Bioenergy in the Avon

SEDO Project No. P588

Study Report for AVONGRO

Enecon Pty Ltd
ABN 34 006 087 494

Suite 5, 651 Canterbury Rd (PO Box 175)
Surrey Hills, Victoria 3127, Australia
Tel: (61 3) 9895 1250
Fax: (61 3) 9895 1299

EPL Job no. 0606 –14th September 2007
Issued: Rev 1 – Issued to Avongro

Table of Contents

Acknowledgement:

Enecon Pty Ltd and Avongro Tree Cropping gratefully acknowledge the financial support provided for this study by the Sustainable Energy Development Office of Western Australia.

Disclaimer:

This report has been prepared by Enecon Pty Ltd, in association with Stephen Schuck and Associates Pty Ltd. Questions and comments are welcomed and should be directed to Colin Stucley at cstucley@enecon.com.au

The purpose of this report is to provide an overview of some of the options for energy generation using farm forestry in the Avon catchment in WA. While care has been taken in the preparation of the information in this document, the work undertaken is preliminary in nature and Enecon accepts no responsibility or liability for any loss or damage that may be incurred by any person acting in reliance on this information. Further, more detailed work is required before Avongro will be in a position to make any major investment decisions on bioenergy.

1. Executive Summary

1.1 ***Background***

Hundreds of thousands of hectares within the Avon catchment suffer from dryland salinity, a damaging phenomenon caused largely by localised waterlogging that brings salt to the surface. If nothing is done it is expected that the area damaged by salinity will keep increasing. Farms, public land, roads and country towns all face increased damage, at significant cost to the local communities and the state as a whole.

It is generally recognised that strategic tree planting will help to reduce water logging and thus prevent or minimise dryland salinity in susceptible areas. Hundreds of farmers in the region have planted trees across sections of their farms. However while the environmental benefits of such tree planting may take years or even decades to fully manifest, the planting itself and the use of land for trees represent real short term costs to farmers, and act as a disincentive to planting on a larger scale. The full environmental benefits of large-scale tree planting in the Avon catchment are not currently being realised.

For the planting that does occur, mallee eucalypts are the favoured tree. If planted in rows or alleys they provide water management and environmental benefits while still enabling other farming activities between the rows. Also, once established, these trees may be harvested regularly. The trees coppice and so new growth takes place from the stumps after each harvest. If commercial uses can be found for the harvested biomass it is felt that the scale of planting will increase significantly, with attendant increase in the environmental benefits that the trees provide.

Low rainfall across much of the Avon catchment contributes to low growth rates for trees. Coupled with long transport distances to ports, it is not commercially feasible for farmers to plant eucalypts for export wood chips such as occurs in the higher rainfall coastal regions of WA. New businesses are required to catalyse large-scale tree planting in the Avon and bioenergy is considered as a possible source of such new business. With the general acceptance of climate change and the use of renewable fuels as one method of reducing carbon emissions, bioenergy has received much greater support in recent years than previously. This study has been commissioned to review recent developments in bioenergy with a view to determining their applicability to the Avon catchment as a catalyst for large scale tree planting and new rural businesses.

The WA Sustainable Energy Development Office recently commissioned a general review of bioenergy technologies and it was not the intention of this study to repeat that work. Instead, this study has sought to examine technologies that offer immediate or near term opportunities for the Avon. Four technologies have been considered:

- Wood pellets - an immediate opportunity could exist and further development work is recommended
- Fast pyrolysis – now available commercially, but likely to be limited by markets in the short term
- Biomass to liquid fuels – not commercial scale yet, but expected to be so in the next five years

- Biomass to ethanol – has just received major funding support in the USA that means commercial scale plants are very likely in the next five years.

Further data on each technology, and implications for farmers, are summarised below and presented in more detail in the accompanying report.

1.2 Wood Pellets

If wood is ground to small particles and dried it may then be processed with readily available equipment to make wood pellets. Compared with the original wood these pellets have relatively high energy content, are easy to transport and store, and may be utilised for heat and power.

The use of pellets in Australia is limited. In Europe, however, pellet consumption is already significant for both domestic and industrial applications. European consumption is forecast to grow rapidly in coming years, particularly as a result of renewable energy legislation within the European Community. Japanese consumers use pellets for heating, and at least one Japanese power company is trialling large scale pellet use for renewable energy.

Pellet plants can be built at a wide range of sizes. Smaller plants will require less feed. Larger plants will generally offer economy of scale, but may also face greater costs for feed brought in from a larger growing area.

Preliminary modelling has been carried out to estimate the costs for production, transport and storage of pellets made in the Avon catchment and shipped to Europe. A pellet business appears to be quite profitable for a range of publicly quoted European pellet prices. However, pellet pricing in Europe varies significantly by country, and pricing within countries may vary significantly from year to year. So it is difficult to predict the actual pricing that would apply to pellets supplied from the Avon catchment.

Recommendation - Further analysis should be undertaken for a business to supply wood pellets into Europe. The immediate requirement is for additional product market analysis, and possibly direct discussions, to develop a reliable understanding of the pricing and duration of pellet supply agreements. Depending on the outcomes of this work, additional development of a processing plant can be undertaken, to match equipment to mallee feed and optimise the capital and operating costs.

1.3 Fast Pyrolysis

Fast pyrolysis is a process that converts woody material into a liquid called bio oil. Charcoal is also produced during pyrolysis. The process will work with any form of biomass provided it is first reduced to a suitable particle size and low moisture content.

The bio oil can compete with conventional fossil fuels in a number of situations. It can be used to generate heat and power. Chemical extraction is already carried out for niche markets in the USA. Research is underway for other chemical applications and also for the use of the bio oil in slow speed diesel engines. Bio oil cannot yet be used commercially in road transport applications

Pyrolysis technology is used commercially in a limited number of plants in Canada and the USA. While bioenergy applications may offer larger markets in the longer term, current markets for the oil are primarily for local chemical production; markets that are not duplicated in Australia.

The North American pyrolysis plants typically require around 100,000 tonnes or less of green biomass feed each year. As farm forestry develops over coming years in the Avon catchment this would appear to be a more achievable feed target than the hundred of thousands of tonnes required for BtL or ethanol plants described later in this report.

Short term applications for wood pyrolysis in the Avon appear limited by lack of suitable markets for the products. With further research over the next few years into product applications and high value chemicals it is possible that commercial opportunities will develop. This research will be initiated and undertaken by pyrolysis technology providers and a number of universities that are already engaged in fundamental investigations of pyrolysis.

Recommendation – The commercial operations established overseas, together with the work being undertaken on new markets and opportunities, mean that pyrolysis may offer a business opportunity in the Avon catchment in the next few years. It is recommended that Avongro maintain a watching brief on these developments.

1.4 Biomass to Liquids

Biomass to Liquid (BtL) fuels are at the advanced research to early commercialisation stage of development. BtL involves the gasification of biomass into simple molecules of mainly hydrogen and carbon monoxide (called “syngas”), followed by a synthesis step to produce a range of alternative fuels, most notably methanol, dimethyl ether, and synthetic diesel.

The most commercially advanced work is being undertaken by Choren in Germany. A large scale BtL synthetic diesel plant is currently under construction, and this is expected to be followed by construction of the first commercial scale plant (sized to use one million tonnes dry biomass per year as feed supply) in Germany towards the end of this decade.

The core technologies for BtL are established, but they require integration and optimisation for application with biomass, such as mallee trees. Cost would currently be more expensive than conventional liquid transport fuels, but with further technology development and suitable feedstock price and availability, BtL is a good prospect for the future, probably within a decade. A particular attraction of this technology for WA is the ability to use the produce synthetic diesel that may be integrated into the existing liquid fuels market in WA with minimal disruption.

Recommendations:

- For the next few years, maintain a watching brief over Choren’s progress.
- The mallee industry needs to determine how it could develop and supply biomass at rates of one million tonnes per year.
- A related issue is the characteristics of mallee as a fuel for Choren’s BtL process. Tests could be arranged at Choren’s R&D facilities in Germany. However these tests should not be pursued until the mallee industry has a clear strategy for fuel supply at the quantities

required and a better indication that a BtL industry in WA will be commercially viable. The latter point will depend in part on long term legislation for renewable transport fuels in Australia (remembering that policy and legislation supporting the commercial application of this technology in Europe may be quite different to policy and legislation in Australia).

1.5 Biomass to Ethanol

It is technically feasible to make ethanol from biomass. Wood contains significant quantities of sugar that may be converted to ethanol, provided these sugars are first "released" from the wood and made available for fermentation. It is also possible to break the wood into small molecules ("syngas") via gasification, then rebuild those molecules into ethanol via chemical synthesis.

These different technologies have been broadly understood for many years but have never moved past the pilot or demonstration stage. This may change over the next few years, as earlier in 2007 the US government announced significant funding support for six commercial-scale biomass to ethanol plants to be built in the USA. The total investment on these projects over the next five years could exceed A$1 billion. In less than ten years it should be possible to engage with companies offering proven biomass to ethanol technology for the construction and operation of biomass to ethanol plants in the Avon catchment.

In addition to reliable, competitive technology, any biomass to ethanol plants in the Avon need reliable, competitive feed and markets. A full scale biomass to ethanol plant is expected to use more than half a million tonnes of green biomass each year. Ethanol may be used as a blend with petrol in WA. However the market for such blends may be fully met by grain to ethanol plants before any biomass to ethanol plants are operational. Therefore the ethanol produced may need to be transported to markets outside WA.

Recommendations:

- For the next few years, maintain a watching brief over progress, especially in the USA.
- The mallee industry needs to determine how it could develop and supply biomass at rates of at least half a million tonnes per year.
- Progress on biomass to ethanol should be compared against progress with BtL, as the latter appears to offer a fuel that is more easily integrated into the WA markets for liquid fuels.

1.6 Implications for Growers

Recent developments overseas have significantly enhanced the prospects for a major bioenergy industry to be developed progressively in the Avon catchment:

- The European Community is pro-actively seeking increased use of renewable energy, which has created major markets for biomass pellets.

- Technical, legislative and funding developments in the US, Canada and Europe mean there is a real likelihood that several processes to make liquid fuels from biomass will be commercially demonstrated in the next five years.

Two of the technologies reviewed (pellets and pyrolysis) are commercially available now. One of those (pellets) also has large, well established product markets and may offer an immediate opportunity for mallee growers.

The remaining two technologies (ethanol and synthetic diesel) have clear, well-funded and managed pathways to the first commercial plants.

Pellet plants and fast pyrolysis plants both need biomass at 100,000 tonnes per year or less (green basis). In contrast, each commercial scale plant for ethanol or synthetic diesel next decade will require at least 500,000 tonnes and possibly more than one million tonnes of biomass per year.

For all of these technologies it will be possible to engage with experienced equipment suppliers or technology providers. For the pellet plants it is not clear whether third parties exist that will take on a funding and operation role for the plants. For all other technologies, the technology developers or licensors identified in this study are also engaged in funding and operational aspects of their businesses.

The scale of tree planting possible in the Avon catchment is enough to support multiple new bioenergy businesses over time. Sufficient land could be available to enable biomass production to reach several million tonnes per year[1]. If planting is carried out with due regard for hydrology, ongoing farm operations and other factors, these levels of planting will also achieve environmental benefits across hundreds of thousands of hectares.

It remains to be seen how the farm forestry industry will develop and engage with the biomass processors to develop this opportunity. Significant short term issues include:

- The lack of reliable pricing for delivered mallee biomass to enable potential processors to undertake detailed studies of the viability of new businesses.

- The lack of a harvester for mallee trees, which have a unique set of harvesting requirements not fully addressed by existing equipment. Until a harvest and transport system is designed and tested, growers are unable to provide reliable supply pricing to processors.

- Targeted planting close to proposed processing sites, and thus capable of lower cost delivery than similar levels of plantings right across the wheat belt.

- The extent to which carbon trading or other mechanisms may provide the funds to allow farmers to establish commercial quantities of trees, with regional planting rates at orders of magnitude greater than what has occurred to date.

If these short term issues are addressed and the multiple benefits of tree planting in the Avon catchment are coupled with bioenergy, the result will be a unique “win-win” opportunity for Western Australia.

---

[1] The recent bioenergy report by SEDO notes that one hectare planted to mallee could yield 12.5 green tonnes per year (this will vary from location to location with rainfall, soil type and other factors). For the whole Avon catchment, planting trees on 10% of cleared land could achieve biomass yields of 9.25 million green tonnes per year.

2. Selection of Case Studies

2.1 Summary

Opportunities for electricity generation in the Avon catchment are limited by the need to compete with cheap fossil-fuel alternatives and by lack of infrastructure to support any large scale distributed power generation.

Co-production of electricity and value-added products can improve the commercial viability of new businesses. The Integrated Wood Processing (IWP) technology being commercialised by Verve Energy falls into such a category. IWP is already the subject of a separate commercialisation strategy and so is not considered here

Bringing a technology from the initial research stage to commercial scale typically requires many millions of dollars and years of work. So to identify near term opportunities for the Avon catchment this study has focused on technologies that are either commercial already or have a well funded and managed program to achieve commercial scale and operating businesses over the next five years. The following technologies have been considered:

- Wood pellets, for export to Europe or Japan
- Fast pyrolysis, to manufacture liquid fuel, charcoal and, potentially, higher value chemicals
- Biomass to liquid fuels, via gasification and catalytic reforming, particularly to make synthetic diesel fuel
- Biomass to ethanol via several different pathways, as is the subject of considerable work in the USA over the next few years.

2.2 Electricity Generation

(a) Large Scale

The majority of the modern bioenergy industry around the world is based on power generation. In many cases in this is combined with heat production: or combined heat and power ("CHP"). Examples include power and heat at Australian sugar mills and biomass-fired power stations in the USA and Europe. The technology is mature. The markets for electricity are substantial. But the commercial viability of these plants depends upon the cost of feed and the price paid for power and heat:

- In Europe the electricity is valued more highly than in Australia (they do not have coal or gas at the same low Australian costs)
- In Europe there may also be a value gained for sale of heat (typically as district heating) in CHP systems
- In the USA wood feed is often wood waste from cities or large wood processing operations, with negative value

- In Australia the sugar industry has sugar cane fibre (bagasse) as feed that would probably incur a disposal cost if it was not burnt. Its combustion generates revenue from both heat and power.
- In most cases economy of scale is achieved with plants that generate tens of MW.

Unfortunately the same opportunities do not exist for bioenergy in the Avon catchment:

- At most parts of the catchment the local grid could not accommodate more than a few MW of electricity.
- The basic cost of electricity generation (as opposed to the retail cost to domestic consumers) is generally lower than in Europe.
- The incentives available for renewable energy are less than those in Europe.
- There is little or no opportunity to sell significant quantities of heat on a long-term basis.

This difficulty of achieving competitive stand-alone electricity production in rural Australia is part of the reason that Verve is seeking to develop Integrated Wood Processing, as has recently been demonstrated at Narrogin. The additional revenues from activated carbon and eucalyptus oil improve the overall economics of the IWP plant.

(b) Small Scale

It is technically feasible to generate electricity at a small scale. Equipment is commercially available to produce as little as several kilowatts from biomass. This equipment may be small steam cycle engines[2] or gasification equipment[3,4]. Such equipment may be suitable for off grid applications where the alternative cost of grid connection or diesel generation justifies the bioenergy plant. Commercial viability of each project will be very site specific and will depend in particular on:

- alternative costs of power (particularly in off-grid use)
- whether the power is needed continuously or intermittently
- whether the full cost of labour (feed supply, feed size reduction, feed drying, plant operation, plant maintenance etc) is factored into the project.

Such small scale power projects may use from just a few tonnes of wood per year to more than 100 tonnes per year and may be useful for demonstration value. The requirements for wood feed preparation must be taken into account. Gasifiers typically require feed as chunks or chips, with fine material and oversized material removed. Feed must usually be dried to less than 20% moisture before use.

Small, grid connected equipment is also available, for example to generate 1 or 2 MW and sell power into the grid. Unfortunately such bioenergy plants are very capital intensive. To operate effectively the core equipment (gasification or combustion) needs feed preparation

---

[2] http://www.strathsteam.com
[3] http://www.martezo.fr/indexa.html
[4] http://www.gasificationaustralia.com

and storage systems, grid connections, control systems and site works. The total installed project cost may be 2 or 3 times the cost of purchase of the core bioenergy equipment.

Because of the high capital cost per unit of electricity produced the equipment should be operated at capacity 24 hours per day to seek the maximum electrical output and return on investment. Plants of this size may be competitive against continuous power generation from diesel gensets. However, current grid prices for electricity in the wheat belt, particularly at night or weekends, are simply not high enough to provide a commercial return on such bioenergy plants.

2.3 Selection of Case Studies

(a) Research versus Commercial

There is interesting and useful research underway around the world to develop new bioenergy technologies and to make improvements to existing technologies. However, when considering bioenergy business opportunities possible in the next few years, it is important to be aware of the typical pathway from research work to commercial operation. By the time they reach commercial scale it is quite common for bioenergy technologies to operate at more than 1,000 times the scale that was first developed in the laboratory. A typical "scale up" sequence can include the study, design, funding, construction, operation and review of:

- Bench scale plant in the laboratory and used for small trial runs
- Larger plant in laboratory working continuously
- Pilot plant adjacent to the laboratory
- Demonstration scale plant
- First commercial plant
- Second commercial plant, which incorporates lessons learned from the first commercial scale plant.

It is quite common for this sequence to take ten years or longer.

Following commissioning of the first or second commercial plant, the technology owner or licensor should be ready to move into new markets for the technology and provide the levels of guarantee and risk mitigation required to raise funds for new projects on a competitive basis. This process takes considerable time and can be very expensive. For example, by the time the first commercial scale biomass to ethanol plants begin operation in the USA (targeted by 2011) the overall investment on biomass to ethanol world wide will be well in excess of $1 billion, or several times the cost of a full scale plant.

This study has sought to examine opportunities for the Avon catchment that will be commercially viable now or in the near term. For this reason there as been no consideration of technologies that are not at commercial scale or have a demonstrable path to that scale over the next five years.

(b) Project Partners

Availability of suitable technology is one major component of a successful new bioenergy business. There is also a need for organisations to arrange funding for the processing plant(s), to build, own and operate the plant(s), and to sell the product(s). Projects will have a greater chance of success if organisations proficient in these activities are available to collaborate with feed suppliers. The more sophisticated and costly the technology, the more important it is that such organisations are part of the project. Examples of such organisations include the following:

- Verve Energy - developers of the Integrated Wood Processing plant at Narrogin
- Australian Renewable Fuels – developers of biodiesel plants
- Babcock & Brown – developers of bioenergy projects
- Renewable Oil Corporation – seeking to develop commercial wood pyrolysis projects.

