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Biomass energy production in Australia

Status, costs and opportunities for major technologies

by C.R. Stucley, S.M. Schuck, R.E.H. Sims, P.L. Larsen,
N.D. Turvey and B.E. Marino

RIRDC Publication No 04/031
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An Australian Government Initiative

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A report for the RIRDC/ FWPRDC L & W Australia/ MDBC Joint Venture Agroforestry Program
(in conjunction with the Australian Greenhouse Office)

by C.R. Stucley, S.M. Schuck, R.E.H. Sims, P.L. Larsen, N.D. Turvey and B.E. Marino

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Researcher Contact Details

C.R. Stucley* and B.E. Marino
Enecon Pty Ltd
651 Canterbury Road
Surrey Hills VIC 3127
Phone: 03 9895 1250
Fax: 03 9895 1299
Email: cstucley@enecon.com.au
** Principal Contact*

Prof. R.E.H. Sims
Institute of Technology and Engineering
Massey University
Palmerston North, New Zealand

Dr S.M. Schuck
Stephen Schuck & Associates
7 Grassmere Rd
Killara, NSW 2071 Australia
Phone/Fax: 02 9416 9246
Email: sschuck@gibpond.net.au
Web: www.bioenergyaustralia.org

Dr P.L. Larsen and Dr N.D. Turvey
Greenfield Resource Options Pty Ltd
Unit 10, 43 Lang Pde
Milton, Qld 4064 Australia

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON   ACT   2600
PO Box 4776
KINGSTON   ACT   2604

Phone: 02 6271 4100
Fax: 02 6271 4199

Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

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Foreword

This project report was originally produced and released by RIRDC in 2004. It was jointly funded by the Joint Venture Agroforestry Program (JVAP) and the then Australian Greenhouse Office. At that time JVAP was supported by three R&D Corporations — Rural Industries Research and Development Corporation, (RIRDC), Land & Water Australia and Forest and Wood Products Research and Development Corporation (FWPRDC), together with the Murray-Darling Basin Commission (MDBC). Due to demand for printed copies of this report, it has become necessary to reprint this report. The reprinting of this report is funded by Bioenergy Australia (http://www.bioenergyaustralia.org), a government-industry alliance of more than 70 member organisations, set up to foster the development of biomass for energy and biobased products. RIRDC is Bioenergy Australia's lead organisation.

There is appreciation across much of rural Australia of the benefits that may be realised from increasing tree cover on farms, while still maintaining existing farming activities such as cropping and livestock production. Increased tree cover offers multiple benefits that will vary from location to location. These benefits can be significant and may include:

- environmental improvements, such as salinity, water quality and soil protection
- protection of biodiversity and remnant vegetation
- commercial opportunities for farmers to use farm forestry as an additional income stream.

Benefits may be both on-farm and off-farm. Flow on benefits include greater opportunities for sustainable agricultural practices, diversity of income streams for farmers, protection of rural infrastructure, and a generally improved outlook for Australia's rural communities.

While environmental and social benefits are admirable reasons for tree planting, farm forestry has a greater chance of adoption if it includes commercial returns for farmers. However there are large parts of Australia that do not have the necessary rainfall or proximity to coastal markets and ports to compete with existing plantations of softwoods, or with eucalypts such as blue gum. New products from wood are needed if these inland, low rainfall areas are to reap significant benefits from farm forestry. While any new industry will offer returns to the growers that supply it with wood, products that require large quantities of wood will catalyse tree planting on a scale that many agree is needed to offer a substantive solution to major issues such as salinity.

In the search for large, new industries that could utilise wood as feedstock, particular attention is being paid to renewable energies. Not only does renewable electricity offer its own environmental benefits, it also offers the potential of large markets for sustainably-grown trees across many parts of Australia.

This reprinted report complements RIRDC's diverse range of over 1000 research publications, and stems from our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. Since the original publication of this report, RIRDC has produced several bioenergy and bioproduct reports. Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/fullreports/index.htm
- purchases at www.rirdc.gov.au/eshop

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation
November 2008

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A number of individuals have generously provided assistance to the report team. Particular thanks go to Dr Roslyn Prinsley of RIRDC, who assisted in development of the study and its concepts, and in the arrangements for co-funding of the work.

Authors’ Disclaimer

This report has been prepared to assist with the appraisal of technologies and costs for projects involving energy from biomass. While every care has been taken in its preparation, the study work and report are preliminary only and no responsibility will be taken by the authors for omissions or inaccuracies, or for the use of this information by any other party.

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Executive Summary

This report examines the use of biomass to generate electricity and produce liquid transport fuels. There are many different forms of biomass, from forestry and agriculture and from a range of process industries. The main focus of this study is on biomass from forestry, particularly new forestry that may also achieve other environmental benefits in Australia's dryland regions.

The report is generally structured as follows:

a) Biomass is discussed first, including:

- Its properties and characteristics with respect to bioenergy
- The components and variables in the supply chain for harvesting biomass and transporting it to bioenergy plants
- Experience with specific feedstocks
- Costs of delivery for specific feedstocks.

With an emphasis on new tree planting in this study, examples of several short cycle tree crops are provided. Growing and harvesting short cycle mallee eucalypts in Australia is already reported by RIRDC [1], and the authors are not aware of other published work on short cycle forestry in Australia. This study has therefore used overseas experience for much of its discussion of biomass harvesting and transportation.

b) Technical sections are then provided to introduce current and projected technologies for production of electricity and liquid fuels from biomass feedstocks.

c) Following the technical sections is a summary of costs for several hypothetical examples of electricity and alcohol fuel plants, as well as overall costing of bioenergy systems and a preliminary sensitivity analysis.

d) With a view to understanding opportunities for new tree planting in Australia, case studies have been developed that examine short cycle (tree) crops for bioenergy and also for more conventional long rotation plantations. Locations examined are in south east Queensland and the Murray Darling Basin.

e) The work undertaken for the study showed that in many cases bioenergy alone is not a viable commercial driver for the new tree planting that the Joint Venture Agroforestry Project (JVAP) is encouraging across much of Australia. The report therefore examines other products that may be possible if biomass supplies are established for a bioenergy industry. Also considered are the other environmental and social benefits that would result from new tree planting and bioenergy in rural areas.

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[1] Integrated Tree Processing of Mallee Eucalypts. www.rirdc.gov.au/reports/AFT/01-160sum.html

1. Introduction - Biomass to Energy

1.1 Summary

Biomass is organic matter originally derived from plants, produced through the process of photosynthesis, and which is not fossilised (such as coal). Biomass can act as a store of chemical energy to provide heat, electricity and transportation fuels, or as a chemical feedstock for bio-based products.

Biomass resources include wood from plantation forests, residues from agricultural and forest production, and organic waste streams from industry, livestock, food production, and general human activities. Examples are wood chips, sawdust, cotton ginning trash, nut shells, manure and human sewage. This study has focused principally on biomass from trees and then agricultural crops. Other sources of biomass, such as animal and human wastes, are not considered here.

Biomass for energy is a unique form of renewable, solar energy. Of the massive 178,000 x 10^{12} Watts of solar energy that falls on the Earth's surface, some 0.02% or 40 x 10^{12} Watts is captured by plants via photosynthesis and bound into biomass energy. This translates into the production of some 220 billion 'dry' tonnes of biomass per year, which as an energy source represents some ten times the world's total current energy use. Currently some 15 percent of the planet's energy requirements are met from biomass, mainly for cooking and heating in developing countries, but also increasingly for fuelling a growing number of large scale, modern biomass energy plants in industrialised countries.

Bioenergy is essentially renewable or carbon neutral. Carbon dioxide released during the energy conversion of biomass (such as combustion, gasification, pyrolysis, anaerobic digestion or fermentation) circulates through the biosphere, and is reabsorbed in equivalent stores of biomass through photosynthesis.

Bioenergy plants can range from small domestic heating systems to multi-megawatt industrial plants requiring several hundred thousand tonnes of biomass fuel per annum each. There are also a variety of technologies to release and use the energy contained in biomass, such as combustion technologies that are well proven and widely used world-wide, and more efficient gasification plants that are currently at the demonstration stage but with potential for significant cost reduction as the technology is commercialised in multiple plants.

1.2 Background to Study

The Joint Venture Agroforestry Program (JVAP) was established in 1993 to foster agroforestry research and development. It is managed by the Rural Industries R&D Corporation on behalf of that organisation as well as the Land & Water Australia, the Forest and Wood Products R&D Corporation and the Murray Darling Basin Commission.

In response to the urgent need to develop new commercially driven tree production systems to manage dryland salinity, the program's highest priorities are:
- to develop new tree products;
- to redesign agricultural systems to incorporate woody perennials

for medium to low rainfall areas.

The introductory paragraphs of two recent publications by JVAP provide a summary of the situation:

"The replacement of native vegetation with crops and pastures that use less water has resulted in rising groundwater levels, causing salinity damage over wide and growing areas. The problem can be alleviated by tree planting, but this requires careful planning based on knowledge of the affected catchment"[1].

"Farm forestry is important to Australia's sustainable natural resource management. Tree planting has particular environmental rewards in areas with low to medium rainfall (400 – 700). Unless trees are profitable for farmers in these areas they will never be planted on a sufficient scale to achieve desired environmental benefits"[2].

The dryland agricultural regions that are already affected by salinity, or are susceptible to future salinity damage, cover much of the Western Australian wheat belt and also large parts of the Murray Darling Basin. Together they represent many millions of hectares that are either already damaged or are expected to be damaged if nothing is done. Commercial returns for biomass will catalyse tree planting by farmers. Each project to commercialise tree planting in an area can be of benefit to that area. However, solutions that can be seen to catalyse tree planting on a large or regional scale are of particular interest to groups such as JVAP.

Bioenergy, either as electricity or as liquid fuels, represents a huge potential market for new tree plantings. As such, bioenergy is of considerable interest to JVAP. The renewable nature of such energy is also of interest to the Australian Greenhouse Office as a potential method for large scale reduction of carbon dioxide emissions in Australia.

The extremely varied nature of biomass, and the many routes possible for converting the resource to bioenergy, makes the whole topic of biomass to energy a complex subject. For energy from wind, solar and hydro the conversion technology is the key component, whereas for biomass the whole system needs to be included. This entails gaining an understanding of the range of diverse biomass resources; how to cost-effectively process and deliver these resources in a useful form to the conversion plant; how biomass can be transformed into heat, electricity, or both in a co-generation plant, or how biofuels can be used for transport fuels. The use of biomass for building and construction materials (to displace the higher energy-containing steel, aluminium or concrete) or as a chemical feedstock (as a substitute for petro-chemicals) is largely beyond the focus of this report.

1.3 So what is Biomass?

From a renewable energy perspective, biomass can be defined as:

Recent organic matter originally derived from plants as a result of the photosynthetic conversion process or from animals and which is destined to be utilised as a store of chemical energy to provide heat, electricity, or transport fuels.

Biomass resources include wood from plantation forests, residues from agricultural or forest production, and organic waste by-products from industry, domesticated animals, and human activities.

The chemical energy contained in the biomass is derived from solar energy using the process of photosynthesis. (Photo means to do with light and synthesis is the putting together). This is the process by which plants take in carbon dioxide and water from their surroundings and, using energy from sunlight, convert them into sugars, starches, cellulose, lignin etc which make up vegetable

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[1] Trees, Water & Salt: An Australian guide to using trees for healthy catchments and productive farms – The JVAP Research Update Series No. 1, October 2000

[2] Emerging products and services from trees in lower rainfall areas - The JVAP Research Update Series No. 2, October 2000

matter loosely termed carbohydrates (and shown for simplicity as $[CH_2O]$). Oxygen is produced and emitted.

Light

$$CO_2 + 2H_2O \longrightarrow ([CH_2O] + H_2O) + O_2$$

Heat

All plant matter on Earth, both terrestrial and marine, is formed using this process. Animals that consume plant material and even carnivorous species all depend directly or indirectly on photosynthesis. Thus many animal products and wastes can also be classified as forms of biomass if used for energy purposes. Only a very small portion of the solar radiation reaching the Earth is used for photosynthesis (Figure 1-1).

World-wide, photosynthesis produces approximately 220 billion tonnes (dry weight) of biomass per year. As an energy source, this represents some ten times the world's current energy use. Globally around 55EJ/year of biomass is currently used for energy purposes, mainly for cooking and heating in developing countries, but also for running a growing number of large scale modern biomass energy plants. This is some 15 percent of the world's energy use. By comparison the world population consumes around 10EJ/year of energy in the form of food, which of course is a biomass energy resource in itself.

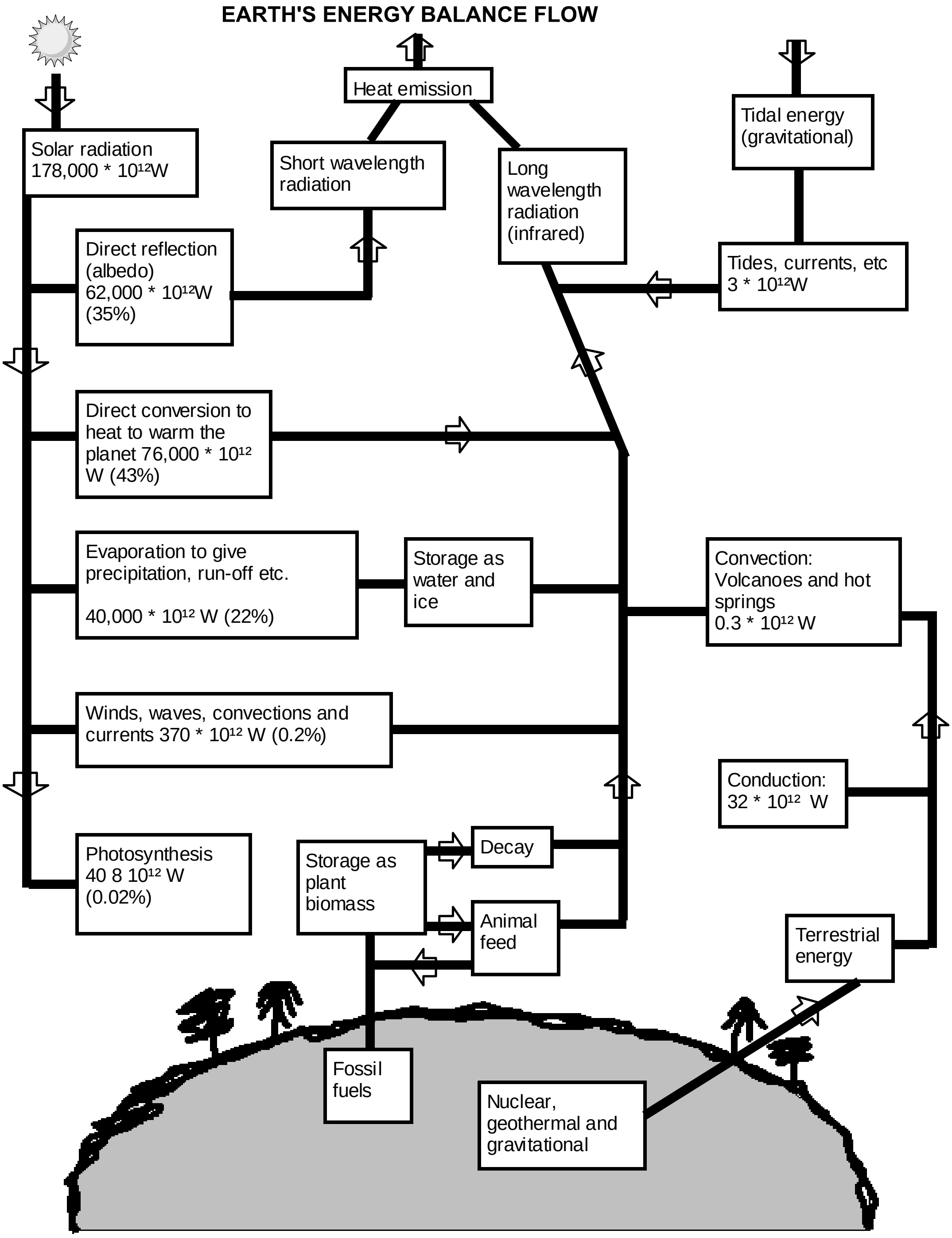

Figure 1-1: The Earth's energy flows are in balance
(Most of the Earth's energy supply comes from the sun but due to continuous heat losses to space, the Earth's energy flows are in balance.)

1.4 Biomass Fuels

Fuels resulting from biomass may be any solid, liquid or gaseous fuel produced from a wide range of organic raw materials, either directly from plants or indirectly from industrial, commercial, domestic, forest or agricultural wastes and produced in a variety of ways. These cover a very wide range of energy sources and scales (Figure 1-2), from simple firewood for small domestic fires to 500,000 tonnes of sugar cane residue (bagasse) a year used to fire a 50MW co-generation plant at a sugar mill.

Size	Properties served	Annual fuel demand	Vehicle movements	Conversion technology	Physical size	Investment cost
Domestic heating (15kWt)	Family dwelling	3 - 5 odt wood	2 - 3 tractor loads /y	Boiler or wood burner	Large suitcase	$ 100s
Small business heating (350kWt)	School or small factory	80 – 120 odt wood or straw	40 tractor loads /y	Boiler or straw burner and fans	Garage for one car	$ 10,000s
Small electricity generating plant (250kWe)	200 – 300 houses or small industry	1500 – 2000 odt wood or straw or wet wastes	6 x 20t trucks / week	IC* engine or gasifier	Small barn	$ 10,000s
Medium electricity generating plant (5MWe)	4000-6000 houses or small industrial estate	20 – 30,000 odt of range of biomass fuels	50 x 38t trucks / week	IC engine or steam turbine or gasifier	Petrol service station	$100,000s
Large electricity generating plant (30MWe)	25-35000 house or industrial estate	120-140,000 odt using dry biomass fuels	250 x 38t trucks / week	Steam turbine or gas turbine or combined cycle	Large church	$ millions
Combined cycle gas turbine or coal-fired station (500MWe)	500,000 houses or large industrial site	800 Mm3 gas or 1Mt coal	Pipeline Or 900 x 38t trucks / week equiv	Gas turbine and / or steam turbine	Large barn or Sydney Opera House	$ millions

*IC = internal combustion engine

Figure 1-2: An indication of the relative scales of energy conversion plants using biomass fuels and a comparison with fossil fuel power plants
[Source: Wood Fuel from Forestry and Arboriculture, Department of Trade and Industry & ETSU, July 1999].

The larger the project then usually the less the investment cost in terms of $/MW installed capacity. If the biomass is already collected on site, as in the case of wood process residues from a sawmill, then the size of bioenergy plant is usually limited by that available resource. Where the biomass is brought into a central plant location, the transport distance and corresponding cost will be a limiting factor to the commercially viable size of bioenergy plant.

Whilst they are not considered in any detail in this report, waste-to-energy processes are also included under the general term “biomass” as they mainly consist of what were originally plant or animal products derived from their use for purposes other than for energy (e.g. paper, packaging, pallets). Urban, commercial and industrial wastes, sometimes classed as municipal solid wastes, can have the inorganic and non-combustible fractions (e.g. glass and metal) removed, leaving mainly waste of biological origin – apart from the plastic component which is fossil fuel derived but also combustible.

Combustion of fuel with atmospheric oxygen provides energy as heat. Natural decomposition of biomass is a similar oxidation process, but the chemical energy is released as heat much more slowly. Both processes produce carbon dioxide and water. But that is not the end of the process, as nature completes the cycle putting energy (from the sun) back into these end-products via growing plants to create more fuel and oxygen.

Some materials will burn and others, such as sand and water, will not. Combustion of a fuel needs oxygen to chemically react the carbon and hydrogen containing molecules of the fuel. Heat is produced. Therefore a fuel can be defined as a substance which interacts with oxygen, changes chemically, and thereby releases its stored chemical energy.

For example, methane (CH4), a common fuel as contained in natural gas, biogas, or landfill gas, reacts with oxygen (O2) as follows:

$$\mathrm{CH4 + 2O2 \longrightarrow CO2 + 2H2O} + \text{energy}$$

This chemical reaction typifies the burning of any common fuel: a compound containing carbon and hydrogen interacts with oxygen (usually from the air though there are cases when pure oxygen is used) to produce carbon dioxide and water.

Section 2 of this report considers the combustion properties of biomass feedstocks.

1.5 Biomass for Renewable Energy and Greenhouse Gas Mitigation

Scientists are now confident that an enhanced greenhouse effect is occurring and that a substantial part of the observed change in climate is due to human activities. Fossil fuels are abundant and projections from the World Energy Council suggest that oil, coal and gas should all be available throughout most of this century and that they will remain the dominant energy source for the foreseeable future.

As a response, carbon dioxide emissions to the atmosphere can be reduced by:

- lowering the levels of energy services
- providing energy or consuming energy services via more efficient technologies and systems thereby reducing energy intensity
- switching from fossil fuels to renewable sources of energy, including biomass, or to nuclear energy, or switching from higher carbon fuels (coal) to lower carbon fuels (gas)
- removing carbon from fuels and combustion exhaust gases or from the atmosphere and storing it in some way in perpetuity (sequestration).

Biomass is a renewable energy resource that results in a negligible net contribution of CO_2 to the atmosphere. Plants during growth take up CO_2 which is later released during bioenergy processes.

Where agricultural land is transferred to energy crop production, a net uptake of CO_2 also often results from the increased 'carbon density' of the land use and possibly in the soil too. Other forms of biomass utilisation such as landfill gas or the collection of forest residues otherwise left to decompose on the forest floor, also reduce the release of methane (a more potent greenhouse gas) into the atmosphere.

Biomass has the dual advantage of acting as an energy substitute for fossil fuels (a carbon offset) and also as a means of sequestering carbon (a carbon sink). Hence it is recognised widely that bioenergy will play an important role in the objectives of the United Nations Framework Convention on Climate Change (UNFCCC). An excerpt from the International Energy Agency Bioenergy News from 1998 best sums up the potential of using bioenergy.

Modern bioenergy options offer significant, cost-effective and perpetual opportunities toward meeting emission-reduction targets while providing ancillary benefits. Moreover, via the sustainable use of the accumulated carbon, bioenergy has the potential for resolving some of the critical issues surrounding the long-term maintenance of biotic carbon stocks. Finally, wood products can act as substitutes for more energy-intensive products, can constitute carbon sinks, and can be used as biofuels at the end of their lifetime [1].

CO_2 emissions can be reduced by approximately 97% and 93% where suitable biomass is combusted for electricity generation and substitutes for coal or gas respectively. However, the use of more efficient bioenergy conversion systems such as gasification, can further improve emission reductions.

1.6 So what is Bioenergy?

A number of conversion routes exist to change biomass into useful forms of energy, as shown in simplified form in

Figure 1-3. Many of these will be covered in detail in later sections of this report. The owner of a biomass resource can work in partnership with a project developer to convert that resource into useful energy projects in order to maximise the return on the investment. Where the resource is a waste product, avoiding any treatment or disposal costs can lead to dual benefits, or a "win/win" opportunity.

The biomass conversion routes can determine whether or not a project is commercially viable and the costs for these conversion processes are often very site and project specific. They vary with the source of raw biomass, its moisture content, the transport distance, the complexity of the process involved, the plant scale, the value of any co-products, the savings of disposal cost if a waste, the reduction in greenhouse gas emissions, the market value for the bioenergy, and whether there are subsidies and incentives available. Careful analysis and risk assessment are therefore required to get a good overview of what is involved and the chance of commercial success for each project.

Costs for many bioenergy plant options can be determined by working with experienced technologists or equipment suppliers, and the more accurate the data provided, the more accurate will be the estimates of project costs.

Over time it is expected that bioenergy project costs will reduce as industry knowledge increases with regard to feed materials, technical alternatives for processing, and operating characteristics. It is possible to learn from projects already in place. As for any technology, bioenergy plants should progress steadily down the experience curve as a result of "learning by doing". In rough terms the installed cost of a plant will reduce by 20% for every doubling of the total installed capacity. Some bioenergy technologies such as wood combustion are relatively mature (though some increased

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[1] *IEA, 1998*

efficiencies are still being gained for little extra investment costs). Others, such as aspects of wood gasification, are still at the demonstration stage with potential for rapid cost reduction when replication occurs.

This report examines in some detail the elements of bioenergy, from the nature of biomass as a fuel source, issues related to its production, harvesting and transport, its conversion into primary and secondary energy products and services, costs and economics of bioenergy in its various forms, and co-values and co-products associated with bioenergy.

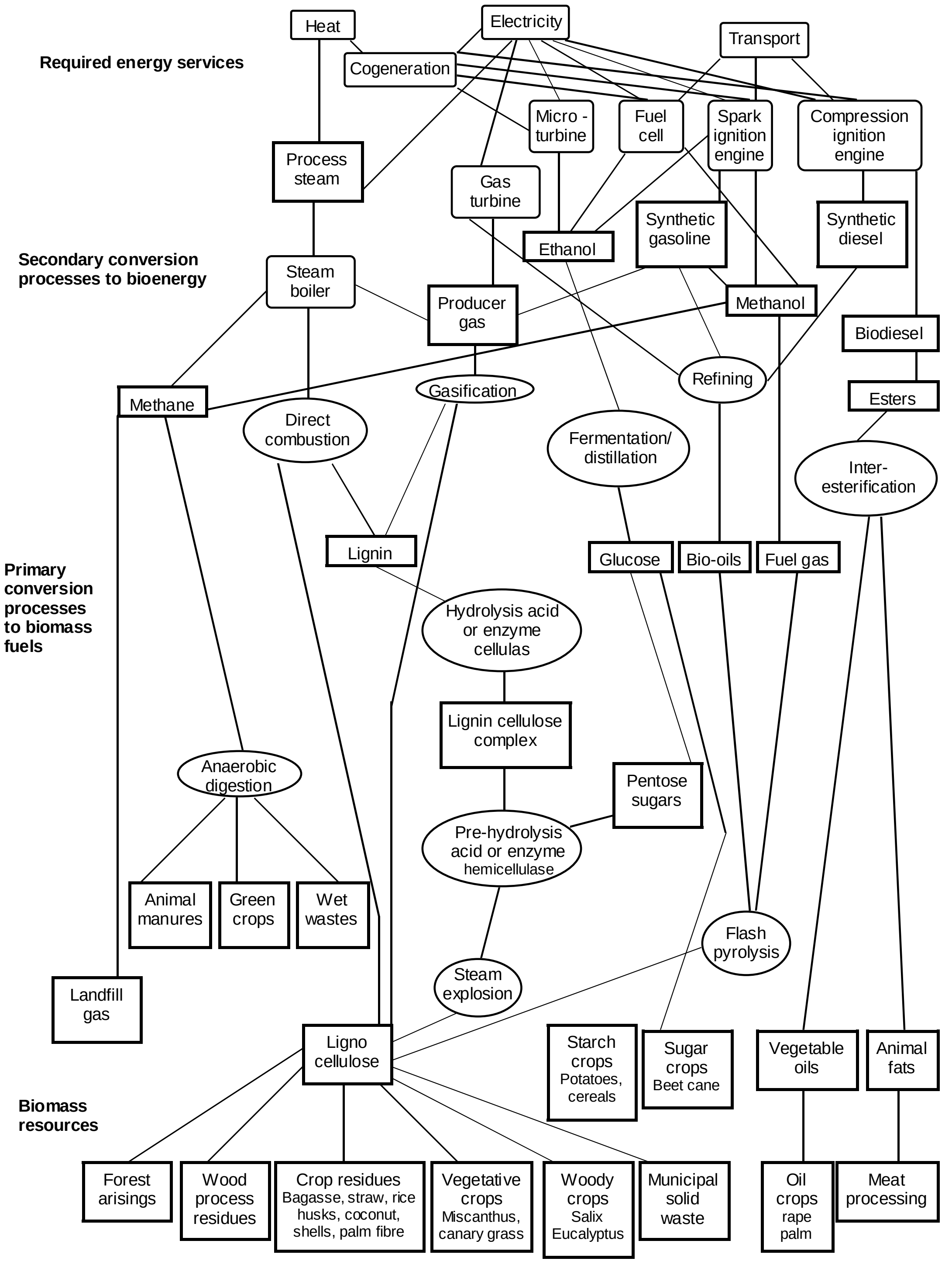

Figure 1-3: Some routes for converting a number of different biomass materials into useful energy products

A note on Terminology

During the course of the study several different names were identified for groups of trees that would be harvested regularly in cycles of several years, as opposed to the cycle times of fifteen years or more. The latter times typically apply to plantations established for sawlogs or processing for other wood products. In defining these short cycle trees attention was given to whether the tree:

- is to be harvested in short "rotation" or short "cycle". In forestry the two terms are similar, however in agriculture rotation can be taken to mean a change of crop rather than a time for growth.

