fuels is still under development and is likely to be some years away from commercialization.

**Table 28: Basic cost analysis of some fuel options**

Product	Indicative Production costs \$/GJ	Market value \$/GJ	Typical scale and CAPEX
Compressed solid fuels	\$6-8 <sup>136, a</sup> (\$120-160/tonne)	Up to \$10 (in Europe \$200/tonne)	<ul style="list-style-type: none"> <li>Scale: plants available with capacity 0.25 - 20t/hr</li> <li>Capital cost: \$1-1.5million per t/hr</li> </ul>
Bio-oil <sup>77</sup>	\$3-6	\$4-15 to displace NG for heating \$10-20 if blended with diesel	<ul style="list-style-type: none"> <li>Scale: initial commercial plant 500t/day (~165,000 dry tonnes per year)</li> <li>CAPEX: \$222m with fuel upgrading (KiOR)</li> </ul>
Ethanol <sup>103</sup>	\$20 (\$0.47 per litre)	\$25 (\$0.60 per litre)	<ul style="list-style-type: none"> <li>Scale: 76 million litres per year ethanol output (under construction - Mascoma)</li> <li>CAPEX: \$1.77/litre/year</li> </ul>

<sup>a</sup> Assuming 0.80 EUR = 1.00 AUD

An assessment of the markets for pyrolysis oil and char in Europe found the following to be the best options from a size and value perspective <sup>137</sup>:

- pulp mill lime kilns, cement kilns
- co-firing in coal, oil and natural gas power plants (many natural gas power plants are configured already to run on alternate fuels)
- district heating plants, chiefly those with unloading facilities on a coast, or inland waterway

In Germany, policies favour small power, so substitution of pyrolysis oil for diesel in new power plants of up to 20MW is an excellent and growing market. In Australia some of these same opportunities exist as well as some additional ones such as co-firing in biomass fuelled power generation or co-generation systems, particularly where there is a shortage or seasonal demand for alternate biomass fuels, such as in the sugar industry.

If wood pellets were to be produced for the purpose of exporting, obviously the cost of transportation of this fuel would be a major part of the costs involved. In order to export, there are three charges involved, the loading rate, the charter rate and the unloading rate. These charges differ depending variables such as the type of product being exported.



## 5.2 Non-energy products

Sawmill residue has more uses than merely as an energy product. There are a large number of non-energy based commodities which can be produced, including chemicals, food additives, engineered wood products and more conventional uses such as composts.

The conversion of sawmill residues into useful chemicals, particularly to displace products derived from fossil fuels, is one area of research and development. The first products that have been brought to market are industrial resins and food flavourings, derived from bio-oil as a co-product with bio-fuels for stationary heat and power. A wider range of chemical products are being developed from bio-oil but these are not yet commercially produced. Other products which are under development are those formed as co-products in the production of cellulosic ethanol. This means that lignin may be used for more than its energy content and instead for potentially producing a whole range of chemicals. Processes under development are focusing on the conversion, firstly into intermediate or platform chemicals from which products such as speciality chemicals, commodity chemicals, resins, pesticides or herbicides may be derived. Research in this area is promising but confined largely to laboratories, hence there is little cost modelling available.

The production of non-energy related char products from wood via thermo-chemical conversion may be carried out independently or as a co-product in the generation of heat, power or liquid fuels. The use of char for filtering or as a metallurgical reductant is not new but may be of interest to traditional users as an environmentally friendly alternative to fossil fuel derived carbon.

The use of wood derived char as a soil additive to increase soil carbon content and potentially enhance crop yields is a relatively new concept. Additionally, this concept is being explored as an alternative means to sequester carbon for considerably longer periods than in natural biological cycles, without the risks associated with gaseous geo-sequestration. The use of agri-char is an area of growing interest, research and funding, but at this stage there is only sketchy evidence of agricultural benefits and no established market or commercially available plants. At present, there is no official recognition from regulatory bodies of char sequestering as a means of Greenhouse Gas reduction and consequently there are no incentives available.

Of lesser importance in this review, but worth noting are some novel engineered wood products emerging that may be practical alternative uses for some residues.

### 5.3 Case Study of Wood Residues from Generic Saw Mills

If we consider three different sized Australian mills, notionally hardwood, with kiln drying and across a range of typical sizes, the assumed residue types and quantities are laid out in Table 28. The next step would be to explore the specific characteristics of each mill; its location, neighbours, relevant community features, operation hours, energy demand, fuels and costs.