(c) Case Studies Selected

This study initially sought bioenergy opportunities that satisfy the following criteria:

- Commercially proven technology
- Equipment suppliers or project partners available
- Existing markets for products
- Commercial viability.

Bioenergy for electricity was not considered, for the reasons outlined above. The Verve Energy Integrated Wood Processing business was not considered as it is already under development by Verve.

A number of other bioenergy technologies are considered in the following sections. The case for wood pellets is presented first. Pellets have readily available, well-proven technology and large, growing product markets.

No other bioenergy technology/business offered the same degree of maturity as pellets. It was agreed to provide a case study for pellets and an overview of several other technologies that are either commercial now or are near commercial and with a clear pathway to commercial operation.

Fast pyrolysis is presented as the first of these other technologies. Commercial pyrolysis plants are already in operation overseas but not yet in Australia. A wood pellet plant or fast pyrolysis plant would use quantities of mallee feed that are similar to current plantings.

Biomass to other liquid fuels (BtL) and biomass to ethanol are also presented. Neither technology is commercial at present. However current developments in the USA (for ethanol) and Europe (for BtL) suggest that the first commercial scale plants will be operational in those regions within five years. Both technologies require biomass feed supply on a much larger scale that that required for pellets or pyrolysis.

3. Potential Biomass Supply

This study has been commissioned to examine new bioenergy businesses that may support large-scale tree planting in the Avon catchment. The tree planting is proposed:

- to provide environmental benefits on farms, principally to protect farmland and the surrounding region from water logging and the salinity that this water logging causes.
- as a commercial venture for the farmers involved. Planting large quantities of coppicing mallee eucalypts is viewed as a valuable diversification for farmers if it can provide a commercially attractive alternative to grain or sheep. Such commercial viability may also catalyse tree planting at a larger scale than what will be achieved for environmental works alone. This planting can take place alongside other farming operations.

Considerable work has been undertaken over many years to understand the use of mallee eucalypts and other tree species on farmland in the WA wheat belt as a preventative measure against dryland salinity. Mallees have received particular attention for new farm forestry applications, in part because of the potential for commercial scale plantings driven by the extraction and sale of the eucalyptus oil in the mallee leaves. Eucalyptus oil extraction may occur as part of any bioenergy project involving mallees. However other tree species could also be acceptable for bioenergy applications.

The prevailing situation and work to date are well summarised in the following paragraphs[5]. The authors thank John Bartle of the Western Australian Department of Conservation and Environment (DEC) for permission to use this extract:

"There are strong societal drivers for increasing the proportion of perennial plants in dryland farming systems in the south west of Australia. A substantially increased perennial component in the landscape could retard the process of secondary salinisation; thereby helping to protect the agricultural land resource, remnant biodiversity and town and transport infrastructure. Diversification into new perennial crops could also make farming businesses more robust in the face of climate change and the long-term trend of declining terms of trade for conventional food production. However, the inclusion of perennial species into farming systems remains a challenge. To make a meaningful impact on landscape sustainability, a sizable component of existing annual crop and pasture systems will need to be displaced by perennials. Existing perennial crop options are constrained by low profitability and complexities associated with their integration into existing land use (Lefroy et al. 2005[6]; Pannell et al. 2006[7]). Therefore, existing options need to be improved or new perennial crop options need to be developed.

---

[5] Huxtable et al (2007) 'Factors affecting the economic performance of mallee production systems; CRC for Plant Based Management of Dryland Salinity Workshop: Capacity of integrated production systems to use water and mitigate dryland salinity.'

[6] Lefroy, E.C., Flugge, F., Avery, A., Hume, I. (2005). Potential of current perennial plant based farming systems to deliver salinity management outcomes and improve prospects for native biodiversity: a review, *Australian Journal of Experimental Agriculture* 45, 1357-1367.

[7] Pannell D, Marshall B, Barr N, Curtis A, Vanclay F and Wilkinson R (2006) Understanding and promoting adoption of conservation practices by rural landholders, Australian Journal of Experimental Agriculture 46(11) 1407 – 1424.

Mallee eucalypts have been proposed as an alternative crop plant for the production of bulk industrial products such as reconstituted wood products and bioenergy (Bartle and Shea, 2002[8]). Eucalyptus oil is an additional product, which is currently used for low volume specialty uses but with potential for large-scale industrial use (Coppin, 2002[9]). Several mallee species endemic to the south-western agricultural region have been identified as having good potential for domestication. A key advantage of mallee is its strong coppicing ability, allowing harvesting on a 3-5 year cycle indefinitely. Mallee is also quite resistant to grazing by sheep, enabling it to be dispersed amongst annual crops and pastures with relatively minor modifications to farm management. The major disadvantage of integrated belts of trees is the potential to create a substantial zone of suppressed crop and pasture yields adjacent to the trees, due to lateral tree roots competing for soil moisture (Sudmeyer et al. 2002[10]).

Western Australian farmers have recognised the potential for mallees to improve landscape sustainability and provide enterprise diversification. Although markets for mallee biomass are largely undeveloped, some 20 per cent of wheat belt farmers (~1000 farmers) have planted in aggregate more than 12,000 ha of mallee; most of which is configured in narrow belts within cropping and grazing paddocks. The uptake of mallee to date has been motivated largely by the provision of environmental services, such as erosion control and recharge reduction. However, the promise of an emergent industry has also been important.

Industry development will require the synchronisation of products derived from mallee and their receiving markets, to accommodate potentially large volumes of biomass. Given this rationale, bulk commodity markets must be targeted which have a low risk of being oversupplied (Cooper et al. 2005[11]). To be economically competitive, it is likely that mallee will need to generate multiple products from different plant components (Bartle et al. 2002[12]). Additional "product value" could be afforded by the valuation of environmental services, such as carbon sequestration and the protection of biodiversity. Maximising the return from each biomass component will be made more efficient through integrated processing technologies, sometimes referred to as the biorefinery concept (Bartle et al. 2007[13]; Ragauskas, 2006[14])."

[8] Bartle J, Shea S (2002) 'Development of mallee as a large-scale crop for the wheat belt of WA.' In 'Australian Forest Growers 2002 National Conference: Private Forestry - Sustainable accountable and profitable'. Albany, WA, Australia pp. 243-250.

[9] Coppen J.J.W (2002) Production, trade and markets for Eucalyptus oils, in Eucalyptus – The genus Eucalyptus (ed. JJW Coppen), pp 183-201 (Taylor and Francis: London).

[10] Sudmeyer R, Hall D, Eastham J and Adams M (2002) The tree–crop interface: the effects of root pruning in south-western Australia, Australian Journal of Experimental Agriculture 42(6) 763 - 772

[11] Cooper D, Olsen G and Bartle J (2005) 'Capture of agricultural surplus water determines the productivity and scale of new low-rainfall woody crop industries.' Australian Journal of Experimental Agriculture 45, 1369-1388

[12] Bartle J, Shea S (2002) 'Development of mallee as a large-scale crop for the wheat belt of WA.' In 'Australian Forest Growers 2002 National Conference: Private Forestry - Sustainable accountable and profitable'. Albany, WA, Australia pp. 243-250

[13] Bartle J, Olsen G, Cooper D, Hobbs T (2007) 'Scale of biomass production from new woody crops for salinity control in dryland agriculture in Australia'. International Journal of Global Energy issues in press.

[14] Ragauskas A.J, Williams C.K, Davison B.H, Britovsek G, Caimey J, Eckert C.A, Frederick W.J, Hallet J.P, Leak D.J, Liotta C.L, Mieleaz J.R, Murphy R, Templer R, Tschaplinski T (2006) The path forward for biofuels and biomaterials, Science, 311: 484-489

4. Wood Pellets

4.1 Summary

If wood is ground to small particles and dried it may then be processed with readily available equipment to make wood pellets. Compared with the original wood these pellets have relatively high energy content, and are easy to transport, store and utilise for heat and power.

The use of pellets in Australia is limited. In Europe, however, pellet consumption is already significant for both domestic and industrial applications. European consumption is forecast to grow rapidly in coming years, particularly as a result of renewable energy legislation within the European Community. Japanese consumers use pellets for heating, and at least one Japanese power company is trialling large scale pellet use for renewable energy.

Pellet plants can be built at a wide range of sizes. Smaller plants will require less feed. Larger plants will generally offer economy of scale, but may also face greater costs for feed brought in from a larger growing area.

Preliminary modelling has been carried out to estimate the costs for production, transport and storage of pellets made in the Avon catchment and shipped to Europe. A pellet business appears to be quite profitable for a range of publicly quoted European pellet prices. However, pellet pricing in Europe varies significantly by country, and pricing within countries may vary significantly from year to year. So it is difficult to predict the actual pricing that would apply to pellets supplied from the Avon catchment.

Particular emphasis has been given to a pellet business opportunity in this study because of its potential for short term commercial exploitation. It is recommended that further analysis be undertaken for a business to supply wood pellets into Europe. The immediate requirement is for additional product market analysis, and possibly direct discussions, to develop a reliable understanding of the pricing and duration of pellet supply agreements. Depending on the outcomes of this work, additional development of a processing plant can be undertaken, to match equipment to mallee feed and optimise the capital and operating costs.

4.2 Wood Pellet Markets

(a) Overview

Over the past decade wood (and other biomass) energy pellets have filled a minor niche in North American and European energy markets, mainly in the domestic heating sector. However in recent times wood pellets have become an increasingly important energy source for both the domestic and industrial energy sectors, mainly as a result of increased emphasis on renewable energy sources. This is expected to increase further as a result of policy initiatives by various governments, particularly in Europe. The European Union's Biomass Action Plan for its 25 country members has an ambitious plan between 2003 and 2010, to increase:

- Bio-electricity from 20 million tonnes oil equivalent (Mtoe) to 55 Mtoe
- Heat supplied by biomass from 48 to 75 Mtoe

- Liquid biofuels from 1 to 19 Mtoe.

This is illustrated in Figure 4-1 below.

Wood Pellets - are short cylindrical pieces of biomass with a diameter 6-8 mm and are produced from sawdust, cutter shavings, chips or bark by grinding the raw material to a fine powder that is pressed through a perforated matrix or die. The friction of the process provides enough heat to soften the lignin in the wood. During the subsequent cooling, the lignin stiffens and binds the material together. The manufacturing process increases the bulk density of the feedstock from typically 100 to 650 kg/m^3. The energy content of pellets is approximately 17.5 GJ/tonne with moisture content of 8-10 percent.

(1 Mtoe is equivalent to 42 GJ of energy. 1 million tonnes of pellets are equivalent to 17.5 GJ; so 1 Mtoe is equivalent to 2.4 million tonnes of pellets. Thus the proposed increased use of biomass for heating, if all achieved by pellets, would equate to a pellet usage of (75-48) x 2.4 = 65 million tonnes per year.)

At present energy from biomass contributes approximately 4 percent of the total EU energy supply, predominantly in heat and, to a lesser extent, in combined heat and power (CHP) applications. By 2010, biomass is expected to account for as much as 8 percent of the total EU energy supply.

This target underpins the European Energy White Paper (COM-1997-599) to double the EU's renewable energy sources from 6 to 12 percent of gross energy consumption, and is also an element of the plan for the EU countries to meet their overall European Kyoto Protocol target. Use of biomass has been encouraged in several European countries through the introduction of domestic carbon taxes and grants for low carbon fuels.

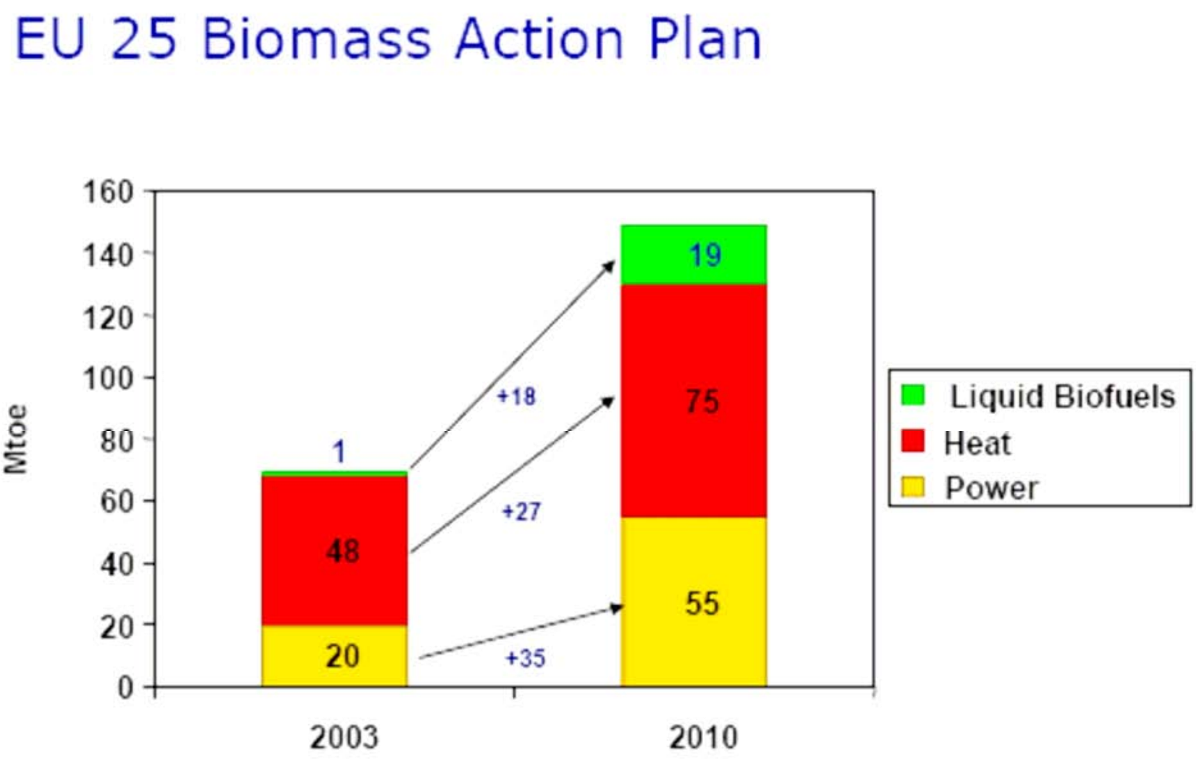


Figure 4-1: European Biomass Action Plan

Wood pellets have become much more widely used than many other forms of biomass for several reasons:

1. High energy content
2. Low ash content
3. Ease of handling, storage and transport.

Bulk density - Solid biomass fuels are generally characterised by a lower bulk density (kg per cubic metre) and lower energy density (GJ per tonne), compared to coal. Solid biomass fuels often have relatively high moisture content, requiring specific designs for their combustion. One of the ways of making biomass a more attractive fuel is to simultaneously address these two relative disadvantages by densifying the biomass (at a cost) and by lowering the operational moisture content through, for instance, pelletising or briquetting the biomass.

Table 4-1 illustrates the bulk densities of some typical forms of wood biomass on a dry, ash free basis, to illustrate the much higher density of pellets compared with wood chips, sawdust and planer shavings.

Table 4-1: Typical Wood Biomass Types and Their Densities

Wood Type	Bulk Density (kg/m3 daf)

Hardwood chips	227
Softwood chips	179-192
Pellets	556-625
Sawdust	161
Planer Shavings	97

As can be seen from Table 4-1, the bulk density of wood pellets is considerably higher than other forms of biomass from the same source.

Moisture content - In practice the moisture content of fresh wood chips, a common form of wood fuel, is generally in the range of 45-55 percent, giving an operational calorific value of the fuel in the range of 7 - 9 GJ/tonne. Wood pellets have moisture content in the range of 8-10 percent, giving a typical heating value of 17-18 GJ/tonne. Their uniform size, high density and low moisture content make wood pellets a versatile and reliable fuel. Wood pellets are easily conveyed by pneumatic means into bulk storage at domestic or industrial users. Alternatively, pellets can be purchased at the retail level from supermarkets in Europe and North America.

Figure 4-2 shows a typical bulk wood pellet tanker being loaded at the pellet factory.

Figure 4-2: Bulk Wood Pellet Tanker in Sweden

The two main established markets for wood pellets are the domestic heating market and, more recently, the use of wood pellets as an industrial fuel.

(b) Domestic Sector Market

This market mainly relates to wood pellet heaters for space heating and to small-scale boilers for water heating. Figure 4-3 shows a typical wood pellet stove in which the wood pellets are burned in a crucible, charged automatically via a computer controlled auger. These stoves are extremely efficient (typically 96 percent) compared to open log fires. In the northern hemisphere, a prime application of wood pellet heaters is to replace oil burning and gas heaters.

Figure 4-3: Typical Wood Pellet Stove

At a larger scale, wood pellets are now commonly used in several countries for district heating. Figure 4-4 shows a medium sized district heating plant in central Sweden fuelled by wood pellets. Shown are two pellet silos and the adjacent boiler housing.

Figure 4-4: Wood Pellet Fuelled Central Heating Plant in Sweden

(c) Industrial Fuel Market

A recent trend in some parts of the world is to use multifuel combustion plants, including use of biomass fuels. A prime example is the Avedore 2 Combined Heat and Power (CHP) plant located a few kilometres outside Copenhagen in Denmark. The output of this large CHP plant is 570 MW_e and 570 MW_{th} or, if operated in electricity only mode, 590 MW_e. This is the same scale as Australia's largest coal fired power station units. The plant has a multifuel capability, using both solid biofuels and natural gas. The main biomass fuel is wood pellets, which can provide up to 70 percent of the total input energy of the main boiler. The pellets are produced at nearby Køge in a large mill consisting of 18 pellet presses. On a yearly basis Avedore 2 consumes 150,000 tonnes of straw and 300,000 tonnes of wood pellets. The pellets are transported to the power plant by barge.

Figure 4-5 shows the Avedore 2 unit to the rear of the number 1 unit, which is coal fired.

Figure 4-5: Avedore 2 Combined Heat and Power Plant

Another example of such large scale industrial use of wood pellets is at the Les Awirs Power Station in Belgium, where a 125 MW coal fired power station unit has been converted to be fuelled exclusively on imported wood pellets. In modifying the plant, its capacity has been derated to 80 MW_e to cater for the altered fuel. The feedstock originates from all parts of the world, with wood pellets being delivered in a 'just in time' mode of operation by flat boats from the port of Antwerp and also by road. The plant consumes 350,000 tonnes of wood pellets annually, or approximately 1,000 tonnes per day. These pellets are reduced on site to wood dust which fires the power plant. The utility has a stringent wood pellet certification scheme to certify the origin of the biomass, to ensure it is from ecologically sustainable sources. Another Belgian plant, the Rodenhuize Power Station similarly mills and uses wood pellets to produce 80 MW electricity.