- is planted for energy alone or for energy and other uses. Unless the usage is specifically for energy for illustrative purposes (for example in the Australian case studies developed as part of this project) we have endeavoured to avoid the use of "energy", to promote the concept that crops planted for multiple products or purposes are more likely to be commercially viable than trees planted for energy alone.

- coppices (resprouts from the cut base after harvesting). We have endeavoured to avoid the term "coppice" as some tree species with potential for biomass and other uses do not coppice.

- is part of a plantation, forest or crop. There are no apparent distinctions between each word. We have endeavoured to use "crop" to focus on the difference between these short cycle trees and current use of "plantations" to describe stands of pine and blue gum.

This report therefore uses "short cycle crops" as its preferred terminology but also makes use of other, similar terms where it is felt appropriate.

2. Thermal Properties of Biomass Feedstocks

2.1 Summary

Biomass from plants is characterised by a number of physical and chemical properties that require special consideration for its use as an energy source in combustion, gasification and pyrolysis plants. The main determinants of fuel properties are:

Moisture content: Dry, ash free biomass typically has a heating value in a narrow range of 18-21 MJ/kg, irrespective of plant species. However, moisture content is the major determinant of the operational heating value. Biomass with higher moisture content will have lower energy content per unit weight. Boiler efficiencies are reduced by high moisture content in the biomass fuel. Biomass fuels can vary in moisture composition from less than 10 percent in cereal straw to more than 50 percent for freshly harvested wood. Moisture content needs to be carefully considered in the design and operation of a bioenergy combustion plant. Dry biomass burns much hotter than moist biomass; potentially placing different requirements on materials of construction and emission controls. Moisture content also influences the storage durability of biomass, as degradation and spontaneous combustion can result.

Ash content: Ash is an inorganic, incombustible component of biomass, and is a major determinant of fouling, slagging, corrosion and erosion of bioenergy plant components. Ash is inherent in biomass cell structure and can range from 0.2 percent in tree species to over 20 percent in rice hulls. Ash is also derived from sand and soil absorbed in bark and incorporated dirt in the fuel. Some components of ash pose greater problems for energy plants than others however, in general terms, the lower the ash levels the better.

Volatile matter content: Upon heating, biomass gives up a large fraction of its weight in the form of combustible gases. This volatile component of biomass can be as high as 80 percent for dry wood. Volatile matter determines the gas flows within boilers and gasifiers; a design parameter. Another consequence of high levels of volatiles is that energy may be lost from fuels in storage via the loss of volatile organic compounds.

Elemental composition: The elemental composition of plant biomass is relatively uniform. Carbon is the principal constituent of biomass, making up 30-60 percent of its dry mass. As a fuel, biomass is highly oxygenated compared to conventional fossil fuels such as coal and petroleum products. Typically 37-45 percent of the mass of dry biomass is oxygen. The third major constituent is hydrogen at 5-6 percent. Nitrogen, sulphur and chlorine are also present, generally at levels below one percent. These elements can be determinants of gaseous emissions from biomass power plants. Chlorine also plays a major role in corrosion mechanisms, and in the production of acid emissions. Various inorganic elements can also be found in biomass and have implications for the design and operation of the bioenergy plant, as they establish fouling, corrosion and erosion conditions during operation. Important inorganic elements in biomass feedstocks are alkali metals, most notably sodium and potassium and silica in grasses and straw. These are heavily implicated in fouling of boiler tubes and need to be controlled.

Heating Value: Heating value does not vary significantly across various biomass fuels. An empirical formula for the (higher) heating value of dry biomass, based on the elemental composition of the biomass, is:

$$HHV_{d.b.} = 0.3491*C + 1.1783*H + 0.1005*S - 0.0151*N - 0.1034*O - 0.0211*Ash \text{ [MJ/kg]}$$

The operational heating value declines linearly with increasing moisture value.

Bulk density and particle size: The density of biomass fuel determines much of the economics of fuel transportation and storage. The energy density (energy per unit volume) of biomass fuels can be as low as one-tenth that of fossil fuels. For instance planer shavings can have a bulk density of a mere 97 kg/m^3. This requires plant and equipment to cater for high volumes of biomass per unit of energy output.

In general, bioenergy plants can be readily adapted to specific fuel parameters through careful design and operating procedures. Guiding values for unproblematic utilisation of biomass fuels have been developed, and are presented in detail in Figure 2-6 of this Chapter. If guiding values cannot be attained, then various technological solutions can often be applied to ensure trouble free operation of the bioenergy plant. For instance NOx emissions may be controlled through staged combustion (better mixing of oxygen and fuel), use of flue gas scrubbers, temperature control within the furnace and use of catalytic converters.

Note that design of an energy plant to operate on a particular feed does not mean that the plant will operate as well on other biomass fuels. Good data on fuel properties during design, and consistent fuel during operation are most important for a successful bioenergy project.

A number of Australian organisations with experience and capability in analysing biomass fuels exist, confirming Australian capability with biomass fuels over several decades.

2.2 Biomass as a Fuel

Biomass is the product of plant photosynthesis. Via photosynthesis, solar energy contributes to the chemical energy in the biomass and may be recovered by thermal processes such as combustion, gasification or pyrolysis. As a fuel, biomass is highly oxygenated compared to conventional fossil fuels such as coal and hydrocarbon liquids. Typically 37-45 percent by weight of the dry matter in biomass is oxygen (O). Carbon, the principal constituent of biomass makes up 30-60 percent of the dry matter, depending on ash content. Hydrogen (H) is generally the third major constituent, comprising typically 5-6 percent of the dry matter. Nitrogen, sulphur and chlorine are also present and are usually well below one percent of dry matter, although on occasions they exceed this value. Various inorganic elements can also be found in biomass and they potentially have important implications for the design and operation of the bioenergy plant, as they establish the fouling, corrosion and erosion properties of the products of thermal processing. These elements include alkali metals, most notably sodium and potassium, and silica in grasses and straw. Of note, silica is the third largest component at 10-15% of dry matter in rice straw.

The Van Krevelen diagram below (Figure 2-1) illustrates the chemical composition of biomass compared to other solid fuels. The high O/C and H/C ratios for biomass fuels are responsible for biomass fuels being more volatile than peat and coals, and the high O/C ratio results in biomass having lower heating values. The diagram also illustrates that biomass as a fuel is on a continuum with coals and peat.

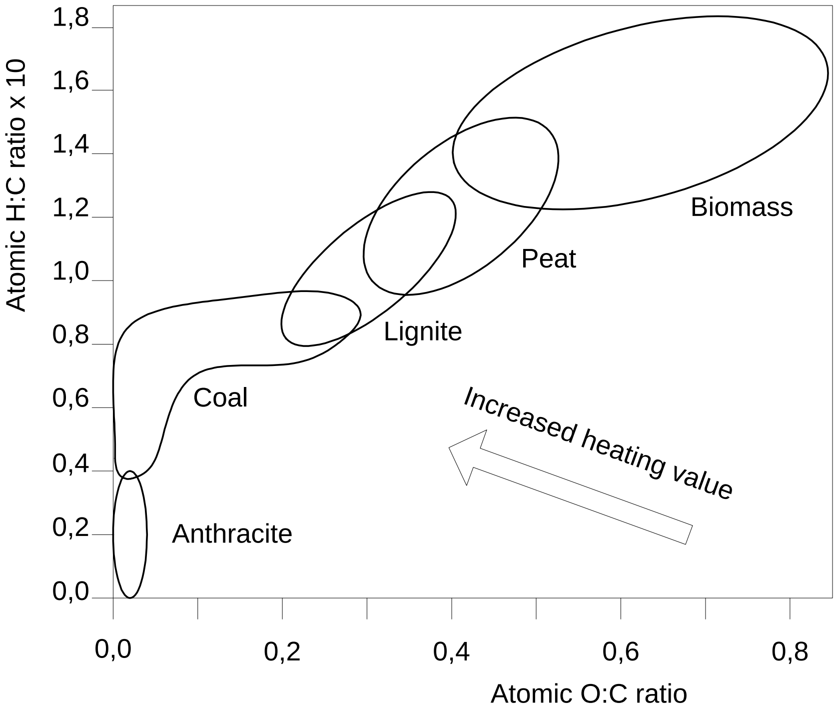

Figure 2-1: Van Krevelen Diagram for Solid Fuels [1]

2.3 Determinants of Fuel Properties

The most important properties of biomass relating to their thermal energy conversion properties are:

- Moisture content
- Ash content
- Volatile matter content
- Elemental composition
- Heating value
- Bulk density and biomass particle size.

2.3.1 Moisture content

The moisture content of biomass is the quantity of water in the biomass, expressed as a percentage of the material’s weight. This weight may be on a wet basis, on a dry basis (d.b.), or on a dry-and-ash-free (d.a.f.) basis. If expressed on a wet basis, the moisture content is expressed as a percentage of the sum of the weights of the water, ash and dry-and-ash-free matter. Moisture content is an important parameter. Increased moisture content reduces the energy content of the fuel (usually expressed in MJ/kg), and the remaining combustible material will also have more of its energy utilised to evaporate the water present. The design of bioenergy combustion plants needs to take the fuel moisture content into account, as dry biomass with its higher energy content will result in higher release of energy and can result in overheating and consequent damage to furnace components, while wet biomass with its lower energy content may require the combustion chamber to be insulated to maintain boiler efficiency and enable continuous combustion to take place without the need for supplementary fuel. Knowledge and control of the moisture content range of the fuel can be very important, as biomass can have a wide range of moisture content (on a wet basis), ranging from less than 10 percent for cereal grain straw up to 50-70 percent for freshly harvested wood. Moisture

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[1] Baxter, L. Ash Deposition during Biomass and Coals Combustion. *Biomass and Bioenergy*, Vol 4, No. 2, 1993, Pergamon Press Ltd, pp. 85-102.

content of the biomass will also impact on storage durability of the biomass, susceptibility to fungus and degradation, plant design, and potential for spontaneous ignition.

2.3.2 Ash content

The inorganic, incombustible component of biomass, termed ash, can similarly be expressed as a percentage of the biomass weight. Usually ash content is expressed as a percentage on a dry basis. Ash is undesirable as it leads to particulate matter in the flue gas that requires capture and disposal. Ash is also the major determinant of fouling, slagging, corrosion and erosion of bioenergy power plant components.

Ash in biomass fuels comes from two sources. The inherent ash is an integral part of the biomass structure and consists of a wide range of chemical elements. Inherent ash can be as low as 0.2 percent for certain Australian tree species, 5 to 10 percent in diverse agricultural crop residues, and over 20 percent in rice hulls[1]. The other source of ash in biomass is derived from sand and soil absorbed in the bark of trees and from dirt incorporated into the biomass during harvesting, handling and transportation.

The total ash content of the biomass and the chemical composition of the ash are both important to bioenergy projects. The composition of the ash affects its behaviour under high temperatures of combustion and gasification. Primarily potassium (K) and partly sodium (Na) based salts in biomass result in “sticky” ash which may cause deposits on boiler components. In addition, K and Na, in combination with chlorine (Cl) and sulphur (S), play a major role in corrosion. Biomass fuels with a molar S:Cl ratio below 2 can cause corrosion problems, because of the formation of significant amounts of alkali metal chloride salts. Furthermore, the volatilisation and subsequent condensation of volatile metals can lead to the formation of sub-micron fly ash particles (aerosols) which are difficult to precipitate in dust filters, form deposit layers on boiler tubes and can raise ecological and health risks. Accordingly, the lower the amounts of potassium and sodium salts in the biomass fuel, the better.

Heavy metal concentrations in biomass ashes are of considerable importance for ash utilisation and disposal. The ecologically-relevant elements are cadmium (Cd) and to a smaller extent zinc (Zn) if only untreated biomass is considered. Straw, cereals and grass ash contain significantly smaller amounts of heavy metals than wood and bark ash. This is explained by the longer rotation periods of wood which allows heavy metal accumulation, the higher deposition rates in forests and the lower pH value (acidic) of forest soils that increases the solubility of most of the heavy metals. Fortunately, biomass ash generally contains very low levels of toxic metals, and the ash can often be used as a soil amendment.

2.3.3 Volatile Matter Content

Upon heating (400°C to 500°C), biomass gives up a large fraction of its weight in the form of combustible gases. This requires combustion chambers to be designed to provide the combustion air where these gases are burned. The percentage of volatile matter on a dry basis in biomass typically ranges from 63 percent for rice hulls to over 80 percent for wood. By contrast, the volatile matter in bituminous coal, as used in NSW and Queensland, is under 20 percent. The high levels of volatile matter in biomass feed also have implications for gas flows within boilers and gasifiers. Another consequence of high levels of volatiles is that energy may be lost from fuels in storage piles, via the loss of volatile organic compounds. This is usually countered by limiting storage at power stations, using a ‘just in time’ method of operation which also lowers the cost of storage.

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[1] Jenkins, B.M., Baxter, L., Miles T.R. Jr, Miles T.R.. Combustion Properties of Biomass, in Proceedings of Biomass Usage for Utility and Industrial Power, Snowbird, Utah, 28 April to 3 May 1996.

2.3.4 Elemental composition

The elemental composition of biomass on a dry-ash-free basis is relatively uniform. Figure 2-2 shows the elemental composition of some typical biomass feedstocks.

Component or Attribute		*Pinus radiata*	*Eucalyptus globulus*	Wheat straw	Rice hulls	Sugar cane bagasse
Carbon	C % d.b.	51.3	48.2	44.9	38.8	48.6
Hydrogen	H % d.b.	6.0	5.9	5.5	4.8	5.9
Oxygen	O % d.b.	42.6	44.2	41.8	35.5	42.8
Nitrogen	N % d.b.	0.11	0.39	0.44	0.52	0.16
Sulphur	S % d.b.	0.01	0.01	0.16	0.05	0.04
Chlorine	Cl % d.b.	0.01	0.02	0.23	0.12	0.03
Ash	ash % d.b.	0.33	1.1	7.02	20.3	2.44
Volatiles	% dry matter	81.8	81.6	75.3	63.5	85.6
Higher Heating Value	MJ/kg d.b.	20.3	19.2	17.9	15.8	19.0

Figure 2-2: Elemental Composition of Typical Biomass Fuels

Figure 2-3 [1] illustrates in more detail the levels of nitrogen, sulphur and chlorine in a variety of biomass feedstocks, showing the higher nitrogen, sulphur and chlorine levels typical of several agricultural residues.

	Nitrogen (N) mg/kg (d.b.)	Sulphur (S) mg/kg (d.b.)	Chlorine (Cl) mg/kg (d.b.)
Wood chips	900 – 2,000	70 – 300	50 - 60
Bark	3,000 - 4,500	350 – 550	150 - 200
Straw (winter wheat)	3,000 - 5,000	500 - 1,100	2,500 - 4,000
Miscanthus	4,000 - 6,000	200 - 1,400	500 - 2,000
Triticale (cereals)	6,000 - 9,000	1,000 - 1,200	1,000 - 3,000
Hay	10,000 - 20,000	2,500	2,500 - 4,500
Needles (conifer)	12,000 - 15,000		
Grass	19,000 - 25,000	800	2,600

Figure 2-3: Nitrogen, Sulphur and Chlorine Compositions of Biomass Feedstocks

The chlorine level in the biomass is important as it plays a major role in corrosion mechanisms. It also determines levels of HCl (hydrochloric acid) emissions and is related to the formation of dioxins and furans. Chlorine levels in wood are generally very low at about 0.01 percent, but may be high in agricultural crops residues such as maize, where it can be as high as 1.5 percent on a dry basis. Chlorine levels in agricultural crops are to an extent dictated by chlorine levels in fertilisers. This may be controlled by using Cl-free fertilisers.

Fuel-bound nitrogen (N) is substantially responsible for the formation of NOx, an atmospheric pollutant, at combustion temperatures in the range 800°C to 1,100°C. The balance of NOx produced arises from nitrogen contained in the combustion air, and occurs at combustion temperatures above

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[1] Obernberger, I. Biomass and Bioenergy, Decentralised Biomass Combustion: State of the Art and Future Development, Vol. 14, No. 1, 1998, page 33-38.

950°C. NOx can be limited by controlling the use of N supplied with fertilisers and by using low combustion temperatures and staged combustion.

2.3.5 Heating Value

The heating value of a fuel is an indication of the energy chemically bound in the fuel. A measure of this heating or calorific value is the gross or higher heating value (HHV), which includes energy used to evaporate moisture of the biomass during thermal conversion.

The higher heating value (HHV, MJ/kg, d.b.) of biomass fuels does not vary significantly across different types of fuel. It usually varies between 18 and 21 MJ/kg (d.b.), and can be calculated reasonably well by using the empirical formula [1].

$$HHV_{d.b.} = 0.3491*C + 1.1783*H + 0.1005*S - 0.0151*N - 0.1034*O - 0.0211*Ash \text{ [MJ/kg]}$$

where C,H,S,N,O, Ash are the content of carbon (C), hydrogen (H), sulphur (S), nitrogen (N), oxygen (O) and ash in wt % (d.b.). As can be seen from the formula, the content of C, H and S contributes positively to HHV, while the content of N, O and ash contributes negatively to the calorific value.

The lower heating value (LHV) discounts the energy included in evaporating the moisture, including that formed from the chemical conversion of the hydrogen in the fuel to water. The operational, or as received (ar) HHV and the LHV are given by the formulae [2]:

$$HHV_{ar} = HHV_{d.b.}(1-w/100)$$

$$LHV_{ar} = HHV_{ar} - 2.442\{8.936H/100*(1-w/100) + w/100\}$$

where w is the moisture content, expressed as a percentage on a wet basis. The above two formulae show that there is a double effect of moisture on heating values. Moisture reduces the amount of combustible material in each kilogram of biomass and, if the heat of evaporation is not recovered, the available energy of the fuel is further reduced through the energy required to evaporate the moisture in the fuel. Moisture content is therefore a major determinant of the operational heating value of biomass fuels, which will typically be 9.7-11.7 MJ/kg for fresh wood chips and 14.8-15.8 MJ for wheat straw [3].

For an accurate assessment of the energy that may be usefully recovered from a fuel, it is important to be quite clear as to moisture content (including its potential variations) and whether the heating values being discussed are HHV or LHV. Figure 2-4 is indicative of the variation in heating values with moisture content.

2.3.6 Bulk Density and Biomass Size

Density refers to the weight of the biomass per unit volume. Biomass bulk densities tend to be low compared to conventional fossil fuels such as coal. This lower density, taken together with biomass' lower energy per unit of mass gives biomass an energy density (energy per unit volume), that is only approximately one-tenth that of fossil fuels such as high quality coal. On a dry-ash-free basis, bulk densities of different types of biomass can themselves vary significantly as shown in Figure 2-5[4].

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[1] Gaur, S. & Reed, T.B. An Atlas of Thermal Data for Biomass and Other Fuels, NREL/TB-433-7965, UC Category:1310, DE95009212.

[2] PHYLLIS database of biomass compositions, www.ecn.nl/phyllis/defs.html

[3] Wood for Energy Production, Technology-Environment-Economy, The Danish Centre for Biomass Technology, second edition, 1999, p31. ISBN 87-90074-28-9.

[4] Biomass Conversion Technologies, European Commission, EUR 18029 EN, Nov 1998, page 37.

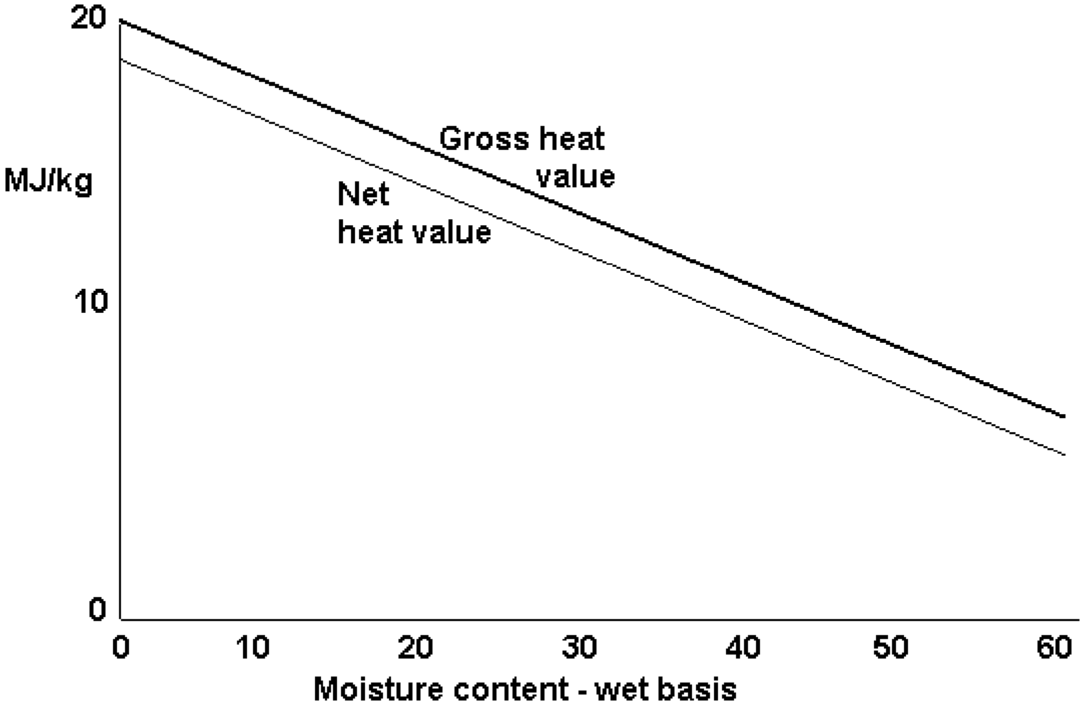

Figure 2-4: Variation of heating values with moisture content for typical biomass fuel

Biomass Type	Bulk Density (kg/m^3 daf)
Wood	
Hardwood chips	227
Softwood chips	179-192
Pellets	556-625
Sawdust	161
Planer Shavings	97
Straw and stover	
Loose	20-40
Chopped	20-81
Baled	111-204
Moduled	97-1250
Hammermilled	20-101
Cubed	323-667
Pelleted	556-714
Orchard Prunings-hammermilled	141-204

Figure 2-5: Bulk Densities of Various Biomass Fuels

The implication for biomass transportation logistics and energy conversion is that designs of plant and equipment need to cater for the high volumes of biomass per unit of energy output. Feed systems need to be appropriately designed for bulk handling of the biomass. Fine biomass particles and volatile organic matter in fuel piles are susceptible to being lost during transportation and storage.

2.4 Guiding Values for Biomass Fuels

Obernberger [1] has developed guiding values for biomass fuels and biomass ashes to help avoid problems during thermal conversion of biomass fuels. These values are presented in Figure 2-6 below. The table also suggests technological solutions if the guiding values are exceeded.

In general, bioenergy plant designs can readily be adapted to the fuel parameters. Organisations in Denmark in particular have used agricultural straw for Combined Heat and Power plants with great success. The fuel requirements, as indicated in Figure 2-6 can readily be accommodated in the plant designs.

Element	**Guiding concentration in the fuel (wt % on d.b.)**	**Limiting parameter**	**If guiding concentration ranges are not kept, problems can occur for**	**Technological alternatives if the guiding ranges are not fulfilled:**
N	< 0.6	NO_x emissions	Straw, Cereals, grass	Primary measures (air staging, reduction zone)
	< 2.5		Waste wood, fibre boards	Secondary measures (SCNCR or SCR process)
Cl	< 0.1	Corrosion	Straw, cereals, grass	- fuel leaching - autom. heat exchanger cleaning - coating of boiler tubes - appropriate material selection
	<0.1	HCl emissions	Straw, cereals, grass	- dry sorption - scrubbers - fuel leaching
	< 0.3	Dioxin, Furan emissions	Straw, cereals, grass	- sorption with act. carbon - catalytic converters
S	< 0.1	Corrosion	Straw, cereals, grass	See Cl
	< 0.2	SO_x emissions	Grass, hay	See HCl emissions
Ca	15 - 35	Ash melting point	Straw, cereals, grass	Temperature control on the grate and in the furnace
K	< 7.0	Ash melting point, depositions, corrosion	Straw, cereals, grass	Against corrosion: see Cl
	--	Formation of aerosols	Straw, cereals, grass	Efficient dust precipitation, fuel leaching
Zn	< 0.08	Ash recycling	Bark, wood chips, sawdust	Fractioned heavy metal separation

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[1] Obernberger, I. Biomass and Bioenergy, Decentralised Biomass Combustion: State of the Art and Future Development, Vol. 14, No. 1, 1998, page 33-38.

Element	Guiding concentration in the fuel (wt % on d.b.)	Limiting parameter	If guiding concentration ranges are not kept, problems can occur for	Technological alternatives if the guiding ranges are not fulfilled:
	--	Particulate emissions	Bark, wood chips, sawdust	Efficient dust precipitation, treatment of condensates
Cd	< 0.0005	Ash recycling	Bark, wood chips, sawdust	See Zn
	--	Particulate emissions	Bark, wood chips, sawdust	See Zn

Figure 2-6: Guiding Values for Unproblematic Utilisation of Biomass Fuels

2.5 Australian Experience and Capability with Biomass Fuels

A number of organisations within Australia and New Zealand have demonstrated capability in analysing solid fuels. These include:

- CSIRO - who also assist the power industry in analysing coal combustion properties. The CSIRO has been assembling a database of biomass fuels and their characteristics which is available online[1]. Their interest is for dedicated bioenergy plants and for co-firing with coal in utility boilers. The CSIRO is moving towards assessing indicative characteristics to rank biomass fuels for their suitability for thermal conversion, concentrating on gasification, fouling and corrosion properties.
- HRL Limited in Victoria – which provides a range of analytical services to the coal industry and can also assess and categorise wood and other biomass for combustion properties and slagging and fouling characteristics
- Forest Research Institute in New Zealand.
- Australian Coal Industry Research Laboratories (ACIRL)
- University of Newcastle
- University of Sydney
- Ultra Systems Technology Pty Ltd, in Queensland
- Biomass Energy Services and Technologies Pty Ltd, in NSW
- Carbon Consulting International Pty Ltd

A number of major technology and equipment organisations have also been involved in bioenergy plant design and construction in Australia, primarily in the sugar industry using bagasse as fuel. Recently, Alstom Power commissioned a 30 MW biomass co-generation power plant at Rocky Point, Queensland for Stanwell Corporation, fired on both bagasse and waste wood fuels. Other companies that offer boiler supply for the industry include:

- Rolls Royce (of which John Thompson is a part)
- Babcock and Wilcox
- Easteel
- Maxitherm
- Tomlinson.

These organisations and others all offer particular designs and skills which are based on their own experience in Australia and overseas and also licensing agreements with other specialist overseas groups.

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[1] www.det.csiro.au/cgi-bin/bfb-search/

3. The Harvesting System and Biomass Supply Chain

3.1 Summary

Plant biomass for energy is available as residues from processing operations such as sawmills and sugar mills. In this case the fuel can often be utilised alongside the processing facility that generated it.

Plant biomass is also available as residues from forestry or agricultural operations, or as purpose grown crops. In these cases, more than fifty percent of the cost of producing energy from biomass can generally be attributed to the costs of producing, harvesting, transporting, processing and conditioning the biomass fuel. As such, the logistics of the biomass supply chain can be critical to the viability of a biomass energy project.

A wide range of options exists for the various components of the biomass supply chain. Selection of each component in the chain often impacts on other components. As was noted in Chapter 2, the very low bulk density of most biomass fuels prescribes that volume and not weight invariably limits the transport of dry biomass.

This study has focused on biomass from plantation or short cycle crops. Key aspects of biomass supply systems for these feeds are:

Overall harvester machine size and design: This needs to conform to the layout of fields and plantations, spacing between crop rows, available turning circle for machinery, harvesting pattern, row lengths and hence material harvested per row, permitted weight to avoid soil compaction, targeted fuel capacity and consumption, and machinery capital cost. Options to be considered include trailed machines or self propelled machines, side cutting heads or central fixed cutting heads, use under wet soil conditions, physical size, and terrain the machinery can operate on.

Harvester capacity and productivity: This determines the harvesting rate in hectares per hour, and duration of harvesting for a specific area. Factors to be considered include: number of machines needed to harvest an area, requirements for support vehicles, economics of ownership versus contract harvesting, overall harvesting costs, and ability to harvest under various terrain and weather conditions. A criterion is to only harvest when soil is firm, or regardless of weather. Ideally capacity should permit uninterrupted harvesting, without stopping to unload cut material.

Width of cut: The cut width has a direct relationship with productivity and the number of passes made across a field. For coppiced biomass crops the cutting head may need to cope with single stem and/or multi-stem trees.

Cutting mechanism: The design of the cutting heads determines the forward harvesting speed, stem diameters that can be cut, width between rows, and possible damage to perennial crops and coppice stools. Susceptibility to damage from stones and soil, and resharpening are important issues. Options include single and double disc cutters, chainsaw type cutters, reciprocating knives, hydraulic or belt drive mechanisms.