These figures relate to the amount of logs input into the mill. The logs may or may not be debarked on site, although hardwood mills tend to receive logs in a debarked state. From these figures and the amounts of waste streams produced mentioned earlier the following approximations were made:

**Table 29: Residues from generic sawmills**

	<b>Input</b> (tonnes wet)	<b>Bark <sup>a</sup></b> (tonnes wet)	<b>Sawdust</b> (tonnes wet)	<b>Shavings</b> (tonnes dry)	<b>Woodchips</b> (tonnes wet)
Mill A	100,000	6,000	7,000	5,000	35,000
Mill B	50,000	3,000	3,500	2,500	17,500
Mill C	20,000	1,200	1,400	1,000	7,000

<sup>a</sup> Hardwood sawmills in Australia usually receive de-barked logs, in which case there would be no bark residues

#### Mill C – Small mill

- Where there is an on-site, neighbouring or nearby community demand for heat and/or cooling, particularly if energy costs are high (for example remote areas), consider burning residues for heat value. Value may be generated in the form of steam, hot water, hot gases, hot oil, or cooled air and water via absorption chillers. New opportunities may arise over time as energy costs fluctuate and increase over time.
- If there were also a demand for and a high cost of electricity, consider a small scale CHP system. Electricity generation at this scale would suit using a boiler and steam engine or a combined gasification and IC engine. These plants are not likely to be economically viable from savings in electricity alone, but subsidies are available for new renewable generation capacity, generation from waste and for remote distributed generation (RRPGP).
- Otherwise consider briquetting fine residues (fine residues require minimal pre-treatment) and selling locally for domestic heating, as is done by the Whittlesea saw mill. The process equipment is relatively cheap and easy to operate. Fuel characteristics do not require tight control for the domestic market compared to pellets, which typically end up in large scale furnaces.
- Technology decisions will be dependent on mill operation hours, type of residue mix, quantity of residue and current market value of various waste streams.

#### Mill B – Medium mill

- As for Mill C, look for opportunities for on-site, neighbouring or nearby community demand for heat and/or cooling, particularly if energy costs are high.
- Look for opportunities to merge supplies with neighbouring sawmills or biomass residue producers (for example forest residues or thinnings, engineered wood product residues, demolition & construction residues, agricultural residues). CHP plant could become viable if sufficient compatible residue quantities can be gathered.

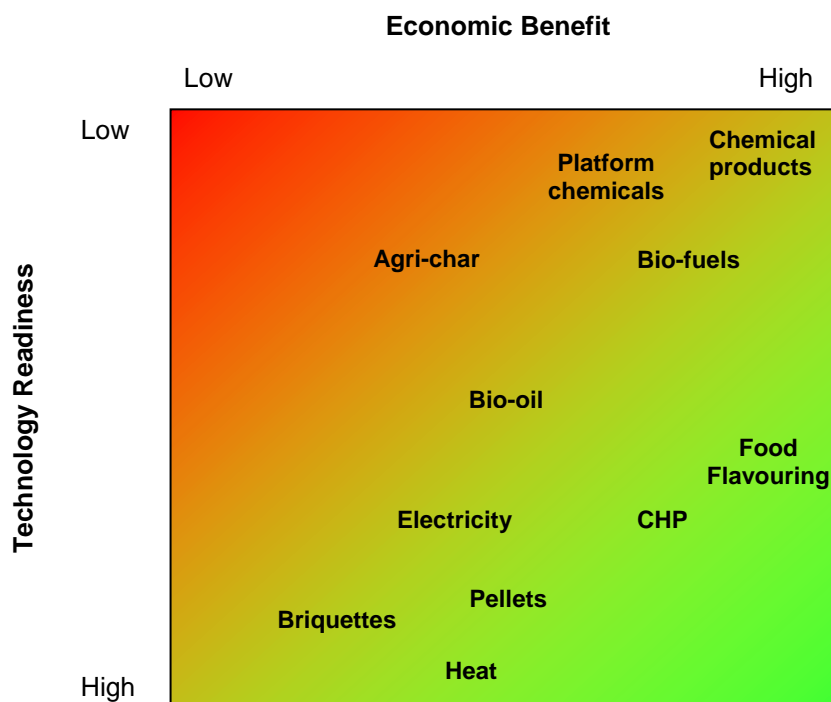
- Consider pelletising and marketing within Australia or exporting. A mobile pelletising plant could be shared between sites (with each site stockpiling) to share capital and operating know-how, quality control expertise and testing equipment. Exporting costs could also be shared.
- Look for a nearby use of wood fuel, such as co-firing utility boilers, lime kilns, and cement kilns. Viable transport distances may be reduced by pelletising.