(d) Production Capacities

Europe - The Swedish based Bioenergy International magazine conducted a survey of the wood pellet industry in Europe in early 2007 and registered 286 pellet producers across Europe with plant capacities greater than 5,000 tonnes per year.

Germany is reported to have 35 manufacturers of pellets, with combined production capacity of 942,000 tons of wood pellets, double the supply of 2005, according to the trade magazine

'Pellets - Market und Trend.' About 550,000 tons will be sold this year and 21 additional production sites are planned for next year to meet rising demand in Germany.

The annual production of wood pellets in Austria has risen from 15,000 tonnes in 1996 to approximately 520,000 tonnes in 2005. In that country, a total of up to 180,000 small-scale pellet heating systems (< 100 kW_{th}) by the year 2010 has been forecast, which would correspond to pellet consumption in Austria of approximately 900,000 tons per year. The forecast for pellet production in Austria in the year 2009 is predicted to be approximately 1.3 million tonnes.

Figure 4-6[15] provides pellet production capacities for 24 European countries, and indicates a total production capacity of some 8.5 million tonnes per year in 2006.

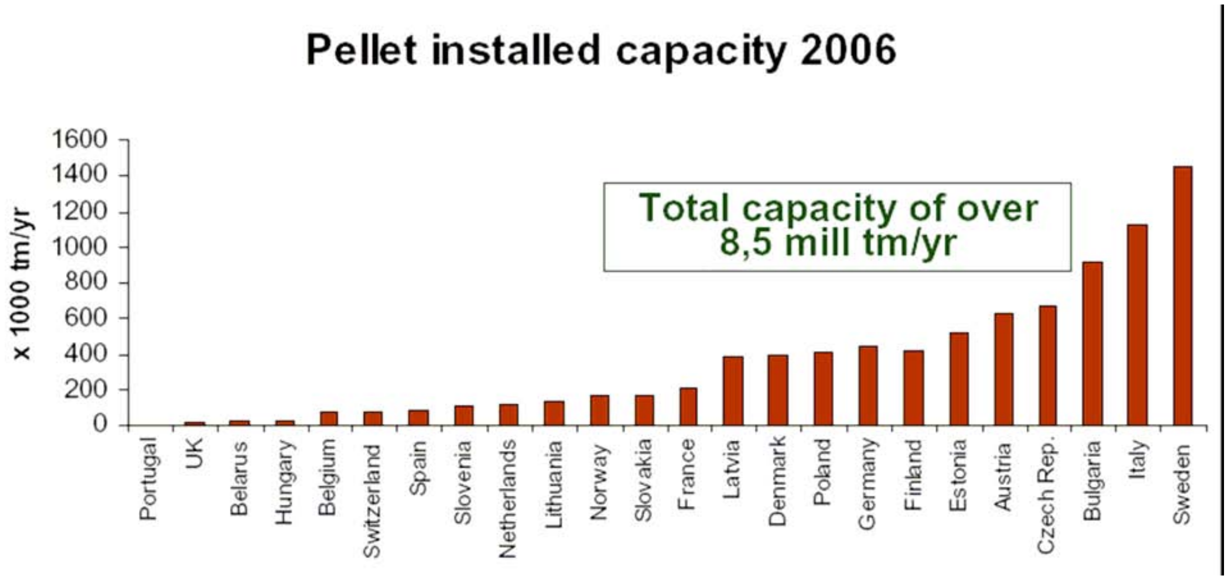


Figure 4-6: Pellet Capacities for European Countries

A summary of pellet production capacity in the Baltic Sea area for 2006 is provided in Figure 4-7 below.[16]

[15] From a presentation delivered by Juan Prados at a pulp wood conference in Melbourne on 27 February 2007
[16] "Biomass fuel trade report in Europe. Summary report VTT-R-03508-07" Eubionet II report EIE/04/065/S07. 38628, published in March 2007

Figure 4-7: Availability of sawdust for pellet production and wood pellet production capacity in the Baltic Sea area in 2006

This figure also shows the estimated production of sawdust in each country, and it can be seen that in several countries the pellet manufacture in 2006 only utilised a small fraction of the available sawdust (although it should be remembered that sawdust may also be used for other purposes).

North America - Wood pellets are mainly used in the domestic sector in colder regions of the USA, such as New England. According to the US Pellet Fuel Institute, over sixty pellet mills across North America produce in excess of 610,000 tons (550,000 tonnes) of fuel per year, a figure that has more than doubled in the last five years.

As an example of growth in the US market, New England Wood Pellet has recently announced the following expansion. It will set up an off-loading, bagging and distribution facility at Palmer, Massachusetts. The company has a five-year agreement with British Columbia pellet manufacturer Houston Pellet Inc. to import by bulk rail about 82,500 tons (a US ton is 907 kg) of premium wood pellets annually. These pellets will be off-loaded from three 100 ton railcars per day on a spur adjacent the facility. They will then be packaged in 40 pound bags, stacked on one ton pallets, and shipped to over 80 retail dealers throughout the northeastern U.S.

Trade – Significant trade between countries already takes place. Ryckmans *et al* [17] present a list of some 26 wood pellet suppliers from various countries and supply capacities. Pellet suppliers to Belgium include Canada, South Africa, Thailand, Russia, Ukraine, Estonia, Latvia, Lithuania, Poland, Sweden and Germany. These exporters have capacities ranging from 8,500 tonnes per annum to 140,000 tonnes per annum.

[17] World Pellets 2006 Proc, page 131

(e) Japanese Pellet Market

Japan has had a fledgling wood energy pellet industry, commencing with pellets imported from the USA, in 1981[18]. From 1982 to 1985 some 30 pellet plants began operation in Japan, in the wake of high oil prices at that time. However after crude oil prices fell no additional plants were built until 2002. Since 2002, renewed interest in renewable energy has seen a resurgence of interest in pellets in Japan, with 15 new pellet plants being established between 2002 and 2005. However, production of pellets in Japan has been low, reported as 2,483 tonnes in 2003. Most of the local pellet mills have low throughput, ranging from 15 kg/h to one of 3,000 kg/h. Pellets are mainly distributed in 10,15 and 20 kg bags for residential use, with commercial bags ranging from 360 – 700 kg. The Japan Housing and Wood Technology Center indicated that in 2005 there were 18 producers locally producing 8,600 tonne wood pellets per year. In mid 2006 one of Japan's largest power companies, Kansai Electric Power announced plans to import 60,000 tonnes per year of wood pellets from north America from 2008 for use in its coal power plants.

4.3 Pellet Specifications

At present there is no worldwide standard for wood pellets. However some pellet using countries have established standards and indeed some large industrial users (e.g. Electrabel in Belgium) and organisations (such as the US Pellet Heating Institute) have also established purchasing specifications.

There is also a move to establish a wood pellet standard for Australia and New Zealand. Key parameters are calorific value, ash content, moisture content, physical dimensions of the pellets and bulk density.

In Germany wood pellets are a standardised fuel in accordance with DIN 51731 "Requirements for Compressed Wood from Untreated Wood" [19]. This standard divides the wood pellets in size classes, and specifies tubing density, the water and ash content, and the heating value. It prescribes limit values for certain trace elements. Wood pellets usually have a diameter of 6 or 8 mm and belong thereby to the size class HP 5. This class covers a length of 5 cm and a diameter from 4 to 10 mm. According to DIN the heating value of the pellets has to amount to 4.9 to 5.4 kW/kg dry weight. They must not contain additional substances and have to be stabilised only by the wood itself and the press process[20].

In Austria, the standard valid for wood pellets is the ÖNORM M 7135 "Requirements for Compressed Wood from untreated wood and crust, pellets and briquettes"[21]. This requires a diameter from 4 to 20 mm, a maximum length of 100 mm, a solid density of at least 1 kg/dm^3, a maximum of 12% water content and 0.5% ash content (related to the dry matter) as well as a heating value of at least 18 MJ/kg dry matter. No additional substances may be added. The standard contains limit values on nitrogen, chlorine, and sulphur. The German (DIN) and the Austrian (ÖNORM) standard for wood pellets are almost similar except for the ash content. Here, a clearly smaller limit value is fixed in the Austrian standard[22].

---

[18] Wood Pellet Fuel Standardization in Japan, Ken'ichiro Kojima, Pellet Club of Japan, page 113-116, Proceedings 2nd World Conference on Pellets, 30 May – 1 June 2006, Jönköping, Sweden
[19] Anforderungen an Presslinge aus naturbelassenem Holz und naturbelassener Rinde, Pellets und Bricketts.
[20] Krapf 1999
[21] Anforderungen an Presslinge aus naturbelassenem Holz und naturbelassener Rinde, Pellets und Bricketts.
[22] Ref: Feasibility Study for new Ecolabels for the Product Group: Wood pellet firings, 2003

The Belgian electricity utility, Electrabel, uses 350,000 tonnes of wood pellets each year to fuel its Les Awir 80 MW unit number 4. It has combined elements of the Swedish (SS 18 17 20), the German (DIN 51731) and the Austrian (Önorm M 7135) wood pellet specifications to establish its own purchasing specification, reproduced in Table 4-2.

Table 4-2: Electrabel Wood Pellets Specification

Wood Pellet Standard		
Parameters	Units	Electrabel
Diameter	mm	4-10
Length	mm	10-40
Volatile Matter		
Water Content	% Dry Matter	<10 %
Bulk Density	kg/m3	>600
Lower Heating Value	GJ/tonne as received	>17
Ash content	% Dry Matter	<1%
Bark Content		<5%
Initial Melting Temperature (red cond)	°C	>1200°C
Chlorine	% Dry Matter	<0.03%
Sulfur	% Dry Matter	<0.2%
Fluorine	ppm	<30
Additives (vegetable oils, pastes)	%	forbidden
Wood Waste	Qualitative	forbidden
Heavy Metals		
As	mg/kg DM	<2
Cd	mg/kg DM	<1
Cr	mg/kg DM	<15
Cu	mg/kg DM	<20
Hg	mg/kg DM	<1
Pb	mg/kg DM	<20
Zn	mg/kg DM	
Benzo-a-pyrene	mg/kg DM	<0.5
Pentachlorphenol	mg/kg DM	<3
Particle size distribution		Minimum
% 3.0 mm (durability)		100%
% 2.0 mm		95.0%
% 1.5 mm		75%
% 1.0 mm		50%

4.4 Product Price

(a) Overall Pricing in Europe

Wood pellet prices across the 15 European countries are presented in Figure 4-8 below [23]. This figure illustrates the price variation across these countries with the range being from approximately €70 to €270/tonne.

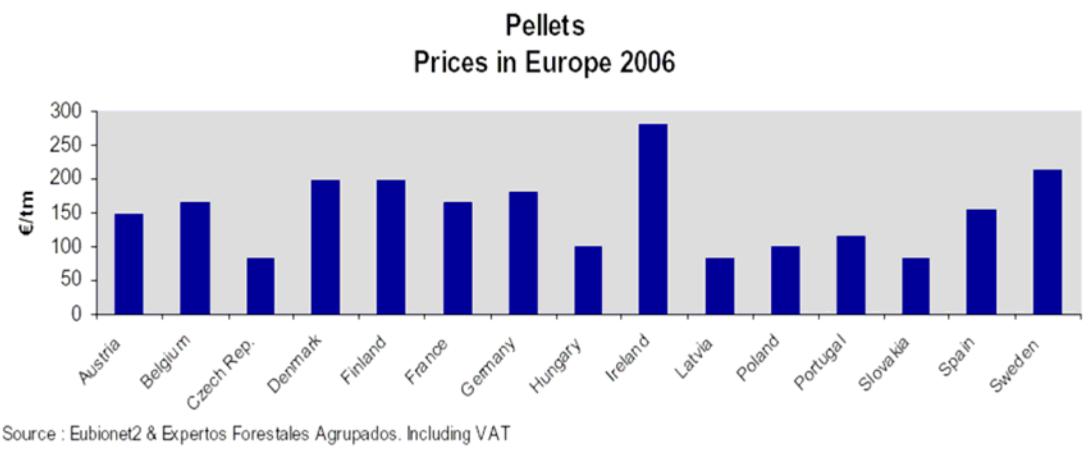


Figure 4-8: Pellets Prices in Europe 2006

The pricing for pellets in several European countries is summarised in Figure 4-9 below[24].

[23] Eubionet II and Expertos Forestales Agrupados (from a presentation delivered by Juan Prados in Melbourne on 27 February 2007)
[24] "Biomass fuel trade report in Europe. Summary report VTT-R-03508-07" Eubionet II report EIE/04/065/S07. 38628, published in March 2007

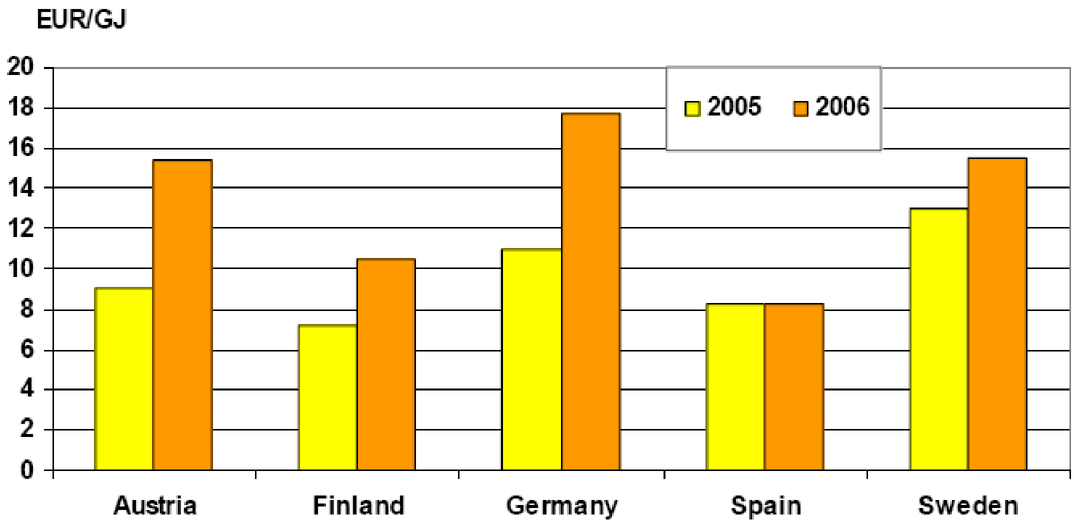


Figure 4-9: Wood pellet price development (including VAT) in Austria, Finland, Germany, Spain and Sweden

There are two key messages from this data:

- The prices paid for pellets vary markedly between countries, with the price paid in 2006 in Germany more than double the price paid the same year in Spain
- Significant price variations can also occur from year to year. The price variation between 2005 and 2006 is approximately 50% in Germany and Austria, but almost negligible in other countries.

Put in the context of export pellets from Australia one set of data suggests a price in Germany of almost €18/GJ, whereas markets elsewhere in Europe are as low as €8/GJ. Clearly any enterprise in Australia needs to be able to make a profit over the longer term, and market volatility such as is shown above can make this difficult.

A new European Union project (EIE/06/020/S12.448557) under the Intelligent Energy Europe program entitled 'Pellets@las' commenced earlier in 2007 and has a three-year duration. The project aims to collect and disseminate detailed information on the European pellet markets and to set up a real-time pellets atlas providing market data such as produced and available quantities and regional sale prices.

(b) Retail Pricing in Europe

Retail data is also available for pellet sales in the UK or Europe, typically in bags or on pallets. This does not provide a good example of costing for bulk supplies as much of the published cost will cover packaging and retail mark-ups. However it does provide an indication of the final destination of pellets which may be brought in by bulk transport.

In the USA, pellets are sold by the bag (40 lb – 18.2 kg), by the ton (50 bags), and by the skid (60 bags). The retail selling price currently ranges from US$120 to US$200 per ton (907 kg)

(US$2.40 to $4.00 per bag) and averages US$150 per ton (US$3.00 per bag). Price varies by region, availability, and season, just like other heating fuels.

As noted above, over sixty pellet mills across North America produce in excess of 610,000 tons of fuel per year, a figure that has more than doubled in the last five years. Pellets are available for purchase at stove dealers, nurseries, building supply stores, feed and garden supply stores, and some discount merchandisers. Pellets are usually packaged in forty-pound bags and sold by the bag or by the ton (fifty bags on a shipping pallet). Some mills offer twenty pound bags for easier handling.

(c) Pricing in Japan

In Japan pellets are mainly distributed in 10, 15 and 20 kg bags for residential use, with commercial bags ranging from 360 – 700 kg. Kojima reported the reported wholesale price of pellets in 2004 as being in the range 190 to 310 Euro/tonne for both small and large bags (exchange rate at time 1 EUR = 134 Yen), without delivery.

4.5 *Wood Pellet Production Technology*

A wide variety of biomass can be pelletised at various scales of production. Wood pelletising technology is available for throughputs of as low as 200 kg per hour to large-scale plants of up to 40 tonnes per hour (i.e. from less than 2,000 to more than 300,000 tonnes per year).

Wood pellets may be made from waste sawdust and other timber residues. A number of processing steps are required, some depending on the nature and quality of the feedstock which can be dry wood shavings, wet sawdust, wood chips or even whole tree trunks. The feedstock entering the pellet mill needs to be of a granular size of approximately 4 mm and a residual moisture content of approximately 10 percent. Accordingly, tree limbs require the maximum processing steps to debark, chipping of the fresh (moist) wood, drying of the biomass, dry grinding, pre-conditioning, pelletising, cooling, storing and loading for transport.

If mallee biomass is presented in shredded form following eucalyptus oil extraction, it is expected that drying and dry grinding will be the first steps in the process.

Drying can often be the most expensive step in the process. For wet raw materials, drying is reported as accounting for some 29 percent of the cost of the pellets[25]. In some instances the pellet plant can be co-located with a combined heat and power plant, using the waste heat from energy production for drying the wet wood. This can improve the economics of pellet manufacture. An opportunity may exist in Western Australia to incorporate solar drying, or use high ambient temperatures to dry the semi-processed oil mallee biomass. However while this may provide low cost energy it may add significantly to handling costs.

A variety of industrial dryers exist and have been incorporated into wood pellet plants. Two main types of dryers are belt and drum dryers. An example of a belt dyer is shown in Figure 4-13 at the Balcas pellet plant in Northern Ireland.

---

[25] Eubionet II and Expertos Forestales Agrupados (from a presentation delivered by Juan Prados in Melbourne on 27 February 2007)

Figure 4-10: Belt Dryer

Belt dryers can operate with a range of thermal energy: hot water, steam, gas, oil or wood itself can provide the energy source for drying.

Figure 4-11 is an example of a drum dryer.

Figure 4-11: Drum Dryer

The dried feedstock is next ground up to a fine meal, generally using a hammer mill.