Comminution: This refers to reducing the size of biomass pieces for handling and transport and affects subsequent drying rates, bulk volume density and hence storage volume and transport costs. Options for comminution are many and varied, applied at in-field operations, at forest landings, or at the energy plant. Options include chipping, hogging, billeting and baling. Moisture content of comminuted biomass stored in chip form should not exceed 20 percent, as biological heating, loss of dry matter and mould formation can result. Spontaneous combustion within storage piles, especially bagasse (sugar cane fibre) and wood chips can also be an issue.

Transfer mechanism from harvester: Support trucks and trailers are required to transfer the biomass from the harvester. The type of support transport is largely determined by access to the field, amount of biomass that can be carried on the harvester, terrain, and soil type and condition. Options exist for stem and stick harvesters and balers and also for chippers and billeting machines. The general preference is for a continuous harvest operation without stopping to unload collected biomass. This helps to maximise productive use of the equipment.

Transport from field to storage: Options for transporting harvested biomass to on-farm or intermediate storage include carrying the cut material on the harvester directly, collection of whole trees or sticks from the field with a grapple and trailer, using a grapple and trailer to collect whole cut stems and sticks from the headland, collection and baling small whole cut trees with a pick-up baler, and collection of bales with loader trailers. For stems, sticks and bales this can be done on flat bed or forestry trailers, and for chips and billets via a bulk commodity trailer.

Road transport to plant: The type of vehicle used needs to address any planning constraints, such as permitted number of daily vehicle movements, and load permitted on the road. Development of the best alternative will include consideration of the distance to the bioenergy plant, transport regulations, road widths and classifications, need to maximise payloads to minimise costs, means of securing loads, and maximum height of loads and length of truck-trailer combinations. Overseas experience shows that 880 kg square bales are usually preferred for low density biomass crops. It has also been found that for long distances, transporting chips can be a better option than transporting arisings or whole trees, provided long term storage (with the possibility of degradation) is not necessary.

Storage of bales and chips: Bales and chips are generally stored uncovered on concrete pads or on bare ground, covered with tarpaulins, or under roofed structures. On occasions undercover storage is only used a few days before biomass use. A key requirement for longer term storage is maintaining moisture levels below 20 percent to minimise “composting” of the fuel stack, loss of dry matter, and deterioration of the chips.

Drying: As noted in Chapter 2, the unit heating value of biomass is enhanced at low moisture contents. This can be achieved through transpirational drying, natural ventilation for in-field storage of billets, stems or sticks; intermittent artificial ventilation; or through heating using waste heat from the energy plant or other sources. Computer simulations have shown that drying chips with waste heat can maximise overall energy capacity of the plant.

3.2 Introduction

Converting biomass resources into useful forms of bioenergy using a wide variety of processes is well advanced and many examples of mature technologies exist in Australia and overseas. Often the major challenge for a project developer is not the conversion technology, but to deliver the biomass fuel to the conversion plant gate in a form that consistently meets an agreed set of fuel quality standards and characteristics and is at the lowest cost in terms of $/GJ delivered. This section discusses the closely inter-related aspects of fuel quality, harvest, transport, process and delivery.

In broad terms, up to fifty percent or more of the cost of producing bioenergy can be attributed to the cost of producing, harvesting, transporting, processing and conditioning the biomass fuels. This “biomass supply chain” is critical to the viability of any biomass energy project, and is therefore covered in some detail in this report. In many respects the Australian biomass industry is still in its infancy and lacks practical examples; so overseas practices and experiences are examined in this report to provide information for the emerging local industry.

A wide range of options exists for each separate component of the harvesting and handling chain. These vary with the nature of the biomass, whether it is animal slurry, straw, wood chips, arisings (residual branches and tops) or whole trees. In all cases the objective is to minimise energy inputs, handling, and storage losses but to maximise the payloads on transport vehicles.

Many equipment combinations are feasible when developing a given biomass supply system, and the interactions between each component of the system can be complex. Selection of one particular option can restrict the choice of components further along the chain. For example if a cut and chip harvester is used for short cycle crops, natural drying of the chips during long term storage in large piles is not feasible due to rapid physical deterioration of the chips. In such cases harvesting and storage of whole trees or branches (Figure 3-1) with chipping immediately before delivery to the plant can be a preferred option, but may carry additional costs for setting down and picking up the material.

Figure 3-1: Whole eucalyptus trees harvested at 3 years old and stored ready for processing

Transport of dry biomass is normally limited by volume not weight. Thus where single stem harvesting of short cycle forest crops is employed, and also for forest arisings, road transport over long distances is often impractical without some form of compaction or comminution to achieve the maximum payload possible.

The individual components of the harvesting and handling chain are closely inter-connected. The key components are listed below. For each, the interactions affecting other components are noted and practical options to design a complete system are provided. The key aspects of a biomass supply system are:

1. Overall harvester machine size and design concept.
2. Harvester capacity and productivity (ha/hour, overall work rates).
3. Width of cut.
4. Cutting mechanism.

5. Comminution.
6. Transfer mechanism of biomass material from harvester to the next step in the supply chain.
7. Transport from field to storage (intermediate or on-farm).
8. Road transport to plant.
9. Storage, if required.
10. Drying, if required.

The technologies for conversion of the biomass into heat, power and liquid fuels will be examined in detail in later sections.

For some forms of biomass such as vegetative grasses, canola and straw, conventional agricultural machinery is available for harvesting and processing. Examples include cereal straw balers, forage harvesters converted for use with coppice willow crops and combine harvesters with modified threshing drums and heading equipment. To extract woody biomass from plantations the use of traditional harvesting equipment may be technically suitable, and the integrated harvesting of the biomass component of the trees along with the stemwood for traditional wood products can be a feasible option. Equipment such as feller bunchers and chipper forwarders may be suitable for use with short cycle forest crops such as eucalyptus, depending on the cycle length for the trees and the consequent piece size.

Where no commercial equipment is available, or there is an opportunity for reducing costs with technical innovation, the need to develop specialist harvesting and handling gear can arise. Many prototype machines have been developed but few have proved successful enough to reach the commercial manufacturing stage. Also, there is often a perception of risk associated with such development which, along with the up-front costs of a thorough development program and the unknown market for such machines, can stifle many attempts to improve supply costs through innovative new equipment. Where it is feasible, using existing, commercially available equipment (perhaps after modifying it) is often seen as the most viable option. For example oilseed rape used for biodiesel is harvested using conventional cereal combine harvesters. Vegetative grasses used for combustion can be cut with conventional crop mowers or windrowers, then baled using hay balers. The baler could then be used for silage bales in spring, for hay bales in summer, for straw bales in autumn, and for miscanthus bales in winter. This would give all year round work to the owner contractor, and spread the fixed costs over a greater number of bales per year, thus minimising the costs per bale. Large quantities of biomass are already harvested in well designed systems. For example, the sugar cane industry has experience of harvesting and handling up to 3Mt/y at any one plant.

Harvesting operations, transport methods, and the distance to carry the fuel feedstock to the conversion plant also impact on the energy "balance" of the overall biomass system. That is, any fossil fuels utilised in the biomass supply chain will detract from the greenhouse benefits achieved by the production of renewable electricity or transport fuels when the biomass is processed. The heat or power generating plant or biorefinery should be located on a site to minimise transport costs since the biomass has a low energy density. However, while feed transport must be considered carefully, experience and analysis also shows that economies of scale possible from the construction of larger biomass-fired plants are often more significant than the additional transport costs involved to provide the fuel for such plants [1].

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[1] Dornburg and Faaij, 2000

3.3 Harvester Size and Design

The machine size and design concept affects the following parts of the biomass production and harvesting system.

- Establishment and layout of fields or forests, to leave optimal access for manoeuvring of machinery.
- Space between the rows and turning circle space at the headlands for either making three point or U-turns to enable the machine to return down the adjacent path to that just traversed.
- Harvesting pattern; for example travelling up one row then back down the next, or working inwards from around the perimeter, or working across the area in “lands”. (Lands were first developed for ploughing with horses to minimise the distance walked with the plough out of the ground).
- The optimum row length depends on the rate of filling the support truck or trailer travelling alongside the harvester or the capacity to carry cut material on the harvester.
- Longer rows give greater field efficiencies.
- Weight of machinery and footprint area of tyres or tracks and hence effects on soil compaction and traction (Figure 3-2).
- Fuel consumption.
- Capital cost investment, which is usually high and therefore requires high annual hours of use to reduce the fixed machine costs per tonne or per hectare harvested.

Figure 3-2: Self-propelled Swedish prototype harvester on tracks
(Tracks to avoid soil compaction during harvest. Note the adjustable cutting height mechanism.)

Machine options to be considered at the early design stage are based on some or all of the following principles.

a) Trailed machine -smaller and lighter, or a self-propelled machine -larger and heavier.

b) Left / right sided cutting head or a central head fixed across the front of the machine.

c) Size and number of wheels and tyre sizes and types to carry the weight or the use of tracks or ½ tracks to reduce soil structure damage and compaction in wet conditions.

d) Carrying the cut material on board till deposited at the headlands for later collection; or the transfer of material as it is cut to the support vehicles/trailers running alongside; or dropping the cut material directly on to the ground for later collection.

e) The physical size of a harvester, which is limited by:

  - tractor power available if trailed or, the engine size to be installed if self-propelled
  - the soil type and expected moisture content range at harvest time, wet clay soils providing poor traction and a high risk of regrowth reducing soil compaction and root damage
  - the nature of the terrain, a low centre of gravity being needed on steeper land
  - whether there is room available to manoeuvre at the ends of the crop or tree rows
  - the ability to operate in small fields or to be transported down narrow rural roads.

3.4 Harvester Capacity and Productivity

Machine capacity and productivity (ha/hour, overall work rates) affect the following:

- the area to be harvested in a season by one machine, which determines whether owning and operating it is an economic proposition or not as the fixed costs are spread further
- the number of machines needed for the total area to be harvested with minimum risk of crop losses due to adverse weather conditions within a limited harvesting period
- the number of support vehicles needed to collect and transport the cut material from the field
- the total harvesting costs, including labour, usually expressed in terms of $/tonne or $/GJ harvested.

The size and design of the harvester is limited by:

- the period available for harvesting to take place
- the soil type and terrain, affecting forward speed, traction and stability
- the typical yield, physical piece size and layout of the crop to be harvested
- the row width and dimensions of the field or plantation
- the machine cutting width
- the ease of transporting the machine by road between jobs
- the need to obtain access through gateways and around storage buildings etc.
- the forward speed possible during harvest and when travelling on the road.

Options available to the grower or harvesting contractor are to:

a) cut only when the soil is firm, and not when wet periods hinder access

b) cut regardless of whether the soil is wet or dry

c) cut all year round if agronomically sound to do so, but particular care is needed for coppice or perennial crops where protecting good crop regrowth is paramount

d) accumulate and carry the cut material on the harvester or transfer it directly to support vehicles

e) design the crop field layout with long rows, sufficient turning space, and transport lanes

g) chose machines with high road speed gear selections.

Land in some areas may be too wet for traffic access at certain periods of the year so it is essential to plan the harvest operation accordingly. The aim should be to maximise machine field capacity by minimising the down time when the machine is turning, being maintained etc. Having to stop to unload cut material should be avoided. This requires good machine design, careful planning and a good crop layout. Where only a short harvest period is possible, long term storage of the biomass is necessary to supply the conversion plant all year round. This storage comes at a cost and so a trade off may be required between selection and planting of areas that offer good harvester access, against costs for storage when harvesting cannot occur.

3.5 Width of Cut

Width of cut is variable and affects a number of other system and machine design parameters including:

- the work rate, in terms of ha/h
- capacity of other components of the harvester, such as an on-board chipper
- the number and width of passes made across the field
- wheel track settings across the width of the machine and any supporting vehicles
- for energy plantations, the tree row width and configuration of the plantation.

Tree crops, sugar cane, sweet sorghum etc are normally grown in rows and so the machine is restricted to travel along the direction of the rows, usually harvesting one or two rows per pass. The cutting width of the harvester is limited by the planted row width. For example, harvesting of Salix in the northern hemisphere is normally achieved by cutting double rows at 750mm spacing as planted (Figure 3-3). Cutting across the row direction where it is advantageous to do so, requires level ground without mounding around the tree seedlings when planted or wheel ruts. With vegetative grasses, cereals and oilseed crops not grown in distinct rows, the harvester cutting width is less of a design issue as the machine can travel in any direction (like a combine harvester in a field of cereals). Then the width of the cutting head relates mainly to the capacity of other parts of the machine to cope with large volumes of bulky and often wet material without blocking.

For tree crops in the northern hemisphere, a number of attachments to feed any protruding side branches into the cutting mechanism have been proven. For coppiced crops a major problem is that the cutting head must be designed to cope with single stems at first harvest but also with multi-shoot, wide stools in the older, coppiced crops.

Figure 3-3: Prototype willow harvester from Ireland cutting a double row in one pass.

3.6 Cutting Mechanisms

Cutting mechanisms have a wide range of designs, the choice of which is affected by:

- forward speed, hence hectares harvested per hour
- the maximum single stem diameter of tree crops at harvest, which therefore limits the rotation length between harvests
- the width between rows
- possible damage to perennial crops and coppice stools which could affect regrowth vigour, disease and plant mortality, thereby reducing the economic life of the stand before replanting becomes necessary.

The selection of the cutting mechanism is governed by:

- for coppice crops, the anticipated width of the stools after ‘x’ harvests
- possible damage to the cut stems and resulting disease
- the frequency of re-sharpening the cutting blades
- damage susceptibility from stones and soil
- the optimum cutting tip speed
- the ability to handle weeds, leaf litter, and trash.

Options available include:

a) single disc or double disc with variable cutting teeth designs, diameter and speed of rotation (Figure 3-4)

b) chainsaw type chain cutters, needing relatively low power but with frequent sharpening requirements and tensioning to overcome chain stretch, a tendency to tear the tree bark and to block in weeds, and the risk of breakage and operator injury

c) reciprocating knife, being either a single knife plus fixed fingers or double knives, both designs having a small maximum stem diameter cut (though some reciprocating knife hedge cutter designs can cut branches up to 125mm)

d) hydraulic or belt drives with some slippage designed in to avoid breakages as might occur with chain and sprocket drives

e) height of cut above ground which is usually variable to suit the crop and soil conditions (Figure 3-2) and also for coppice crops, if cutting higher up the stem is thought to result in more regrowth shoots.

Hard surfacing of blades reduces the frequency of sharpening, as do blades with serrated edges, though these tend to block in weedy conditions. The cutting mechanism used governs the forward speed, particularly in woody crops, since the time to physically cut through a stem limits the travel speed over the ground. If the machine travels too fast there is a tendency to push the trees over.

Figure 3-4: Close up of one type of design of feller cutting head
(For single stem harvest of large trees with a hydraulic grab to hold the cut tree before lying it on to the ground or on to a trailer.)

3.7 Comminution

Comminution consists of breaking the biomass into small pieces, and can affect:

- the subsequent drying rate
- the bulk volume density
- the storage volume
- transport costs
- the need to screen to give a more homogeneous fuel in terms of the particle size range, particular where this is critical to the process at the energy plant.

Chipping, chunking or billeting of whole plant material may require double handling if it is a separate operation. Keeping up with the machine's full capacity is difficult when feeding it either manually or by a grab. Dryer material is usually harder to comminute and hence consumes more energy per tonne of dry matter than when wet. The energy input per tonne of fuelwood product should be minimised by frequent knife sharpening, the moisture content of the materials, and the nature of the bark, especially if the bark is stringy. For a given size of chipper there is a maximum stem diameter it can handle. Keeping the comminuted material within an acceptable range of piece size produced is not always easy, and screening to remove fines, combined with recycle of any larger pieces may be necessary.

The form of the biomass received at the conversion plant is governed by the handling equipment used and the fuel specifications for the combustion or gasification equipment.

The biomass feedstock may be comminuted at some stage of the fuel supply process, or left as whole stems or sticks and handled in bulk or after baling with large round or square balers. The options are many and varied and partly depend on the crop type:

a) Comminute in the field as part of the harvest operation:

  - billet or chunk during harvest operation and then handle in bulk or in bales
  - chip during harvest operation and handle in bulk.

b) Comminute at the forest landing, headland or after temporary intermediate storage:

  - leave as whole sticks and handle in bulk or as bales
  - billet or chunk and handle in bulk or as bales
  - chip using a mobile tractor mounted chipper, hand fed or by a small grab
  - chip using a large, transportable but stationary chipper.

c) Commminute at the conversion plant using fixed comminution equipment, or possibly a mobile version able to be moved on occasions between plants:

  - receive as whole trees, branches or sticks and burn whole (based on a US design of whole tree combustion plant)
  - shred, billet, chip or powder (for co-firing with pulverised coal) on site before feeding
  - receive as bales and either burn whole bales (as for straw, though usually shredded automatically first), or shred, billet, chip or powder
  - receive as billets and burn direct or chip or powder
  - receive as chips and burn direct or pulverise into powder.

Cutting and chipping in one pass in the field has the practical mechanical attractions of easy and reliable handling. Chip harvesters are well proven in the wood chip and pulping industry. But this approach may create drying and storage problems when most of the fuel is not burnt immediately and is stored for long periods. Chips of >20% m.c. can have rapid biological activity which may lead to:

- heating from respiration
- loss of dry matter
- mould formation
- health problems.

Hence chips are more acceptable if they can be taken off the farm or forest directly and used quickly by the power generator.

Billets have a lower surface area and cut area than chips, leading to lower respiration losses and less loss of dry matter. Various chunker designs such as a conical helix chunker have been tested and show potential for billeting. Sticks, branches and stems dry naturally with little dry matter loss, but occupy more space and are harder to handle and transport. Therefore baling them has been investigated and is becoming an alternative.

3.8 Transfer Mechanism from Harvester

The transfer mechanism of biomass material from the harvester affects the need for support trucks and trailers, the optimum length of row, and the harvest work rate in terms of hectares per hour. The type of mechanism used is limited by:

- the weight and volume of biomass that can be carried on the harvester
- the design and capacity of the support trailers available
- available access for trailers to follow the harvester in the field, which may be restricted by the terrain, cut stumps, soil load carrying capacity etc
- the soil type and moisture content.

The options available for the harvester designer are:

a) For stem and stick harvesters and balers:

- to collect the material on board and discharge it on to the ground within the harvest site once the collection bay is full
- to retain bundles of stems or bales until the headlands are reached, then drop the material in stock piles or off-load bundles directly to awaiting trailers at the headland
- to off load stems, sticks or bales continuously by conveyor to trailers running alongside the harvester.

b) For chippers and billeting machines:

- to accumulate chips/ billets then unload at the headland
- to blow or elevate the chips/ billets into a trailer pulled behind the harvester (Figure 3-5)
- to blow or elevate chips/ billets into trailers running alongside the harvester.

Figure 3-5: Chips being blown into a trailed bin
(When full the bin is hydraulically lifted and tipped into high sided trucks for transport to store.)

Transfer of the biomass material to supporting trucks and trailers is more difficult on sloping ground. A continuous harvest operation without stopping to unload usually has a greater field efficiency in terms of hectares harvested per hour. For vegetative grasses, sugar cane residues, cereal straw etc, hay baling principles are well proven and worth considering. After transfer from the harvester, the material needs to be transported directly to the conversion plant or to storage.

3.9 Transport from Field to Storage

As with the supply chain stages already considered above, transport from field to storage (intermediate or on-farm) can be by one of many alternatives, depending on the form of the harvested biomass. The choice affects:

- the overall harvest work rate (ha/h)
- the need for support vehicle/s
- the opportunity for transpirational drying if cut and stored as whole trees
- soil compaction if travel of heavy vehicles is not restricted to the headlands.

The method of transport is limited by:

- the row length between the headlands at either end
- whether the cut material is dropped on to the ground to await collection
- the period before regrowth of stools occurs in a coppice crop
- the carrying capacity of the harvester
- the weight and capacity of the support vehicles.

Options are to:

- carry the cut material on the harvester directly to the on-farm storage site and deposit it in stock piles
- collect whole cut trees or sticks from the field with (see Figure 3-6) use a grapple and trailer to collect whole cut stems and sticks from the headland
- collect and bale small whole cut trees or sticks from the field with a pick-up baler
- collect bales with loader/trailer from the entire field area from where they are dropped
- collect bales with loader/trailer, tractor front loader or fork lift from headland piles.

Figure 3-6: Forwarder in Sweden with grapple and trailer
(For extracting forest arisings and small short cycle crop stems to the landing for chipping.)

A range of trailers and transport equipment is available including:

a) for stems, sticks and bales, a flat bed or forestry trailer

b) for chips/billets, a bulk commodity trailer

  - silage trailer with higher sides added, as biomass harvested for energy use is often a lighter material per given volume than wet green crops
  - high lift tipping trailer
  - roll on/roll off bins and trucks.

c) for whole trees and branches, a trailer fitted with a grapple or a specialist machine with a simple means of compacting the load.

Sticks, branches and stems usually occupy more space and are harder to handle and transport than chips and chunks. Therefore baling could be an advantage where feasible, but it tends to be an expensive option. Transport to the store can either be an integral part of the harvest operation or carried out subsequently.

3.10 Vehicles for Transport to Conversion Plant

Vehicles for transport from field or store to conversion plant help to determine:

- the catchment area to provide sufficient feedstock at the plant
- possible planning constraints due to number of daily vehicle trips
- the capacity of the transport vehicles used
- the number of journeys.

The selection of tractors, trucks and trailers is determined by:

- the average distance travelled to the conversion plant site
- whether rail is available
- transport regulations regarding axle weights and vehicle widths and lengths
- road classifications for the proposed route to be taken
- the road width and traffic density

- handling equipment available at the collection and delivery points (see Figure 3-7)
- the need to maximise payloads to minimise costs
- the means of securing loads
- the maximum height of loads and length of truck-trailer combinations.

Figure 3-7: European example - Unloading straw bales by tractor front loader
(For placing on a conveyor in the building shown, which feeds a shredder and straw burner.)

The options available depend on the nature of the biomass but include:

- chips in a high sided vehicle
- chips in bins on a flat deck truck / trailer
- billets in a high sided vehicle
- billets in bins on a flat deck
- whole trees or sticks in a high sided vehicle (possibly compacted after loading using straps or some form of hydraulic frame)
- whole trees or sticks strapped on to a flat deck
- bales stacked on a flat deck.

Bulk densities for different forms of biomass feedstock vary considerably, which impacts on the choice of transport. Typical examples drawn from overseas experience are shown below, noting large variations in biomass density can occur between types and species.

1. **Whole trees and sticks**	0.10 odt/m^3	= **0.20 t/m^3 fresh wt (50% mc)**
2. **Billets** *220mm length*	0.14 odt/m^3 (poplar)	= **0.28 t/m^3 fresh wt**
	0.125 odt/m^3 (willow)	= **0.25 t/m^3 fresh wt**

Note that in one trial after 250 days in storage, final bulk densities had reduced to
0.155t/m^3 for poplar @ 17.5% m.c.
0.161t/m^3 for willow @17.1% m.c.

100mm length 0.165 odt/m^3 (poplar) = **0.33 t/m^3 fresh weight (f wt)**
Note that after 293 days, final bulk densities were 0.22t/m^3 @18.6% m.c.

3. **Chips**	hardwood	0.174 odt/m^3	= **0.35t/m^3 f wt**
	poplar	0.125 odt/m^3	= **0.25t/m^3 f wt**
	spruce	0.125 odt/m^3	= **0.25t/m^3 f wt**
	mixed species	0.162 odt/m^3	= **0.35t/m^3 f wt**

4. **Bales** (500kg each @ 50%mc) 0.14odt/m^3 = **0.28t/m^3 f wt**

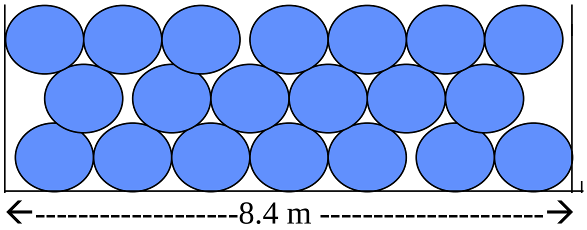
It cannot be assumed that short cycle crops such as eucalyptus or willow will have similar bulk densities and weights as for forestry arisings at the same moisture content. For example, a special heavy duty Swedish prototype baler tested in Scotland was used to form biomass into round bales 1.2m long x 1.2m diameter (1.1m^3/bale) (see Figure 3-8), and resulting bale weights varied by up to 50%:

- lodgepole pine residues off a chain flail delimber	569kg / bale @ 35%mc = 0.37odt/bale
- sitka spruce residues	484kg / bale @ 31%mc = 0.33odt/bale
- lodgepole residues stump dried	391kg / bale @ 23%mc = 0.30odt/bale
- willow sticks from a short cycle crops crop	493kg / bale @ 49%mc = 0.25odt/bale
- willow sticks after natural drying	265kg / bale @ 11%mc = 0.23odt/bale

Figure 3-8: Bales of willow sticks formed by a prototype Swedish Balapress under test in UK.

The willow sticks made poor bales with hollow centres. However if they had first been dried or mechanically “crimped” so that the sticks tend to break on entering the bale chamber, then denser bales may have resulted.

Based on a study of the transport of straw bales, it should be possible to produce 40 bales in an hour of suitable cut biomass material from, say vegetative grasses using a typical round or large square baler designed for hay and straw. An example of designing a transport system for bales, based on 500kg round bales at 50% moisture content follows. A 60.5m^3 capacity truck with a tare weight of 11.6t, 8.4 m long deck, 2.4m wide and with supports 3m high at either end, would hold 7+6+7 x 2 rows = 40 bales of 1.2m diameter at 3 bales high. The bales can be horizontal axis loaded using a tractor front loader.



40 bales = 20t fresh weight payload
Volume of the truck = 60.5m^3
Bulk density of the load = **0.33t/m^3**

If bales of 750kg could be produced, the bulk density would be increased to around 0.5t/m^3
So 40 bales = 30t fresh wt payload. But in this overseas example the permitted maximum gross vehicle weight (GVW) of 38t would then be exceeded.

It is assumed that 30 square bales can be carried on the same 38t GVW truck. If the baler produces large, square bales of 880kg the maximum payload would be met. It would also be easier to stack the bales than round ones. So, square bales are usually preferred for low density biomass crops.

If the same 38t truck was used to transport chips at 330kg/m^3 and 50%mc then a payload of 20t would result; or even less with dryer chips. For whole trees and branches, obtaining a payload of more than 10t would be difficult without some effective form of compaction. So for long distances, chipping can be a better option than transporting arisings or whole trees so long as long term storage is not necessary.

3.11 Storage

Storage of the biomass as bales, chips etc affects:

- the quality of the fuel and its combustion characteristics
- the final total energy content available
- the final moisture content before combustion
- the reliability of fuel supply for the plant over prolonged periods.

Storage of biomass is limited by issues of feasibility and cost, including:

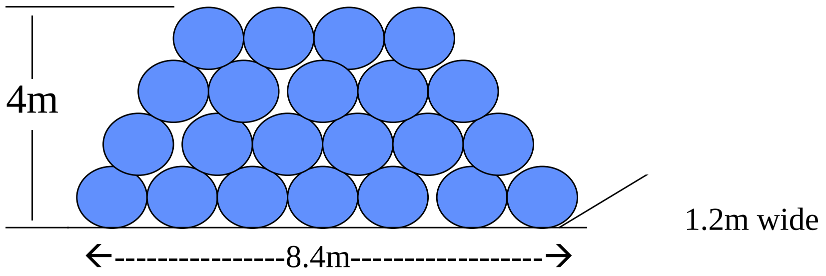
- the initial moisture content
- the size of individual particles if restricting air movement between them
- the period of storage required
- the land or building area available for storing the material
- the volume needed to be stored between harvests
- the availability of storage (ideally covered) at least for 2 or 3 days supply.

Intermediate storage of chips, billets trees or sticks is possible on-farm or in the forest. The material is then brought to the plant as required where it can be stored in a central store readily available to the conversion plant for a shorter period in one form or another. The options include:

- uncovered storage on concrete pad
- uncovered on bare ground
- on concrete pad or bare ground, covered with tarpaulins or roofed structure
- uncovered, but then brought under cover into silos, open barn or A-frame building for last few days before use.

The space needed for storage needs to be calculated for each plant as there can be high costs involved. Taking storage of round bales as an example:

Stack 7+6+5+4 [4 bales high (4m) by 1 wide (1.2m) in rows] = 22 bales / 1bale row width



Floor area of 8.4m x1.2m = 10.08m^2
For bales of 500kg @ 50%mc, average storage density
= 1.1 t/m^2 (0.55odt/m^2) of floor area;
Storage volume of 8.4 x 1.2 x 4 = 40.3 m^3
= 0.28 t/m^3 (0.14odt/m^3) allowing for stack geometry.