#### Mill A – Large mill

- Look for opportunities for heating, cooling or CHP. At larger scales, efficiencies will be improved by using turbine technologies and heat recovery systems.
- As for Mill B, look for opportunities to merge supplies with neighbouring sawmills or biomass residue producers (for example forest residues or thinnings, engineered wood product residues, D&C residues, agricultural residues)
- Look for a nearby use of wood fuel, such as co-firing in utility boilers, lime kilns, cement kilns or bagasse furnaces. Viable transport distances may be reduced by pelletising.
- As for Mill B, consider pelletising and marketing within Australia or exporting. A mobile pelletising plant could be shared between sites (with each site stockpiling) to share capital and operating know-how, quality control expertise and testing equipment. Exporting costs could also be shared.
- Look for opportunities to combine residues to produce CHP – enabling more efficient technologies to be employed. Quantities above 150,000 green tonnes per year could become cost competitive with grid electricity and normal fuels for heating, however there are incentive schemes that could be applied for depending on specific circumstances.
- Consider bio-oil production. The technology has been commercialised by one or two Canadian companies, with subsequent conversion to electricity or industrial chemicals; there is a plant in planning in Darwin which will consume up to 200 tonnes per day of feedstock. Markets for bio-oil are not yet established but markets for derived products may be readily accessible.
- Monitor progress in second generation ethanol commercialisation.

## 5.4 Overall assessment

An overall assessment of the potential technologies for using sawmill residues has been given in Figure 27. In making this subjective judgement, the economic benefit of a product is intended to reflect the potential value of each product to a sawmill operator in Australia. In other words, it is a qualitative indication of the amount of value added to the residues. Technology readiness is intended to reflect the suitability of available expertise and equipment for generic Australian sawmills. Clearly, an option is more appealing if it is closer to the bottom right corner (green corner).



**Figure 27:** Qualitative assessment of economic benefit of each product versus technology readiness

There is a relatively large potential market for chemical products and they represent the highest value of all options reviewed, however they are the furthest from commercialisation. Platform chemicals will probably be commercialised before chemical products but are of marginally lower value.

Bio-fuels such as cellulosic ethanol, Fischer-Tropsch diesel or other Biomass-To-Liquid fuels offer relatively high value but are still largely in the research stage, with ethanol (arguably the most advanced) being an estimated 5 to 10 years from commercialisation. Bio-oil, situated in the middle of the figure, is an evolving technology with one or two commercial players. Bio-oil is a suitable product for a wide range of stationary heat and power applications; with additional processing the product can attain higher value as a transport fuel or chemical products. Industrial resins and food flavourings have been commercially manufactured from bio-oil.

Agri-char is of limited value and is hindered presently by a lack of hard evidence for soil enhancement; however, there is a potentially massive market if significant benefits in agriculture or carbon sequestration were proven.

Electricity produced from wood waste has moderate value in most parts of Australia and technologies for the efficient conversion of wood waste into electricity are limited at size ranges commensurate with typical residue quantities from Australian hardwood sawmills. Government incentives, such as RECs, can provide additional effective value for bio-electricity. Heat is also relatively inexpensive in most parts of Australia due to an abundance of natural gas, however heat can be derived from sawmill residue cheaply and efficiently, so

the benefit is considered moderate. If both heat and electricity are co-generated from sawmill residue, then overall conversion efficiencies are high (provided the mix of roughly 3:1 heat to electricity can be used gainfully) and the combined benefit is higher than each individually.

Briquettes in most parts of Australia are of limited value and there is a relatively small market, for residential heating, which competes with split firewood. As split firewood becomes scarcer, this product may increase in value and the market may grow. Pellets are more expensive to produce than briquettes however they are easier to transport in bulk and can be used in a wider range of applications. The domestic market is relatively small at present and is unlikely to grow; however, there is a large potential export market if economic shipping rates can be secured. Export to Europe requires that the pellets are manufactured and transported by “green” methods.

In the period since the first edition of this report was released certain macroeconomic conditions have changed that impact the appeal and viability of many of the options detailed in this report. Firstly, the value of the Australian dollar has increased relative to the US dollar and the Euro. This creates opportunities to procure new or used equipment for historically low Australian dollar prices.

Secondly, the boom in coal seam gas (shale gas in the US) exploitation has changed the energy mix.