The ground dry biomass then enters the pellet mill, where pre-conditioning often occurs to soften the lignin (with steam), to reduce wear of the die and reduce production energy. There are numerous pellet mill manufacturers in both Europe and North America.

Figure 4-12 is a showroom example of a typical pellet mill and replaceable dies, while Figure 4-13 shows an operating pellet mill at the Balcas pellet factory in Northern Ireland. The horizontal cylinder atop the mill is the preconditioning unit of the mill.

Figure 4-12: Pellet Mill and Dies

Figure 4-13: Pellet Mill at Balcas Pellet Factory, Northern Ireland

Figure 4-14 is a close up photo of a die at the Balcas facility. It consists of over 2,000 holes through which the wood is extruded into pellets.

Figure 4-14: Pellet Die

The newly formed pellets must be cooled following the pressing step, to ensure their structural integrity. After cooling the pellets can be stored in silos prior to bulk transportation.

A question that often arises is the amount of energy required to manufacture and transport the wood pellets, as a proportion of the embodied energy in the wood pellets themselves. With pellets manufactured from dry wood splints or wood dust, the energy input for the pellet production is approximately 3 percent of their energy content. With damp and uncut wood the energy input for the production can rise to between 5 and 20 percent of the energy content[26].

4.6 Biomass Requirements

Wood pellet properties are largely determined by the properties of the feedstock. Wood pellet specifications typically require low ash and other impurities, low moisture content, and a high calorific value. The domestic heating markets in Europe are currently supplied mainly by pellets made from softwood, which can be expected have different density and colour from oil mallees.

[26] Krapf 1999 as quoted in Ecolabel report

Oil mallee stemwood will have a lower level of ash and contaminants than macerated oil mallee leaf, from which oil has been extracted. Tests would need to be conducted to examine the effect of leaf and twig matter in the pellets. The biomass would need to be carefully processed from harvest to pelletising, to ensure extraneous dirt does not add to the level of ash in the feedstock.

It has been reported that the main pelletising plant in Australia, at Woodburn, NSW has conducted trial manufacture of pellets using oil mallee biomass. The product is subject to confidentiality provisions, and no details were available for this study.

4.7 Storage and Transportation

The most widely used storage systems for wood pellets are silos. An example of wood pellet storage silos is shown in Figure 4-4. It is unusual to store pellets at production plants for any length of time, with on site storage typically being less than 10 percent of the annual production capacity. Some smaller pellet producers also use warehouses.

As noted above, the domestic markets for wood pellets in overseas countries are provided by wood pellet tankers from which the pellets are blown into storage hoppers, or through a variety of sizes of bags of pellets. The bags may be purchased individually, or can be supplied on a pallet of some 50 bags. Figure 4-15 below shows pallets of wood pellets.

Figure 4-15: Bags and Pallets of Wood Pellets

Wood pellets are currently transported in bulk via railway cars, articulated tanker trucks, by barges and ships. Some precautions are necessary to ensure heath and safety considerations are met. Hazards to be avoided are breathing in wood dust, build up of micro-organisms, fire and dust explosions. Taking relatively simple precautions can mitigate all these hazards.

There is currently a significant international trade in wood pellets, with European supplies coming from as far afield as the West Coast of Canada.

4.8 Cost Estimates

A number of factors influence the capital and operating costs of a pelletising facility, and hence the per tonne production cost of the pellets. These factors include the location and scale of the plant, the specification placed on the product wood pellets, the nature and cost of the feedstock, the need for drying, local cost of electricity for running the motors and the cost of energy for drying the feedstock, cost of labour, cost of on site storage. Following production, transportation logistics and costs will impact on the competitive position of the pellets in any given market.

(a) Costs for Small Plant

Currently (April 2007) there are two pellet facilities in Australia: a small facility in Tasmania (operated by hop grower) and a one tonne per hour plant at Woodburn, NSW.

The one tonne per hour Woodburn plant had a capital cost of approximately $800,000 [personal communication Rod Bailey 23 January 2007], assumed to be the current replacement cost. It is believed that this plant receives the sawdust feedstock with a suitable particle size and size distribution so that no additional size reduction is required. The extent of storage and handling equipment and other infrastructure is not known.

Adopting a capital recovery factor of $R/(1-(1+R)^{-N})$, where R is the required rate of return, and N is the project life to recover the capital cost, and assuming a rate of return of 10% and a life of 20 years, the capital recovery factor would be 0.1175. For a mill capital cost of $800,000 this equates to an annual capital cost of $93,968. Assuming operation of the pellet mill for 4,000 hours per year, and production of one tonne per hour, the capital cost contribution to the cost of the pellets would be $23.49 per tonne.

Other indicative costs provided for the Woodburn plant for one tonne per hour wood pellets from sawdust are: labour costs $100, drying using gas $35, electricity $22, raw materials (sawdust) $40 and spare parts (dies) $20.

On this basis, the pellet production cost at Woodburn using sawdust as feed is estimated to be approximately $240 per tonne, or $200 per tonne plus the cost of feed.

(b) Costs for Large Plant

Thek and Obenberger[27] conducted a comprehensive analysis on the cost of producing wood pellets in Austria, and compared this with the cost in Sweden. They derived a range of cost elements by examining nine pellet plants in Austria, ranging in production capacity from between 430 to 79,000 tonnes per annum, and annual operating hours ranging between 615 and 8,000 hours per annum. The analysis included costs of all plant, equipment, offices and data processing, market introduction and planning as well as utilisation factors and maintenance costs. It also included the cost and demand of bio-additives, steam used in the

[27] 1st World Conference on Pellets, 2002

conditioning units, storage costs, and took into account the shifts operated. The results of their analysis are presented in Table 4-3, which shows a breakdown of cost elements and their ranges in Euros per tonne (2002) of pellets, ex factory.

Table 4-3: Pelletisation Cost Factors

Cost Element (€/tonne)	(A) Low	High	Average
General Investments	0.6	4.1	2.4
Drying	25.1	29.5	26.6
Grinding	0.3	6.0	2.9
Pelletisation	7.1	14.8	9.9
Cooling	0.1	0.5	0.3
Storage	1.4	4.9	2.9
Peripheral Equipment	0.5	5.2	3.4
Personnel	4.7	17.4	11.7
Raw materials	14.0	51.4	33.5

The highest two cost elements identified for these plants are drying and the cost of the raw wood material. Grinding is usually done with a hammer mill, although the lower cost is obtained by using pre-ground wood with just a sieve. The major sub-element of the pelletisation cost is electricity consumption. For the Austrian case study this averages as 154 kWh per tonne pellets produced, but this may exceed 200 kWh/tonne pellets for non-softwood pellets such as made from oil mallee eucalypts. Peripheral equipment costs include costs of investments and electrical power required for motors on feeding screws, the sieving machine, fans, cell air locks etc.

The above Austrian study found the ex factory production costs to vary between €78.6 and €101.2 per tonne (A$124 – 160 per tonne[28]) on average for wet raw material and between €52.2 and €81.3 per tonne (A$83 – A128 per tonne) for dry raw material.

Figure 4-16 shows the distribution of cost factors in Austria when using wet raw biomass, while Figure 4-17 shows the cost factors when using sufficiently dried raw material for pellet manufacture.

[28] Based on €1 = A$1.58 at 15 June 2007

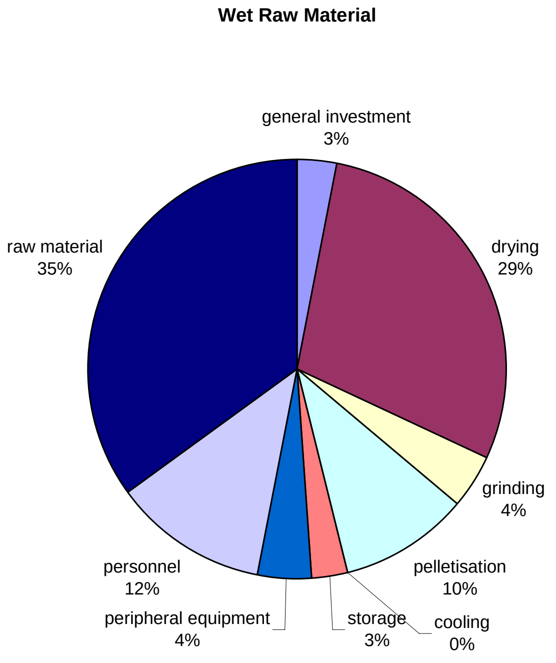


Figure 4-16: Cost Distribution Using Wet Raw Material

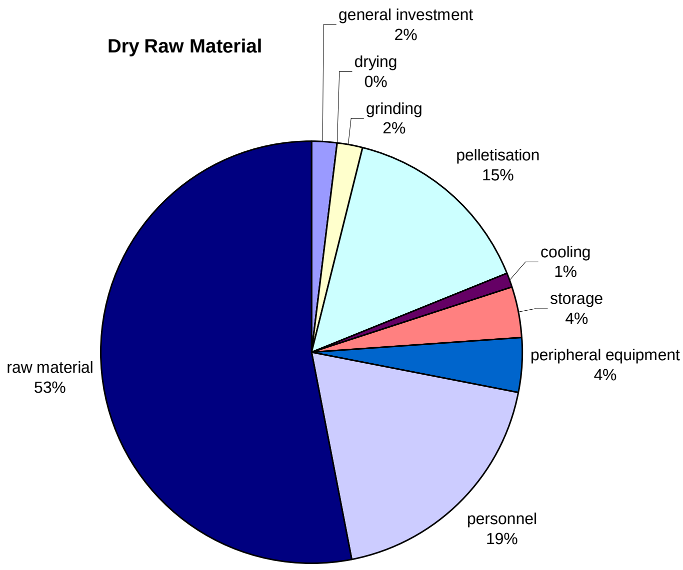


Figure 4-17: Cost Distribution Using Dry Raw Material.

Thek and Obernberger also compared the cost of Swedish wood pellets with Austrian wood pellet costs. Swedish pellet plants tend to be co-located with combined heat and power plants, allowing recovery of superheated steam used for drying to be in part recovered for district heating. They tend to have large production capacity, and electricity costs are also significantly less in Sweden. The specific electricity costs in Sweden amount to only €3.7/tonne pellets, compared to €7.8/tonne in Austria. The pellet production cost was found to be €91.5 per tonne of pellets in Austria for a 24,000 t/a plant, with electricity cost at 51€/MWh, electricity power being 540 kW, plant availability being 90% and moisture content of the raw feedstock being 55% (wet basis). This compared with the Swedish wood pellet production cost of 61.9 €/tonne based on an annual production of 80,000 tonnes and electricity at 27€/MWh.

4.9 Financial Analysis

A simple economic model was constructed to examine the economics of production of wood pellets in the Avon and then export to markets in Europe and Japan.

(a) Assumptions

For the estimation of transport costs a wood pellet plant is assumed to be located in York, WA with its product shipped through the Port of Kwinana. Shipping out through Bunbury was also considered but the initial analysis indicated that this would be more expensive.

Destination markets are Europe and Japan. Arrival ports are assumed to be Rotterdam and Osaka respectively.

Two plant and shipment size scenarios were modelled for each destination market:

- a small capacity plant of 25,000 tonnes per year and shipment sizes of 25,000 tonnes
- a larger capacity plant of 75,000 tonnes per year and shipment sizes of 50,000 tonnes

Indicative costs were obtained for shipping (CIF)[29], port charges[30] and transport costs[31]. Production costs were more difficult to determine, due to the lack of plants in Australia of a similar scale. Data was available on the costs of production in Europe[32] and it was assumed that production costs could be achieved equal to those in Europe for a 25,000 tonnes per year plant. Actual costs may differ due to differences in capital and operating costs in Australia (for example labour rates and energy costs) and also the effect of cost differences and productivity improvements between 2002 and 2007. For the larger capacity plant scenario, it is assumed that economy of scale would result in production costs that are 30% lower.

For the cost of feedstock, a grower plant gate price of $30 per tonne is assumed.

The market price range for wood pellets in Europe was assumed to be the upper and lower prices quoted earlier in this section, namely €70 to €270 per tonne. The price range for the Japanese market was taken from that quoted by Kojima 2006[33] of €190 to €300 per tonne for

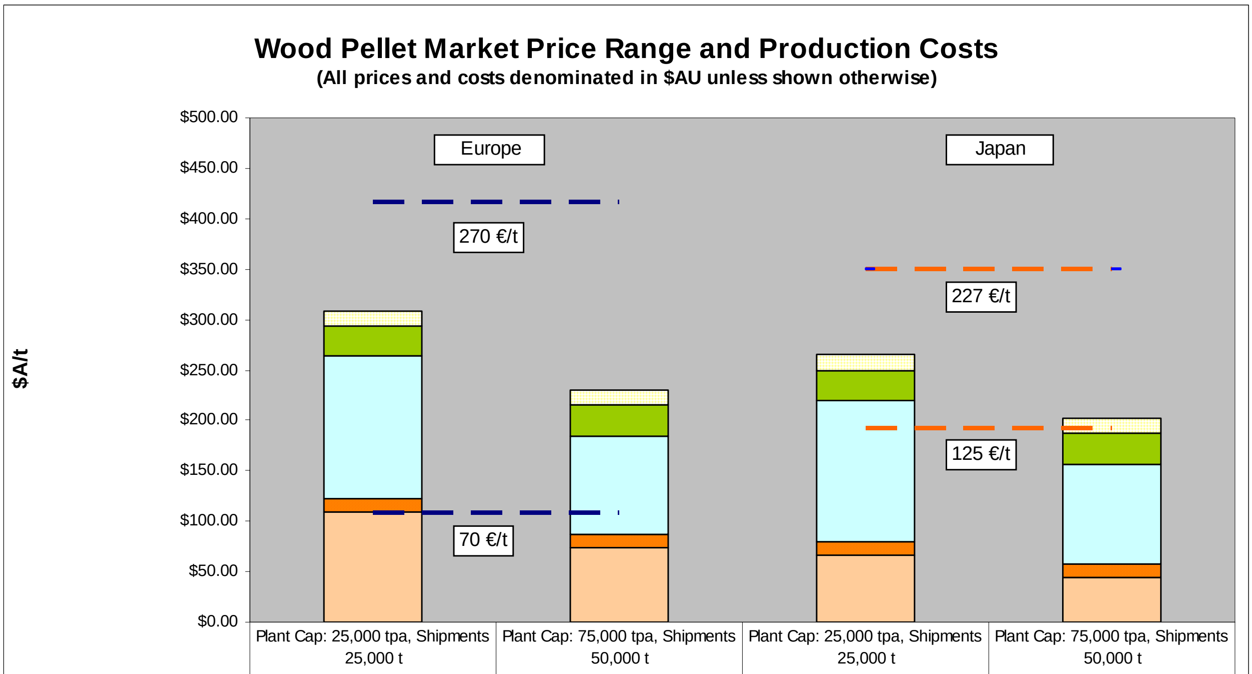
[29] Quote from Braemar Seascape dated 20 Jun 07
[30] Quote from Fremantle Ports Corporation date 6 Jul 07
[31] Quote from Brookes Transport dated 11 Jul 07 for road transport for pocket road trains. A quote was also received from ARG for rail transport on 23 Jul 07. Costs were very similar to road transport for York.
[32] Thek & Obenberger, 1st World Conference on Pellets, 2002
[33] Kenichiro Kojima, Pellet Club of Japan, page 113-116, Proceedings 2nd World Conference on Pellets, 30May-1June 2006, Jonkoping, Sweden

bagged wood pellets. A downwards adjustment $AU100 per tonne has been made to these Japanese prices to allow for packing costs and thus bring the price to a bulk rate. Thus the range modelled for Japan was €125 to €227 per tonne.

(b) Results

The results of the economic modelling are shown in Figure 4-18. The results indicate that wood pellet production is uneconomic at the lower price range for both Europe and Japan, regardless of plant scale. At the higher end of the price range, both small and large-scale plants are economic.

The break-even market price is around the middle of the price ranges used in the model. The breakeven prices for each scenario are shown in Table 4-4 below.



	Plant Cap: 25,000 tpa, Shipments 25,000 t	Plant Cap: 75,000 tpa, Shipments 50,000 t	Plant Cap: 25,000 tpa, Shipments 25,000 t	Plant Cap: 75,000 tpa, Shipments 50,000 t
Port Costs	$14.95	$14.95	$14.95	$14.95
Growers Feed Price	$30.00	$30.00	$30.00	$30.00
Production costs	$140.77	$98.54	$140.77	$98.54
Transport to Port	$13.20	$13.20	$13.20	$13.20
Shipping	$109.64	$73.25	$65.96	$44.88
Market Price JPN - Low			192.31	192.31
Market Price, JPN - High			349.23	349.23
Market Price EU - Low	107.69	107.69		
Market Price, EU - High	415.38	415.38		

Scenario

Figure 4-18: Economic Modelling Results

Table 4-4: Break-even Market Price

	Europe	Japan
Small Capacity Plant	$A309 or €201	$A265 €172
Large Capacity Plant	$A230 or €150	$A202 €131

4.10 Discussion and Conclusions

Wood pellets are rapidly gaining acceptance in Europe, Japan and northern America as a high quality, renewable fuel. While they presently account for only a small proportion of bioenergy in Europe, they are rapidly gaining in market share in both the domestic and industrial sectors. This is being underpinned by high taxes in some European countries on fossil fuels, and concessions for renewables and bioenergy.

Wood pellet technology is relatively simple and there are multiple suppliers of pellet mills and other required plant. The market for wood pellets is relatively underdeveloped, with a variety of specifications for pellets and little price transparency at present.

Pellets command a price premium over some other forms of biomass, such as logs and wood chips, mainly due to their higher energy density and ease of handling and use. It is expected that for large scale, reliable pellet supplies, with environmental credentials provided by oil mallee plantings, that the overseas markets could be accessed, provided the mallee pellets meet the required price hurdles. Key markets are the larger industrial sectors, such as for power stations, and also for the domestic sector, although in this market the product would need detailed market acceptance studies.

Based on published data and the preliminary financial modelling undertaken for this study, it appears that pellet manufacture in the Avon catchment for European markets may be commercially viable. The principle uncertainty is the prices that can be negotiated for these pellets, as the published prices across Europe vary considerably.

5. Fast Pyrolysis

5.1 Summary

Fast pyrolysis is a process that converts woody material into a liquid called bio oil. Charcoal is also produced during pyrolysis. The process will work with any form of biomass provided it is first reduced to a suitable particle size and low moisture content.