For bales of 750kg @50%mc, average storage density
= 1.65 t/m^2 (0.83odt/m^2) of floor area
Storage volume = 0.42 t/m^3 (0.21odt/m^3)

Chips stored in piles 5 m high x 10m base width = 0.3-0.35 odt/m^2.

Large scale chip storage at moisture contents >20% can lead to biological activity which can give:

- heating in the stack, loss of dry matter, and deterioration of the physical quality of the chips
- health issues when handling due to high dust and spore concentrations.

However, there are also many examples of successful chip storage, such as in the export wood chip industry where chips are stockpiled prior to being shipped overseas.

In all cases, storage adds to the cost of the biomass that is finally supplied to a bioenergy plant. As such, storage should be considered as part of the overall system design, to balance issues such as:

- the benefits of operating a bioenergy plant all year
- possible difficulties in harvesting all year
- security of feed supply on a short term basis
- potential for drying the feed during storage.

3.12 Drying the Biomass

Drying the biomass affects:

- the available energy content contained within the fuel
- the energy ratio of the system
- the ease of comminution.

Drying can be accomplished artificially or naturally (which takes longer but is normally the cheaper option). Transpirational drying of whole trees is possible but only if cut when in leaf and extra costs from double handling may result. Where waste heat is available from the conversion plant some artificial drying may be possible, and this can be essential in cases where deterioration is expected to occur in storage if the material remains wet. The acceptable moisture content for the fuel is determined by the type of conversion plant.

The drying options for the fuel supply contractor include:

- transpirational drying of arisings or whole trees if leafy in the field
- natural ventilation in field store of billets, stems or sticks
- intermittent artificial ventilation in field store of chips or billets
- natural ventilation in central store of billets, stems or sticks
- intermittent artificial ventilation of chips or billets in central store
- raise temperature of artificial drying air using waste heat from plant
- raise temperature of drying air using gas or electricity.

Energy consumption used for intermittent drying with fans running for only 6-8% of the time has been shown to be as follows:

Covered chip pile	95 days	3.72 kWh/odt	
Uncovered		8.51 kWh/odt	
Covered		225 days	5.23 kWh/odt
Uncovered		10.63 kWh/odt	

Drying chips by continuous ventilation of ambient air is not economic. Natural convective ventilation of the chips is not feasible as it does not prevent respiration and mould growth. Natural convection has been shown to cool both 220mm billets and whole sticks but both continued to respire and to lose some dry matter (6-12 and 4-16% for willow and poplar). For 100mm billets however some ventilation may be necessary to avoid mould and to reduce dry matter loss.

Thermal power plants often produce some waste heat which may be useful for biomass drying. However if the flue gases are cooled too much in the process (e.g. by using a heat exchanger) they will condense inside the flue, leading to operational problems, corrosion and the possibility of unacceptable emissions.

There is a need to inhibit deterioration and dry matter losses during storage of undried biomass material for long periods of time so drying may be necessary for such extended storage. Where a range of fuel suppliers is used by a plant operator there may be need for a buffer store from which the various fuels with varying characteristics can be direct fed into the boiler to minimise local variations in moisture content. A payment system can be developed to give a premium for fuels within the desired moisture content range.

Computer simulations have shown that drying chips with waste heat by continuous flow drying will minimise energy consumption and maximise drying capacity per m^2 of storage area. Getting the moisture level within 1-2% of 30% is easier than getting it within 1-2% of 15%. Drying wood from 50% to 25% removes 667kg of water/odt and to reduce it to 12% removes 864 kg. Remember that, while drying may improve the efficiency of the power plant, each type of thermal process is usually designed for feed of a certain moisture content. Using feed that is dryer than expected can actually lead to operational difficulties and emission problems.

4. Harvesting Specific Feedstocks

4.1 Summary

A pivotal issue for the economic viability of biomass energy crops is reduction of the cost of the harvested biomass fuel. This has resulted in the development and use of improved mechanised harvesting systems to reduce handling operations. This section provides an overview of several harvesting machinery options. In the absence of documented Australian work on this topic, systems studies from overseas are the principal source of material for this section.

Tree species biomass may be harvested using a *feller buncher*, with a *forwarder tractor*, or purpose build *forwarder* used for extracting the biomass from the harvesting area. For steeper terrain, *cable haulers* are often used. These may be tractor or truck mounted. Harvested stems may be extracted from the harvesting area using a variety of *skidders*. *Bed, grapple, tractor mounted* and *sliding boom processors* are used to delimb and cut tree limbs into specific lengths for transport.

Harvesting technology for short cycle tree crops has largely grown out of the agricultural sector, with equipment being adapted for tree crops grown for energy. For example Claas has a harvesting and processing machine that directly chips the biomass material as it is harvested, reducing the chance of soil contamination. Similarly an Austoft sugar cane harvester has been adapted in Europe for harvesting and chipping short rotation willow in one process.

Harvesting equipment for short cycle crops needs to take account of the branching characteristics of the tree species to be harvested. For instance many eucalyptus trees have different branching characteristics from conifers.

A recent New Zealand study examined a 100ha coppice eucalyptus crop. Five harvesting options covered in the New Zealand work included use of manual felling, a feller buncher, and both a large and a small forwarder. Extraction options were a tractor-trailer, tractor and chip bin trailer, and a large forwarder. The delivered cost of biomass varied considerably depending on the choice of equipment.

Comminution (reduction of the biomass piece size by mechanical means to obtain a more uniform and useful bulk material) is considered in some detail in this section. Several chipper configurations are presented, from trailer mounted chippers to self propelled vehicles. Energy used by chippers tends to increase with shorter chip lengths, while the opposite applies to hammermills. The energy input into chipping is a very small fraction of the inherent energy in the chipped biomass (typically 0.5%). Chunkers or hoggers comminute biomass into larger pieces than chippers, with some advantages for drying.

Drying of the biomass fuel and its impact on the thermal efficiency of the bioenergy plant is considered. Further information on transpirational drying, evaporative drying, and forced air drying is covered, noting the energy production benefits of combusting drier biomass.

Harvesting agricultural residues, including rice husks, bagasse, maize cobs, nut shells and cereal straw is also covered in this section. It is noted that such wastes tend to have moisture contents in the range 10-30 percent (wet basis) and are therefore well suited for combustion. The 11 million tonnes of bagasse (sugar cane fibre) produced by the Australian sugar industry is discussed as an energy source. It is noted that use of cane tops and leaves could raise electricity generating capacity in the sugar industry to over 1,000 MW. Supplementing cane wastes with woody biomass in the non-crushing season could theoretically expand energy production even further. However, removal of in-field cane harvesting wastes could be detrimental to nutrient balances, and further research is needed. Another possible development could be the move by the sugar industry to higher fibre cane varieties, to increase energy production.

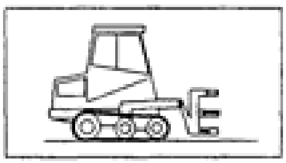
Cereal straw, with potential disposal costs, provides another opportunity for bioenergy. Of interest are many long term evaluations which show that there is little benefit to soil nutrient levels from returning straw into the soil. This has led countries such as Denmark to lead the world in using straw for energy production. However, in the Australian context, straw collection has been estimated to cost around $50/t for raking and baling, leading to electricity costs in excess of those from alternative sources of renewable energy.

High yielding, short cycle tree crops and plants such as sugar cane and sorghum can store energy equivalents of over 400 GJ per hectare per year at a commercial scale, leading to very positive energy input/output balances. Similar analysis indicates that oil bearing crops only provide energy yield in the range 60-80 GJ per hectare per year. Nonetheless, biodiesel does provide good greenhouse gas performance and reductions in air emissions.

4.2 Conventional Forestry Harvesting

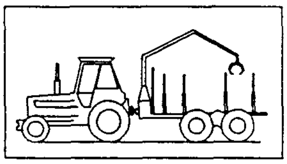
There are several methods for harvesting trees, the manual chainsaw remaining the most common. However due to safety reasons as well as economic ones, there is a trend towards more mechanised systems. Once cut, the material has to be removed from site and many designs of extraction machines are available which are used on a wide range of terrains and with various sizes and species of tree. What suits one forest may not suit another. Some common designs are shown below. These methods could be easily adapted to harvest energy plantations where the trees are as large as traditional forest crops. More likely is that the stemwood will be extracted after harvesting by these traditional machines then the arisings can be used for biomass.

Harvesting is by manual chainsaw, or by feller buncher with a chainsaw type cutting head or hydraulically actuated guillotine type cutter.

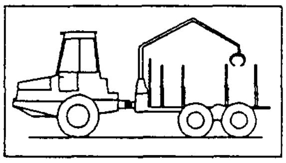


Feller buncher is a purpose built forest vehicle with front mounted felling and accumulation head which cuts the trees and holds them until dropped on to a site ready for collection.

Extraction of the cut material from the forest to a road or to a “landing” for further processing can be accomplished in numerous ways.



Forwarder tractor is a four-wheel drive agricultural tractor with linked trailer and grapple which extracts shortwood, logs, and cut stems and small trees entirely clear of the ground (Figure 4-1).

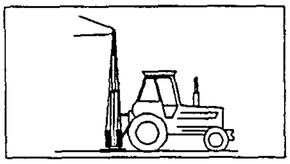


Forwarder is a purpose built, frame steered forestry vehicle with integral timber bunk and grapple to load the logs or trees (Figure 3-6, Figure 3-7 and Figure 4-2).

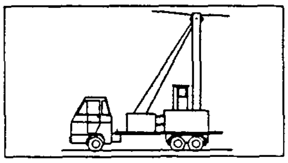
Figure 4-1: Forwarder tractor or forestry logging trailer with hydraulic loading boom and grapple
…which can be operated behind a standard agricultural tractor.

Figure 4-2: Specialist forestry forwarder with articulated chassis

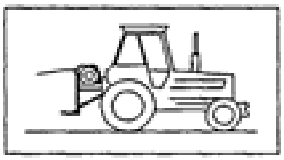
Cable haulers are used to extract forest material on steeper terrain where wheeled vehicles cannot safely go. Costs are higher and, unless pulled out as whole trees, extraction of harvests is not economic.



Tractor mounted cable crane using a tower and tractor power take off (pto) for a drum winch, and capable of extracting loads of stemwood or whole trees on steep country being totally or partially clear of the ground.

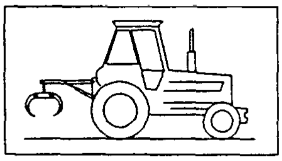


Truck mounted cable crane tower with drum winch also capable of extraction of loads totally or partially clear of the ground but normally of greater load capacity than tractor mounted systems (Figure 4-3 and Figure 4-4).

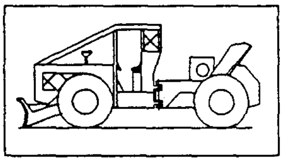


Skidders are simple machines designed to pull harvested stems or whole trees to the landing for further processing and/or loading on to transport vehicles. They are usually capable of extracting whole trees by lifting one end of the load clear of the ground during extraction. Even so soil and stone contamination is often a problem.

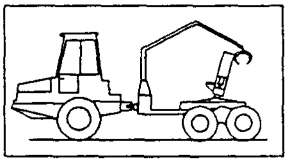
Agricultural tractor winch skidder is a four wheel drive forest tractor fitted with rear mounted winch powered by the power take off (pto).



Agricultural tractor grapple skidder is also a four wheel drive forest tractor but fitted with a rear mounted skidding grapple.



Articulated winch skidder is a purpose-built four wheel drive, frame steered, forestry vehicle with integral drum winch (Figure 4-5).

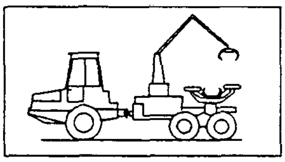


Clam bunk skidder is a purpose-built frame-steered forestry vehicle with bunk mounted hydraulic clam and integral grapple.

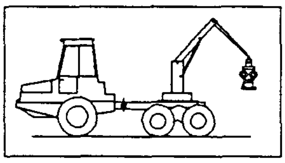
Once the whole trees have been delivered to the landing, various designs of processors are used to strip the limbs from the stemwood, to cut off the tops, and to cross cut or “section” the stem wood by cutting it to desired specific lengths. The logs are then ready for transport to the processing plant. The residues left at the landing may be returned to the forest, burnt, or used as biomass when they are normally chipped and transported to the heat or power plant.

Figure 4-3: Cable hauler tower in *P. radiata* plantation
…extracting whole trees down to landing for processing. (Note bulldozer used for anchor only).

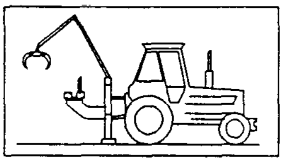
Figure 4-4: Cable hauler extraction of logs in steep terrain
…up to landing for manual chainsaw sectioning to length.



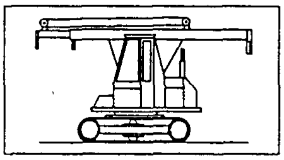
Bed processor is a two grip unit mounted on a forwarder chassis and capable of delimbing and cross cutting whole trees to specific lengths.



Grapple processor is a single grip unit mounted on a forwarder chassis or on a semi-portable fixed platform (Figure 4-6).



Tractor mounted processor is a two grip bed processing unit mounted on an agricultural tractor.



Sliding boom processor is a purpose-built processor, capable of delimbing and cross cutting but not always to specific lengths (Figure 4-7).

Figure 4-5: Articulated winch skidder working in poorly managed plantation
(30 year old *P. radiata* plantation with a large proportion of material suitable only for bioenergy use.)

Figure 4-6: **Grapple processor delimbing, topping and sectioning stemwood to desired lengths.**

Figure 4-7: **Sliding boom processor at landing delimbing logs.**
Note: the arisings are available for collection or for returning into the plantation if there is no local demand for energy purposes.

Figure 4-8: Harvesting large or small trees
(or in this example, 3 year old coppice *Eucalyptus* regrowth) can be done manually using a chainsaw with varying cutter bar lengths to suit the tree stem diameter.

4.3 Short Cycle Crop (SCC[1]) Harvesting Technology

Whether the biomass is grown as an energy crop, either as a single stem or coppice regime, or is a by-product of a crop grown primarily for other purposes, harvesting it and collecting it from the field is a key operation. Manual chainsaws may be satisfactory for small firewood plots (Figure 4-8) but on an industrial scale mechanised harvesting machines should be used where possible, particularly units that are normally reliable and well tested. Using such machines can help spread the fixed ownership costs over more hectares and longer harvesting seasons.

One of the key aspects to successful biomass production systems is matching the right harvesting machinery and method to the type of plantation. The method of harvesting can have a large effect on the sustainability of short cycle (tree) crops, the total biomass produced, and the overall feasibility of growing SCC.

Harvesting of single stem, short rotation tree crops for pulpwood using variations of conventional forest harvesting systems is not currently practised in Australia. However it is common practice in parts of the northern hemisphere and so the discussion provided here is based almost completely on overseas examples. There are few purpose-built harvesting machines commercially available for use with SCC but due to increasing interest in SCC as a source of fuelwood and fibre, new machines are being developed. Machinery adapted from agricultural crops is being used to harvest predominantly small stemmed crops such as Salix (willow) grown in Europe, Scandinavia, UK and Northern America. Other machinery derived from forestry origins is being used to harvest larger diameter SCC trees mainly for fibre production in places such as southern USA, Central America and South Africa (Figure 4-9).

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[1] The phrases Short Cycle Crop or Short Cycle (tree) Crop are generally used in this report in preference to Short Rotation Forest or Short Rotation Coppice. Many Australian farmers see “rotation” as meaning rotating different crops (e.g. trees then wheat) instead of the European meaning of a permanent tree crop with the period between harvests being much less than for traditional (saw-log) plantations.

The information provided here shows that harvesting SCC biomass is quite feasible, and that a number of alternative harvesting methods exist. Equipment selection must occur on a case by case basis. The particular methods applicable to Australian SCC biomass may be similar to methods and equipment used overseas, however they must also take into account attributes of the trees (for example multi-stemmed evergreen eucalypts as opposed to single stem, deciduous willow), the planting patterns, quantities required and so on.

Figure 4-9: Feller buncher with accumulating head developed for SCC harvesting of poplars in the USA.

Specialised equipment for felling and bunching SCC, like the Canadian FB7 (Figure 4-10) and the Irish Loughry coppice harvester (Figure 3-3) harvest and bundle small diameter trees. Direct harvest/chip machines like the Claas forage harvester with specialist cutting head (Figure 4-11) are being commercially operated in Europe for the production of willow fuel chips but are yet to be evaluated with other species and under different conditions.

Figure 4-10: FB7 prototype harvester
(Developed in Canada for harvesting SCC poplar trees up to 7 inches (175mm) diameter.)

Figure 4-11: The Claas forage harvester twin disc cutting head developed to SCC willow

4.3.1 Selection of SCC and coppice harvesting machinery

The decision as to which harvesting method to use will often be a compromise between maximising sustainable yields and minimising costs. As discussed in Section 3, points to consider during harvesting are the immediate and long term effects from stump damage, soil and root compaction, and damage that might be caused to unharvested trees. Consideration must also be given to the form in which material is required for further processing.

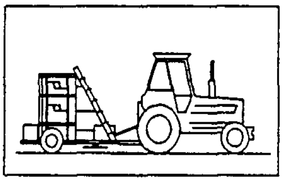
Machines like the Claas directly chip the material as it is harvested and reduce the chances for soil contamination. However these machines are often heavy and may create soil compaction problems, especially on wet sites. The condition of the site after harvest can influence the vigour of regrowth and the chances of disease build up. Slash left on site can create an ideal environment for encouraging disease and impeding regrowth. Also the land use and condition of the site prior to harvesting are going to determine the felling and extraction techniques.

Harvesting and processing can be performed separately, or integrated into a continuous process. In Sweden and the UK agricultural machines like the Claas and the Austoft sugar cane harvester have been adapted to harvest and chip SCC willow in one process. Other machines such as the Loughry coppice harvester (Figure 3-3) and the Hydroaxe feller buncher (Figure 4-12) cut and bundle coppice material for further processing at a later stage.

Short cycle crops tend to have many smaller trees and harvesting them individually can be a problem. Traditional forest thinning machines can be used and also feller bunchers but the work rate or productivity in terms of t/h or ha/h is generally slow and hence expensive in terms of $/GJ harvested. Harvesting multi-stemmed coppice regrowth as opposed to single stem trees can be even more problematic. The base of the tree increases with age as more stems are produced after each harvest. Few commercial machines exist but many prototypes have been evaluated.

Figure 4-12: Hydroaxe feller buncher harvesting poplars.

The challenge to harvest other coppice crops such as *Populus* or *Eucalyptus* has yet to be resolved satisfactorily. One additional problem is the need to minimise damage to the cut stool in order to reduce fungal infestation and tree mortality and to encourage shoot regrowth. A number of prototype machines have been developed.



*Coppice harvester is a p*urpose built unit, powered and drawn by four wheel drive agricultural tractor or self-propelled and capable of felling, bunching and processing of coppice stems.

Harvesting has to be carried out efficiently and with the right equipment to minimise costs. Specialised machines that offer high productivity and efficiencies also tend to have high capital costs so they must be kept operational as much as possible, which is often impractical. Less specialised equipment like a chainsaw, can therefore be cost competitive even though more labour intensive, though productivity and efficiency may be compromised.

The harvesting system should be considered at the outset of any integrated bioenergy project development, as it is closely associated with the tree selection and growth strategy, and with the likely delivered costs of biomass. This would also allow the careful planning of row width and access ways based on the physical requirements of the harvesting equipment.

When deciding on suitable equipment, consideration should be given to:

- the resource (wood/tree) characteristics
- desired end product characteristics
- terrain characteristics
- scale of operation.

Weight reduction of a load can be achieved by allowing felled trees to transpirationally dry on site before extraction. This practice is also beneficial when weight restrictions limit the amount of material that can be transported on roads.

The size and type of machinery used in SCC harvesting will be influenced by the general shape and growth of the trees. Typically the growth form of *Eucalyptus* trees is different from traditional coniferous forests such as *Pinus radiata* (Figure 4-13). Generally eucalypts have the bulk of their crown concentrated towards the top of their bole (stem), with the bole having a gradual taper so that the centre of gravity is higher than that of pines. The height of a *Eucalyptus* tree for a given diameter is also generally greater than comparable coniferous trees. As a result of these factors the crown can exert a greater influence over the direction of fall when the tree is felled. This may create problems for conifer forestry machines when harvesting large *Eucalyptus* trees.

The branching characteristics of *Eucalyptus* trees may also require a different delimbing technique than coniferous trees. Traditional delimbing heads may not work effectively on some Eucalypts because of the smaller angle between the stem and branches.

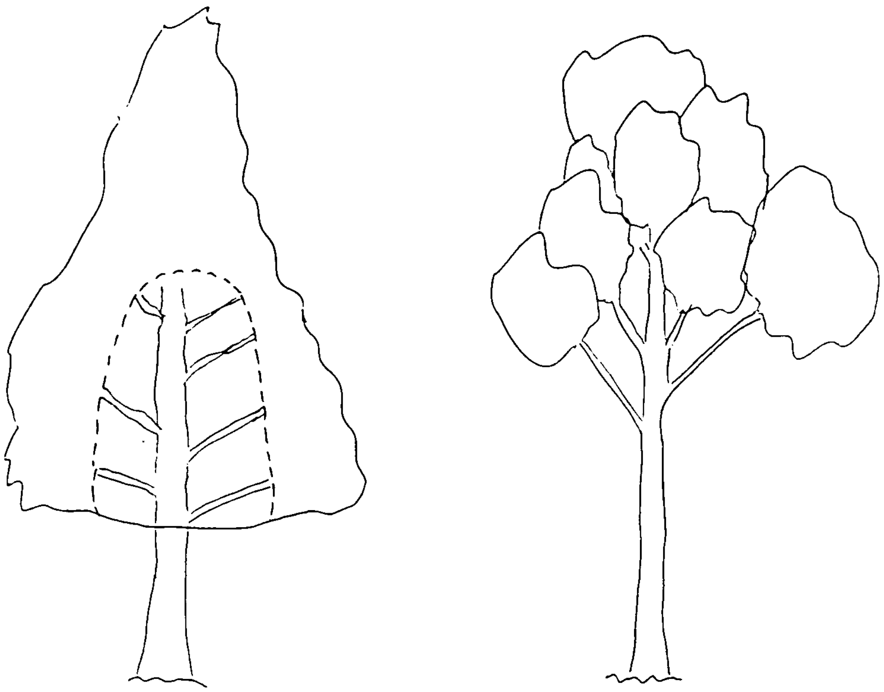


Figure 4-13: Growth form difference between Pinus and Eucalyptus species

Manual felling techniques using chainsaws can be inexpensive, simple and versatile whereas fully mechanised systems of harvesting SCC (i.e. felling and bundling or direct harvest chip) are being used more commonly overseas. Different crop factors such as species and stocking rates, and different terrain characteristics, affect the productivities of these machines.

One other factor which may affect harvesting productivity is the presence of foliage. The majority of northern hemisphere machinery has been developed for harvesting deciduous SCC crops in the winter, when leaves are absent. Eucalypts maintain their leaves all year round so machines must be able to harvest trees in full foliage, which can be more challenging.

Modifications to current SCC production systems may have to be made before any of these harvesting machines could be used on a commercial scale in Australia. For example in Sweden willow trees are now grown in paired rows, and at higher densities to provide easier and quicker harvesting using a Claas forage harvester. Alternatively, the harvesting machinery available could be modified to accommodate local SCC systems.

It may be possible that specialist machines like the Canadian FB7 harvester could only be operated satisfactorily under a limited set of conditions and with selected SCC crop species after considerable modifications, whereas direct harvest/chip machines may work well under a range of current SCC management practices. These machines appear to be an attractive option because of their `single pass' operation, but wet chips result. A`two pass' operation could have benefits of allowing on-site transpirational drying prior to extraction, reducing the power requirements of the felling machine, requiring smaller and less expensive equipment, and providing an overall reduction in harvesting costs.

Under current popular eucalypt SCC management practices, a single stem is harvested at the end of the first cycle. During successive cycles multiple coppice stems need to be cut from the initial stump. Over this period the stump width can increase from a single narrow stump of around 150-200mm diameter to a wide and many branched stump over 0.5m in diameter. Most current harvesting machines operate over a relatively narrow range of diameters so that variations in stump diameter over time, and a large number of small stems, may cause difficulties and hence reduce efficiency for harvesting operations.

4.3.2 Harvesting machinery options

For a 100ha coppice eucalyptus crop grown in New Zealand, five harvesting options were identified and analysed.

1. Motor manual: Felling using two chainsaws and two persons. For compliance with the NZ Health and Safety Act a minimum of two people must work together in the felling operation at any one time.

2. Feller-buncher: A machine that physically holds the tree then cuts and places it in a pile. There are several forest machines available which are suitable. A tracked excavator would minimise ground damage while having adequate traction, especially in the wetter areas of the plantation. However there are considerable costs associated with maintenance of tracked machines and an excavator would be confined to moving only up and down rows to avoid stump damage when crossing them. It is possible that flotation tyres could be fitted to improve manoeuvrability and minimise damage but they might be subject to side wall damage from the cut stumps.

3. Large forwarder: A forwarder adapted to harvest the trees and extract to a landing site. There are only a few of these machines available. They may be too expensive if there are relatively short transport distances within the 100ha plantation and high annual costs. They may be better suited to larger plantations.

4. Small forwarder: A tractor towing a forestry trailer with feller/grapple saw mounted on a hydraulic arm to harvest the trees and extract in a similar way to the large forwarder but at a slower rate.

5. Contractor: Employ a contractor to undertake the felling using any of the above methods for harvesting, extracting and chipping the trees. However, there is a lot of uncertainty as to the actual costs involved in the operation in regions where it has not been previously undertaken. If several plantations were available for harvesting during the year thus reducing costs, it would be a more economical proposition for the contractor to invest in necessary equipment. Then the machinery could be specialised and still operate for longer periods. Initially the cost quotes and productivities supplied and calculated can only be estimates as it will take at least one harvesting season before an accurate assessment of the actual methods and costs can be made.

4.3.3 Extraction and transportation

The method of harvesting and the final usage of the material can influence the extraction method. It is undesirable to have biomass that is contaminated with soil because of difficulties encountered during and after combustion. Small, whole trees and billets offer advantages during extraction by forwarders (self propelled logging trailers) by minimising the risk of soil contact and contamination, because they can be lifted from their felled site, rather than dragged. Forwarders are capable of moving through a plantation, depending on the tree spacing, and removing selected material. It is also possible to fit a felling mechanism to their grapple arm to allow both felling and extraction of the thinnings to be integrated into a single process. Forwarders are becoming common in forestry operations mainly for collecting residue material and small wood pieces, but they can also be used for extracting timber logs. Logging trailers pulled by agricultural tractors can perform similar tasks to a forwarder but at a lower productivity rate.

Extraction is the relocation of the trees or biomass material from the plantation. Four options for this process are feasible which can be incorporated into, or run in conjunction with, the harvesting and comminution operations.

1. Tractor and trailer: Use a tractor and forestry trailer to transport the whole trees from the plantation site where they are felled to an intermediate storage area or direct to a chipper.

2. Tractor and chip bin trailer: Use a tractor and bin trailer to extract chipped material from the plantation to the silo or shed where chips will be stored.

3. Large forwarder: Use a feller-forwarder for transporting whole trees. The same reasoning applies as for the feller-buncher in harvesting option 3. In a larger plantation the forwarder without a tree felling unit could be suitable for just extraction.

4. Contractor: Use a contractor to extract the trees. This will more than likely be incorporated into a harvesting operation, and may offer machinery that is well-utilised across several sites in addition to the one in question.

4.3.4 Comminution

One of the first steps in using biomass for energy is processing the raw material into a form that can be utilised efficiently as fuel. Raw material, being whole trees, forest residues, cereal straw etc, needs to be converted to a state that enables it to be easily and consistently handled. Forms of biomass used in the energy conversion process include billets, specially ground material, wood chips, chunks, briquettes etc. The process which reduces the size of the biomass so that it can be used efficiently in a combustion appliance is called **comminution**, and is defined as "the reduction of biomass by mechanical means to obtain a more uniform and valued bulk material".

The end use of the product and the energy requirements should be considered when selecting a comminution form or technique most appropriate for an individual situation. Comminution is usually carried out by one of two main techniques. The first involves chipping or chunking when using sharp cuttings edges to cleave or shear the biomass into particles. The second employs a blunt impacting tool to crush or shred the material, producing particles of indistinct geometry. This latter process is usually called hogging or shredding.

The strength of the wood affects the power required to reduce it from solid wood pieces to chips or chunks. A wide range of comminution machines exist such as chippers, hammermills and shredders. Each type consumes different amounts of energy per tonne of biomass processed. Those with sharpened edges to the cutting blades need regular maintenance to minimise energy inputs.