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143. <http://www.nature.com/nature/journal/v165/n4200/abs/165694b0.html>
144. <http://www.freepatentsonline.com/20050166857.html>
145. [http://links.jstor.org/sici?sici=0317-0861\(199412\)20%3A4%3C400%3AIONRPO%3E2.0.CO%3B2-H](http://links.jstor.org/sici?sici=0317-0861(199412)20%3A4%3C400%3AIONRPO%3E2.0.CO%3B2-H)
146. <http://www.itto.or.jp/live/PageDisplayHandler?pageId=217&id=280>
147. <http://www.abs.gov.au/ausstats/abs@.nsf/94713ad445ff1425ca25682000192af2/4b7a31d84292bb3dca256b35007dc5c4!OpenDocument>
148. <http://www.fpl.fs.fed.us/documnts/fplrn/fplrn208.pdf>
149. [http://whatcom.wsu.edu/ag/compost/fundamentals/biology\\_aerobic.htm](http://whatcom.wsu.edu/ag/compost/fundamentals/biology_aerobic.htm)
150. [http://www.biofuelz.com/products/wood\\_pellets.php](http://www.biofuelz.com/products/wood_pellets.php)
151. <http://www.ciwmb.ca.gov/ConDemo/Wood/>
152. <http://www.palletenterprise.com/articledatabase/view.asp?articleID=2224>
153. <http://www.patentstorm.us/patents/6544649-description.html>
154. <http://www.seconference.org/pdf/Parrent-BiomassEnergy.pdf>
155. <http://www.madehow.com/Volume-4/Charcoal-Briquette.html>
156. <http://www.fao.org/docrep/s4550e/s4550e0c.htm#briquettes%20instead%20of%20fuelwood>

## APPENDIX I

Spilling estimates of equipment required for each mill.


Saw Mill	Wood Input (tonnes /year)	Wood Waste (tonne/hr)	Estimated Humidity	Estimated Steam Production (tonnes/hr)	Engine Type	Steam Pressure (boiler outlet, kPa)	Steam Temp (boiler outlet, °C)	Steam Pressure (engine inlet, kPa)	Steam Temp (engine inlet, °C)	Steam Pressure (engine outlet, kPa)	Steam Flow Rate (tonne /hr)	Electrical Output (kW)	Thermal Output (kW)	Price of Steam GenSet with Accessories (A\$)
A <sup>a</sup>	100,000	7.4	50%	18	6-cylinder, type 3/3H12	2600	270	2500	260	50	14	1170	8060	862,400
B	50,000	3.7	50%	9	4-Cylinder, type 2/2H12	2600	270	2500	260	50	9	760	5180	662,500
C	20,000	1.5	50%	3.5	2-Cylinder, type 1/1H12	2600	270	2500	260	50	3.5	300	1990	438,800

a. The maximum steam flow rate through the biggest Spilling steam engine, a 6-cylinder-type, is for the inlet and outlet pressures stated. In this case it would need to be decided either to limit it to that size or to use two 4-cylinder-engines or one 2-cylinder-engine and one 6-cylinder-engine or to use a steam turbine. With two engines (2 x 4-cylinder or 1 x 6-cylinder and 1 x 2cylinder) the total electrical output with 18 tonnes per hour of steam flow would be approximately 1520kW and the total thermal output approximately 10,350kW.


Note: These prices do not include engineering, documentation, packing, transport and commissioning.

## APPENDIX II

The following data sheets are intended to be an easy reference tool for sawmill operators to quickly assess the suitability of these options for their particular circumstances.

<h3>Wood Briquettes or Synthetic Logs</h3> <ul style="list-style-type: none"> <li>• <b>Lower energy density than liquid fuels and pellets, but higher than wood chips</b></li> <li>• <b>Much lower market value than pellets, but cheaper to produce</b></li> </ul>	
Typical plant capacity	Small to medium; that is up to 25,000 green tonnes per year of residue
Feedstock requirements	Dry (Moisture Content 6 - 16% w.b.) Saw dust (particle size 3mm or less), chips and bark are also possible but require size reduction
Equipment	Grinder - for size reduction depending on size of feed material Classifier - particle size sorting Drier - moisture content reduction (depending on feed material) Material handling – May include feed hopper and conveyors Briquette Press/Extruder - compacts loose and fine wood particles into a dense body through the application of high temperatures of approximately 300 to 350°C and moderate pressure
Total plant cost	Grinder \$50,000-\$150,000 Drier \$80,000-\$200,000 Briquette Extruder \$75,000-\$160,000
Services	Electricity
Operational cost	Depending on capacity of machine: Mechanical Press – requires 22kW for initial start up, then runs using a fly wheel Hydraulic Press – constantly requires 37kW
Operational issues	Can be fully automated Hydraulic oil change after first 1000hrs
Product	<ul style="list-style-type: none"> <li>• Artificial log with diameter from around 50 to 100mm and length 60 to 150mm</li> <li>• Used in domestic heaters</li> <li>• Additives can be combined with wood during pressing to provide aesthetic appeal of flames during burning</li> <li>• Break up very easily when handled</li> <li>• Can be carbonized to increase energy content and aid ignition</li> </ul> 
Market	There is only a very small market for wood briquettes in Australia Recommended to be sold to locals directly from the saw mill or through local retailers
Relevant incentive schemes (as of October 2012)	Low Carbon Australia (Federal) Cleaner Fuels Grant Scheme (Federal) Cleantech Partnering Program (SA) Strategic Waste Initiatives Schemes (WA)
Suppliers	<ol style="list-style-type: none"> <li>1. Woodfield Machinery – (03) 9899 8660</li> <li>2. Henan Jingxin Diamond Machinery - susan [shwpcd@263.net]</li> </ol>