The bio oil can compete with conventional fossil fuels in a number of situations. It can be used to generate heat and power. Chemical extraction is already carried out for niche markets in the USA. Research is underway for other chemical applications and also for the use of the bio oil in slow speed diesel engines. Bio oil cannot yet be used commercially in road transport applications

Pyrolysis technology is used commercially in a limited number of plants in Canada and the USA. While bioenergy applications may offer larger markets in the longer term, current markets for the oil are primarily for local chemical production; markets that are not duplicated in Australia.

The North American pyrolysis plants typically require around 100,000 tonnes or less of green biomass feed each year. As farm forestry develops over coming years in the Avon catchment this would appear to be a more achievable feed target than the hundred of thousands of tonnes required for BtL or ethanol plants described later in this report.

Short term applications for wood pyrolysis in the Avon appear limited by lack of suitable markets for the products. With further research over the next few years into product applications and high value chemicals it is possible that commercial opportunities will develop.

5.2 Technology

Pyrolysis is the name given to the heating of biomass in the absence of air or, more importantly, oxygen. With no oxygen present the biomass cannot burn or gasify. Heat is therefore not produced and pyrolysis is not an exothermic reaction. Instead, external heating of the biomass is required. This distils (breaks down) the biomass into solid, liquid and gaseous fractions. The temperature, time for heating and other variables determine whether the pyrolysis action produces predominately charcoal solids (typically via slow processes) or bio oil liquids (typically via fast pyrolysis).

The fast pyrolysis process commercialised by Canadian company Dynamotive (www.dynamotive.com.au) heats wood feed to almost 500^{O}C in approximately one second, and typically converts two thirds of the biomass feed into liquid bio oil. The remaining biomass is converted into charcoal and non-condensable gases, and the latter are used in the process as fuel to heat the pyrolysis reactor.

The Dynamotive reactor is a fluidised bed; a large bed of sand that is "fluidised" by passing inert gas through the base of the reactor. Heat is applied to the sand via heating tubes and woody biomass is introduced to the hot sand where it rapidly reaches the target temperature and is pyrolysed. All the pyrolysis products leave the reactor as a vapour stream. From this stream the charcoal is separated (spun out in cyclones), the liquid is captured in a large quench vessel (via contact with cooled bio oil) and the gases that cannot be condensed are returned to be used as fuel in the heater that keeps the actual pyrolysis reactor at the required temperature. There is no waste and no effluent streams from such a pyrolysis process.

Dynamotive has demonstrated this technology at commercial scale. Another Canadian group Ensyn (www.ensyn.com), and European group BTG (www.btgworld.com) also offer fast pyrolysis technology that has been demonstrated at large scale. Ensyn has operated commercial scale plants for more than ten years to manufacture food flavourings and BTG has recently built its first commercial scale plant.

Fluidised bed reactors appear to be popular for fast pyrolysis as they provide rapid heat transfer and offer good control for the pyrolysis reaction. Other methods for fast pyrolysis are available, for example BTG utilises a rotating cone reactor.

Slow pyrolysis operates with different temperatures and residence times and achieves a different product mix to fast pyrolysis. Notable in Australia is the pyrolysis technology being developed by BEST Energies in New South Wales[34]. A demonstration scale plant is operational in NSW and it is understood that the focus of this plant is to process biomass for charcoal and syngas rather than the maximisation of liquid products as targeted in fast pyrolysis processes.

The fundamentals of pyrolysis are widely researched. The CSIRO, Melbourne University and Monash University have all operated research scale pyrolysis processes over recent years. In Europe the Pyne network [35] links many research groups and provides a wealth of general information about pyrolysis.

It is important to remember that the progression from research to commercial scale generally involves several steps that allow the technology to be progressively increased in scale. This allows the operating characteristics of the process to be developed and optimised at larger scale, with the final commercial operation sometimes representing a size more than 1,000 times greater than the original research plant. The Dynamotive scale up history provides an example of this. Following laboratory research that began in the 1970s, Dynamotive has developed its technology in progressively larger plants:

- A pilot plant to process 2 tonnes per day (tpd) of dry biomass
- A demonstration plant to process 10-15 tpd
- A commercial plant to process 100 tpd (at July 2007 this was being upgraded to 130 tpd)
- A modular commercial plant to process 200 tpd (under commissioning at July 2007).

As might be expected, this development process has involved the expenditure of tens of millions of dollars over a period of more than ten years.

[34] www.bestenergies.com
[35] www.pyne.co.uk

5.3 Product Markets

(a) Liquid fuels

Fast pyrolysis can convert the majority of its biomass feed into a liquid product. Such liquids are typically:

- Slightly denser than water and significantly denser than petrol or diesel
- Slightly acidic and have a smoky odour
- Have an energy content that is less per unit of volume than petrol or diesel
- Have higher viscosity than petrol or diesel

Bio oil is quite different to the biodiesel that is produced form tallow, palm oil or other oilseed crops. For example bio oil does not readily mix with petrol or diesel. The two liquids have different feedstocks, production processes and chemical compositions. Biodiesel mixes readily with conventional diesel fuel and has application as a fuel for road transport. In contrast, bio oil cannot currently be used in vehicle engines, although research is underway at Monash University and in Europe and the USA to resolve this.

Work by various pyrolysis groups around the world has shown that bio oil can be used quite effectively as a fuel for heating or steam generation, in a similar fashion to the No 2 or No 6 heating oils that are widely used in the northern hemisphere. Bio oil can also be used as a fuel for power generation in gas turbines. The Canadian company Orenda (part of the Magellan group) has spent several years adapting its OGT 2500 industrial gas turbine to run successfully on bio oil. This unit can generate 2.5 MW of continuous renewable electricity using bio oil as fuel. With suitable heat recovery equipment the electrical output can be increased to approximately 4MW.

Bio oil cannot be produced at a cost that will make it competitive with Australian coal or natural gas, which are among the cheapest fossil fuels in the world. However it does have a number of immediate applications that may be commercially competitive on a case-by-case basis:

- For supply of electricity at remote locations as a replacement for diesel generators
- For supply of heat, for example process steam, in locations that do not have access to natural gas
- As a replacement for heating oil (e.g. in Japan or other locations using this fuel).

(b) Charcoal

There is considerable interest in pyrolysis charcoal for a variety of product markets.

Industrial fuel – It is technically feasible to use charcoal as a renewable fuel.

It has been considered as a renewable feed component for coal-fired power stations because the charcoal can be handled in the same fuel preparation system that is used for coal.

Dynamotive has demonstrated that pyrolysis charcoal can be mixed with the bio oil and the resulting slurry can be pumped, transported by tanker and then fired in boilers to replace other liquid fuels.

Cooking briquettes – Charcoal can be made into cooking briquettes such as those used in many western countries for barbecue cooking. Cost must be considered carefully however, as in countries such as Australia and the USA most cooking briquettes are actually made from coal, which is expected to be a cheaper fuel than pyrolysis charcoal.

Metallurgical charcoal – The CSIRO has examined the use of wood charcoals as a reductant in various metallurgical industries. Of particular interest in Western Australia is the possibility of using charcoal derived from mallee trees as a reductant in the mineral sands industry. Currently this industry uses WA coal for a reductant. Coal is expected to be cheaper than wood charcoal, but the CSIRO work to date has indicated that wood charcoal may offer processing advantages that help to offset its higher cost[36]. Interestingly the different fractions of the mallee tree (leaf, wood and bark) make charcoals that have different properties as reductants.

Soil improvement – Adding carbon to soils via charcoal ("agrichar") appears to have multiple benefits:

- The carbon is sequestered (with the possibility that carbon sequestration payments may be included in future trading regimes)[37].
- The carbon appears to enhance the yields of plants grown in the improved soils[38].

It has also been suggested that the addition of charcoal to soils creates a micro-environment that is conducive to increased microbial activity and thus enhanced productivity.

Research and trials are underway to examine some of these opportunities in more detail. Earlier in 2007 the second world agrichar conference was held in New South Wales[39]. BEST Energies of NSW is engaged in the evaluation of agrichar. In North America, Dynamotive recently announced a large-scale trial of its pyrolysis charcoal for agricultural application.

Slow release fertilisers – It has been suggested that pyrolysis charcoal can provide a mechanism for the managed application of nitrogenous fertilisers[40]. It is expected that the chemical binding of nitrogenous material to the charcoal will reduce the likelihood that it is leached prematurely from the soil. Such a result would both enhance the economic benefits achieved from the fertiliser and reduce the amount of fertiliser-induced contamination of nearby waterways.

Activated carbon – As with many other charcoal materials, it should be possible to make activated carbon from pyrolysis charcoal. This could be achieved via steam activation or acid activation. We are not aware of any data describing specific examples of activated carbon

[36] The use of Mallee Charcoal in Metallurgical Reactors by Langberg D.E. et al, Proceedings of the Green Processing Conference, NSW June 2006
[37] A Handful of Carbon by Johannes Lehmann. Nature Vol 447, 10th May 2007
[38] The Real Dirt on Rainforest Fertility by Charles C Mann. Science Vol 297, 9th August 2002
[39] http://www.iaiconference.org
[40] US Patent No. 5,676,727 Radlein et al

that could be produced from pyrolysis charcoal. It is likely that the quality and market potential would vary considerably according to feedstock, pyrolysis pathway and activation pathway.

Some of the markets described above are well established in other countries and already use wood charcoal from other processes. Some of the markets (particularly agrichar) are not yet well established, but offer considerable potential. It would appear that pyrolysis charcoal can provide a useful product in all of these applications, however the competitive commercial position for the charcoal against other feed materials is less clear. The commercial viability of each market must be judged on a case-by-case basis.

(c) Chemicals

Food flavourings – Fast pyrolysis is already used in North America for the production of chemicals. Ensyn has operated small commercial pyrolysis plants for a number of years to produce feedstock for the production of smoke flavourings for food. This activity is carried out in association with the US speciality food company Red Arrow and information on markets and values for these chemicals is not publicly available.

Resin chemicals - A number of research groups around the world have demonstrated that bio oil can be used in the manufacture of resins. More specifically, the phenolic materials present in the lignin can replace other materials that are currently used in phenol formaldehyde resins and also other, similar resins. These resins are widely used for engineering wood products (including plywood and oriented strand board) and have many other industrial applications.

5.4 *Biomass Requirements*

One of the more useful attributes of pyrolysis is its ability to process any form of biomass. Dynamotive, for example, have pyrolysed more than 100 different forms of biomass.

For successful fast pyrolysis the biomass feed requires some preparation, which is broadly similar to the preparation needed to make wood pellets:

- The biomass must be ground into small particles. This allows the particles to heat rapidly when they are introduced onto the pyrolysis reactor and facilitates the conversion to large percentages of oil.
- The biomass must be dried, and preferably contain around 10% moisture or less. Moisture in the biomass feed carries through the process and dilutes the oil that is produced.

The sizes of fast pyrolysis plants, and thus their biomass requirements, are dictated by the commercial work carried out by each technology provider:

- Dynamotive's first commercial plant was designed for 100 tpd of feed. More recently Dynamotive has built a plant that process 200 tonnes per day of dried wood feed. This equates to approximately 65,000 dry tonnes of wood feed per year.
- BTG's first large scale plant is reportedly designed to process 50 tonnes per day of feed (16,500 dry tonnes per year)

- Ensyn has built several biomass pyrolysis plants at sizes up to 70 tonnes per day of feed (16,500 dry tonnes per year).

So pyrolysis lends itself to a mixed, whole tree feed as might be provided by mallees. It also provides commercial plant designs at a scale that allows processing plants to be built for far less biomass feed than is expected to be required for ethanol or biomass-to liquids (see subsequent sections).

5.5 Cost Estimate and Project Opportunities

(a) Capital Cost

A new commercial pyrolysis plant will include the following components:

- Feed receival, preparation and storage
- Pyrolysis plant
- Storage for oil and charcoal
- Utilities and services for the plant
- Roads, buildings and other site-related works

Renewable Oil Corporation Pty Ltd (ROC) is an Australian company based in Melbourne. It is the exclusive Australian licensee for Dynamotive and is currently estimating the costs of pyrolysis plants for potential Australian projects. Costing is based on a plant that is similar to the 200 tonne per day plant just built by Dynamotive at Guelph near Toronto. Associated costs will depend on the site-specific requirements for feed, product and related facilities. The figure below shows the main elements of a commercial pyrolysis plant as provisionally set out for another site in Australia.

Figure 5-1: Typical layout for 200-tpd pyrolysis plant including feed receivals, preparation and storage, pyrolysis, product storage and associated facilities, courtesy Renewable Oil Corporation Pty Ltd

Based on detailed cost estimates by ROC for other sites in Australia, the construction of such a plant now in the WA wheat belt is expected to cost between $40 and $50 million dollars depending on the extent of facilities, location and site works required. As more full-scale pyrolysis plants are built and operated over coming years, these costs are expected to reduce.

(b) Current Opportunities

For mallee feed at a cost of $30 per tonne, such a pyrolysis plant could produce liquid fuel at a cost roughly comparable with current prices for LPG, heating oils and diesel. However there are barriers to developing projects on this basis:

- Using bio oil Western Australia does not appear to have significant industrial users of LPG and heating oil.
- Major markets do exist in Asia, however the cost of transport to these markets reduces the competitive position of bio oil.
- Use of bio oil to replace diesel for remote power generation in WA requires installation of gas turbines because bio oil cannot yet be used routinely in diesel engines. The turbines have a significant capital cost that reduces the competitive position of bio oil.

(c) Medium Term Opportunities

While the immediate opportunities for pyrolysis in Western Australia appear marginal, this situation is expected to improve over the next few years.

A sustained price increase for crude oil (see section 8) will improve the competitive position for bio oil.

Bio oil technology, while commercial, is still at the early stages of its development. Cost reductions are to be expected as more operating experience is gained.

Research and development is underway in Australia and overseas to use bio oil in slow speed diesel engines. In particular, the development of appropriate fuel handling systems will assist in this regard. Success with such work could allow bio oil to be used in existing engines (generation, marine, agricultural) and in new systems that can be built for lower capital costs than equivalent gas turbines.

Additional research and development is focused on the extraction of high value chemicals form bio oil. Independent R&D groups around the world have demonstrated that whole bio oil or bio oil extracts can be substituted for the components of phenol resins. Recovery of these materials as a small percentage of the bio oil, leaves the remainder of the bio oil to be used for its energy value, but the high value achievable for the chemicals means that the overall revenues achieved are significantly greater. Renewable Oil Corporation advise that a pyrolysis plant making and selling oil for energy plus a minor stream of high value resin chemicals can be commercially competitive:

- on current prices for crude oil and phenol
- with the inclusion of transport charges to markets in Asia
- with a gate fee paid for the supply of mallee feed.

A pyrolysis industry in Australia may develop now on the basis of niche opportunities for feed supply and product off-take. In the longer term with some or all of the factors above coming into play, pyrolysis can offer commodity fuels and chemicals for Australian and Asian markets. Success in regional markets would mean that multiple plants could be built in the WA wheat belt if the economics of mallee as feed are competitive with other feeds.

6. Biomass to Transport Fuel

6.1 Summary

Biomass to Liquid (BtL) fuels are at the advanced research to early commercialisation stage of development. BtL involves the gasification of biomass into simple molecules of mainly hydrogen and carbon monoxide (called "syngas"), followed by a synthesis step to produce a range of alternative fuels, most notably methanol, dimethyl ether, and synthetic diesel.

The most commercially advanced work is being undertaken by Choren in Germany. A large scale BtL synthetic diesel plant is currently under construction, and this is expected to be followed by construction of the first commercial scale plant (sized to use one million tonnes dry biomass per year as feed supply) in Germany towards the end of this decade.

The core technologies for BtL are established, but they require integration and optimisation for application with biomass, such as mallee trees. Cost would currently be more expensive than conventional liquid transport fuels, but with further technology development and suitable feedstock price and availability, BtL is a good prospect for the future, probably within a decade. A particular attraction of this technology for WA is the ability to use the produce synthetic diesel that may be integrated into the existing liquid fuels market in WA with minimal disruption.

6.2 Product Descriptions and Markets

A variety of liquid transportation fuels can by synthesised using thermo-chemical conversion of woody biomass, such as oil mallees. Examples of such fuels are:

- Methanol
- Dimethyl ether (DME)
- Synthetic diesel fuel created via the Fischer Tropsch process.

Methanol is an established chemical commodity that is currently produced around the world from natural gas and coal. It has well-established international markets and provides the feedstock for the manufacture of several bulk chemicals such as formaldehyde. Methanol is not currently a major transportation fuel, but has been identified as a suitable fuel for use in future fuel cell vehicles. Concept fuel cell cars using methanol have been demonstrated, for instance in the USA. Methanol is not favoured as a fuel additive, due to its toxicity, relatively low energy density, corrosiveness and incompatibility with current fuel system materials. However, small quantities of methanol are blended with petrol in China. The Federal Government has been considering developing a fuel Standard for methanol, and to this end engaged the CSIRO to assess methanol as a transport fuel. It is now unlikely such a Standard will be produced, as methanol is not currently well regarded as a short-term fuel.

DME is an extremely clean burning fuel, with physical properties very similar to LPG. It is used in a number of chemical processes but at this stage it is still regarded as an experimental fuel, with motor vehicle companies such as Volvo in Sweden trialling its use. The energy density of DME is approximately 57 percent that of diesel and coupled to this it requires high-pressure storage, further limiting its tank range. Figure 6-1 below shows a

Volvo truck fuelled on DME being shown to a conference group at a Swedish biofuels conference in 2005.

Figure 6-1: Volvo Dimethyl Ether (DME) truck

Fischer Tropsch (FT) synthetic diesel has exceptionally good fuel characteristics. It typically has a high cetane index of approximately 80 (cetane index is a measure of the ignition quality). This is substantially in excess of that of traditional diesel derived from crude oil. FT diesel also has a slightly higher calorific value compared to petroleum diesel, and low sulphur and aromatics contents.

Fischer Tropsch synthesis of fuels and chemicals is well established from fossil fuels, most notably coal. For the past 50 years South Africa has provided a substantial part of its liquid fuel needs from its Fischer Tropsch Sasol plants, using coal as the feedstock. Its Sasol II and Sasol III plants, based on the South African coalfields, currently produce 150,000 barrels of fuel per day. Trials have also been conducted to produce this product using a combined feed with a small component of biomass together with the coal.

Fischer Tropsch diesel may be used as a direct substitute for diesel, as this fuel meets the specifications for petroleum diesel (although the density is slightly lower).

Australia's diesel market is some 14 billion litres per year. As diesel vehicles are more fuel-efficient than petrol vehicles, there has been a trend towards a greater proportion of passenger vehicles powered by diesel engines entering the Australian market. Most heavy vehicles, such as trucks, semi-trailers, trains and ships are based on diesel engines.

Fischer Tropsch diesel would be an ideal fuel for the WA mining industry, as it is extremely similar in properties to petroleum diesel.