It should also be noted there is a strong interaction between the particle size of the biomass, the ability to minimise transport costs by maximising payloads, and the rate of burn, fermentation, hydrolysis etc. depending on the conversion system used.

4.3.4.1 Chippers

Chipping equipment ranges from large stationary machines developed for the pulp industry, down to small tractor-operated designs suitable for on-farm use for woodlots. Selection of comminution equipment should fit into the overall handling and delivery system and relates very much to end product specifications.

Energy inputs of chippers tend to increase with shorter chip length and lower moisture content, whereas the reverse is the case with hammermills. Hardwoods, with shorter fibres, tend to require more energy than softwoods to produce the same size chip. Over a range of machines, moisture content and materials, the energy input needed to comminute one oven dry tonne (odt) of roundwood (logs) to 25mm nominal chips ranges from 5 MJ to 250 MJ. Since 1odt contains approximately 20 GJ of available energy, comminution is only a small proportion of the total. Minimising the energy input is an important factor, but it has to be balanced against cost and time. The chipper machine productivity in terms of tonnes processed per hour is an important selection criterion, as are the maintenance costs and the capital cost.

Due to the low bulk density of unprocessed woody biomass, transport costs can be considerable. To increase the density and thus reduce transport costs, whilst at the same time improving the fuel handling and combustion properties, processing the fuel into a higher bulk density and more uniform fuel is often required. At times this can be through comminution, though for some biomass forms (such as reject logs and even straw) it can reduce the bulk density.

Tree diameters, stand volumes and species affect chip size for any given method and production goals affect the size of comminution equipment required for a given system. The quantity and quality of the raw woody material varies with tree age, species, moisture content and the components present (ie stem, branches, leaves). As a result many different forms of comminution equipment are available, each suited to converting a particular raw fuel to a processed fuel with a distinct particle size distribution and fuel quality.

Disc and drum chippers can produce chips with varying size and dimensions, with variations achieved by altering parameters such as the pitch or angle of the blades, the number of blades, the speed of the material being fed in, anvil clearance, and disc rotation speed. To obtain a uniform particle size and maintain an even work load on the chipping blades and motor, in-feed rollers are used to control the rate at which the wood is fed onto the cutting surfaces. If the rotational speed of the chipping blades slows, the machine’s ability to blow the chipped material out the discharge chute is reduced and blockages can result. Many chipper designs have the forward speed of the feed roller dependent on the fly wheel or drum speed to reduce the chance of blockage and maintain an even work load on the motor by allowing sufficient fly wheel speed to be maintained. This gives improved uniformity of chip size.

The blade orientation of some chippers produces an inward pulling effect, thereby reducing the need for feed rollers. However, it is advisable to have feed rollers on the machine when chipping brushy material, such as whole eucalyptus trees with leaves and branches, because without them the irregular nature of the material can produce uneven chip sizes and cause the motor load to vary. However the majority of small chippers do not have feed rollers because the final use for the material (or chip quality) is not critical and the cost of adding rollers would substantially increase the total cost of the machine.

4.3.4.2 Chunkers

The concept of chunkwood was developed to improve the utilisation of small trees and forest residues and because drying studies indicated that there are advantages in having larger particles than chips. Chunking requires less energy than chipping, provides a denser material for storage, trucking and hauling (and so requires less storage volume), and permits better drying because of larger air spaces between the chunks. Chippers have difficulty producing chips with lengths greater than 70mm whereas chunkers can produce blocks 50 to 250mm long, though the cross-sectional area is very variable. Chunks are produced by sharp knives making regular cuts into the material which is fed in at a controlled rate. There are two main chunking methods; spiral head (or cone screw), and involuted disc chunkers.

4.3.4.3 Chip and chunk quality

The comminution method used has a large effect on chip quality, one of the most important factors being moisture content. The comminution method and moisture content together can affect the drying and storage characteristics of the material, which inevitably affects the fuel quality (though there are many other factors used to evaluate the quality of fuel).

There is a need for a quantitative standard for classifying fuel quality with respect to its handling and burning properties. However, a classification system would be difficult to establish because of the variety of fuel particle types required by different energy conversion systems. The ability of a furnace to burn various types of biomass depends on its design. Some combustion units are exclusively wood chip burners, whereas others are suitable for burning combinations of wood chips, bark, sander dust, straw coal etc. Bark and foliage, along with other irregularly shaped material such as oversized chips, twigs etc. can create mechanical problems for handling equipment, and possibly cause blocking of conveyers and storage silos.

In the products from any comminution process, apart from the material with the required particle size range there will also be some smaller and larger material. Comminuted woody material can therefore broadly be divided into three major size categories:

- acceptable material
- fines
- oversize.

Acceptable material is suitable for the final end use, its dimensions being within a suitable range. Requirements for pulping (for the paper industry) may be different from those for combustion, and the latter requirements will also vary according to the design of the conversion unit being used.

Fines are comprised of small components including bits of bark, foliage and inorganic impurities. Chips produced from SCC whole trees, forest arisings and stumps can have a high portion of fines, and the effect of this fine material on the end use of the material is variable. For fuel use, chip bulk density is the most critical characteristic. Foliage and soil content can have an effect, whereas bark contamination is not normally a problem, though it is for pulp chips. By reducing the portion of fines in a biomass feed stream, more air can circulate through a pile of chips aiding moisture loss, minimising temperature and micro-organism increases, and consequently reducing biomass losses.

Oversized material is typically too large for its desired end use and is excluded by a screening process based on size (length and/or diameter) and sometimes weight. A high proportion of oversize chips can be produced when small diameter, often dry and stringy material, like branches and forest arisings, are comminuted. This can create problems for conveying equipment and cause bridging in silos and hoppers. Oversize material generally presents a greater problem to smaller scale installations, where material flows are not large and openings are narrower. Also the separation of the oversized material is often less effective when using cheaper, small scale screening systems.

To reduce biomass wastage and handling difficulties it is normally recommended that there should be uniform material size. Reducing the portion of oversize material will help to minimise handling difficulties by reducing bridging and decreasing the angle of repose.

Remember that most types of solid biomass fuels have low energy densities compared to fossil fuels. As a result, the volumes that have to be handled per energy unit are often larger than in the fossil fuel industry. This means that storage areas and handling equipment have to be relatively larger to maintain the same energy output capacity. However, the size of an intermediate storage facility prior to the boiler or gasifier is often more dependent on the rate of fuel supply required and issues of feed continuity.

4.3.4.4 Screening

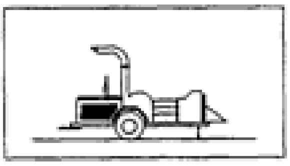
This involves separating two or more fractions of material on the basis of size and/or weight. Screening can be difficult with biomass because of considerable variation between crop species and with other factors such as moisture content. Raw or unclassified material generally requires two screenings to firstly remove the large oversize material and secondly to remove the smaller fines. The greater the difference between any two wood fractions the easier it is to separate them. However, with most screening operations there is some overlap which will produce a small percentage of impurities in the pure fraction.

Screens are either flat vibrating designs or rotary drums. The shape of the holes in a screen can influence the quality and size distribution of the chips. Round screen holes will produce a product with a more constant size compared to square holes. Square holes have a diagonal size 1.4 times the nominal side length and produce a product that is then dependent on how it is presented to the screen. Despite this, square holes enable a larger percentage of the screen to be open to sieve the material, as round holes do not interlock and therefore present greater surface area/m^2 of screen.

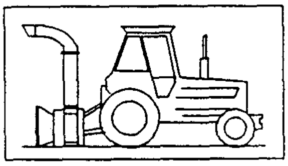
The vibrating or rotating speeds of a screen have an effect on screening efficiency, however the efficiency is also dependent on the type of screen being used and other factors such as moisture content and portion of oversize/fines. Screening of the fuel is also possible when necessary at the site to ensure a consistent quality enters the boiler feed system.

Solid biomass with a low moisture content tends to have better handling characteristics than wetter biomass. This complements the need for dry wood to reduce storage losses and maximise energy conversion. Dry chips require smaller holes and less agitation to screen than wetter chips thus aiding accurate classification. However over agitation of dry chips can increase losses by forcing marginal chips into undesirable categories and increasing the portion of fines from the physical breakdown of these chips. Over agitation of dry chips can also cause an increase in fines and create more dust.

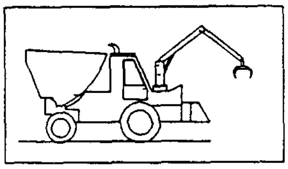
Various forms of chipper are commercially available for use by the forest industry and which can be adapted for biomass use.



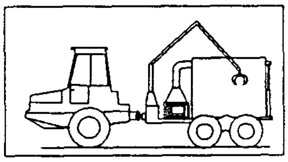
Trailer mounted chipper being a comminution unit with integral power source rather then being connected to a tractor (Figure 4-14).



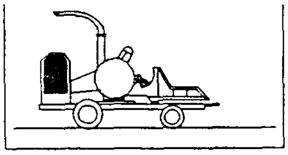
Tractor mounted chipper being a comminution unit powered from the tractor power-take-off (Figure 4-15).



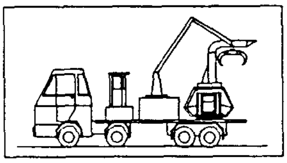
Self-propelled chipper being a purpose built forest vehicle with front mounted grapple to feed the chipper unit, and with a rear mounted chip bin.



Forwarder mounted chipper being a large self-propelled comminution unit with integral power source and chip bin, mounted on a forwarder chassis (Figure 4-16).

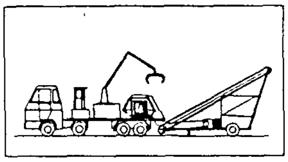


Heavy duty trailer mounted chipper being a large comminution unit with integral power source mounted on a heavy duty chassis and trailed by truck or forest vehicle (Figure 4-17).



Truck mounted chipper being a large comminution unit with integral power source and grapple, mounted on a truck chassis.

Chunkers can be in similar format to the chippers above but there are fewer commercially available machines manufactured; the following being the most common.



Truck mounted chunker being a large comminution unit with integral power source and grapple, mounted on a truck chassis, and used in conjunction with an elevator for loading the chunks which are too heavy to blow.

Figure 4-14: Trailer mounted chipper with auxiliary power supply
(Also available in smaller sizes than shown)

Figure 4-15: Tractor mounted chipper for small scale applications
(At 5 odt/h and grapple or manually fed)

Figure 4-16: **Using large mobile chipper to collect and chip *P. radiata* plantation thinnings**

Figure 4-17: **Heavy duty chipper handling SCC poplar at around 30 odt/h with grapple feed**

4.3.5 Drying the biomass fuel

There is an interaction between moisture content, transport, storage and conversion of biomass so it is worth briefly returning here to discuss drying the fuel as part of the supply chain process. When using wood, which naturally contains significant amounts of water, the heat required to raise the feed temperature and evaporate the moisture has to be generated by the wood itself. Since a typical heat plant (furnace or boiler) is designed to maintain sufficiently high exhaust gas temperatures to avoid condensation in the stack or chimney, much of this exhaust heat is usually not recoverable (though there are exceptions such as condensing turbines) (Figure 4-18). Hence the thermal efficiency of the overall system will be reduced when using fuels of higher moisture content. The heat lost in the exhaust gas is also directly attributable to the moisture content of the fuel, which directly effects the efficiency of the system. The loss will vary from <2% of the total heat input when the fuel is at around 8% m.c., to nearly 15% when the fuel is at 50% m.c. So, for greater efficiency, the drier the biomass fuel the better. In addition, losses in thermal efficiency occur due to unburnt fuel being carried into the ash (possibly 0.5% loss) and surface heat loss from the actual plant of around 3% (but which varies with the plant design, and extent and temperature of the external radiating surfaces).

Figure 4-18: Drying a two day supply of fuelwood
(Occurs in the ‘A Frame’ building using waste flue gas heat at a 30MW wood-fired power generation plant in the USA.)

In addition to the fuel moisture content, biomass contains a quantity of hydrogen atoms which react to form water during the combustion process. The heat required to raise the temperature and evaporate this “extra” water also becomes unavailable to the system and has a similar effect on the overall heat recovery efficiency. The effect on the combustion system efficiency of both the free moisture and that formed by combustion of the hydrogen has been calculated (Figure 4-19).

Fuel moisture content (% wet basis)	Resultant energy losses (%)
0	19.6
10	20.9
25	24.8
40	30.2
50	34.5

Figure 4-19: Typical heat losses during combustion

Due to the moisture content of the biomass fuel and combustion of the hydrogen contained in the fuel.

The environmental ambient conditions, (mainly temperature, air movement and humidity), together with particle size and the structure of the tissues of the specific biomass, determine the release of moisture from the biomass by transpiration and evaporation, and the rate of release.

Transpirational drying is the loss of water via the foliage of the plant. It occurs continually whilst the plant is growing. For example, 4 – 5 m tall, three year old *Eucalyptus saligna* trees grown as short cycle crops, can each transpire over 30 litres of water during a sunny summer day, or approximately 2 – 3 l/day when it is overcast and cooler. Transpiration can continue for some time after trees are harvested, a process which can be utilised to lower the biomass moisture content with minimum cost inputs.

Evaporative drying is the loss of water from the cavities of plant cells, which occurs mainly as a result of evaporation of the moisture present. Energy is required to evaporate the water during the drying process. When only the moisture in the cell walls remains, this is known as *fibre saturation point* and is normally between 20 – 26% m.c. As fresh biomass dries, using either solar or artificial energy to heat the drying air in order to carry more moisture away before it becomes saturated, the 'free' water in the cell voids is lost first. Below the fibre saturation point, additional energy is needed to release the water molecules which are held hygroscopically in the cell walls. This energy requirement amounts to 2.43MJ per kg of water evaporated.

Evaporative drying can be achieved by the natural ventilation of air passing through the biomass when stored outside in piles, or by using forced air flows from fans through biomass stored in buildings with controlled ventilation. Natural drying depends on weather conditions and hence takes longer and is harder to control. A large storage area for woody biomass is usual (in the open) as drying may take weeks or even months. The drying biomass represents an investment tied up for this period. No capital equipment is needed, though concrete pads are preferred.

If forced air drying is used it needs controls, and is capital and energy intensive. However, particularly if heated air is used, it may take only hours not weeks to reach the same optimum moisture levels. The decision to install such drying systems can be made on the basis of comparing its capital and operating costs with the financial return from efficiency gains via use of a dryer feed.

The rate at which drying occurs to fibre saturation point varies with plant species, ambient temperature and humidity and, for woody biomass, whether or not there is bark cover left on the logs and branches. Any further moisture loss down to the *equilibrium moisture content* is slower. This is the point at which the moisture content of the biomass is in balance with the relative humidity of the surrounding air, so it will normally vary around 10-15% m.c. day by day.

The smaller the piece size the greater the surface area / volume ratio which favours greater initial moisture loss. In woody biomass, the cells are longer going “with the grain” so cutting across the grain gives faster moisture loss. In addition the geometry of the pieces (i.e. the chip shape) affects the way in which the pieces arrange themselves when placed into piles. This determines the ventilation and hence the rate of moisture loss from the pile. Shrinkage can occur at lower moisture contents in wood when cut mainly tangentially to the growth rings rather than along the grain. Subsequent moisture uptake can result in re-swelling.

If the drying biomass is left outside, the rain will wet the outside of the material. If stored in large piece sizes as logs or chunks with good air movement between, this will soon dry again by evaporation. Conversely, smaller piece size (e.g. when cut into chips or stored as shredded bagasse or rice husks) will result in an increased exposure of cell cavities.

4.4 Agricultural Residues

Since biomass in all its forms is widely distributed it has good potential to provide rural areas with a renewable source of energy. The challenge is to provide the sustainable management, conversion and delivery of bioenergy to the market place in the form of modern and competitive energy services.

Agricultural crop residues often have a disposal cost associated with them. Therefore, the “waste-to-energy” conversion processes for heat and power generation, and even in some cases for transport fuel production, can have good economic and market potential. They have value particularly in rural community applications (Figure 4-20), and are used widely in countries such as Sweden, Denmark, Netherlands, USA, Canada, Austria and Finland.

Figure 4-20: Biomass has good potential to provide rural areas with a renewable source of energy

Large quantities of crop residues are produced world-wide and are often under utilised. These include rice husks, sugar cane fibre (bagasse), maize cobs, coconut husks (copra), coconut, groundnut and other nut shells, and cereal straw. Coconut and nut residues tend to be used only on a small scale, whereas larger quantities of rice husks, bagasse and straw can be accumulated in one place. Such wastes tend to be relatively low in moisture content (10-30% m.c. wet basis) and therefore more suited to direct combustion and gasification rather than to anaerobic digestion (which normally uses wet wastes such as tomato skins, meat cuttings or reject fruit).

Crop residues such as straw, bagasse and rice husks, if not having to be returned to the land for nutrient replenishment and soil conditioning, could be used more in the future for power generation, possibly at times in co-combustion with coal or gas and in appropriate conversion equipment with low emissions now that such technology is well proven. In Australia the major residues produced are those from winter cereals, sugar cane and sorghum. Current farming practice is to plough these residues back into the soil, or they are burnt, left to decompose, or grazed by stock. A number of agricultural and biomass studies have concluded that it may be acceptable to remove and utilise a portion of the residues for energy production, hence providing large volumes of material. The costs of collection, transport and storage will need to be factored into any potential use for energy.

4.4.1 Rice husks

Rice husks are an abundant agricultural residue, making up 20-25% of the harvested rice grains on a weight basis and separated out at the processing centre. Indonesia alone for example produces around 8Mt per year. The husks have a high silica content which can cause an ash problem and possible slagging within the boiler on combustion, but their homogeneous nature lends them to technologies such as gasification, requiring a uniform fuel quality for best results. Several commercial rice husk gasification plants have operated for a number of years in SE Asia and Australia.

4.4.2 Bagasse

Bagasse is a fibrous material left after the sugarcane is crushed and the raw sugar juice is extracted at a sugar mill. Over 11 million wet tonnes of bagasse are produced annually in Australia, with a total energy content of around 120PJ. Annual volumes vary from year to year, and are produced only during the sugarcane crushing season, which may last as little as 18 weeks between mid June and mid December. Currently all sugar factories are self sufficient in energy via the combustion of bagasse, with around 250MW_e of total capacity installed. At present not all bagasse is utilised for energy generation and there is potential to upgrade (at significant cost) the co-generation facilities at a number of mills.

Bagasse has considerable potential as a biomass fuel since it arises mainly at sugar factories where flows of bulky volumes of biomass in the form of sugar cane (Figure 4-21) are already well organised. Each fresh tonne of sugar cane brought into the factory for processing yields around 250kg of the residual fibre. Any country which grows sugar cane, including Australia, therefore has a significant biomass energy resource available in the form of the crop residue remaining after sugar extraction (Figure 4-22) which has been already collected and delivered to the processing plant. Most sugar factories use this bagasse as a source of heat for raising steam to process the cane juice and extract the sugar, but because the large volumes of bagasse can also create a disposal problem, they have tended to burn it inefficiently just to avoid accumulation of surplus wastes.

Figure 4-21: Sugar cane billets from the harvester
(Delivered then fed by belt conveyor into the sugar processing plant.)

Figure 4-22: Fibrous bagasse residue after extraction of the sugar
(This residue can create a disposal problem since, unlike the sugar beet pulp in Europe, there is little demand for it as livestock fodder.)

Many sugar factories also generate around 2-3MW electricity from the heat for their own use but at present only a few export significant quantities of surplus power because of operational and contractual difficulties of selling the power only during the cane crushing season. The potential to generate 20 to 30MW_e all year round by using other biomass in the 6-8 month non-crushing season has created recent interest in a number of countries including Australia.

Studies conducted in Thailand, Jamaica, Brazil and Zimbabwe (*inter alia)* have shown that optimisation of bagasse combustion for energy, together with the utilisation of some of the cane trash (the tops and leaves) usually left in the field after harvest, or burnt off before harvest to make access easier for the machines, could provide fuel for up to 50GW of generating capacity world wide based on more than 800 sugar mills each with >5MW_e capacity (of the world total number of 1670 mills) mainly situated in India, Pakistan, S.E. Asia, China, South Africa, Central America, the Caribbean, and South America. The practice of burning the crop prior to harvesting to remove the trash is declining due to environmental concerns and now around two thirds of the Australian crop is "green harvested" without burning.

Without plant up-grades to improve their energy efficiency, the annual power export capability of the 27 Queensland sugar factories in 2000 using excess bagasse was around 450GWh from 120MW_e capacity. With plant up-grades (requiring high capital investment) the available excess bagasse could supply over 1000MW_e capacity generating nearly 4000GWh / year. If the additional trash in the field was also collected and used for fuel, then these estimates could be doubled.

In Australia there are 31 sugar mills and if all were upgraded to utilise the bagasse and woody biomass in the non-crushing season efficiently for cogenerating of heat and electricity, then the total plant capacity could potentially supply as much as 3400MW_e (or 3.4GW). More than 20 TWh/y of electricity could be generated, which would reduce carbon emissions by over 16$MtCO_2$ - assuming electricity from coal would be displaced. Cost analyses have shown the generating costs using modern gasification could be as low as 6-7c/kWh or around 2-3 c/kWh above the base load, coal-fired plants. This would be competitive with many other renewable energy technologies and within the capped price for the 9,500GWh under the mandatory renewable energy target (MRET) legislation. For many plants the sale of the electricity would provide a useful second revenue stream. However not all of the mills might be able to economically benefit due to the need to have guaranteed supplies of suitably priced biomass feed for the period each year when bagasse is not available, over the entire economic life of the project. When new generating equipment is installed at high capital cost, it is essential that the plant is fully utilised for as much of the year as possible to achieve the lowest cost electricity. With the sugar cane crushing season lasting as little as 18 weeks, this places pressure on project developers and operators to secure reliable low cost feed for some 30 weeks each year.

The link between the power industry and the sugar industry will lead to different sugar cane management practices, the need for partnerships, and possibly third party investment in capital plant. This could be a slow process as traditional management and ownership attitudes may remain for some time.

A power generating company also has to consider the prospect that the world and Australian sugar industries are not buoyant, and a company that it partners with in a new power plant development may not survive for the time taken to recover the significant, up-front capital costs. There are risks for both the power industry and the sugar industry that need to be fully analysed when a project is being evaluated.

The flows of materials and energy in the sugar cane processing industry are worth highlighting with regard to the potential biomass supply as a co-product (Figure 4-23).

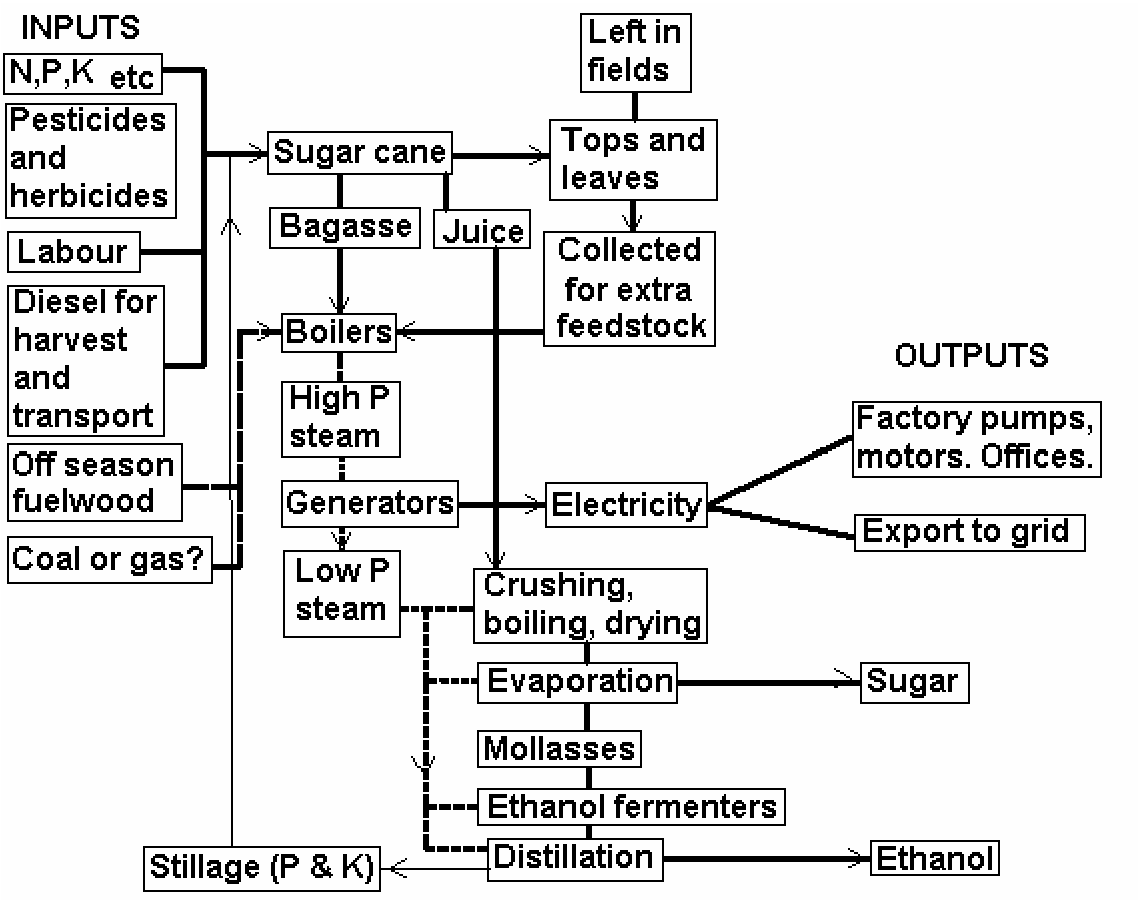


Figure 4-23: Energy and material flows during the sugar cane production and processing operation.

Most sugar cane is grown on high rainfall coastal plains and river valleys and is an important part of the economies of these regions. In Australia over half a million hectares are dedicated to cane growing, having increased 40% since 1990. Most cane farms are family owned and are between 30 and 120ha, producing around 6000t/y on average. Only 2.5% of the cane is grown by sugar mill owners. Water is critical for good cane production and two thirds of cane growers have some form of irrigation. Each year over 40Mt of harvested cane produces nearly 6Mt of raw sugar giving an average of 100t/ha of cane and 13.7t/ha of sugar. Around 80% of sugar is exported and is therefore subject to fluctuations in international prices. International prices have been particularly low over the past few years.

Current cane harvesting practices were developed to leave around half the biomass in the field to reduce subsequent disposal costs. If there is a demand created for these residues for energy purposes, then the volumes of biomass that could become available as feedstock for additional power generation for export off site could double. This assumes there is no soil nutrient deficiency risk as a result of collecting and removing this material, which also helps to retain valuable soil moisture and to suppress weed growth. Research to ascertain how much can be removed without detrimental affects is underway. But it should be noted that in the traditional harvest method of pre-burning, little trash remained. The additional revenue from electricity generation could change the agronomy of sugar cane production since both sugar and fibre yields could become equally important. High fibre cane varieties grown at high density plantings and refining the harvesting method to integrate field trash recovery may all become common place to meet the demands of co-generation.

An interesting factor is that sugar cane has been grown successfully on the same land for many years, often without much crop rotation being possible due to the fixed infrastructure of light rail collection systems linking the fields and used to take the cane to the factory (Figure 4-24 and Figure 4-25). Queensland sugar mills own, operate and maintain 4,100km of narrow gauge (610mm) railway used to deliver the cane to the mills. In some regions, including northern NSW where light rail is uneconomic due to the cane fields being less concentrated, bins designed to be easily loaded on to trucks are filled by the harvester in the field and then used for transporting the cane to the plant.

Figure 4-24: Transport of sugar cane from field to factory by small rail and bins
Representing a well developed biomass transport process.

Figure 4-25: Rail bins being filled in the field by the harvester support trailer

Sugar cane is a C4 plant as is sorghum, meaning they have a better photosynthetic efficiency and hence ability to convert carbon dioxide using sunlight than do other more common C3 plants. It also usually requires only minimum inputs of pesticides and herbicides compared with growing cereal and other crops. Whether it can be considered to be grown on a truly sustainable basis is debatable as some nutrients such as N need to be added in the form of fertiliser to replace those removed in the crop. However if the stillage or effluent from the crushing and distillation process and the ash from the bagasse were to be returned to the fields, (particularly where the cane trash was also removed for energy purposes), then only N would be in deficit.

Increasing public and scientific concerns that monocultural crops are not sustainable and that emissions from biomass-fired power stations need to be addressed. There is some evidence that excessive use of water and fertilisers to sugar cane in some areas of Queensland is contributing to environmental problems such as damage to the Great Barrier Reef. If sugar cane is to be used extensively for energy purposes, research is needed into new practices including new varieties to extend the season, organic production using minimal agri-chemicals, and increased crop rotation using other plants which can also be used for fuel in the non-cane crushing season.