<b>Wood Pellets</b>	
<b>A solid fuel energy product that is easy to convey, transport and combust.</b>	
<ul style="list-style-type: none"> <li>• <b>Pellets have higher bulk energy density than sawdust or woodchips but lower energy density than liquid bio-fuels</b></li> <li>• <b>Pelletising plant involves relatively high initial capital outlay</b></li> </ul>	
Typical plant capacity	Medium to large; that is typically greater than 25,000 tonnes per year of residues Very high pressures are used to compress the wood, making small scale plants less cost effective
Feedstock requirements	Dry (Moisture Content less than 7% w.b.) Saw dust (particle size 3mm or less), with minimal bark Dependent on market and compliance with relevant standards
Equipment	There are a variety of configurations depending on supplier. Generally includes: <ul style="list-style-type: none"> <li>• Size reduction – grinder or hammer mill</li> <li>• Drying – sometimes steam is used</li> <li>• Homogenisation/classifier – Blending and sorting for size, sometimes combined with drying</li> <li>• Press Rollers – high pressure and temperature (a starch binder may be required)</li> <li>• Cooling tower- may be needed</li> <li>• Materials handling – feed and product hopper</li> </ul>
Total plant cost	~\$1.5-2.5 million per tonne per hour (depending upon moisture content)
Services	Electricity Water (if steam drying is used)
Operational cost	\$120-160 per tonne including drying \$90-135 per tonne excluding drying
Operational issues	Regular change out of dies due to wear
Product	<p>Robust, dense Excessive handling makes them become dusty Must meet AS/NZS 4014.6:2007 European standards are more stringent, particularly in terms of calorific value, ash and other contaminants contents. EN 14961-2 A1 &amp;A2 Quality Assurance testing and certification probably required for export</p> 
Market	Very small market in Australia (no price data) Sold in Europe for \$100 to \$350 per tonne
Relevant incentive schemes (as of Oct 2012)	Low Carbon Australia (Federal) Cleaner Fuels Grant Scheme (Federal) Cleantech Partnering Program (SA) Strategic Waste Initiatives Schemes (WA)
Potential Suppliers	1. Andritz Pty. Ltd - <a href="http://www.andritz.com/ANONIDZ6E39CFC10C95C63D/index">http://www.andritz.com/ANONIDZ6E39CFC10C95C63D/index</a>

## Electricity generation – Steam turbine

**An established, robust technology suitable for medium to large scale base load electricity production. Smaller systems may be viable with equivalent Organic Rankine Cycle (ORC) technology, which in essence replaces steam with a lower boiling point organic fluid as the heat transfer medium.**

Typical capacity	<p>Steam turbine generation is only suitable above ~5MW<sub>e</sub> although marginal proposition below 10MW<sub>e</sub>. ORC system can be viable down to around 1MW<sub>e</sub>.</p> <p>Annual wood volume greater than about 60,000 dry tonnes per year, better above 100,000 dry tonnes per year.</p>
Feedstock requirements	<ul style="list-style-type: none"> <li>• Almost any feed with a positive net heating value is possible.</li> <li>• Dirty or high alkali content feedstocks (eg, bark, sweepings, etc) can increase boiler scaling, contribute to clinker formation, increase ash production and create undesirable emissions. Generally, this will add cost to the system.</li> <li>• Blend different residue streams to regulate composition and moisture content.</li> </ul>
Main Equipment	<p><b>Materials handling</b> Larger systems generally employ conveyors directly from mill or stockpile via surge bin into combustor. Smaller system may be fed by front end loader. Tramp metal removal is advisable.</p> <p><b>Pre-treatment</b> Dependant on furnace type and feedstock.</p> <p><b>Combustor</b> Wide range of furnace types and configurations. Stoker-grate is advisable, for balance of cost and function. Staged combustion systems generally give higher efficiency and lower emissions.</p> <p><b>Emission control</b> Baghouse filter probably required to reduce particulate emissions to &lt;100-250ppm (depending on location). Possibly scrubber or thermal oxidiser depending on fuel, combustor design and location.</p> <p><b>Boiler</b> Water tube boiler with superheater. Economiser used for air pre-heat. Consider condensing economiser to increase heat recovery by condensing steam entrained in flue gas.</p> <p><b>Turbine/genset</b> Condensing turbine for optimal efficiency.</p> <p><b>Water purification</b> Commonly Reverse Osmosis (RO) plant, required to remove dissolved minerals and salts. Purity depends on boiler pressure.</p> <p><b>Condenser</b> Usually part of condensing turbine unit unless backpressure turbine is used.</p> <p><b>De-aerator</b> Used to remove dissolved gas from water prior to feed into boiler, reducing pitting corrosion inside boiler.</p> <p><b>Cooling tower</b> Wet or dry. Wet towers will require water for evaporation. Dry towers are larger and require more parasitic power. Cooling pond is a possible alternative in certain circumstances.</p> <p><b>Pumps/fans</b> For water return and blowing air</p> <p>Grid interconnect (if required)</p>
Total plant cost	<p>\$5-6million per MW<sub>e</sub> of installed capacity for new plant.</p> <p>It is possible to trade off efficiency for cost to reduce CAPEX, for example by reducing steam pressure, however these CAPEX savings generally result in increased operational costs.</p>
Services	<p>Water for make-up in boiler (roughly 10% of steam flow rate);</p> <p>Fuel for start-up and peak load following through auxiliary burner;</p> <p>Chemicals for corrosion prevention in boiler;</p> <p>Grid connection with suitable level of excess capacity (if required).</p>