6.3 Technology

BtL fuel is produced in a two-step process. The first step involves preparation of synthesis gas (a mixture of carbon monoxide and hydrogen) from a biomass feedstock and, second, conversion of the synthesis gas into liquid fuel via chemical processing, involving catalyst beds. This is illustrated in Figure 6-2.

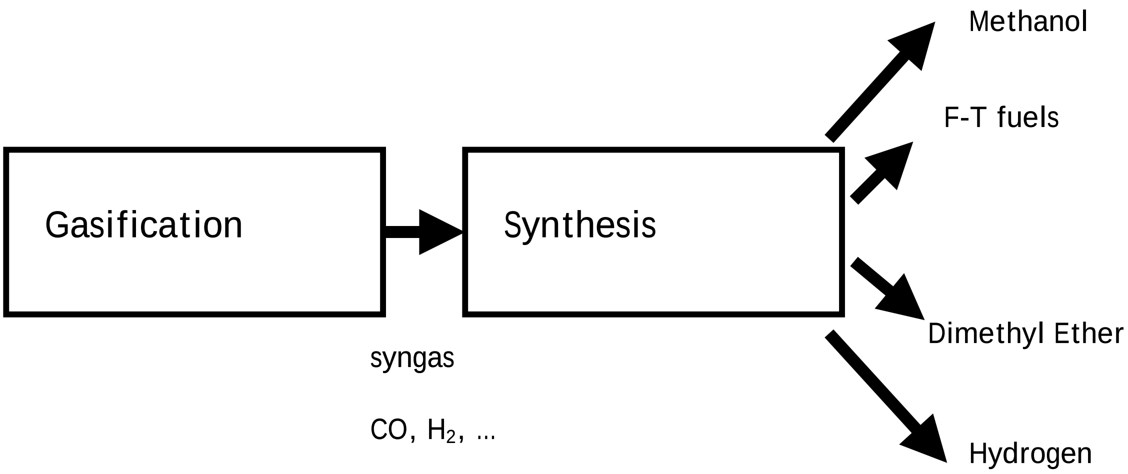


Figure 6-2: Biomass to Liquids Synthesis

Biomass gasification is a relatively well-developed technology, with some large-scale gasifiers having operated for close to two decades. Such an example is the Lahti gasifier in Finland, which has gasified biomass for co-combustion with coal.

Gasification is a high temperature process, which operates in an oxygen-starved environment. The biomass generally needs to be pre-conditioned to obtain the appropriate biomass particle size, size distribution and moisture content to match the gasifier's specification. The gasification medium can be air, oxygen or steam. If air is used, the diluting nitrogen in the producer gas stream needs to be removed, to arrive at a carbon monoxide rich, hydrogen rich gas.

The synthesis process involves passing the gas over catalytic beds tailored for the end product fuel. The gasification process can use a variety of biomass types, within compositional constraints, as the objective is to transform the biomass into the simple molecules of carbon monoxide and hydrogen. For this reason, the synthesis process is largely independent of the original feedstock, as long as the gasifier's output gas is within the required specification for the BtL synthesis process.

For Fischer Tropsch (F-T) synthesis, the hydrogen and carbon monoxide molecules created during gasification are transformed into synthetic fuel according to the chemical equation:

$$CO + 2H_2 \text{-->} \text{-}CH_2\text{-} + H_2O$$

Where $–CH_2–$ is a component of the synthetic biofuel polymer with a chain length ideally 18 for synthetic diesel.

F-T plants are invariably required for technical and economical reasons to be large industrial facilities. Not all of the biomass may be converted directly to liquid fuels and so F-T plants often use the low molecular weight off-gases for the co-production of electricity. Figure 6-3 shows a possible configuration for producing Fischer Tropsch fuel as well as synthetic natural gas and power.

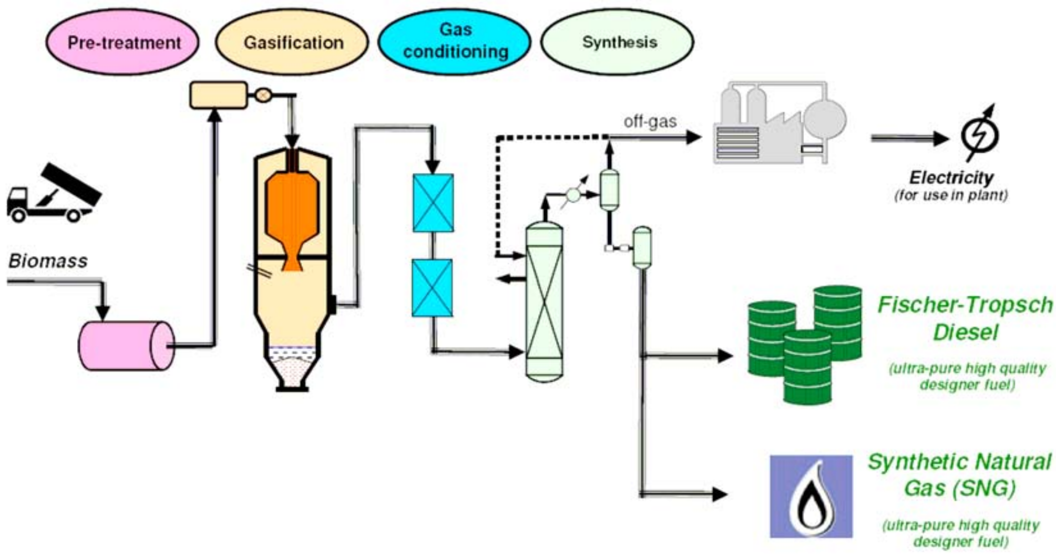


Figure 6-3: Fischer Tropsch Diesel Co-production with SNG and Electricity (source: ECN)

The commercial success of Btl using gasification and F-T synthesis depends on its ability to consistently maximise the production of liquid fuels that work seamlessly in engines designed for petroleum diesel. In particular:

- The electricity, SNG and F-T diesel shown in the diagram above are all forms of renewable energy, and they compete with conventional forms of energy that have considerably different values. Diesel is a far more expensive product per unit of energy than grid-delivered electricity or pipeline natural gas. So the commercial success of a BTL plant will depend on its ability to maximise the production of high-value liquid fuels, and minimise the production of electricity and SNG.
- Natural gas is a homogeneous and consistent feedstock containing negligible amounts of oxygen and lends itself to reliable conversion to liquid fuels. In contrast, woody biomass is a feed that varies according to the part of the tree that is being used, and possibly the season and type of wood being processed. It contains ash and other material and also contains a significant quantity of oxygen. As such it is a more complicated feed than natural gas for the production of hydrogen and carbon monoxide required for BtL synthesis.
- While there is considerable experience world wide in the gasification of biomass to produce a combustible gas, this is not the same as gasification of biomass to maximise the production of H and CO (and minimise the production of unwanted compounds).

So gasification as a preparatory step to catalytic synthesis of liquid fuels requires a different set of design parameters to gasification for heat or power.

Although F-T fuel technology is well established by the likes of Sasol in South Africa, based on coal, a fully integrated F-T plant using biomass at a semi-commercial scale is only now being constructed.

German company Choren, in association with strategic partners Daimler Chrysler and Volkswagen, and also in partnership with Shell, are currently constructing the world's first large scale BtL plant at Freiburg, Germany. This 'Beta' plant (the second large scale prototype and a scale up from the previous "alpha" plant) will have a 45 MW thermal capacity, and convert some 68,000 tonnes dry biomass feedstock into 15,000 tonnes/annum (16.5 ML/a) syn-diesel, trade named by Volkswagen SunDiesel®. Figure 6-4 shows an aerial photo of this plant under construction (March 2007).

Figure 6-4: Choren BtL plant under construction at Freiberg, Germany (source: Choren)

The Choren plant has a three-phase gasifier, gas treatment, Fischer Tropsch synthesis and includes a hydrocracker to optimise the hydrocarbon fuel properties. Mechanical completion of the Freiburg plant is due in the third quarter 2007, with first fuel expected in late 2007 or in 2008. Choren has announced a roll out of 'Sigma' plants at the 1 million tonnes dry biomass per year scale and has nominated Schwedt and Lubmin in Germany to be the sites of the next, scaled up plants. These scaled up plants represent full economy of scale and will produce 200,000 tonnes per annum product.

While the Choren group has the most advanced BtL facilities in terms of scale up toward commercial plants, other groups are also investigating BtL technology. A high profile European BtL demonstration and research plant is in south-eastern Austria at Güssing. This 8 MW (fuel input) plant was originally set up as a steam gasification demonstration for combined heat and power production, and has subsequently been used to research and develop BtL. The gasifier has to date had some 30,000 hours of operation on wood chips and currently has an availability of over 90 percent. The steam gasifier produces a syngas with a hydrogen content of some 35-45%, carbon monoxide of 22-25% and methane in the range 9-11 percent. A slurry bed Fischer Tropsch reactor operating at 200-300 °C and 20-30 bar pressure has been used to research and develop F-T diesel and also to produce synthetic natural gas. Figure 6-5 illustrates this development plant.

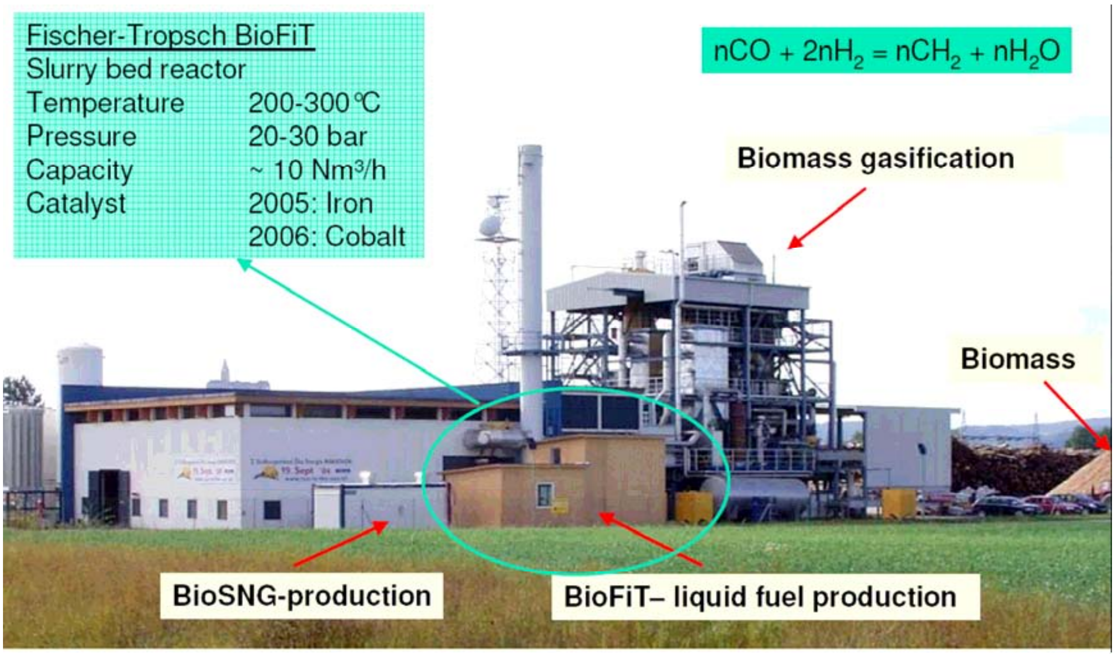


Figure 6-5: Güssing BtL Research Plant in Austria (source: reNet).

Another major BtL plant in Europe is the CHRISGAS project at Värnamo, Sweden where an 18 MW (thermal) gasifier with over 8,500 hours of operation in gasification mode (from an earlier demonstration of integrated gasification combined cycle operation) is being used under an EU research program to research methanol, DME, Fischer Tropsch diesel and hydrogen production. Swedish company Chemrec is also researching the use of gasified black liquor (from a pulp mill) for the production of DME and methanol elsewhere in Sweden.

6.4 Biomass Requirements

As noted above, Choren is sizing its commercial plants to achieve the economies of scale possible with large industrial facilities. The scale of these plants requires some 1 million tonnes per annum of dry biomass, which equates to almost double this tonnage of fresh biomass (i.e. with fresh mallee between 40% and 50% moisture content on a wet basis). In European trials stem wood is usually the feed, so gasification of whole mallee trees (including leaves and bark) would require specific development work. (Note that the gasifier at the Narrogin IWP demonstration plant successfully gasified leaves.). As illustrated in Figure 6-3 incoming biomass would be treated to remove dirt, dry it to the required moisture level, and obtain the required biomass particle size specifications. Oil mallee biomass would in principle be a suitable fuel.

6.5 Product Storage and Use

The BtL fuel that is mainly being targeted for production is synthetic diesel, as it has very similar, and indeed in many respects superior properties to petroleum diesel. It can use the same storage and supply logistics as petroleum diesel, and can be blended in any proportion with such fuel. As such, the entire range of current petroleum diesel storage and transportation infrastructure can be used with BtL syn-diesel. Importantly, if this fuel is a direct substitute for diesel (and does not require a blended fuel such as ethanol-petrol blends) this syn-diesel could be used directly within Western Australia.

The storage and handling of methanol is well understood within the chemicals industry, where large quantities are already produced from natural gas and coal. Methanol is a major internationally traded commodity. Methanex, a Canadian company, has plants in New Zealand, Chile, the West Indies and elsewhere.

DME has similar physical properties to LPG, and here again there will be no unique storage and transportation issues beyond those required for the similar LPG fuel.

6.6 Cost Estimate

Choren has employed some 100 million Euros in their Beta plant at Freiburg (16.5 million litres per annum BtL). Choren were contacted as part of this study, but were not able to provide any specific costing for their next, full-scale plant.

Hamelinck[41] modelled Biomass Integrated Gasification Fischer Tropsch plants and determined the investment cost of a 367 MW input BIG-FT system to cost in the range $280-450 million US dollars (2004), depending on configuration. Hamelinck calculated that in the short term, the production cost of F-T diesel would be US$15/GJ, and in the longer term with technology refinement, could reduce to US$10/GJ. Assuming a lower heating value of 43.5 GJ/tonne and a density of 780 kg per cubic metre (actual values from the Güssing plant), the near term production cost would be US 50.9 cents per litre. This cost estimate assumes a biomass cost of US$2/GJ (dry biomass, which equates to approximately US$40 per dry tonne or approximately A$25 per green tonne using A$1 = US$0.85). It also assumes electricity cost of 5.7 US c/kWh, the plant operating for 8,000 hours per annum, an interest rate of 10% and a project life of 15 years.

It would be expected that for a relatively remote location in the Avon catchment, higher plant construction costs and the distance to markets would raise the delivered price of such F-T diesel the estimate by Hamelinck. A more detailed analysis would be required to refine the cost estimate for the Avon region.

6.7 Discussion

The production of liquid fuels using thermal gasification followed by synthesis is well established, using coal and natural gas as feedstocks. The challenges for adapting this technology for biomass feedstocks, such as oil mallee biomass, include:

---

[41] Fischer-Tropsch liquids and power from biomass via gasification: exploration of the possibilities, in Outlook for advanced biofuels, Utrecht University, 2004

- securing large, reliable quantities of biomass at low cost
- producing a clean syngas with appropriate composition
- operating at a scale to allow low cost product fuel.

BtL is yet to be demonstrated at a large, commercial scale, although there is considerable investment and activity, most notably in Europe, towards this goal. Choren, one of the leaders in BtL, is currently constructing a semi-commercial scale plant at Freiburg, Germany. Following success with this plant, Choren has plans to roll out commercial scale plants that will each produce 200,000 tonnes per year of synthetic diesel. Production costs are expected to be higher than fossil fuel equivalents for at least several years.

Given the joint drivers of global warming mitigation through renewable fuels (BtL has very good greenhouse gas performance) and the need to find alternatives to fossil fuel in the near to longer term, BtL is one of the more prospective bioenergy technologies on the horizon. One of the strengths of BtL is its ability to produce liquid fuels that will fit into the existing liquid fuel markets in Western Australia. For example, synthetic diesel from BtL facilities will be easier to use in WA than large quantities of ethanol. With the existing vehicle fleet ethanol may only reasonably be considered as a blend with petrol for local use, whereas synthetic diesel may be used as a fuel in its own right to replace diesel made from crude oil.

It must be remembered that much of the technology to be used in a BtL plant is adapted from the fossil fuel industry. The synthesis pathway to make gasified wood into liquid fuels can also be used with gasified coal, or a syngas from natural gas itself. There is already a significant industry world wide that uses natural gas to make chemicals/fuels such as methanol this way and, with rising prices for crude oil, it is to be expected that using some of WA's abundant natural gas to make liquid fuels will also be examined closely.

7. Biomass to Ethanol

7.1 ***Summary***

It is technically feasible to make ethanol from biomass. Wood contains significant quantities of sugar that may be converted to ethanol, provided these sugars are first "released" from the wood and made available for fermentation. It is also possible to break the wood into small molecules ("syngas") via gasification, and then rebuild those molecules into ethanol via chemical synthesis.

These different technologies have been broadly understood for many years but have never moved past the pilot or demonstration stage. This may change over the next few years, as earlier in 2007 the US government announced significant funding support for six commercial scale biomass to ethanol plants to be built in the USA. The total investment on these projects over the next five years could exceed A$1 billion. In less than ten years it should be possible to engage with companies offering proven biomass to ethanol technology for the construction and operation of biomass to ethanol plants in the Avon catchment.

In addition to reliable, competitive technology, any biomass to ethanol plants in the Avon need reliable, competitive feed and markets. A full scale biomass to ethanol plant is expected to use more than half a million tonnes of green biomass each year. Ethanol may be used as a blend with petrol in WA. However the market for such blends may be fully met by grain to ethanol plants before any biomass to ethanol plants are operational. Therefore the ethanol produced may need to be transported to markets outside WA.

7.2 ***Technologies***

A number of alternative process pathways are available to turn woody biomass into ethanol. They all have three main stages:

- Pre-treatment of the biomass to make it amenable for further processing
- Break the wood down into components, via hydrolysis or via gasification
- "Reform" those components into ethanol, via fermentation or catalytic synthesis.

Hydrolysis breaks wood into its basic sugars. The cellulose and hemicellulose components of wood are essentially long, molecular chains of sugar. They are protected by the lignin in the wood, which may be considered as the crystalline structure that binds the biomass together. So-called C6 or hexose sugars are associated with the cellulose. C5 or pentose sugars (the molecule is composed of five carbon atoms) are associated with the hemicellulose. Conventional yeast is adapted to C6 sugars, but the fermentation of pentose sugars to ethanol requires yeasts that are genetically adapted or different micro-organisms altogether.