Mill throughputs range from more than 3 Mt of cane per year to less then 500,000 t/y, depending on the size of the mill. Continually declining real sugar prices are predicted which will encourage increasing crushing rates to provide even greater economies of scale. Generating renewable electricity might be a viable mechanism for the long term economic sustainability of the sugar industry.

The sugar industries of other countries have similar potential to Australia. In Fiji for example the industry is somewhat depressed due to the drought and the political situation. Currently many sugar companies are operating equipment nearing the end of its life. Bagasse is available and several companies have been investigating co-generation opportunities. It could be that developing a sugar/power joint industry would be timely as neither the Australian nor South Pacific sugar industry is competing well with sugar plants in other countries which operate more efficiently and with newer processing plant.

The Rocky Point co-generation project is one of the first of what may be a series of developments, as other schemes are being evaluated. Several research projects are underway to improve the use of bagasse as fuel. For example in northern NSW a project is underway to reduce the moisture content of bagasse leaving the milling process. Hopefully this will lead to technology for improved energy balances in bagasse utilisation for a significant portion of the Australian sugar industry.

4.4.3 Cereal straw

Small cereal crops such as wheat produce around 2.5 – 5 t/ha of straw depending on crop type, variety and the growing season. Maize stover can be higher yielding. Crop residues range from 10-40% moisture content (wet basis), giving a typical heating value of 10-16MJ/kg wet weight.

In terms of comparative gross energy values, 1 tonne of straw equates approximately to 0.5 tonne of coal or 0.3 tonne of oil. It has a higher silica content than other forms of biomass, leading to ash contents of up to 10% by weight.

After harvesting of the grain the straw is often burnt in the field (Figure 4-26) as there is only a limited demand for it for animal bedding, stock feed, mushroom compost or garden mulch. Burning is a cheap method of disposal and can help to reduce the incidence of disease carry-over to future crops. However this practice is now banned in European countries for air pollution reasons and risks of road accidents from drifting smoke. This has led to higher disposal costs by having to bale and remove it or to incorporate it back into the soil by chopping and additional cultivation operations. Many long term evaluations show that there is little benefit to the soil or its organic matter content from such incorporation practices as the straw consists mainly of cellulose and with very low C:N ratios; so it returns limited nutrients to the soil. Hence the utilisation of straw for energy purposes has increased in Europe. Denmark leads the world with thousands of district heating (3-5MW), industrial process (1-2MW), and domestic heating (10-100kW) straw burning facilities in place (Figure 4-27). The straw is normally stored on the farms, only being delivered to the central heating plants as needed. Used on farm at the small scale in Europe, it can be utilised for grain drying or heating animal houses as well as to supply the farm houses with space and water heating.

The NSW Sustainable Energy Development Authority (SEDA) recently commissioned a study of the potential for energy from agricultural wastes in NSW. Copies of the report are available for purchase from SEDA [1].

Figure 4-26: Open air burning of straw as a disposal method causes air pollution
(Also waste of a potential biomass resource.)

Figure 4-27: An example of one of many models of straw-fired burners
As installed in Danish farms for heating the dwelling (in this case the one shown below) and animal houses. Note the door for ash removal.

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[1] http://www.seda.nsw.gov.au/pdf/agwastes.pdf

4.4.4 Costs

If the straw remaining in the field is assumed to have zero economic value, and with the costs of collection at around $50/t for raking, baling etc., then the stored energy in the straw, usually as large round or square bales, would cost around $4/GJ assuming a moisture content of 15% wet basis. Cartage to a central conversion plant site might add another $6-10/GJ if within 25 kms on average, leading to a high electricity generating cost of around 15-20c/kWh. This may be an economic option in Denmark and elsewhere due to their high power prices, heating requirements and various forms of subsidy, but is unlikely to be the case in most other cereal growing countries such as Australia when compared with generation costs as low as 7c/kWh for wind power and 3c/kWh or less for power from large coal-fired stations. Direct combustion of the straw for process heat in nearby plants (such as in malting barley factories for breweries) may be more economic, but in many places unlikely to compete with coal or natural gas.

Part of the reason for the relatively high cost of straw is that it is not normally delivered to the plant as a normal part of the cereal harvesting process as in the case for bagasse. Additional collection, transport and handling operations are required. Although straw has a relatively high energy density (MJ/kg) for biomass due to its low moisture content, even when baled it has a low mass density. So the energy density per truck load is 10 to 20 times less than that of coal or oil, and reaching the maximum truck payload is unlikely.

Conversion equipment, whether for heat and/or electricity, is also more expensive than for the same output capacity when using fossil fuels ($/kW) since larger plant and more complex conveying equipment is needed. To keep transport costs down the plant may have to be limited to around 2-3MW which means it is not possible to achieve economies of scale.

The development of a range of straw pellets and wafers (Figure 4-28) with a greater mass density than bales has occurred in an attempt to try and reduce transport costs and also enable automatic feeding to occur, particularly at the smaller domestic scale (10-30kW heat output). Specialist pellet burners are available on the European market suitable for wood or straw pellets but the cost of the total system is relatively high. The big advantage is that the pellets can be delivered in bulk by small truck to the dwelling or small business as required and fed automatically just like heating oil.

Figure 4-28: A range of commercially produced straw pellet types and sizes
(The longest shown being around 300mm length and 75 mm diameter.)

4.5 Energy Crops

A number of annual and perennial species have been identified as having high efficiency when converting solar energy into stored biomass which can then be converted into heat, electricity or transport fuels with low overall carbon emissions. High yielding, short cycle crop or C4 plants (e.g., sugar cane and sorghum) can give stored energy equivalents of over 400GJ/ha/y at the commercial scale, leading to very positive input/output energy balances for the overall system, provided significant amounts of fossil fuel are not used in processing operations (for example the energy supply to some corn-ethanol distilleries in the USA).

Figure 4-29: Oilseed crop growing in Manawatu, New Zealand

The relatively low energy yields per hectare for many oil crops (around 60 to 80 GJ/ha/y for oil) compared with crops grown for cellulose or starch/sugar (200 – 300GJ/ha/y), has led the US National Research Council advising against any further research investment in this area. However all liquid biofuels, when substituted for fossil fuels, will help reduce CO2 emissions. Therefore, a combination of bioenergy production with carbon sink options can result in maximum benefit from mitigation strategies. This can be achieved by planting energy crops such as miscanthus or reed canary grass into arable or pasture land, which in some circumstances can also increase the carbon density of that land, while also yielding a source of biomass. Utilising the accumulated carbon in the biofuels for energy purposes, and hence recycling it, alleviates the critical issue of maintaining the biotic carbon stocks over time as is the case for a forest sink. Increased levels of soil carbon may also result from growing perennial energy crops, but detailed life cycle assessments are required for specific crops and regions. Correct species selection to meet specific soil and climatic site conditions is necessary in order to maximise yields in terms of MJ/ha/y.

There are many agricultural crops that can be grown specifically as energy sources, including sugar cane, corn (maize), wheat, sorghum, and vegetable oil-bearing crops such as sunflowers, rapeseed (canola), and soya beans (Figure 4-29). The majority of these crops are grown as liquid fuel sources, that is, they are harvested and processed into fuels such as ethanol or biodiesel. The most widely grown energy crops are sugar cane (there is even a special high fibre species known as 'energy cane') and maize (corn). In Brazil over 4 million vehicles have been run on pure ethanol produced by sugar cane, with over 100 billion litres produced since 1975. There is also large-scale use of maize for ethanol in the USA and oilseed rape for biodiesel in Europe where the production of liquid biofuels is subsidised. Currently in many countries such as Australia agricultural crops are not grown specifically as energy sources because it has been uneconomic to do so. However there is a growing interest in ethanol from sorghum and biodiesel from canola.

For biodiesel, seed crops which contain a high proportion of oil can be crushed and the oils extracted and used either directly or after esterification to replace diesel, or as a heating oil, as they have an energy content similar to diesel (Figure 4-30). Other triglycerides that could be used are palm-oil, sunflower-oil, soya bean-oil, tallow (animal fat) and recycled cooking oils. In the Philippines, diesel is blended with coconut oil and used in tractors, buses and trucks, though this would not be feasible in cooler countries as the viscosity of the oil increases and can cause damage to the fuel pumps. Crops grown specifically for energy supply purposes (such as the oilseed rape crop above in Manawatu, New Zealand) have less immediate potential for use for energy than existing crop residues because of the higher delivered costs in terms of $/GJ of available energy. Also land used specifically for biomass production will have an opportunity cost attributed to it for the production of food or fibre, the value being a valid cost which can then be used in economic analyses.

Oil source	Energy content (GJ/t)
Canola	40.4
Safflower	39.7
Sunflower	39.7
Diesel	38.5

Figure 4-30: Typical lower heating values for some vegetable oils and diesel
(Though these all vary with source.)

There are currently some 85 biodiesel plants around the world with a combined capacity of over 1.28 million tonnes. The cost of the raw material is the most important factor affecting the overall cost of production.

There are a number of benefits associated with biodiesel, including a reduction in greenhouse gases of at least 3.2kg of carbon dioxide-equivalent per kilogram of biodiesel, a 99% reduction of sulphur oxide emissions, a 39% reduction in particulate matter, high biodegradability, and energy supply security.[1]

There have been calculations made to indicate that globally there is enough land available to provide the world's population with all its needs for food, fibre and energy. (Equitable distribution of these basic necessities is another issue yet to be resolved). Integrating crop production with all three products is the challenge. Oilseed rape (Canola) for example produces oil which can be used for cooking or energy, an edible high protein meal, and straw which can be used as a paper pulp or combusted.

The role for "Designer Biomass" by developing suitable genetically modified crops cannot be ignored. Certainly the concerns over genetically modified organisms entering the food chain without full and proper evaluation are of considerable concern. However the technology is here to stay and does indeed have great potential. Imagine having several attractive C4 plants which have nitrogen fixing ability, consume relatively little water, are high yielding, easy to harvest and can be grown extensively to produce protein, carbohydrates, fibres and lignin which can all be processed through a "biorefinery" into a range of industrial, edible and energy products. The issues of sustainable production, lack of biodiversity and monocultures would need to be carefully considered. But with some innovative thinking we could be doing things a lot better than we do now in traditional agriculture.

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[1] Korbitz 1998

5. Biomass - Delivered Costs

5.1 Summary

The cost of biomass production, harvesting and transportation based on short cycle crops is a key determinant of the viability of bioenergy projects based on such feed. International experience has shown that the fuel procurement cost can account for some 50-60 percent of the total bioenergy production costs. Of the total delivered fuel cost, biomass production typically accounts for 25 percent, harvesting 50 percent and transportation to the power plant 25 percent.

In Australia, bioenergy from short cycle forestry is yet to be commercially developed. As such there is a need to draw initially on international experience and study methodologies to analyse different biomass delivery systems and their costs for both small and large scale operations, noting differences including local conditions and energy and labour costs.

Some study work has been conducted in Australia for harvest and delivery of SCC biomass. Work in Western Australia has examined the supply of mallee trees to a processing plant, using data from a prototype harvester and taking biomass supply in the sugar industry as an example of an efficient and cost-effective system already proven. Two overseas case studies are then presented to assess biomass delivery logistics and their costs and determinants. While not directly related to Australian crops, these studies do provide useful methodologies for assessing the optimal delivery system and associated delivered fuel cost. They also highlight the significant variability in cost outcomes achieved by selecting different delivery systems.

The first case study uses a computer simulation to analyse and hence minimise the delivered woody biomass cost to an energy plant in the Nelson area of New Zealand over an average transport distance of eighty kilometres and where the forest owner is paid NZ $20/t for forestry residues. Seven systems for transporting and handling the biomass are analysed and compared, taking into account constraints such as maximum legal payloads on highways (23 tonnes). This case study illustrates that there are significant cost variations between various systems resulting in delivered costs ranging between NZ $2.3/GJ and NZ $5.7/GJ. This study shows a major part of the delivered cost is in the handling and transport, which could be reduced by increasing operating efficiencies and maximising truck payloads.

The second case study relates mainly to short rotation coppice willow in the UK. Although this is not a favoured species for Australia, considerable research has been undertaken on this energy crop and it provides a comprehensive methodology applicable to agricultural residues and short cycle forest crops. This study assesses eight delivery systems and their costs to the power plant for a large scale operation (supplying the ARBRE 10 MWe biomass gasification power station) and an on-farm scale operation to supply a 400 kW heating or co-generation plant. The lowest delivered fuel costs are achieved with two options that avoid intermediate storage and deliver fuel directly to the power plants.

This study reveals that the cost of biomass delivered to a power plant is very project specific, with main cost determinants being: source and type of biomass, fuel feedstock production costs, harvesting costs, transport distances, moisture content, fuel quality (penalty for contamination), capital costs of handling equipment, and labour requirements.

The UK study involved considerable stakeholder involvement and aimed to bring together all the relevant information, synthesise it, and then to present a series of options to industry to determine the optimum harvesting and processing systems. Various concepts and scale of operation were investigated. These included large scale cut and chip, large scale cut and billet and large scale stick harvesters for both the large scale power plant and the on-farm co-generation plant. For the large plant the study also examined the interaction between fuel drying and form of delivered biomass.

The UK study identified the desirability of using a one-pass cut-and-bale machine for felling and baling coppice material. Although such a machine does not currently exist, it was included in the studies as a potential equipment item for assessment. The eight components of the UK study are discussed in some detail in this section. The lowest cost option in the study was a Claas forage harvester with no intermediate storage and year round harvesting. Key study recommendations are to:

a) *Bale the cut short cycle crop sticks or chunks into large round or square bales using existing agricultural baling machines mounted on a tractor/mower, to give a one-pass machine, with either:*

   - *bales dropped on ground for subsequent collection by tractor/front loader and transport to trailer or truck*
   - *or bales carried to headland on baler for later collection by truck.*

b) *Develop a billet system around the Austoft sugar cane harvester or a chain cutter/stick harvester with a billeter mounted on the chassis. Either would need a conveyor with support trailer running alongside, or a mounted bin to carry billets to the end of the row for unloading hydraulically.*

c) *For small scale systems on farms with existing grain drying facilities, a manual chainsaw or simple tractor mounted single disc saw blade used for older single stem trees and the trees later manually fed into a mobile chipper.*

The indicative costs for supplying biomass to a plant up to 100km away are:

Wood process residues, bagasse etc used on site	\$0 - 0.20/GJ (or even negative if disposal costs are avoided)
Forest arisings from the landing or collected from the cutover	\$2.00 – 3.20/GJ
Short cycle crops (oil mallee)	\$4.20 – 6.30/GJ
Crop residues – baled and carted	\$4.80 - 8.00/GJ

5.2 Introduction

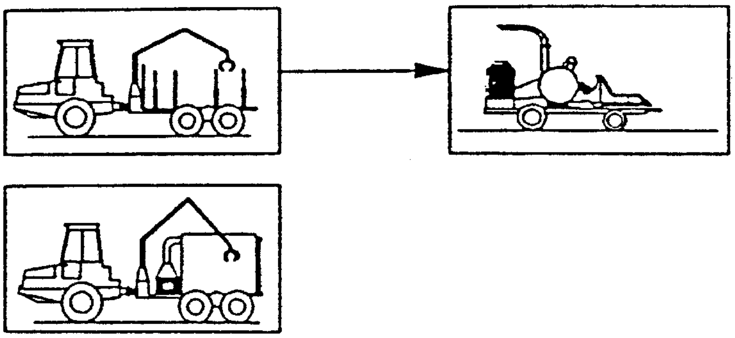
Harvesting is a considerable cost in the production of biomass with production often accounting for 25% of the total delivered fuel costs, transport 25% and harvesting 50%. Overall the harvesting and transportation operation of producing short cycle (tree) crops (SCC) can account for 50-60% of the total bioenergy production costs.

Tending and harvesting operations associated with growing energy tree crops on short cycles in many countries are generally labour intensive. Machinery required to automate forestry harvesting systems is large and expensive, resulting in manual labour being cost effective and consequently little money being invested in the development of new machinery. However, the cost of employing manual labour is increasing due to higher wages and associated costs (including increased insurance rates for high risk forestry operations). At the same time mechanised forestry equipment and its associated technology is becoming cheaper and more readily available increasing the availability and suitability of a range of machines.

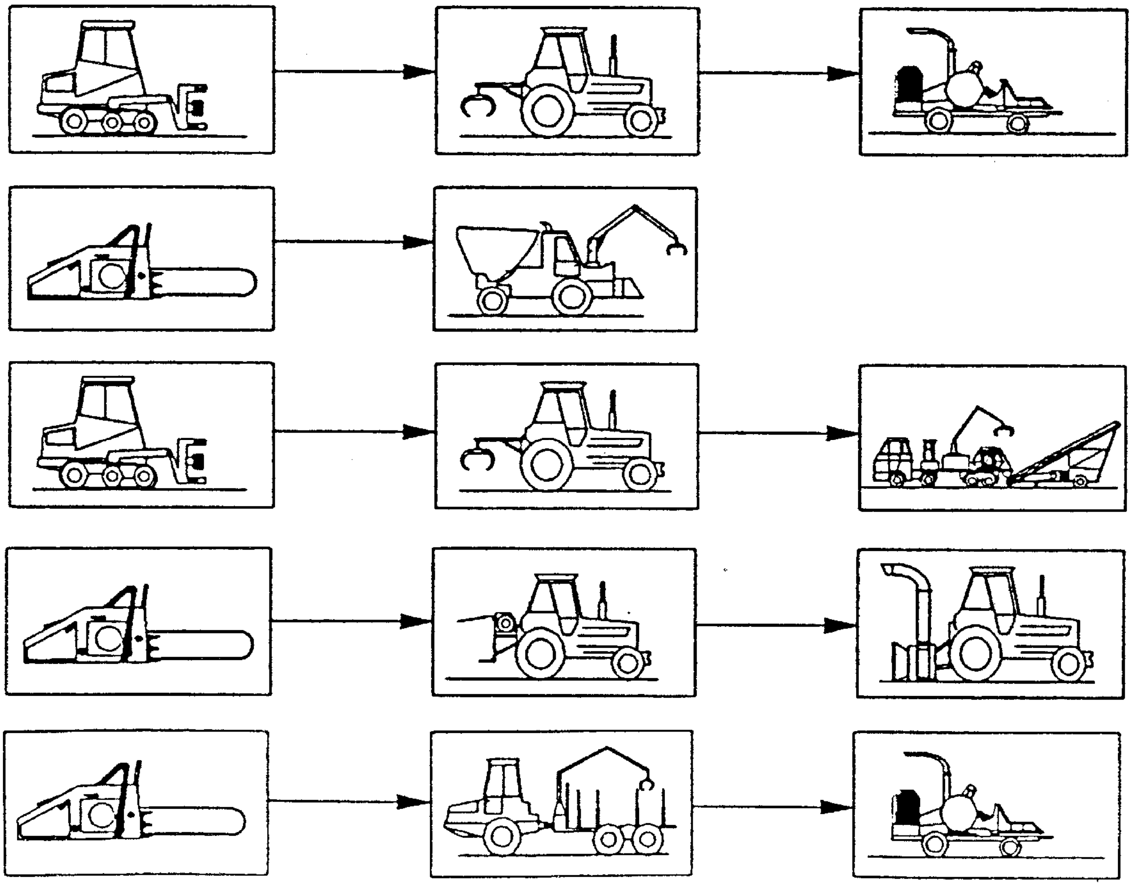
Harvesting costs are influenced by yield, tree size, stocking density, the volume removed from a given area (which will affect the cost of felling and extraction) and the mean annual increment (MAI). These variables will also influence the supply zone radius required and therefore the haulage costs to meet a given demand.

5.3 System Options

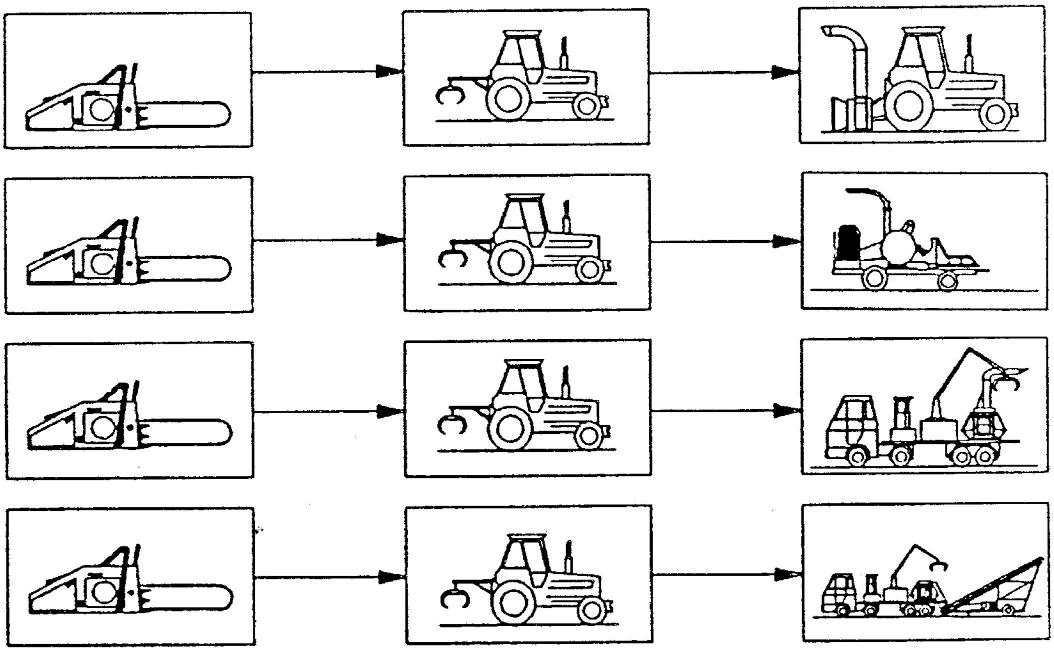
A large number of systems for harvesting, collecting and processing biomass with the intent to use all or part of the material for energy purposes are feasible. Several examples are shown below in Figure 5-1, based on forest arisings as an example and using the symbols defined earlier in this report to depict the machines involved. To be most effective in terms of fuelwood delivered to the power plant at the lowest cost, the productivities of the various machines in terms of tonnes/hour need to match each other to avoid expensive delays and down time.



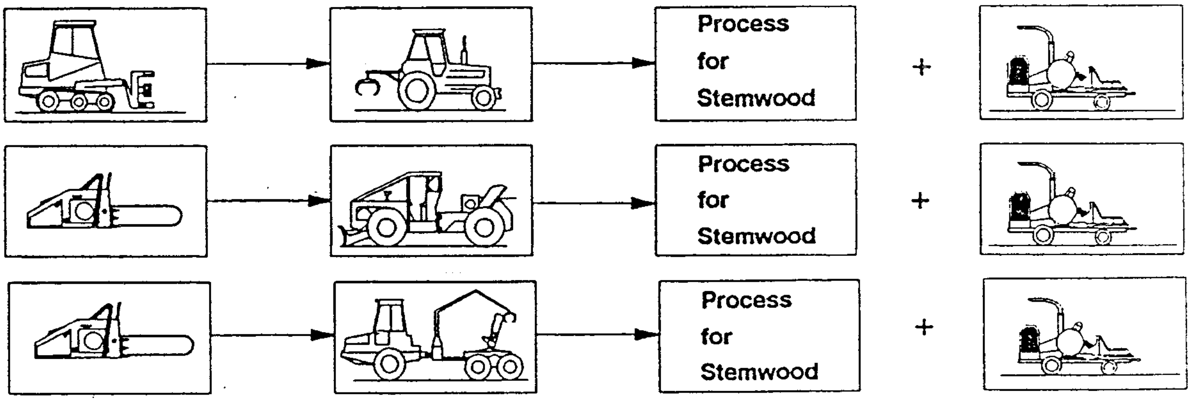
a. Two systems of harvesting of arisings from the forest cutover



b. Whole tree harvest and extraction options for comminution at the landing or in the forest using a mobile chipper or chipper forwarder



c. Four whole tree harvest, extraction and comminution options more suited to thinnings and selective harvesting.



d. Integrated harvesting options of stemwood for timber with the residues used for biomass

Figure 5-1: Range of typical systems used for harvesting, collecting and processing biomass

5.4 Supply System for Mallee Eucalypts

5.4.1 Dryland Salinity

In any consideration of a bioenergy project, the availability of fuel is fundamental. Existing plantations and forests are one source of biomass, where the energy project must be tailored to fit the available feed material. New plantations can be a second source of biomass. Bioenergy is expected to help open up opportunities for dedicated energy tree crops that have other important environmental benefits. In particular, there is considerable interest in the potential for new tree crops to be planted in agricultural regions across the country to reduce the impact of dryland salinity. A brief introduction to salinity is presented below.

Primary and secondary salinity have been well described by others:[1]

"Before European settlement, salt was visible in the landscape, generally in salt lakes and this is referred to as primary salinity. The most common cause of secondary salinity is the replacement of perennial, deep-rooted native vegetation with the annual crops and pastures used in traditional agriculture.

Annual crops and pastures do not use as much of the incoming rainfall as did the original native vegetation. This unused water either runs off or infiltrates beyond the root zone and accumulates as groundwater.

As the groundwater levels rise, salts that have accumulated over thousands of years in the subsoil are mobilised. When groundwater comes close to the surface, salt enters the plant root zone leading to the death of species that are not salt tolerant.

Saline groundwater also discharges at the soil surface and the salinity of the water is concentrated by evaporation, damaging soils on-site and down slopes and eventually draining into streams, rivers and lakes, degrading wetland habitats and water resources."

The impacts of dryland salinity are many, both on farm and off farm. However the end result is always the same; damage to productive agricultural land, damage to waterways and all that they support, and damage to rural towns, roads and other infrastructure. Already Australia has some 2.5 million hectares of saline affected agricultural land, mainly in WA[2]. Already dryland salinity has huge annual costs. The recent dryland salinity assessment by the LWRRDC [3] estimated total on-farm and off-farm costs from salinity to be more than $600 million/year in WA (including major road maintenance costs) and some $250 million/year in eight key catchments of the Murray Darling Basin. If nothing is done, these figures are expected to increase dramatically in the decades to come.

Salinity may therefore be the greatest environmental problem to face our rural areas this century. Answers put forward to the salinity problem range from doing nothing, through a variety of proposals and methods for water diversion and management, to changed patterns of land use and agricultural practice. It is likely that most or all of these alternatives will be utilised across the many, diverse regions that are, or will be, salt affected.   CSIRO Land and Water summed up some of the work ahead in their recent report on emerging land use systems for managing dryland salinity[4]. The report states that a variety of land use changes will be needed for any broad salinity control. In particular CSIRO summarised dryland area tree products as "potentially the most effective land-use option for managing salinity by reducing leakage", noting the importance of commercial incentives for planting and the need for new markets for tree crops to drive reforestation and/or revegetation at the necessary scale.

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[1] www.wrc.wa.gov.au/protect/Salinity/index.htm

[2] Department of Conservation and Land Management Online, 2001, www.calm.wa.gov.au/projects/plantations_tree_crops1.html

[3] Australia's Dryland Salinity Assessment 2000. National Land and Water Resources Audit, Land and Water Resources Research and Development Commission, Canberra

[4] Stirzaker, R., Lefroy, E., Keating, B. and Williams, J. 2000, A Revolution in Land Use: emerging land use systems for managing dryland salinity. Report prepared for the Murray Darling Basin Commission by CSIRO Land and Water.

5.4.2 Mallee Eucalypts

The need for commercial incentives for tree planting cannot be over-emphasised. In Western Australia it has been estimated that an additional three million hectares of trees and shrubs will need to be planted throughout the WA agricultural area, at a cost of $3 billion, to control salination[2].

Unfortunately, while farmers may lose land to salt over many years if they do nothing, large scale tree planting is an unpalatable and difficult alternative given its substantial up front establishment costs and the attendant loss of land that may currently be earning income. Bartle[1] and Pannell *et al* [2] stress the importance of practical work towards new tree crops that are commercial, with Bartle describing the broad applications sought for mallee eucalypts as a major new tree crop for the WA wheat belt.

It is important to note that mallees and other new tree crops are seen as being complementary to current farming practice. Farmers can plant out part of their farms to trees and continue to farm wheat, other crops or livestock between rows or "belts" of trees. Ideally the benefits of new tree crops alongside other, traditional crops, will mean that rural communities can achieve sustainability with minimal disruption to well established professions and lifestyles.

It is also important to note that growing mallee trees for environmental and commercial outcomes is sustainable. The trees are all Australian native species. After they are planted and have established their root structure they may be harvested regularly without the tree being killed. This is because mallee trees "coppice"; meaning they re-sprout from the stump after harvest.