Operational costs	<p>Labour Personnel may be required as follows: Technicians to monitor plant operation, fuel supply, emissions, etc; Mechanical/electrical fitters for maintenance and boiler blowdown; Boilers operators (depending on size and type of boiler – attended/un-attended); Supervisory or QA personnel; shift operation depending on degree of automation and attendance required</p> <p>Feedstock Displacement cost for wood residue (lost revenue from other uses)</p> <p>Maintenance Rule of thumb 3% of CAPEX per year for mature technology. Can rise to 10% for less mature technologies</p> <p>Water Cost of water plus demineralisation</p> <p>Chemicals For corrosion prevention</p> <p>Ash disposal Dependant on feedstock (typically ~3%) to landfill</p> <p>Parasitic power Pumps, fans, conveyors, control systems</p>
Operational issues	<p>Requirements for boiler attendance by ticketed operator depends on state legislation, but usually varies according to size of boiler:</p> <ul style="list-style-type: none"> <li>• Small boilers (typically &lt;10MW<sub>th</sub>) - Unattended operation permitted</li> <li>• Medium boilers (typically 10-20MW<sub>th</sub>) - Limited Attendance required</li> <li>• Large boilers (typically &gt;20MW<sub>th</sub>) – Full Attendance required</li> </ul> <p>Boilers require regular blowdown to remove scaling from heat transfer surfaces to maintain efficient operation.</p>
Product	<p>Electrical conversion efficiency for a steam turbine system will be typically 15-25% (in size range up to 20MW<sub>e</sub>; generally efficiency increases with system size since parasitic losses become proportionally lower.</p> <p>Use of waste heat (eg, in absorption chiller or heat exchanger) can increase overall system energy efficiency.</p>
Revenue	<p>Ideally use to displace either grid procured electricity or a fossil fuel generator, to optimise economic benefit.</p> <p>Can be sold to grid – this will earn wholesale price, grid operators prefer base load and will require a supply agreement. Government assistance is available, particularly in remote areas to encourage distributed generation.</p>
Potentially relevant incentive schemes (as of Oct 2012)	<p>Federal Emerging Renewables Program (ERP) Clean Technology Investment Program Clean Energy Finance Corporation Low Carbon Australia Venture Capital Limited Partnership (VCLP) Early Stage Venture Capital Limited Partnership (ESVCLP) GreenPower</p> <p>SA Clever Green Eco Innovation Program</p> <p>TAS Tasmanian Government Innovation and Investment Fund (TGIIIF) Renewable Energy Loan Scheme (RELS)</p> <p>VIC Technology Voucher Program</p> <p>WA Strategic Waste Initiatives Schemes (SWIS)</p>
Potential Suppliers	<p>There are a large number of suppliers of biomass generation systems worldwide. Recent surveys have shown that many have little interest in supplying into Australia at present. Below is a potential supplier who is active in the Australian Market:</p> <ol style="list-style-type: none"> <li>1. <a href="#">RCR Tomlinson</a> (Sydney)</li> </ol>

## Electricity generation – Reciprocating Steam Engine

This is an established and robust technology that is good for small scale electricity generation, particularly with co-generation. Steam engines maintain relatively uniform efficiencies at high turn down and as such are well suited to variable demand applications.