Gasification breaks wood down into simple molecules such as carbon monoxide and hydrogen.

The processes described below have all been demonstrated at the pilot scale and demonstration at the commercial scale is expected in the next few years with grant support from the US Department of Energy (see section 7.3).

(a) Acid Hydrolysis

Acids can be used to break cellulose and hemicellulose into their component sugars. Both dilute and concentrated acid hydrolysis have been under development for many years, and are mainly applicable to more heterogeneous biomass, including municipal solid and urban green wastes. Being relatively well developed, there is perceived to be less scope for further improvement to reduce costs and increase performance of acid hydrolysis when compared with other methods for hydrolysis. When dilute acid hydrolysis is applied, this tends to be in a single pass process, while concentrated acid hydrolysis invariably requires recycling of the acid for environmental and cost reasons. Acid hydrolysis is considered expensive in terms of capital outlay and ongoing operating and maintenance.

Acid hydrolysis, which liberates the sugars, is followed by fermentation of the sugars to ethanol, and distillation to concentrate and recover the ethanol from the fermentation liquid.

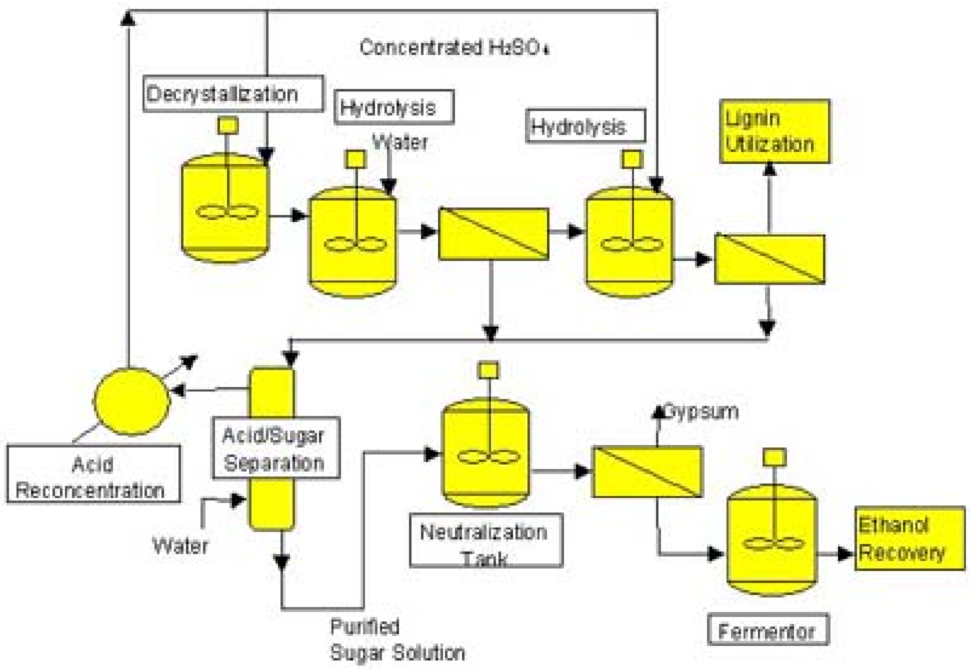


Figure 7-1: Biomass to Ethanol Using Concentrated Acid Hydrolysis

(b) Enzyme Hydrolysis

Hydrolysis can also be achieved using enzymes. The enzymes need to be specifically matched to the biomass feedstocks and the biomass needs to be more homogeneous than for acid hydrolysis. In recent years there has been a dramatic fall in the cost of enzymes, with the US National Renewable Energy Laboratory reporting a thirty fold reduction in enzyme costs for cellulosic ethanol following a government-funded development program with two major enzyme companies. For harvested oil mallees, which would include leaf, twigs, bark, as well as stem wood, enzymes would need to be specifically developed to efficiently and effectively hydrolyse this heterogeneous biomass. The oil component of oil mallees is known to have bactericidal properties, and this or other components of the mallees may further complicate the selection and use of enzymes.

(c) Gasification and Reforming

Synthesis gas from the thermal gasification of biomass, which consists predominantly of hydrogen and carbon monoxide, can be chemically processed using catalysts to produce ethanol. This is another variant on BtL biofuel, covered in Section 6 of this report. An advantage of this approach is that, compared with hydrolysis, the process is not as dependent upon the cellular structure of the biomass.

Gasification enables the biomass to be thermo-chemically transformed into molecular hydrogen and carbon monoxide, and allows a wide variety of feedstocks to be used. The reforming process eliminates the need for micro-organisms to produce the ethanol, which is instead produced via chemical processing.

A leading developer of this technology route, Range Fuels has demonstrated a partially integrated process at 5 tons/day in Colorado, USA and has publicly announced plans to build and operate commercial scale facilities in Georgia, USA for the fully integrated process. Construction permits for the plant were announced in July 2007, and Range advises that the first stage (approx. 80 Ml/year capability) is targeted for completion during 2008[42].

It is noted in Section 6 that other BtL pathways exist, besides this ethanol route, indeed the senior VP Technology for Range Fuels has extensive experienced gained in the coal to liquids plants operating in South Africa. As WA does not have established ethanol infrastructure, there appears to be more merit in adapting the gasification front end to synthetic diesel production, which is totally compatible with existing petroleum fuel infrastructure, unlike ethanol.

(d) Gasification and Fermentation

US company Bioengineering Resources Inc. (BRI) has developed a novel fermentation process that can convert carbon monoxide and hydrogen (product gases of biomass gasification) into ethanol. The process was originally developed to deal with waste gases from the refining industry. BRI began their work in 1994 with funding from the US DOE.

This technology is designed to handle a syngas with approximately 20% each of carbon monoxide and hydrogen. The organism, which belongs to the clostridium family, is reported to be able to tolerate contaminants such as sulphur, methane and nitrogen. The basic process flow is shown in Figure 7-2 below.

[42] http://www.rangefuels.com/Range-Fuels-awarded-permit-to-construct-the-nations-first-commercial-cellulosic-ethanol-plant

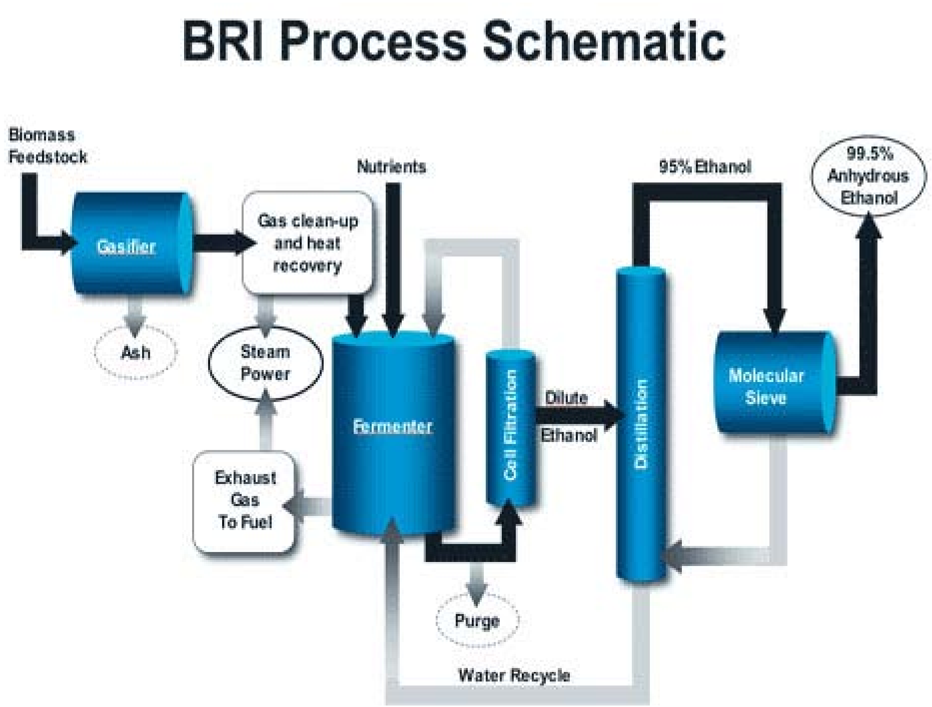


Figure 7-2: BRI Process Schematic

The fermentation vessel operates at slightly above ambient temperatures (37°C) but at moderate pressure (2.8 bar) so that reaction rates are increased. BRI claims that the organism is stable and able to recover after a process upset. Ethanol is toxic to the culture so ethanol concentrations are kept below 3% v/v in the reactor. The organism consumes carbon monoxide, carbon dioxide, and hydrogen to produce ethanol and acetic acid. The acetic acid production is minimized by the recycle of distillation bottoms containing some acid back to the fermenter. BRI reports that the pathways are:

- 6CO + 3H2O > C2H5OH + 4CO2 and
- $6H_2 + 2CO_2 > C_2H_5OH + 3H_2O$

These reactions indicate that carbon dioxide is produced along with the ethanol (as per a yeast fermentation of sugar to produce ethanol). The fermentation will produce an excess of cell mass over time that will have to go either to a treatment plant or possibly, after de-watering, back to the gasifier.

One of the distinct advantages of this gasification-fermentation route is that a wide variety of biomass types can be accommodated, such as whole mallee trees. There would be no co-products involved other than the excess energy generated by the system. This energy would be in the form of methane and could be used in a variety of applications including a gas turbine cogeneration system. Preliminary calculations would indicate that ethanol yields of 375-400 litres per tonne of wood could result.

As noted in Section 6 gasified biomass can also provide a feedstock for catalytic conversion to synthetic fuels, including Fischer Tropsch diesel. As WA does not have an established ethanol industry, syndiesel may be a more appropriate fuel for this region.

7.3 The US Biofuels Initiative

Central to the development of a commercial biomass to ethanol business is the work to take place in the United States over the next decade. This work is largely a result of the "US Biofuels Initiative". The key element of this initiative may be summarised as follows[43]:

"The Office of Energy Efficiency and Renewable Energy's Office of the Biomass Program has implemented the Biofuels Initiative (BFI), with the goal of reducing U.S. dependence on foreign oil by meeting the following targets:

- To make cellulosic ethanol (or ethanol from non-grain biomass resources) cost competitive with gasoline by 2012.
- To replace 30 percent of current levels of gasoline consumption with biofuels by 2030 (or 30x30)."

This initiative has resulted in significant US government support to develop commercial scale biomass to ethanol technology. Most particularly, in February 2007 the US Department of Energy (DOE) made the following announcement[44]:

"…DOE will invest up to $385 million for six biorefinery projects over the next four years. When fully operational, the biorefineries are expected to produce more than 130 million gallons of cellulosic ethanol per year. This production will help further President Bush's goal of making cellulosic ethanol cost-competitive with gasoline by 2012 and, along with increased automobile fuel efficiency, reduce America's gasoline consumption by 20 percent in ten years."

The support offered by the US Government will cover part of the cost of each of the six commercial scale demonstration plants. The proponents of these plants must secure private funding for the balance of their work. Combined with the industry cost share, more than US$1.2 billion will be invested in these new biorefineries[45]. The projects are summarised in Table 7-1 below.

It is important to note that this work builds on a considerable history of research and demonstration of biomass to ethanol in the United States. Enecon prepared a report on biomass to ethanol technologies in 2002 for the Rural Industries R&D Corporation (RIRDC). A summary and download link for the full report are available at the RIRDC website - http://www.rirdc.gov.au/reports/AFT/02-141sum.html

Table 7-1: Ethanol Projects to be funded under the US Biofuels Initiative

Company	*Plant size (Mil US Gal/yr)*	*Feed*	*Location*	*Technology*
Abengoa	11.4	Ag. residues	Kansas	Enzymatic hydrolysis or gasification

[43] http://www1.eere.energy.gov/biomass/biofuels_initiative.html
[44] http://www.energy.gov/news/4827.htm
[45] www.eere.energy.gov/news/enn.cfm, 7th March 2007

ALICO	13.9	Wood and cane	Florida	Gasification then fermentation
BlueFire	19	Urban wood and green waste	California	Concentrated acid hydrolysis
POET (formerly Broin)	~30	Corn residues (integrated with corn plant)	Iowa	Enzymatic hydrolysis
Iogen	18	Straw	Idaho	Enzymatic hydrolysis
Range Fuels	40	Wood residues	Georgia	Synthesis gas then reforming to ethanol and methanol

7.4 Biorefineries

Processing crude oil in an oil refinery is an accepted practice worldwide. Importantly it allows the maximum value to be extracted from the crude oil, by making products for energy, and also products for plastics and other applications.

Many groups are examining biomass in a similar light, with a view to creating commercial "biorefineries". Such processing facilities would utilise biomass for energy, but they would also create additional value by taking some of the processed biomass to make chemicals or other high value products. The logic is simple – maximise the revenue streams to enhance the commercial viability of the business. There are a number of examples of this approach:

- One already under development in Western Australia (and not reviewed here) is the Integrated Wood Processing concept. Whole tree mallee biomass is processed to create electricity and activated carbon, and eucalyptus oil is extracted from the leaves.
- Fast pyrolysis also creates the opportunity to produce multiple products, by fractionating the pyrolysis oil. This technology is discussed in Section 5 of this report.
- Other examples of biorefining include the corn to ethanol industry in the USA. Ethanol is made from one part of the corn, while other parts of the corn kernel have a variety of uses for animal and human food. This is similar to the use of molasses to make ethanol in sugar producing countries such as Australia and Brazil. The sugar mill and distillery are optimised wherever possible to extract the maximum value from the sugar feed, for human consumption, ethanol production and cogeneration of heat and electricity form the waste cane fibre (bagasse).

A number of overseas organisations are developing new processes to turn biomass into plastics and other chemicals. In addition to the renewable fuel initiatives described above, the US Government is allocating significant funds to speed up the development of a commercial biorefining industry. In May 2007 the US Department of Energy made a provisional allocation of up to US$200 million to support a five year program for development of new biomass processing technologies that combine the production of renewable transport fuels with bio-based chemicals and substitutes for petroleum based feedstocks and products[46].

There are already commercial scale plants in the USA that produce renewable plastics. Several plants process starch from corn or other sources. At least two large commercial plants use sugars derived from corn as the starting point for plastics:

- The processing facility in Nebraska owned by Natureworks LLC (part of the Cargill group) has the capacity to produce up to 140,000 tonnes per year of PLA (poly lactic acid) plastics, via fermentation of sugars derived from corn.
- On 8th June 2007 the DuPont Tate & Lyle joint venture officially opened its US$100 million bio products plant in Tennessee, as shown in the photograph below[47]. This plant also uses sugar from corn as the feed for fermentation to make propane-diol, a chemical that in turn may be used as the starting point for numerous materials.

These plants both use corn-derived sugar as the starting point for fermentations. A key outcome of the work underway at present to develop competitive ethanol production from biomass is the cost-effective release of sugars from that biomass. Biomass-derived sugars are somewhat different to corn-derived sugars (as pentose sugars are derived from the hemicellulose in wood). However, if the wood derived sugars can be made at a competitive price, the growing renewable plastics industry will be able to consider them as feedstocks for large-scale plants similar to those described above.

Figure 7-3: DuPont Tate & Lyle Commercial Bio PDO facility at Loudon, Tennessee

7.5 Biomass Requirements

The amount of biomass required for a commercial scale ethanol plant is a function of:

46 http://www.energy.gov/print/5031.htm
47 Reproduced from http://www.tateandlyle.presscentre.com/Content/Detail.asp?ReleaseID=578&NewsAreaID=2

- the size of the plant
- the efficiency of conversion of biomass to ethanol
- other use of biomass on-site, for example energy supply.

The size of a commercial scale ethanol plant (in the US corn industry) typically varies from 100 to 200 megalitre of ethanol output per year.

The US Government's National Renewable Energy Laboratory (NREL) has examined the yield of ethanol from biomass and has also projected the increased yields possible via process improvements[48]. NREL predicted that ethanol yields would progressively increase from 68 to 112 US Gallon of ethanol per dry ton of feed. This equates to a range of 140 – 230 litres of ethanol per tonne of green feed. Biomass requirements may therefore vary as follows:

- For a highly efficient conversion at 200 l/tonne (litres of ethanol per tonne of wood feed) in an ethanol facility producing 100 ML/y, green biomass feed will be required at 500,000 tonne per year.
- For a less efficient plant at say 140 litres per tonne and 200 ML/y of ethanol production, the green biomass requirement will be 1.4 million tonne per year.

7.6 Product Markets

In 2004 Western Australia consumed 1.98 billion litres of petrol and 1.51 billion litres of diesel[49]. On this basis a single large-scale (200 million litre per year) ethanol facility could provide approximately 10% of the state's petrol requirement as an E10 blend with petrol. The use of higher blends of ethanol and petrol will require flexible fuel vehicles which, while not necessarily more expensive than normal vehicles, would involve change over of the WA vehicle fleet. Use of ethanol in diesel requires emulsifiers, which are available but add to the cost of the fuel blend. Also, adding even small quantities of ethanol to diesel changes its flammable vapour emissions, potentially requiring a whole new regime for its safe handling and transport.

So the use of more that 200 ML of ethanol per year in WA in the foreseeable future is considered unlikely and any WA-made ethanol above this amount could be expected to require transport to other parts of Australia or overseas to reach suitable markets. The cost of such transport will need to be considered as part of the economic viability of a large ethanol industry in WA.

7.7 Progress to a Commercial Industry

In a recent presentation in the USA[50], Jacques Beaudry-Losique of the US Department of Energy (DOE) described the timetable for biomass to ethanol. The development of the industry is summarised in Figure 7-4 below.

[48] NREL Report No. NREL/TP-580-26157, July 1999
[49] http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/SUST/BIOFUEL/OverviewWAbiofuelsIndustry.pdf
[50] 29th Symposium on Biotechnology for Fuels and Chemicals, 1 May 2007

First production of ethanol from commercial scale facilities in the USA is targeted for 2011. Production increases are expected thereafter, with cellulosic ethanol providing much of the growth in overall ethanol production in the USA and reaching more than 10 billion litres per year by 2017.

Ethanol from biomass could be commercially available in the USA from 2011. Importantly, the US DOE expects that processing developments will continue to be made through that decade, allowing the cost of ethanol from biomass to progressively decline. The figure below from the Beaudry-Losique presentation summarises the transition that is sought over the next twenty or so years.

Clearly the DOE believes that building a successful commercially competitive industry requires a government-industry-research collaboration that extends well beyond the laboratory and the early commercial plants.