Australia's dryland areas are not well suited to traditional commercial trees such as blue gum and pine. The lack of rainfall makes it hard for these areas to compete in traditional forestry with the wetter coastal regions. Innovation, such as with mallee eucalypts is required. This innovation is needed to help dryland plantations compete in traditional timber industries such as particle and fibre boards. It is also needed to develop new uses for the large amounts of biomass that will be available if significant dryland tree planting occurs.

For the past decade there has been a concerted effort in Western Australia to plant mallee eucalypts across the wheat belt in the south west of the state. Initiated by the Department of Conservation and Land Management (CALM) and with initial financial support from both the state and federal governments, there are now in excess of 20 million mallee trees planted across the WA wheat belt. Some 1,000 farmers are involved in mallee planting, largely via the Oil Mallee Association and the Oil Mallee Company (ref: http://oilmallee.com.au) who manage planting and serve as a focal point for growers and for commercialisation activities.

5.4.3 Harvesting Mallee Trees

For commercial utilisation of the mallee trees the wood and leaf material must be cost-effectively harvested and transported to processing facilities. CALM and the Oil Mallee Company have been working on the development of a harvester that can cope with the particular characteristics of mallee harvesting, which differs in several important respects from the harvesting of deciduous willows and other northern hemisphere short cycle crops.

A precedent for bulk biomass harvesting in Australia is found in the sugar industry, where the chopped cane has a similar value per tonne and similar ex-harvester product density and handling

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[1] Bartle, J., 2001, Mallee Eucalypts - a model, large scale perennial crop for the wheat belt. Paper presented at Outlook 2001

[2] Pannell, D.J., McFarlane, D.J., Ferdowsian, R., 1999, Rethinking the Externality Issue for Dryland Salinity in Western Australia. SEA Working Paper 99/11. www.general.uwa.edu.au/dpannell/dpap9911.htm

characteristics. The harvesting and transport system conceptualised by CALM in a 1999 feasibility study is an adaptation of the cane harvesting and transport system developed for the Ord River sugar industry. Cane is typically harvested and loaded onto trucks for about $5.50 per tonne and transport over a typical 15 km haul distance is $2.50 per tonne.

A significant difference between sugar cane and mallee crops is the concentration of the resource. Cane is grown on small farms and each cane paddock is in close proximity to the preceding and following paddocks. Cane crops can yield up to 200 tonnes per hectare and harvester production can exceed 100 tonnes per hour and average 60 tonnes per hour over a whole season. Mallees are a much more dispersed crop than sugar cane and yields will be about 35 to 40 tonnes per hectare, so mallee harvesting will not be as cost effective as cane harvesting for the foreseeable future.

One example of a balanced operation to provide 100,000 tonnes of fresh biomass each year will involve:

- One harvester cutting 300 tonnes per day to meet the annual requirements of 100,000 tonne for a processing plant.
- Cutting rate will be 35 to 40 tonnes per productive machine hour.
- Allowing one third of its time for maintenance and relocating from site to site, the harvester will supply one plant with an average 75 to 80 hour week.
- One chaser travelling at 20 kph transferring chipped biomass up to 2 km from the harvester to the truck.
- Three road trailer units of two trailers each.
- One prime mover hauling 50 km to the plant.

This example is summarised in the figure below (
Figure 5-2), which includes the main assumptions made by CALM in the 1999 feasibility study with respect to the cost make-up for biomass delivered to a processing plant[1].

This simple harvest and transport system is only a demonstration of how balance could be achieved. There is excess capacity in the harvester, but the system described is focussed upon supplying a full scale ITP plant that uses 100,000 tonnes/year. The use of multiple harvest and transport “units” to supply larger amounts of biomass may be able to achieve greater economies. The costs in this example are greater than those already achieved for supply of sugar cane, but are also less than the costs developed by other studies such as the examples from the UK and New Zealand which follow in this report. With the cane industry highlighting the potential of an established efficient system and overseas tree crop experience showing the variability of costs, it appears critical that more work be done to better understand the particular strengths and weaknesses of a supply system for mallees and other multi-stemmed, evergreen Australian tree species. Unfortunately the rate of progress with mallee harvester development has been limited by lack of funds for several years.

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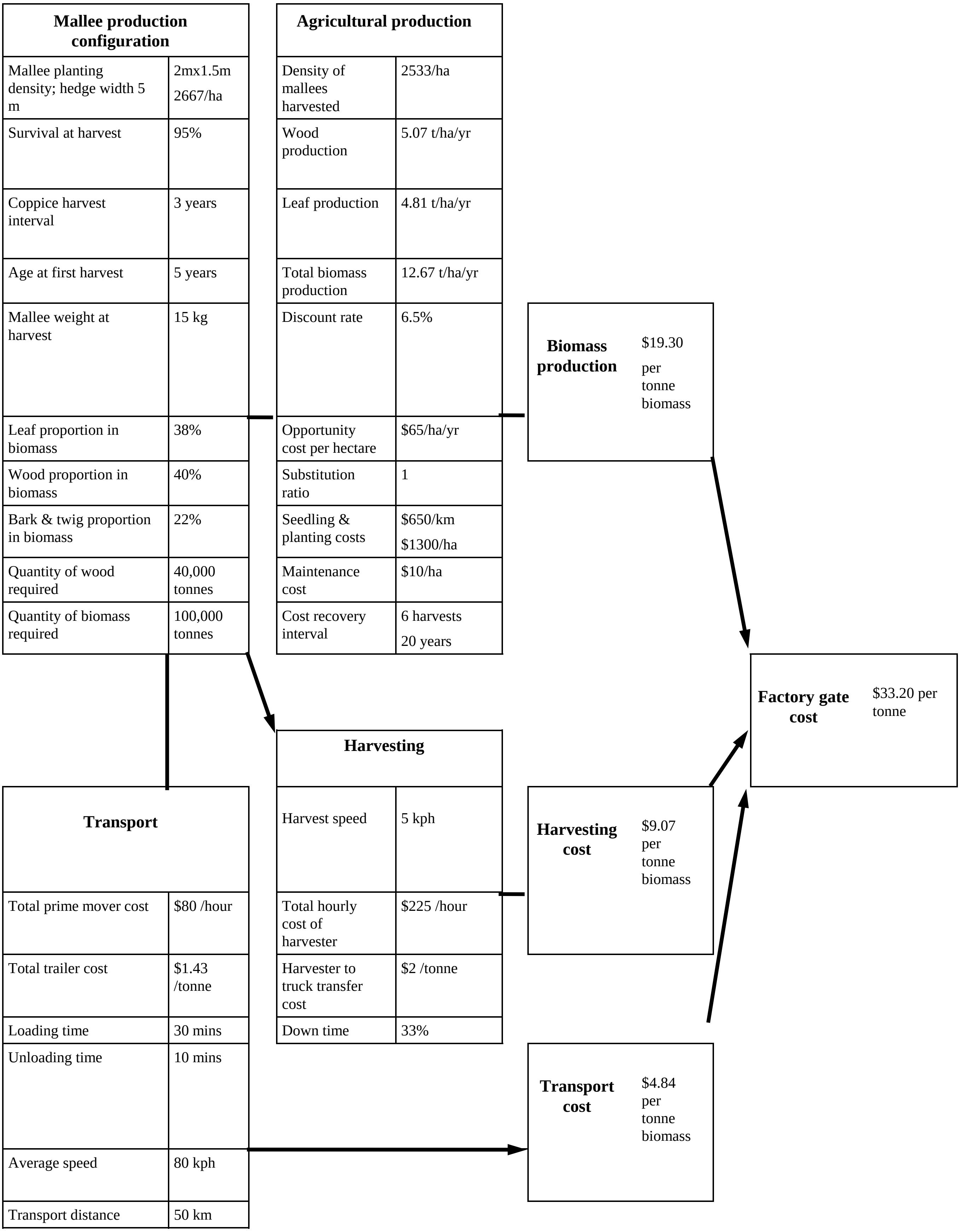
[1] http://www.rirdc.gov.au/reports/AFT/01-160sum.html



Mallee production configuration	
Mallee planting density; hedge width 5 m	2mx1.5m 2667/ha
Survival at harvest	95%
Coppice harvest interval	3 years
Age at first harvest	5 years
Mallee weight at harvest	15 kg
Leaf proportion in biomass	38%
Wood proportion in biomass	40%
Bark & twig proportion in biomass	22%
Quantity of wood required	40,000 tonnes
Quantity of biomass required	100,000 tonnes

Agricultural production	
Density of mallees harvested	2533/ha
Wood production	5.07 t/ha/yr
Leaf production	4.81 t/ha/yr
Total biomass production	12.67 t/ha/yr
Discount rate	6.5%
Opportunity cost per hectare	$65/ha/yr
Substitution ratio	1
Seedling & planting costs	$650/km $1300/ha
Maintenance cost	$10/ha
Cost recovery interval	6 harvests 20 years

Biomass production $19.30 per tonne biomass

Factory gate cost $33.20 per tonne

Harvesting	
Harvest speed	5 kph
Total hourly cost of harvester	$225 /hour
Harvester to truck transfer cost	$2 /tonne
Down time	33%

Harvesting cost $9.07 per tonne biomass

Transport	
Total prime mover cost	$80 /hour
Total trailer cost	$1.43 /tonne
Loading time	30 mins
Unloading time	10 mins
Average speed	80 kph
Transport distance	50 km

Transport cost $4.84 per tonne biomass

Figure 5-2 Feed cost model, including typical values for each variable

5.5 The Overall Biomass Supply System

This section describes a computer model designed (independently of this project) to analyse and hence minimise the delivered costs of biomass by optimising the system components for any given site. Woody biomass is used as an example, though the model can also be used for cereal straw, etc.

Most forms of dry biomass can be handled in a number of ways. For example cereal straw can be handled loose, chopped, baled or briquetted. The chosen method depends very much on the material, its moisture content, the transport distances involved, the storage method, the storage period, and the scale and type of conversion plant. Selecting the components of the overall system to minimise the total delivered fuel costs is a difficult process. Poor selection can lead to more expensive fuel.

Case Study 1 – Assessment of Delivered Biomass Costs – New Zealand

Consider a recent New Zealand study conducted by Massey University and Forest Research Institute of NZ. To provide indicative overall costs, and the relativity of the various cost components when delivering biomass from forest residues (or “arisings”) to an energy plant in the Nelson region, a number of supply scenarios were considered. The values shown in the graph (Figure 5-3) are in $NZ (NZ$1 = A$0.8 approx.) and it was assumed that the residues were sourced from forests within the Nelson region with an average transport distance of 80km to the energy conversion plant located in Nelson city. The price paid to the forest owner for the residues was $20/t.

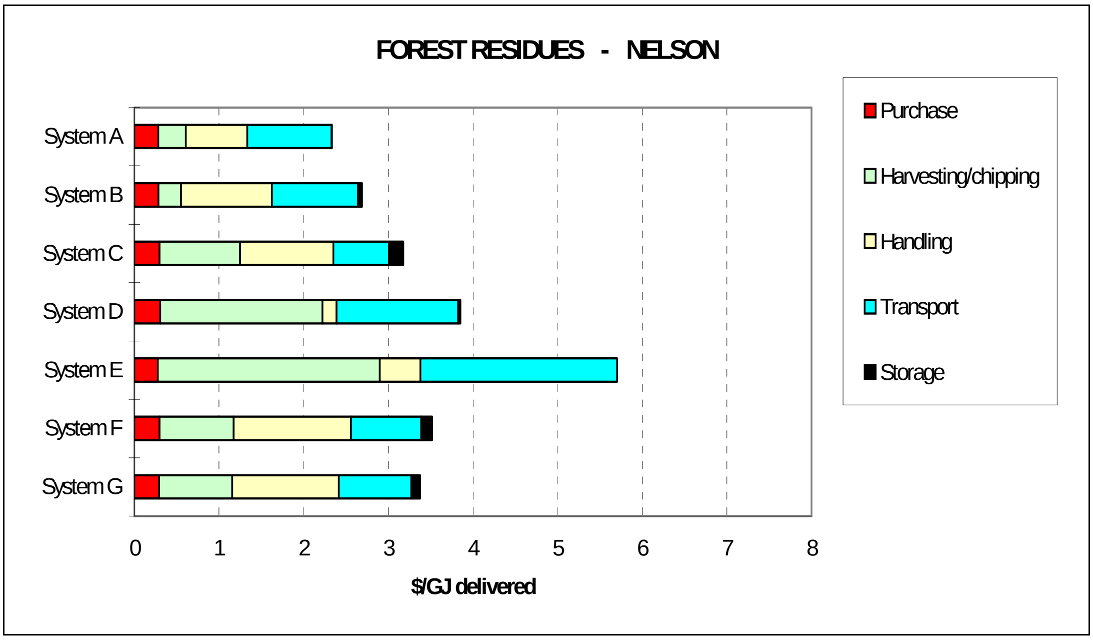


Figure 5-3: Costs of delivered fuel from forest arisings from seven different systems.

Systems of transport and handling compared

A: *Landing residues only* - load onto on-highway truck; transport to energy plant; unload and chip.

B: *Cutover residues* - forwarder to landing; load onto on-highway truck; transport to energy plant; unload and chip.

C: *Landing residues* - load onto off-highway truck; transport to central processing yard in forest (5km or less); unload, chip with mobile chipper direct into on-highway truck; transport to energy plant.

D*:* *Cutover residues* - chipper forwarder; transport to stockpile (10% fibre loss); front-end loader to load on-highway truck; transport to energy plant.

E: *Cutover residues* - chipper forwarder and transport to landing; transfer into set-out bins; collect bins with hook truck; transport to energy plant.

F: *Cutover residues* - forwarder to roadside; stockpile (indefinite storage); chip using mobile chipper; stockpile (10% dry matter fibre loss); front -end loader to on-highway truck; transport to energy plant.

F: *Cutover residues* - forwarder to roadside; stockpile; chip using mobile chipper into on-highway trucks; transport to energy plant.

The model used is very detailed, allowing for travel distances over a series of road types (tracks, B roads, motorways etc) as occurs in practice and it even accounts for the time taken, and hence cost, to cover a truck load of chips with a tarpaulin. The main assumptions used to provide detailed data for the transport model in the New Zealand study included the following:

The harvest and process machines used in these systems were:

- 20 tonne excavator-based grapple loader
- mid-sized rubber tyred front-end loader with hi-lift bucket for top loading chip trucks
- electric/hydraulic knuckle-boom unloader at conversion plant;
- Morbark EZ 30 mobile drum chipper, trailer mounted
- Bruks electric powered drum chipper (70cm), fixed installation
- Kockums/Bruks chipper forwarder
- 15 tonne forwarder with modified load space.

The costs of each machine were calculated using the following common assumptions:

- discount rate 9%
- all in-forest equipment working one shift/day
- 235 working days per annum
- all equipment at plant working two shifts per day.

The on-highway truck had a maximum legal payload of 23t and the off-highway truck used only on private forest roads had a 40t payload.

It can be seen from the summary graph that there are significant cost variations between systems, resulting in delivered costs ranging between NZ$5.7/GJ and NZ$2.3/GJ. Also the results show a major part of the delivered cost is in handling and transport, which could be reduced by increasing operating efficiencies and ensuring truck payloads are maximised.

Case Study 2 – Assessment of Delivered Biomass Costs - UK

Details of a similar project to Case Study 1 above, conducted for ETSU in the UK to identify the optimum method for harvesting, processing and transporting of woody biomass produced from short cycle crops willow crops, are given in the in-depth Case Study 2, starting in the next part of this section. Although willow is not the first choice of energy crop in Australia it is the preferred species in Northern Europe and more research has probably been undertaken on it than on any other energy crop in the world. The reason it is included here is that the principles used in the methodology also relate to agricultural residues and short cycle crops.

A summary of the analysis is given in Figure 5-4. Systems E and B show the lowest delivered fuel cost. This is not surprising as for these options there was no intermediate storage, the fuelwood being delivered directly to the plant for immediate use. This is appropriate in some circumstances, for example in Scandinavian district heating plants where the main heating demand season matches the season for harvesting *Salix* coppice crops. In many other situations (such as for electricity generation or process heat), it is more likely that storage will be needed to provide a plant with fuel supplies all year round. This will increase the costs of supply due to the additional handling operations and storage losses which may result.

Where short cycle crops are to be the major fuel source, this study shows the potential cost reductions that could be achieved if the crop were to be harvested all year round. Provisional studies, both in New Zealand on coppice *Eucalyptus* and in the UK on *Salix*, have shown that there is potential for such a management system without loss of yield over a sustained period. The advantages which would result in terms of reduced dry matter losses, together with lower handling and storage costs, justify further research.

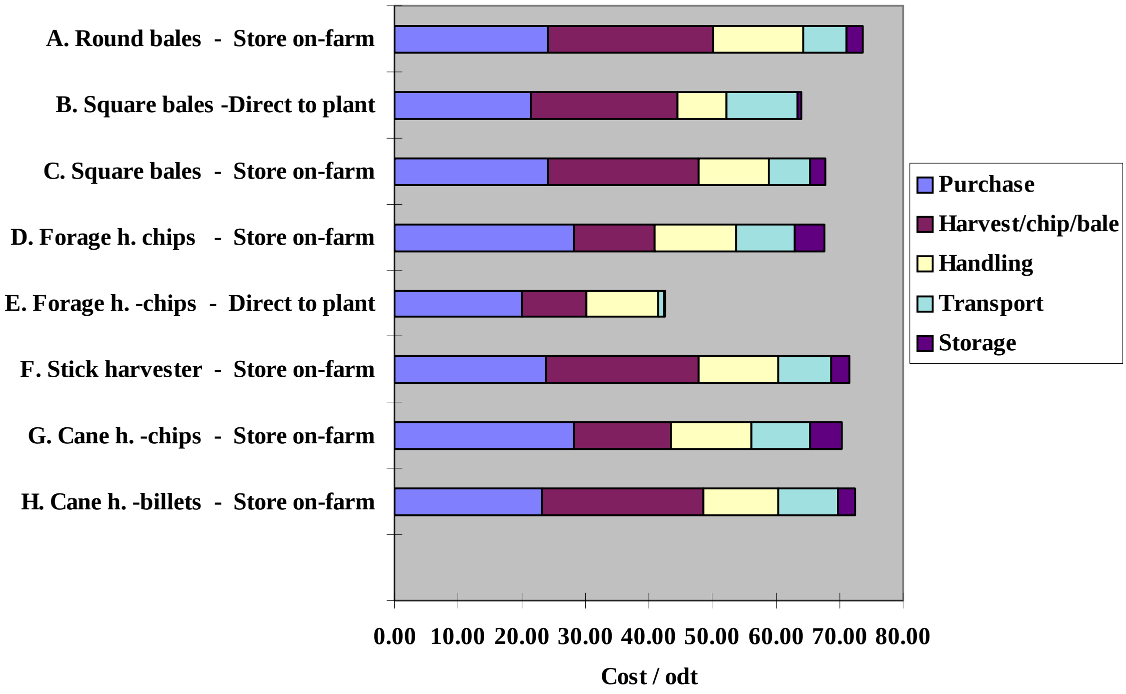


Figure 5-4: A comparison of delivered costs of a tonne of oven dry fuelwood
(Delivered to the power plant gate (£/odt) for the eight selected system options.)

Where storage of fuelwood is necessary to provide an all year round energy supply to a plant, the costs will be increased significantly. This confirms the benefits of having a mix of fuels from a range of sources so that the amount of fuel going straight from source to plant can be maximised. For a wood-fired plant such sources might include wood process residues, forest arisings and SCC.

In some circumstances it may be appropriate to mix fossil fuels with the biomass to ensure a low cost supply. An example of such a flexible fuel plant is the 34MW (electric) co-generation plant operated by Carter Holt Harvey at their Kinleith pulp and paper plant in New Zealand, which uses both natural gas and wood. This reduces the risk associated with obtaining secure supplies of fuelwood or the long term and gives time for confidence to be generated in the supply chain by the plant operators.

In systems where fuel storage is required, the study showed that cut-and-bale or billeting systems could be competitive with chip systems and are worthy of further investigation. The big advantage of billets and bales, which was not fully evaluated in the analysis, is that the fuel delivered to the plant in these forms has a lower moisture content than do chips from the same source and suffers less degradation in store over any given period. However chipping and screening would probably be necessary at the plant to produce a consistent quality fuel.

The results of both these studies clearly show that the cost of biomass delivered to a conversion plant ($/GJ of useful energy output) is very much project specific. The delivered costs will vary with:

- source and type of biomass
- fuel feedstock production costs
- harvesting costs
- transport distance
- moisture content
- fuel quality (with a penalty for contamination)
- capital costs of handling equipment relating to scale of plant
- labour requirements.

In addition the capital cost of the plant and equipment, annual hours of use, discount rate, conversion efficiency, and load characteristics all affect the final heat or electricity costs. In all cases a detailed analysis is considered necessary to identify the cheapest production, processing and transport option from the many variations possible.

To provide an indication of the range of costs for delivering and utilising biomass sources, a summary of typical cost ranges, based on various recent unpublished analyses, appears below.

Biomass fuel costs for GJ useful energy delivered to the plant up to 100km range:

Wood process residues, bagasse etc used on site	$0 - 0.20/GJ (or even negative if disposal costs are avoided)
Forest arisings from the landing or collected from the cutover	$2.00 – 3.20/GJ
Short cycle crops (oil mallee)	$4.20 – 6.30/GJ
Crop residues – baled and carted	$4.80 - 8.00/GJ

5.6 Analysis of Short Cycle Willow Crops Under British Conditions.

There are several forms in which willow can be handled –

- whole sticks (typically 2 – 4m long and up to 50mm diameter at the base)
- chunks (which are the sticks cut into sections of 100 – 200mm length)
- chips (which tend to be small flat pieces around 10-30mm across).

The Reason for this Analysis:
Short rotation coppice willow (*Salix)* has been identified as a potential sustainable energy source but there is no proven, cost-effective system in place for delivering the fuel in the most acceptable form to either small or large scale users. A study was therefore undertaken:

- to develop an optimum design configuration and detailed specification for a coppice harvester
    a) for a large scale operation to supply a 10 MWe power station
    b) for an on-farm scale of operation to supply a 400kW heating or co-generation plant.
- to ensure the selected concepts for designing an “ideal” willow coppice harvester conform with the optimum system for growing, handling, comminuting, transporting, and storing of the biomass.

There appear to be many different ideas for SCC tree harvesting methods. This is a common problem in many countries, not just the UK. It was therefore intended that this study should serve to assist members of the British woody biomass industry by endeavouring to obtain consensus on the best way forward for SCC, based on the existing level of knowledge. This in turn would enable investors and other funding organisations for harvesting system development to direct the very limited funds available towards providing the best solutions.

To lead the way forward, an efficient and reliable coppice harvesting and handling system needs to be identified. A number of prototype machines exist and have been evaluated under UK conditions over recent years. In addition scientific studies have been conducted on SCC yield production, drying, storage, and transport options. The aim of this case study was to bring together all the relevant information, synthesise it, and then present a series of concept options to the industry to determine the optimum harvesting and processing system.

Harvesting short cycle crops for energy purposes cannot be considered in isolation from the subsequent activities necessary to get the material delivered in the most suitable form at the conversion plant and at minimum cost. In addition the establishment, layout and agronomic management practices of the crop should be determined in part by the harvesting method anticipated. In this case study willow was the chosen crop but similar principles apply for a range of biomass crops. Willow is deciduous and normally harvested during winter after leaf fall. In addition, under British conditions, poor weather at this time can restrict harvesting operations, which were assumed to operate for only approximately 50 days each year.

In order to produce a high quality biomass fuel on a sustainable basis and to minimise the delivered costs, the whole process needs to be viewed as a **system**. The harvested crop can be quantified in terms of GJ/ha/year, but losses during the harvest, storage and transport operations will reduce the energy available for conversion to heat and power. Minimising these losses needs to be given due consideration during the development of the optimum system.

In the assessment of harvesting options, it was assumed there is only a short harvest window in the winter period, but that the fuel will be required constantly at the energy plant over a 12 month period. If electricity production is the main objective, then a 10 to 12 month storage period is inevitable in order provide constant feed that will maximise return on investment in the generation plant. All year round harvesting could serve to partly overcome storage and drying problems but, although worthy of further investigation, was not considered in this study.

5.6.1 Concepts and scale of operation

A number of broad harvesting categories, based partly on the scale of operation, can be identified. Examples are given below.

- Large scale cut and chip, self propelled machine. Chips stored on farm or at conversion plant.
- Large scale cut and billet, self propelled machine. Billets transferred to simple on farm storage initially (Figure 5-5) then later comminuted to the form required at the conversion plant.
- Large scale stick harvesters, self propelled machine. Where no indoor storage facilities exist for large volumes of material, which is the case on many farms, sticks can be stored outside in piles, in tied bundles or as compressed bales. Comminution to produce the biomass in a form suited to feeding into the conversion plant could then be undertaken later, either on the farm if for local use or to maximise transport payloads, or at the power station.
- Medium scale machines mounted around conventional self-propelled power units for stick, chip, billet or bale production as above.
- Small scale, trailed, stick harvester for grower / contractor use on smaller areas using conventional agricultural tractors as power units (Figure 5-6).

Figure 5-5: Billets of willow stock-piled on farm
(Ready for later comminution or transport to power plant.)

Figure 5-6: Tractor powered stick harvester suitable for small scale harvesting

Depending on the scale, comminution can be accomplished either:

- on the farm if the fuelwood is destined for local use
- on the farm in order to maximise transport payloads
- at the power station if it is cheaper overall to do so and also to provide a consistent fuel quality to suit the conversion plant design in terms of piece size and moisture content.

Until the market for fuelwood from SCC willow develops there will be only a limited demand for harvesting equipment. Therefore it would be impractical and not economically viable for a business to consider manufacturing harvesting equipment to suit all the above categories. In this case study only the two extreme categories were considered:

- a large scale system to supply a 10 MWe power generation plant by harvesting at least 1,000ha of SCC per year
- a small scale system to supply the grower with sufficient fuelwood to be used on site for heating alone or possibly for co-generation with grid connection to export excess power.

5.6.1.1 Large Scale System

This case study was based on the Yorkshire ARBRE project which is for a commercial scale biomass-fired power plant buying in the fuel from local growers under contract.

- Combined cycle gas turbine plant
- Capacity: 10MWe gross, 8MWe to be exported
- Fuel demand: 5 odt/h, @ 8,000 h/y (which assumes 91.3% availability) = 40,000 odt/y
- Fuel storage: need 34,000 odt stored on a hard stand area of >100,000 m2, the other 6,000 odt being fed into the plant directly on delivery during the harvest period of 50 days.
  Storage area *filled* over 90 days @ 50 odt/h, and being delivered for 8 h /day.
  Storage area emptied over 275 days @ 5odt/h for 24 h / day.

Note, various other options would be feasible such as emptying at 15 odt/h over the 275 days for 10h /day, the choice depending on the optimum time and period for power generation in order to maximise revenue i.e. to supply base load or peak load.

Alternatively it could be possible to have long term storage off site and only short term storage and drying on site.

Drying: Fuel moisture content of <20% (w.b.) is required by the gasifier:

a) For chip piles at a drying capacity of 40kg/h/m2 using air at +28°C above ambient from power plant waste heat (which can be assumed to be free), the floor area needed would be 125m2 with a bed depth of 0.4m. A 300kW fan is required to give a constant fan pressure of 1.5 kPa. Energy consumption will be 80kWh/odt which at £0.05/kWh is £4/odt.

b) Modified grain dryers could be used for drying the fuelwood where available on a farm, (the willow being harvested at a different season to the cereal crops). This will need:
   - a batch storage / drying system for 5 days fuel capacity = 720 odt chips
   - a drying floor of 20 bays of 145m^2 each and 2m depth
   - drying from 50% w.b. at harvest to 15% w.b. in 4 days using air at 23°C

The final desired form of woody biomass feedstock material is determined by the fuel specifications of the conversion plant in terms of acceptable moisture content and particle size ranges. Delivery of fuelwood to the power plant site can be in a wide range of forms since the final processing operation can be conducted on site immediately prior to feeding the feedstock into the conversion plant. A wider range of fuel moisture contents may also be acceptable if the desired level can be reached by blending wet biomass with dry, or if the plant has some form of artificial drying facility. However a cost penalty to the grower for supplying wet fuelwood is likely.