Typical capacity	Technology most suitable at sizes less than a few MW <sub>e</sub> Or at an annual wood volume of less than ~50,000 dry tonnes per year
Feedstock requirements	Almost any feed with a positive net heating value is possible. Dirty or high alkali content feedstocks (eg, bark or sweepings) can increase boiler scaling, contribute to clinker formation, increase ash production and create undesirable emissions. Generally, this will add cost to the system
Main Equipment	<p>Materials handling For small quantities, consider simple front end loader feed via surge bin into combustor.</p> <p>Pre-treatment Trade-off between drying, size reduction and furnace/boiler cost. Simpler to dry within furnace by blending fuels to maintain average heating value. If climate permits and space is available, consider solar drying of green residues.</p> <p>Combustor Simple grate fired system to minimise cost. Travelling grate will increase fuel flexibility but add cost over stationary grate.</p> <p>Emission control Baghouse filter probably required to reduce particulate emissions to &lt;100-250ppm (depending on location). Possibly scrubber or thermal oxidiser depending on fuel, combustor design and location.</p> <p>Boiler Consider simple fire tube boiler for lower pressure systems to lower cost compared to water tube boiler. Slight degree of superheating of steam is best to prevent corrosion within engine. Consider economiser for water pre-heat from flue gases.</p> <p>Engine/genset Engines usually operate in backpressure mode since expansion to atmospheric pressure is costly. Ideal if steam at 1-2barg can be effectively utilised (consider use of steam accumulator to even out steam demand).</p> <p>Water purification Commonly Reverse Osmosis (RO) plant, required to remove dissolved minerals and salts. Purity depends on boiler pressure.</p> <p>Condenser Enables water to be pumped back into boiler. Not required if steam can be used and condensed as part of external process.</p> <p>De-aerator Used to remove dissolved gas from water prior to feed into boiler, reducing pitting corrosion inside boiler.</p> <p>Cooling tower Wet or dry. Wet towers will require water for evaporation. Dry towers are larger and require more parasitic power. Cooling pond is a possible alternative in certain circumstances.</p> <p>Pumps/fans For water return and blowing air</p> <p>Grid interconnect (if required)</p>



**Two 6-cylinder Spilling steam engines**

Total plant cost	Indicative costs for steam engine and generator system are included below, but do not include costs for combustor/boiler system.				
	<i>Approx. annual wood quantity (green tonnes/yr)</i>	<i>Engine type</i>	<i>Typical electrical /thermal output (MW<sub>e</sub> / MW<sub>th</sub>)</i>	<i>Steam flow rate (tonne/hr)</i>	<i>Indicative cost - engine/genset only</i>
	43,000	6-cylinder	1.6 / 10	14	\$862,400
	28,000	4-cylinder	0.8 / 5	9	\$662,500
	11,000	2-cylinder	0.3 / 2	3.5	\$438,800
Services	Water for make-up in boiler (roughly 10% of steam flow rate); Fuel for start-up and peak load following through auxiliary burner; Chemicals for corrosion prevention in boiler; Grid connection with suitable level of excess capacity (if required).				
Operational costs	Labour	Personnel may be required as follows: Technicians to monitor plant operation, fuel supply, emissions, etc; Mechanical/electrical fitters for maintenance and boiler blowdown.			
	Feedstock	Displacement cost for wood residue (lost revenue from other uses)			
	Maintenance	Rule of thumb 3.0% of CAPEX per year for mature technology. Can rise to 10% for less mature technologies			
	Water	Cost of water plus demineralisation			
	Chemicals	For corrosion prevention – less than steam turbine system			
	Ash disposal	Dependant on feedstock (typically ~3%) to landfill			
	Parasitic power	Pumps, fans, conveyors, control systems			
Operational issues	Small boilers can generally operate unattended, provided size is less than legislated threshold for unattended operation (typically 10MW <sub>th</sub> , but dependent on location). System can be made to operate automatically, provide fuel supply is maintained.				
Product	Electrical conversion efficiency for a steam engine system will be typically 10-15%, (operating in back-pressure mode). Good turn down efficiency results in good load following capability Use of heat will increase overall system energy efficiency.				
Revenue	Ideally use to displace either grid procured electricity or a fossil fuel generator, to optimise economic benefit. Can be sold to grid – will earn wholesale price, grid operators prefer base load and will require supply agreement. Government assistance available, particularly in remote areas to encourage distributed generation.				