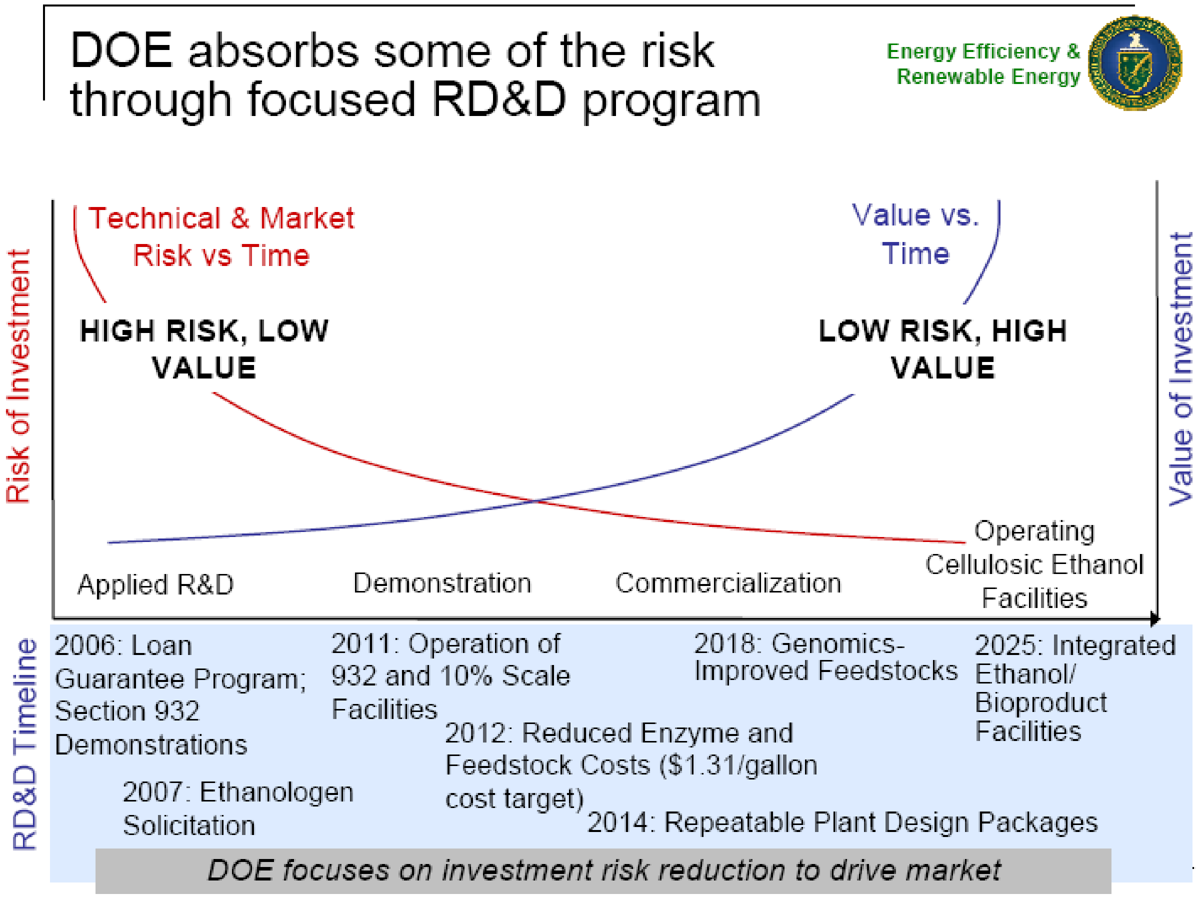


Figure 7-4: Timeline for commercial development of biomass to ethanol

7.8 Discussion

With the financial support being provided by the US government as described above, ethanol from biomass appears to be better placed now than ever before for a move from technical feasibility to commercial operation. If work in the USA goes according to plan there will be commercial scale examples of biomass to ethanol in operation in a few years, although it will take several more years before the lessons learnt from the operation of these initial plants are used to design and build additional plants. Nevertheless, access to working, reliable, commercial scale biomass to ethanol technology may be achieved within ten years.

Ethanol from any source may be blended with petrol (typically up to 10%) and used in most of the existing petrol-fuelled transport fleet in Australia. Higher blends with petrol require specific vehicles, such as the flexible fuel vehicles being used increasingly in countries with significant local ethanol production such as the USA and Brazil. It is not clear whether the introduction of flexible fuel vehicles (with attendant maintenance and support requirements, dedicated transport and storage for ethanol fuels, modifications to service stations etc) is feasible for WA. In the absence of such changes the use of ethanol in WA will probably be limited to a 10 % blend and this may be met via proposed grain to ethanol plants before any biomass to ethanol plant is possible. Biomass to ethanol may therefore need to be considered as a means to making fuel for export, adding the cost of transport to the base cost of the fuel.

8. Discussion and Moving Forward

8.1 Technologies Reviewed

Four bioenergy technologies are reviewed in this report. Their short to medium term business potentials are summarised below:

(a) Wood Pellets

From the data developed during this study it appears that a viable business is possible now to make wood pellets in WA and transport them to markets in Europe or Japan. Such a business could be able to pay growers for biomass feed and also return a profit to the developers and operators of the pellet making facility.

This finding comes with qualifications. The published prices for pellets in Europe and Japan vary considerably between countries and over time. The variability in pricing found in the published literature may be due to one or more of the following:

- price spikes, caused by lack of short term production capacity to meet increases in demand
- variable demand caused by unseasonable weather
- variation in government energy policy over time and between countries
- published prices referring, without sufficient clarity, to different stages of the supply chain (from arrival in bulk at major ports, through to bagged pellets for domestic consumers in a retail environment).

Preliminary modelling shows a profitable business based on the upper price range quoted for pellets. However, at the lower part of the price range, a pellet business based on farm forestry in the Avon is not commercially viable.

The key factor in creating an Avon pellet industry therefore appears to be gaining security over suitable product pricing and the length of supply contracts, so that funding for pellet plants in the Avon may be sought on a low risk basis and favourable terms.

Pellet mills can be built at almost any size. Importantly for the Avon they can be geared towards realistic levels of biomass supply which take into account issues such as planting densities and transport distances from farms to the pellet mill.

The European and Japanese pellet markets are in transition, as the policy-driven, large scale renewable energy aspects of pellet fuels take a greater role. Pellets from mallee trees may look and behave differently to the pellets currently being made for the European and Japanese markets. Mallee pellets may need careful marketing to the "traditional" customer base, which is familiar with pellets made from northern hemisphere wood. New, large scale users such as power companies may be more accepting of mallee pellets in the short term but may also seek different pricing.

In addition to market perceptions, the applicability of processing equipment will need review. The particular requirements of preparing and pelletising hardwood mallees, as opposed to softwoods, may require design modifications or reappraisal of machine throughputs and wear characteristics. Tests with mallee biomass and pelletising equipment can be undertaken to better understand such issues and allow more accurate operating and capital costs to be developed.

Recommendation – A pellet industry in the Avon is possible, and further work is recommended to clarify this opportunity.

- In the short term this should focus on gaining a better understanding of selling prices and contract terms, via discussion with potential customers in Europe and Japan. Financial support for such work may be available from Austrade or COMET (federal government) or from various support programs operated by the state government.
- Markets for household pellet use and large scale renewable energy applications should both be investigated. The multiple environmental benefits of the mallees should be emphasised.

(b) Fast Pyrolysis

Fast pyrolysis technology is commercially available now, with three overseas organisations having built and operated full scale plants in recent years. One of the technologies, that of Canadian group Dynamotive Energy Systems Corporation, is already licensed into Australia via the Renewable Oil Corporation (ROC) in Melbourne. ROC is planning to have Australia's first commercial scale pyrolysis plant under construction in 2008, using wood wastes as feed.

Pyrolysis technology is still at the early stages of commercial development, and cost reductions though design improvements and operating experience are to be expected over coming years. Pyrolysis plants overseas are focusing on markets for food flavourings and using bio oil as a replacement for heating oil. Unfortunately neither market represents a significant short term opportunity for pyrolysis plants built in the Avon catchment.

If bio oil is competing directly with fossil fuels, increases to the price of crude oil will enhance the opportunities for bio oil. Goldman Sachs Group, the world's largest securities firm, predicts that crude oil may reach US$100 per barrel by 2009 or even earlier[51]. It must be remembered, however, that short-term price spikes for crude oil are not enough to initiate the capital expenditure required for pyrolysis plants or other alternative technologies. The organisations funding new bioenergy businesses need to see a profit margin that is sustainable over many years to recover the capital cost of such facilities.

Research into biomass pyrolysis is underway at many locations world wide, including several groups in Australia. Much of this research is being carried out to develop new uses and markets for the pyrolysis oil and charcoal, which will increase the opportunities for fast pyrolysis as well as its commercial competitiveness.

Fast pyrolysis works with any form of biomass, provided that the biomass is first dried and ground to a suitable size. The largest fast pyrolysis plant in the world requires 65,000 tonnes of dry biomass feed, equivalent to approximately 110,000 tonnes of green mallee biomass per year.

---

51 ttp://economictimes.indiatimes.com/Markets/Commodities/Oil_at_100_may_be_months_away_not_years/articleshow/2228840.cms

Recommendation – The commercial operations established overseas, together with the work being undertaken on new markets and opportunities, mean that pyrolysis may be ready to offer a business opportunity in the Avon catchment in the next few years. At such a time Avongro will need to make a compelling case as a feed supplier to be considered for investment and plant construction.

It is recommended that, as a minimum, Avongro maintain a watching brief on these developments.

If further action is possible, we recommend that Avongro continues to work towards being able to offer reliable biomass supply in terms of quantity, quality and cost. On-farm yields and costs are a part of this information and are currently better understood than the other part: cost-effective harvest and delivery to a processing plant. There is still work to be done by Avongro and others before they can offer a reliable delivered price for biomass to bioenergy plants.

(c) Biomass to Liquids

Biomass to Liquids (BtL) technology is not yet commercially available. However the key process steps are understood and a demonstration scale plant is nearing completion in Germany. This plant represents the initiatives of specialist BtL company Choren Industries along with technology from Shell. Successful operation of the demonstration plant will assist the construction of one or more full scale plants later this decade.

BtL technology targets the production of liquid fuels that may be integrated seamlessly into the current transport fuel industry, typically as a blend with, or replacement for, diesel transport fuel. As such the output of several BtL plants in WA could be used within the state.

If the work goes according to plan, Choren will be able to consider construction of commercial scale plants in the next decade. These plants are expected to require approximately one million tonnes of dry biomass each year, so the preliminary work required to provide a reliable and sustained feed supply from mallees is at a much larger scale than anything achieved in WA thus far.

Recommendations:

1. For the next few years, maintain a watching brief over Choren's progress.
2. The mallee industry needs to determine how it could develop and supply biomass at rates of one million tonnes per year.
3. A related issue is the characteristics of mallee as a fuel for Choren's BtL process. Tests could be arranged at Choren's R&D facilities in Germany. However these tests should not be pursued until the mallee industry has a clear strategy for fuel supply at the quantities required and a better indication that a BtL industry in WA will be commercially viable. The latter point will depend in part on long term legislation for renewable transport fuels in Australia (remembering that policy and legislation supporting the commercial application of this technology in Europe may be quite different to policy and legislation in Australia).

(d) Biomass to Ethanol

Biomass to ethanol is not yet commercially viable. However, major government/industry initiatives are underway in the USA that are expected to result in a number of commercial-scale plants being built over the next few years. According to the development timetable of the US Department of Energy there will be up to six commercial scale biomass to ethanol plants in operation in the US by 2011. Subsequent plants are expected to embody lessons learned on these plants, as well as process improvements developed by a number of concurrent research programs over the next 5-10 years.

There are several different process pathways to produce ethanol from biomass. Each pathway has its own particular characteristics, which impact on its applicability to a whole tree mallee feedstock. Acid hydrolysis and gasification appear to be better than enzymic hydrolysis for the use of a mixed feed such as whole tree mallees.

A commercial scale biomass to ethanol plant can be expected to require between 500,000 and 1.5 million tonnes per year of green biomass. As noted for BtL above, work required to provide a reliable and sustained mallee feed to a commercial ethanol plant is at a much larger scale than anything achieved in WA thus far.

It is likely that ethanol will only be blended in small proportions with petrol over the foreseeable future in WA. This limits the size of the local market for fuel ethanol and suggests that (with the likelihood of grain to ethanol plants being built to satisfy WA demand) any ethanol made from biomass will need to be transported to other Australian or Asian markets.

Recommendations:

1. For the next few years, maintain a watching brief over progress, especially in the USA.
2. The mallee industry needs to determine how it could develop and supply biomass at rates of at least half a million tonnes per year.
3. Progress on biomass to ethanol should be compared against progress with BtL, as the latter appears to offer a fuel that is more easily integrated into the WA markets for liquid fuels.

8.2 A Possible Future Scenario

The Avon catchment has the land area to support a farm forestry industry that could supply millions of tonnes of biomass each year. This is subject to the progressive development of sustainable businesses that purchase the biomass and provide a mix of commercial, environmental and social benefits to the growers, their customers and the state.

The potential size of this farm forestry opportunity means that there is ample scope for more than one new technology to be utilised in the Avon catchment. Multiple plants using a variety of technologies can be developed over time as the area planted to trees increases. One <u>hypothetical</u> development scenario is as follows:

- Several pelletising plants are built over the next five years. These utilise existing mallee plantings (and residues from the plantations that support the existing export wood chip industry) and catalyse further mallee plantings. Overall size of industry will depend on longer term development of the pellet markets in Europe and Japan.

- Pyrolysis plants enter the market in approximately five years when the price of crude oil, coupled with value-added products and Australian participation in international carbon trading, make it viable to make commodity fuels and chemicals for Asian markets. Access to large, regional, commodity markets suggests up to twenty plants built over a fifteen year period.
- The diversity and extent of planting created by these industries (and others such as Verve Energy's IWP) creates an environment where feed supply is deemed sufficiently reliable to establish the first biomass to liquids plant in the latter part of the next decade.

So further work on an industry can begin immediately, and by 2020:

- Farm forestry in the Avon catchment could produce several million tonnes of biomass per year and support multiple businesses that utilise several different technologies.
- All processing is in rural WA, with each new processing facility becoming a major source of direct and indirect employment in a country town.
- Tree planting occurs at a scale many times that which would be achieved without a commercial industry, contributing to the sustainability and profitability of farms and preventing ongoing damage to non-farm land and rural infrastructure.
- Some products help to further reduce greenhouse gas (GHG) emissions in WA.
- Other products are exported and achieve GHG reductions in Asia and Europe.

8.3 Implications for Growers

Two of the technologies reviewed (pellets and pyrolysis) are commercially available now. One of those (pellets) also has large, well established product markets and may offer an immediate opportunity for mallee growers.

The remaining two technologies (ethanol and synthetic diesel) have clear, well-funded and managed pathways to commercial plants in the next five years.

Pellet plants and fast pyrolysis plants both need biomass at 100,000 tonnes per year or less (green basis). In contrast, commercial scale plants for ethanol or synthetic diesel next decade will require at least 500,000 tonnes and possibly more than one million tonnes of biomass per year.

For all of these technologies it will be possible to engage with experienced equipment suppliers or technology providers. For the pellet plants it is not clear whether third parties exist that will take on a funding and operation role for the plants. For all other technologies, the technology developers or licensors identified in this study are also engaged in funding and operational aspects of their businesses.

For all of these technologies, mallees will need to "compete" to become a feedstock:

- The European pellet market is currently dominated by European sawdust as feed, and also by pellet supply from Canada's huge forest products industry.
- An Australian organisation, Plantation Energy, is considering a pellet plant in WA, with feed coming from residues created already by the plantation eucalypt industry that supports the export wood chip businesses in WA. The tops and branches from this industry are also under consideration by at least two organisations seeking to develop large,

conventional bioenergy plants connected into the main SW grid in Western Australia at appropriate points (most of the SW grid in the low rainfall regions is not capable of taking such quantities of electricity without major upgrade).

- Renewable Oil Corporation is initially seeking low value wood waste in major Australian cities as feed for its fast pyrolysis plants.
- US ethanol companies are focused on huge US market for ethanol, with feed supplied from agricultural residues such as straw, corn cobs and purpose grown biomass on marginal land in the USA.
- Choren in Germany expressed interest in the opportunity in WA but did not have time to provide any more information for this study due to commitments in Europe and the US.

All of the technologies reviewed in this study require significant investment for construction of commercial plants. All of them require fixed sites for construction and operation. All of them will require a high degree of reliability for biomass feed. The three main characteristics of biomass feed supply are:

- Cost
- Quantity
- Consistent quality.

Variability on each of these characteristics may be possible, but only within the limits determined by technical and commercial sensitivity analysis during feasibility work for a proposed bioenergy project.

Some of the elements that will improve the likelihood of a bioenergy industry in the Avon catchment are:

1. Determining the delivered cost of mallee biomass and implementing a plan that will achieve that delivered cost so that commercial decisions a can be made on it and risks understood and apportioned. This point is fundamental to any bioenergy industry in the Avon. The requirements for cost-effective harvest and transport of mallee biomass are unique because of the physical characteristics of the trees, the preferred planting layouts to maximise growth and benefit other farm operations, the distributed nature of the plantings and the need to harvest within a region for 11 or 12 months of the year so that processing plants have constant feed and no handling and storage costs.

2. Recognition and management of the "chicken and egg" situation regarding biomass growth and use. The developers of any new processing plant will need to be confident that the plant will have access to adequate supplies of biomass as soon as it starts operation. New plantings will generally require five years to reach the point that they can be harvested with low mortality. In the long term there may be a general pool of biomass that is available for a variety of customers. However for the development of the industry in the short term (perhaps a decade or more) it is likely that specific plantings will be arranged to match specific processing plants.

3. Maximising the recognition given to the non-commercial aspects of large scale tree planting. The environmental and social benefits provided by tree crops should be featured prominently in work and publicity by Avongro. They help to differentiate Avongro as a supplier and secure the support of government and industry.

4. Understanding and addressing any concerns that may be held by the Avon community. These may include:

    - the impact of large scale tree planting on general water availability
    - pollution and other impacts of bioenergy plants
    - the ability to actively participate in the industry at all levels rather than simply as a provider of raw materials
    - the sustainability of such an industry. Will bioenergy plants be reliable purchasers of biomass over ten years or more? What pressures will impact on biomass supply prices?

5. Looking for synergies between bioenergy and other uses for wood in the region. For example:

    - Can material for bioenergy be combined with production of wood fibre for medium density fibreboard or other engineering wood products?
    - Can material for bioenergy be combined with the production of high value, long rotation crops such as salmon gum or red morrell?
    - Can the MIS industry be usefully engaged, to enhance the commercial opportunities tree crops and bioenergy in the region?

9. Public Meeting

A presentation was made at a public meeting at York in WA on 7th August. This considered the activities of the study and its key findings.

A PDF file of this presentation should be available separately at the Avongro and Enecon websites.