Potentially relevant incentive schemes (as of Oct 2012)	Federal	Emerging Renewables Program (ERP) Clean Technology Investment Program Clean Energy Finance Corporation Low Carbon Australia Venture Capital Limited Partnership (VCLP) Early Stage Venture Capital Limited Partnership (ESVCLP) GreenPower
	SA	Clever Green Eco Innovation Program
	TAS	Tasmanian Government Innovation and Investment Fund (TGIIF) Renewable Energy Loan Scheme (RELS)
	VIC	Technology Voucher Program
	WA	Strategic Waste Initiatives Schemes (SWIS)
Potential Suppliers	Only one supplier of reasonably sized reciprocating steam engines has been identified – Spilling Engine Systems – who are based in Europe, USA and Asia. A spilling steam engine is used by Big River Timbers, NSW, to provide heat and power for their sawmill operations. <a href="http://www.spilling.de/uk/index-spillingwerk.htm">http://www.spilling.de/uk/index-spillingwerk.htm</a>	



## Electricity generation – Gasifier and IC engine

**Gasification systems coupled with IC engine/gensets are suitable for small scale electricity generation or cogeneration. These systems offer flexibility in terms of electrical (and thermal) load following. Availability is currently limited by reliable and verified gas clean-up systems.**

Typical capacity	Small scales, typically from 5kW <sub>e</sub> to 6MW <sub>e</sub> .
Feedstock requirements	<ul style="list-style-type: none"> <li>• Low moisture content fuels are best, typically less than 15% w.b. Higher moisture contents impact gasifier performance and reduce energy content of syngas, reducing conversion efficiency.</li> <li>• Size – Dependent on gasifier technology; typically uniform particle size is desirable for optimal gasification and to minimise particulate content in gas stream.</li> <li>• Composition – Dirty fuels will increase ash content and ash removal rate and may impact on gas clean-up equipment.</li> </ul>
Main Equipment	<p>Pre-treatment      Depends on furnace type and feedstock, may include size reduction and drying.</p> <p>Gasifier              Wide range of different furnace types and configurations. Small scale gasification is best suited to fixed bed rather than fluidised bed gasifier. Down-draft generally produces cleaner gas.</p> <p>Gas train             Gas must be cooled before combustion in engine to increase gas density then filtered and scrubbed for particulates and tars. Each engine manufacturer will have its own strict requirements on gas stream composition (impacting energy content) and contamination.</p> <p>Engine/genset      Essentially the same as a gas or diesel fuelled engine-genset.</p> <p>Grid interconnect (if required)</p>
Services	<p>Back-up fuel (eg, natural gas or LPG) possibly for start-up and dual fuel operation for demand following</p> <p>Grid connection (if required)</p>
Operational cost	<p>Labour                To maintain fuel supply, remove/dispose of ash and monitor gasifier and engine operation.</p> <p>Feedstock           Displacement cost for wood residue (lost revenue from other uses)</p> <p>Maintenance       Filters and scrubber maintenance heavily dependent on fuel used and gasifier characteristics. Usual engine/generator maintenance regime also required.</p> <p>Fuel                    For start-up and back-up supply</p>
Operational issues	<p>Main operational issue is cleaning gas and maintaining quality of gas entering engine. Gas train reliability testing is underway by many developers.</p>
Product	<ul style="list-style-type: none"> <li>• Electrical conversion efficiency is typically 5-15%. Generally efficiency increases with system size since parasitic losses become proportionally lower.</li> <li>• Syngas may be directly combusted to provide process heat as required. Engine has fast response time to fuel supply.</li> <li>• IC engine also has good load following ability, limited by gasifier response time unless dual fuel engine is used. Dual fuel may impact on incentive scheme eligibility.</li> <li>• Waste heat from engine exhaust can be extracted via heat exchangers.</li> </ul>
Market	<p>Ideally use to displace either grid procured electricity or fossil fuel generator, to realise maximum economic benefit.</p> <p>Can be sold to grid – will earn wholesale price, grid operators prefer base load and will require supply agreement</p>

Potentially relevant incentive schemes	Federal	Emerging Renewables Program (ERP) Clean Technology Investment Program Clean Energy Finance Corporation Low Carbon Australia Venture Capital Limited Partnership (VCLP) Early Stage Venture Capital Limited Partnership (ESVCLP) GreenPower
	SA	Clever Green Eco Innovation Program
	TAS	Tasmanian Government Innovation and Investment Fund (TGIIF) Renewable Energy Loan Scheme (RELS)
	VIC	Technology Voucher Program
	WA	Strategic Waste Initiatives Schemes (SWIS)
Potential Suppliers	<p>Suppliers in Australia are limited. The list below shows examples of Australian and overseas suppliers.</p> <ol style="list-style-type: none"> <li>1. Energen Solutions-Brisbane</li> <li>2. Community Power Corporation (<a href="http://www.gocpc.com">www.gocpc.com</a>) USA</li> <li>3. Zeropoint Clean Tech (<a href="http://www.zeropointcleantech.com">www.zeropointcleantech.com</a>) UK</li> <li>4. ANDRITZ (<a href="http://www.andritz.com/products-and-services">www.andritz.com/products-and-services</a>) Finland</li> </ol>	