Industry representatives' comments on the potential for this scale of operation were as follows:

- Could use a single stem system on the large scale area by felling larger trees later using forestry harvesters, transpirationally drying the biomass as whole trees, grapple feeding into chippers, and then replanting the area.
- Need to densify the crop to maximise payloads. Based on growers' experience, a 90m3 truck carries 22 wet tonnes of willow chips at 240kg/m3 (150kg dry matter/m3).
- Cheap chip storage using a pole barn and natural ventilation to reduce deterioration and dry matter loss may be satisfactory.
- Dry matter losses of only 8% over 6 months are reported.
- Using a well designed grain drying floor and heated air, 200t of chips can be dried down from 38% m.c. to 8% m.c. in a 10 day period.
- If intention is to use grain drying facilities for SCC chips, then will need to have the grain out and sold before SCC harvest. Then can spread the capital costs of the dryer over more crops. If not sold at that time, will require construction of extra storage for the grain which would be a cost against SCC production along with a share of the capital costs of the drier and the running costs.
- Billets are easy to store on farm if a good floor or ground surface is available and with no dust or spores. Less power is needed for artificial ventilation than for chips.
- Need to include in with the unloading times used in the model the inevitable queuing delay when delivering many loads to the power station.
- Large scale biomass purchasers can dictate the form of material delivered.
- Bales of SCC are compatible with bales of forest residues, straw (Figure 5-7) and bagasse (Figure 5-8) for handling at the plant, but some plants may also have a dump pit to unload the chips by tipping truck (Figure 5-9).
- Harvesting the SCC as whole sticks with cheap headland storage and then chipping at the headland before transporting to the power plant has practical applications.
- On steeper terrain chipping of residues is not economically feasible so in field chipping of SCC sticks may not be possible. Estimates are £1.65/odt to chip at the power plant but £8/odt to chip

in the field. A sawmill chipper handling 80,000t / y costs £4/ wet tonne. Contract chipper charges are around £25/h.

- Further comminution of billets at the plant may require modifications to chipper designs.
- Bales are easy to measure by counting and the system would suit a range of crops and materials. Could take samples after chipping to confirm payment level on fuel quality but the cost of baling is a limitation.
- There is a risk of foreign bodies (e.g. stones) being in the fuelwood material supplied, especially if put on to the ground and later retrieved. Payment on quality must include a penalty for such contaminants.
- Farmers want ownership of the crop, and to be contracted by the developer who takes responsibility for harvesting the material (as for processing frozen peas). The power plant owner could hire contractors and oversee management of the crop, such that the farmers simply provide the land. The company could purchase a harvester for a contractor to use, lease it back and guarantee a minimum area.
- Projects are often proposed based on having to store fuel year round rather than use a mix of fuels coming on stream when needed. The model output, (system E, Figure 5-3) clearly shows the advantages of direct delivery without storage if all year round harvest were possible.
- Reception areas for feed delivery at the plant have significant cost so there is a saving in having only one delivery system such as bales or chips, but not both.
- Whole bales could be burnt in heating systems. Billets could also be fed in.

**Figure 5-7:	Large square straw bales stored at the power plant ready for use**

Figure 5-8: Bagasse baled and stored for use in a sugar processing co-generation plant during the non-cane crushing season

Figure 5-9: Chips being delivered to a Canadian wood-fired power plant by tipping truck

5.6.1.2 Small scale system

This second British case study was based on a grid connected, on-farm co-generation plant where the heat can be usefully used and the fuel is grown by the farmer.

- Gasifier and gas engine operate 5,000 – 6,000 hours per year.
- Capacity: 100kWe, 80% of power exported; heat used for grain drying, space heating of house and buildings, and hot water.
- Fuel demand: 300 odt/y
- 30 ha planted in SCC willow; 2 year rotation; yield of 10 odt/ha/y.
- Fuel storage: Use bulk grain store if empty (i.e. if cereals have been sold off the farm by the time of harvest). If not available, piles of chips outside are an alternative, ideally covered with plastic sheets.
- Drying: two stage:
    1) using heat from grain drying plant in batch drying at harvest, and
    2) using exhaust heat from co-generation plant immediately prior to delivery to the gasifier.

Comments from industry representatives on this small scale operation are given below.

- A front-mounted chip harvester/ tractor/ towed trailer would be satisfactory for on-farm use.
- An adapted maize harvester is possible - but it would be expensive at £60,000 so needs to be used for areas more than 400ha /y to achieve good cost recovery.
- At the farm scale, existing farm machine designs should be used wherever possible to spread overhead costs.
- Use grain drying facilities where available for chips, or ventilate in a cheap store.
- Single stem harvesting could be an alternative option to coppicing. Yields of 8 odt/ha/y are feasible after 8 - 10 years growth under UK conditions. This system could be more suitable for poplar and eucalypts.
- Harvesting single stems with a simple saw blade on a tractor mounted frame has potential, dropping the trees and collecting them later.
- Sticks are good for natural drying but this is partly offset by handling difficulties.

5.7 Study Methodology

Recent project reports on SCC harvesting and drying were reviewed and a summary table of all characteristics of the harvesters that had been tested and evaluated in the field was compiled.

Informal discussions were held with a wide range of stakeholders in the industry both in the UK and Europe to ascertain their personal concepts for harvesting SCC and priorities for Research and Development. There was no obvious consensus and many personal preferences were evident. So no opportunity resulted to “pick a winner” from all the harvesting options presented.

Design variables were developed for a SCC harvester. For each specification parameter (i.e. overall machine size and design, work capacity, width of cut, cutting mechanism, comminution, transfer mechanism, transport from field, road transport, storage, drying) its effect on the other variables, the limitations imposed by other factors, and a list of options was produced. This summary clearly identified the fairly complex inter-dependencies of any one factor on the others.

A simple computer spreadsheet was developed to calculate storage and transport volumes for baled SCC. A method of comparing the selected systems in broad general terms based on a 5 star rating of ten characteristics was also developed. Bales and billets showed a slight overall advantage over chips, with sticks and single stem harvesting of older trees least favoured at the larger scale, but with some potential for the small scale grower/user.

Cost comparisons for various systems were made possible by adapting the biomass transport model originally developed by the University of Westminster and Scottish Agricultural College. This model was also used after further adaptation in a New Zealand study of forest arisings as briefly outlined above.

Finally a meeting was held with biomass industry representatives and growers to discuss harvester options. Some general comments have already been presented above but others received are summarised below.

As a result of this overall process, the preferred concepts for harvesting machines and developing new handling and transport fuel supply systems were identified.

5.8 Assessment of SCC Harvesting and Fuel Supply System Costs

5.8.1 Assumptions

The standing crop to be harvested and processed was 2 year old willow coppice yielding 40 wet t/ha in a 12 ha field. The harvesting and various supply chain systems were modelled for power station supply from the standing crop through to the power station gate 39.5 km away from the farm gate. Additional costs for loading and chipping / shredding at the power station were included as a separate cost. In the analysis, the costs presented are for oven dry tonnes (odt) of dry matter delivered to the power station. In the base case, the cost the growers are paid for the standing crop was taken as £20/odt, but this could be modified or excluded from the calculations if desired.

The different harvesting systems result in the biomass being delivered in different forms: as bales, billets, or chips, and as green or partly air-dried material. An allowance for dry matter losses in store was made with assumptions of 4% per month loss for chips, 2% for bales and for sticks and 1.5% for billets. The user must decide what value should be put on biomass materials and dry matter losses in each different form to suit the specific case.

The scenarios listed below have been chosen to represent various practical options. The cut and chip harvesters and the Empire 2000 stick harvester have been evaluated in field trials and the performance data is based on these results. The assumptions for capital cost, work rate etc. for each harvester machine used in the model are listed in Figure 5-14.

There is interest in the use of a one-pass cut-and-bale machine for felling and baling coppice material in the field (see Recommendation 1 below). No such machine yet exists so, in order to model this option, three scenarios were presented (A, B, C) based on experience from straw baling, one for round bales and two for large square bales. These scenarios illustrate what might be achievable if such a machine were to be built. The concept would be a cutting head attached to the front of a commercial baler such as the Claas Rollant or the Hesston square baler, with the cut sticks being possibly crimped or billeted before being fed into the baler directly. Dropping the cut sticks onto the ground for subsequent collection, possibly after a period to allow some drying to occur, would have some advantages but would be difficult to achieve without high field losses and damage to the stools by the baler pick-up.

5.8.2 System descriptions as used in the model

A. Large round bales

Based on the Claas Rollant baler with options for net wrapping or twine, the former being faster. A summary of the assumptions used is given in Figure 5-14. The scenario is based on the performance of a round baler for straw with some account taken of the trials on forestry residue bales using the Swedish 'bala press'. The steps involved in the supply chain are similar to those outlined for well established straw baling and handling systems. Mowing was assumed to cost £36/ha with the mower attached to the baler and a simple crimping or billeting system installed before the baling section. From the 12 ha area used in the analysis, 960 bales of 500kg each can be produced. The bales are dropped in the field for later collection by loader on to a flatbed trailer for delivery to the headland or farm store. A six months average store period was assumed and then the bales are collected and transported by a heavy goods vehicle (HGV) (Figure 5-10). Alternative options would be for the baler to carry the bales directly to the headland for stacking and intermediate storage assuming the HGV could gain access to this point, or for a loader to transfer the bales from field to headland one bale at a time. The HGV is unloaded using a front loader at the power plant and the bales are then fed into the boiler directly (Figure 5-11).

In this and all other system scenarios (except B and E which are transported directly to the power plant), the transport distance assumptions were:

Travel in field	0.5 km	(8km/h average)
Travel on farm track to farm store	0.5 km	(10km/h average)
Travel from farm store on farm track	0.5 km	(10km/h average)
Travel on unclassified roads	9.5 km	(40km/h average)
Travel on single carriageway A/B roads	30 km	(55km/h average)
Total travel distance one-way	**41 km**	

Figure 5-10: Transport of round bales on heavy goods vehicle and trailer

Figure 5-11: Round bales fed into shredder on automatic conveyor to feed straw burner
(24 hours a day unattended)

B. Large square bales direct to power plant.
This scenario is based on a Hesston high density baler, which is widely used for handling straw in Danish power plants (Figure 5-12) and for industrial applications in the UK. It is assumed that these bales are bound with twine.

The steps involved in the supply chain are those broadly used for straw baling systems, except it was felt that a self-loading bale carrier would not work satisfactorily amongst coppice stools. So the modified system is:

- mowing, here using a Claas header or similar attached to the baler
- baling, directly after mowing without dropping the cut material
- Fastrac tractor and loader to take single bales from the field 0.5 km direct to the HGV
- 35t gross HGV travels 1km on farm tracks at 10km/h average, 9.5km on unclassified roads at 40km/h, and 30 km on single lane A/B roads to the power plant at 55 km/h
- Unloading by front loader.

600 square bales were produced from the 12 ha field, each weighing 800kg.

C. Large square bales to farm store
As for system B above but with a front loader and tractor/trailer to transport the bales from the field to the farm store since it was assumed a self-loading bale carrier would not work. Unloading at the farm store and collection by HGV after an average period of 6 months. The HGV is a 35t gross articulated low-bodied flatbed trailer which is loaded and unloaded by a front end loader.

Figure 5-12: Straw bale being dropped into shredder to feed combustion plant

D. Claas forage harvester (cut-and-chip)

Short rotation coppice material is cut and then chipped involving the following steps :

- direct cut and chip blowing into one of two 15 m3 trailers pulled by 85 kW tractors
- in-field transport tipped at intermediate store
- pushed into a heap on hard standing by loader and stored for 6 months on average
- loader used to fill 38t articulated bulk tipping HGV
- HGV takes chipped biomass to power plant where it is tipped.

Based on Forestry Commission (UK) trials a harvesting rate of 10 odt/h was assumed which is equivalent to 0.5ha/h. Two tractor/trailers were used to convey the chips 1 km on average to the farm store for later collection.

E. Claas forage harvester with no storage.

This uses the same harvesting machine as system D but the material goes straight from the field to the plant using three 45m3 trailers to collect the material direct from the harvester in the field. This illustrates a harvesting operation suitable for dry soils in fields within a reasonable transport distance (40 km) of the plant. It would be the most probable scenario if year round harvesting was proven to be feasible. Wet chips at around 50% moisture content (wb) are delivered.

The steps involved are:

- direct cut and chip blowing into trailers
- in-field transport and road transport in trailers pulled by a Fastrac tractor then tipped at the plant.

As for other systems the transport scenario was:

In field	0.5 km
Farm track	1.0 km
Unclassified roads	9.5 km
A/B roads	30.0 km

The 480t of chips delivered would require a storage area of 125m long, 7m wide (for which land rent is included in the analysis) and be piled 3m high.

F. Empire 2000 stick harvester

The costs/ hour and work rates for this system were taken from UK Forestry Commission calculations (see Figure 5-13). The steps are:

- sticks cut and carted to the headland by the harvester
- loader loads trailer and tractor
- on farm storage of sticks after stacking by loader
- chipped on farm direct into 38t HGV tipping trailer
- driver and articulated truck arrive to collect the full trailer for delivery to power plant.

A productivity of 7odt/h was assumed which equates to 0.35 ha/h.

Figure 5-13: Willow stick harvester with collection platform to accumulate load till drop off when full.

G. Austoft harvester (cut and chip).

As for the Claas chipper system D above but using the Austoft modified sugar cane harvester at the assumed higher cost of £82.81 / hour. A productivity rate of 10odt/h was assumed based on Forestry Commission trial results data.

H. Austoft harvester (cut and billet).
This is the same system with the same steps as for systems D and G above but with the Austoft harvester modified to produce billets rather than chips. The hourly cost is slightly lower as less power is required for billeting than chipping and less knife maintenance is required. This results in lower storage costs but the other input data remains the same (Figure 5-14). The definition of a billet is a piece size which is bigger than a chip but is small enough to allow the bulk material to be handled by bucket loaders and on belt conveyors. It is large enough to allow air to naturally ventilate in a stack and prevent spontaneous heating. The work rate, machine costs and product bulk density were assumed to be the same for the Austoft harvester in both cut-and-chip and cut-and-billet modes of operation.

System	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	Mower/ round baler (farm store)	Mower/ square baler (direct deliver)	Mower/ square baler (farm store)	Claas harvester (chip & farm store)	Class Harvester (direct and store at plant)	Empire 2000 (stick, farm store & chip)	Austoft Harvester (chip & farm store)	Austoft Harvester (billet & farm store)
Machine cost (£k)	?	?	?	182	182	91	190	190
Hourly harvester cost (£/h)	36.51	78.38	78.38	65.12	65.12	44.75	82.81	80.00
Work rate (odt/h)	10	16	16	10	10	7	10	10
Road transport payloads (odt)	11.25	12.0	12.0	14.85	14.85	8.7 for sticks 14.68 chips	14.85	13.5
Total loss during storage (%odt)	12	2	12	24	0	9	24	9

Figure 5-14: Key assumptions of machine costs and performance rates used in the base case models

Note the dry matter losses during storage vary with time but for the same period (e.g. 6 months on average) are greater for chips, than for bales, than for billets or sticks. Where the biomass is taken directly to the power plant for immediate use the losses are negligible.

5.8.3 Industry comments on short rotation willow coppice harvesting and processing systems studied.

For this UK case study a one day meeting was held for industry representatives to help identify priority areas for future research for SCC harvesting development. Existing harvesters were considered along with the new concepts recommended.

Discussions were held on each factor relating to the harvesting and supply chain for each of five systems, based on fuel supply to a 10MW$_e$ biomass-fired power station. The consensus opinion of the growers present is shown below. Using a subjective 5 star rating methodology with equal weighting for the each of the 10 factors, the systems of delivering harvested SCC material to the power plant gate in the 5 different forms gave the following ranking.

Billets:	**41** points
Bales:	**39** points, based on large square or round bales
Single stem:	**37** points using forestry equipment to harvest larger trees
Chips:	**35** points due to storage problems causing the lower ranking
Sticks:	**29** points due to handling and transport problems. If chipped on the farm immediately prior to delivering to the plant, the point score increased to **35**.

The transport model was described to the group and the comparative costs presented for the 8 separate systems (as outlined above). Harvester costs used were based partly on Forestry Commission figures (Deboys, 1996). Since this was a comparative exercise and similar assumptions had been used for all eight systems, the comparisons were considered to be valid.

Whether or not to include the cost of comminution when at the power plant with the other costs was discussed. If the material is delivered to the plant in a form that requires further processing, this cost should be included in the overall payment calculation. Thus there would be some theoretical advantage for growers delivering the biomass in chip form rather than bales. However since chipping at the farm scale is likely to be more costly than chipping at the plant, the grower may in fact be penalised for delivery in this form.

The following general points and comments were raised by the growers and industry representatives.

- The less travel on the field by the machines the better, to avoid soil compaction.
- Growers should seek value added opportunities incorporating costs within their existing business.
- Contractors would be an alternative option to owning harvesting machinery, but are not yet operating in most regions due to limited demand.
- A simple single disc saw on a tractor-mounted frame could be more suitable for harvesting single stems than the use of manual chainsaws.
- Leaving bales in the field for later collection should be avoided as it could damage the coppice stools.
- Sticks and bales can be stored on headlands, but it would be economic to also plant the headlands to utilise all field space and to gain traction across the field when wet with machines due to the root mat. Harvesting the headlands first is logical to give access, but then a place to store the material will still be needed.

5.9 Study Recommendations

The following recommendations are based on using state of the art technology, and assumptions that a fuelwood supply is required all year round for power generation but that harvesting SCC willow is only feasible in winter. Detailed comments on each of these three options by industry representatives are also given.

Recommendation 1

Bale the cut SCC sticks or chunks into large round or square bales using existing agricultural baling machines mounted on a tractor/mower to give a one-pass machine with either:

- *bales dropped on ground for subsequent collection by tractor/front loader and transport to trailer or truck, or*
- *bales carried to headland on baler for later collection by truck.*

It is possible that large scale wood-fired power stations in the UK will use a mix of existing forest arisings and wood process residues as their main fuels, together with fuelwood from SCC. Therefore delivering the range of biomass material in a standard form is essential for cheaper and easier handling at the plant. If one truck load delivers biomass in the form of bales and the next truckload arrives as chips, it would be more difficult to handle and process than if all trucks delivered bales or all delivered chips. It must be borne in mind that for very large plants there may be one truck arriving every 5 – 10 minutes, so there is little time to handle the material. Hence having a standard form of delivery is essential.

Bales could be an ideal method of densifying the material to provide transport economies in terms of maximising truck payloads. However the costs of baling are likely to remain uneconomic unless higher throughputs can be achieved than at present and the balers can be used for other crops or purposes during the year in order to spread the fixed costs of ownership.

Since it would be extremely difficult to design a machine to pick up harvested sticks dropped on to the ground after cutting without damaging the remaining cut stems, a mower/baler machine combination seems a desirable design goal. The German company Deutz-Fahr has designed and tested just such a self-propelled prototype machine based on using either a Claas round baler or Heeston square baler. The concept was tested on willow biomass material in the field and by feeding in cut material in a test laboratory. The machine has not yet been made commercially available. An evaluation and cost analysis of this option is given in Systems A, B and C of the cost analysis.

Baling of SCC would also be suitable for the small grower supplying the power plant if a contractor in the locality could be hired or if the baler could be supplied by the owners of the plant for hire by the growers (which would help to maximise the use of the equipment and thus allow more time over which the fixed costs could be recovered).

This bale system could possibly be used by a small farmer growing SCC to supply any heat demand on farm or nearby if the bales could possibly be fed into a whole bale burner as developed for straw bales in Denmark (
Figure 5-15). However if a small gasifier is preferred, a small uniform piece size is desirable so the bale would first need comminuting. This would then require specialised and costly equipment.

Figure 5-15: Whole bale burner under development in Denmark.

Recommendation 2

Develop a billet system around the Austoft sugar cane harvester or a chain cutter/stick harvester with a billeter mounted on the chassis. Either would need a conveyor with support trailer running alongside, or a mounted bin to carry billets to the end of the row for unloading hydraulically.

The advantages of this system were assumed to be as follows:

- Uses existing equipment, the base machine being available for chipping as well as for billeting but with some modifications required.
- Harvesting cost of around £10/odt is cheaper than using whole stick harvesters.
- Work rate of around 0.25ha/h will require 16 x 10 hour harvest days to complete 15 ha of 10 odt/ha crops, so the harvester could be shared with 4-5 other growers on a syndicate basis if 50 harvesting days are available during the season.
- Acceptable soil compaction, even on wet sites, due to half-tracks.
- At a work rate of 0.4 ha/h and assuming 50 x 20 hour working days, the large scale plant would need 3 similar harvesters to harvest 1000 ha / year.
- Harvesting costs for billets delivered to the power plant would probably be similar to chips at approximately £70/odt, but storage of billets rather than chips over long periods provides an overall advantage as a result of less dry matter losses whilst in store, lower energy inputs, and cheaper drying. (Note: use of the Austoft sugar cane billet machine was modelled using the transport programme and is reported as System H).

As mentioned earlier, year round harvesting, if agronomically feasible under UK conditions, would have a significant effect on harvesting costs and storage systems.

Recommendation 3

For small scale systems on farms with existing grain drying facilities, a manual chainsaw or simple tractor mounted single disc saw blade used for older single stem trees and the trees later manually fed into a mobile chipper

After cutting with a chainsaw or tractor mounted sawblade, a simple harvesting system could be envisaged at this scale with a front-mounted chipper on a farm tractor with trailer towed behind. The chipper would be manually fed, which would limit the size of tree that could be harvested. However after being left to dry for some weeks, the tree weight would be less due to moisture loss. Trailer transfer when full would occur at the headlands. The commercial availability of such systems and the potential market for them need to be identified but they would use mainly existing equipment. The proposed drying system would also need to be fully tested and analysed to ensure it works with this chipped biomass material.

This concept has been well researched and developed, but now needs to be commercially proven.

It must be reiterated that the example above was developed in the UK, and it has been provided in the absence of similar studies carried out for Australian fuels or conditions. Nevertheless it serves to show the considerable differences between different delivery strategies, both for small and large scale operations and even within similar requirements for fuel quantities. It is quite conceivable that different strategies would also be used across Australia according to differences in fuels available, existing machinery, harvesting limitations due to seasonal conditions or soil types, storage options and so on. Note also that the prices paid for renewable energy in the UK are greater than those paid in Australia, and so the economic viability of a process in the UK (or Scandinavia) does not immediately indicate that a similar system would be competitive in Australia.

5.10 Further Reading

Allen J, Browne M, Palmer H, Hunter A, & Boyd J (1996) *Transport and supply logistics of biomass fuels: Vol 1- Supply chain options for biomass fuels.*University of Westminster. ETSU B/W2/00399/REP/1.

CEC, (1999) *Evaluation of biomass-to-ethanol.* Californian Energy Commission Report P500-99-011, August.

Deboys R (1996) *Harvesting and comminution of short cycle crops*. ETSU report B/W2/00262/REP

Dornburg, V. and Faaij, A., 2000*. System analysis of biomass energy system efficiencies and economics in relation to scale. Proc. 1st World Conference and Exhibition on Biomass for Energy and Industry.* Sevilla. CARMEN

ETSU (1990) *Wood fuel supply strategies.* Aberdeen University, Contract report ETSU B 1176–P1. ETSU, AEA Technology, Harwell, UK.

FCA (1997) *Baling forest residues in the United Kingdom* Press release. Forest Contractors Association 3 January, 1997.

Hall P., Sims R E H, and Gigler J K (2001) Delivery systems of forest arisings for energy production in New Zealand. Biomass and Bioenergy. In press.

Livingston W. R. (1996) Project Arbre: the storage and drying of short cycle crops woodfuels. Mitsui Babcock Energy Ltd. Internal Report to ETSU 34/96/50

Lowe H T, Sims R E H, & Maiava T (1994). Evaluation of a low cost method for drying fuelwood from short rotation tree crop for small scale industry. Proc. 8th European Biomass Conference, Vienna. 1, 461-467. Pergamon.

Moreira, J.R. and J. Goldemberg, (1999) The Alcohol Program, Energy Policy 27, pp 229-245.

Nellist M E (1997) *Storage and drying of arable coppice.* Aspects of Applied Biology 49, 1-11.

Sims R E H (2001).*The Brilliance of Biomass – in business and in practice*. James and James (London), 316 pages.

Sims R E H and Culshaw D (1998*) Fuel mix supply reliability for biomass-fired heat and power plants*. Proc. 10th European conference “Biomass for Energy and Industry”, Wurzburg. June. pp 188-191. CARMEN.

Sims R E H, Lowe H T, & Maiava T (1994). All year round harvesting of short cycle crops eucalyptus. Proc. 8th European Biomass Conference, Vienna. 1, 507-514.

6. Energy Technologies – Electricity and Heat

6.1 Summary

The conversion of biomass to heat and power is well established commercially, with 90 percent of the world's modern bioenergy plants operating using combustion process. The maturity of combustion technology is evidenced by 12 GW of installed bioenergy capacity in the USA alone. Emerging thermo-chemical technologies for biomass conversion are gasification and pyrolysis of biomass.

Conventional combustion technologies raise steam through the combustion of biomass. This steam may then be expanded through a conventional turbo-alternator to produce electricity. A number of combustion technology variants have been developed. Underfeed stokers are suitable for small scale boilers up to 6 MWth (thermal capacity). Grate type boilers are widely deployed. They have relatively low investment costs, low operating costs and good operation at partial loads. However, they can have higher NOx emissions and decreased efficiencies due to the requirement of excess air, and they have lower efficiencies. Fluidised bed combustors (FBC), which use a bed of hot inert material such as sand, are a more recent development. Bubbling FBCs are generally used at 10-30 MWth capacity, while Circulating FBCs are more applicable at larger scales. An advantage of FBCs are that they can tolerate a wider range of poor quality fuel, while emitting lower NOx levels. Cogeneration, or the combined production of electricity and useful heat improves the overall thermal efficiency of combustion plants.

Gasification of biomass takes place in a restricted supply of oxygen and occurs through initial devolatilisation of the biomass, combustion of the volatile material and char, and further reduction to produce a fuel gas rich in carbon monoxide and hydrogen. This combustible gas has a lower calorific value than natural gas but can still be used as fuel for boilers, for engines, and potentially for combustion turbines after cleaning the gas stream of tars and particulates. If gasifiers are 'air blown', atmospheric nitrogen dilutes the fuel gas to a level of 10-14 percent that of the calorific value of natural gas. Oxygen and steam blown gasifiers produce a gas with a somewhat higher calorific value. Pressurised gasifiers are under development to reduce the physical size of major equipment items, however these gasifiers are generally at the precommercial stage. A variety of gasification reactors have been developed over several decades. These include the smaller scale fixed bed updraft, downdraft and cross flow gasifiers, as well as fluidised bed gasifiers for larger applications. At the small scale, downdraft gasifiers are noted for their relatively low tar production, but are not suitable for fuels with low ash melting point (such as straw). They also require fuel moisture levels to be controlled within narrow levels.

Pyrolysis is the term given to the thermal degradation of wood in the absence of oxygen. It enables biomass to be converted to a combination of solid char, gas and a liquid bio-oil. Pyrolysis technologies are generally categorised as "fast" or "slow" according to the time taken for processing the feed into pyrolysis products. These products are generated in roughly equal proportions with slow pyrolysis. Using fast pyrolysis, bio-oil yield can be as high as 80 percent of the product on a dry fuel basis. Bio-oil can act as a liquid fuel or as a feedstock for chemical production.

The bio-oil route has a number of inherent advantages for bioenergy. Liquid fuels are relatively easy and cleaner to use, retro-fits of existing plant can readily be achieved, production of bio-oil can assist in removal of ash and problematic alkali metals, and the bio-oil can potentially be used as a renewable replacement for diesel in engines and gas turbines. A key advantage is that the energy density of bio-oil is a relatively high 61% (by volume) of that of diesel. This potentially overcomes limitations of transporting low density, solid biomass fuels such as chipped biomass to power plants some distance from the fuel supply.

A range of bio-oil production processes are under development, including fluid bed reactors, ablative pyrolysis, entrained flow reactors, rotating cone reactors, and vacuum pyrolysis. This section provides information on the physical and combustion properties of pyrolysis bio-oil. Bio-oil is very different from hydrocarbon fuels, in that it is not as chemically stable, contains water, is more difficult to ignite, is acidic, and does not naturally mix with petroleum derived fuels. Bio-oil can be upgraded to control the moisture content and hot-filtered to remove fines and problematic alkali metals. Chemical upgrading aims to reduce the oxygen content, the cause of a number of unwanted characteristics of bio-oils.

Studies of bio-oil economics have indicated bio-oil used for electricity or cogeneration via gas turbines will offer competitive pricing for renewable electricity. However it must also be remembered that, world-wide, only one company (Ensyn) currently operates commercial pyrolysis plants. Plants using Ensyn technology principally sell value-added products derived from the oil, with the balance of the oil used to fire conventional boilers. Other developers have pilot scale experience. The main research network for pyrolysis is the PyNe network, headed by Professor Tony Bridgwater of Aston University in the UK.

This section does not examine oils from agricultural or nut crops, often referred to as “bio-diesel”.

6.2 Introduction

Biomass-fueled heat generation, power generation and co-generation systems are well established commercially in many parts of the world, including in the Australian sugar industry, demonstrating the successful industrial application of bioenergy. Approximately 90 percent of the world’s large scale bioenergy plants operate through combustion processes. It is of interest to note that the USA alone has some 12,000 MW of installed bioenergy capacity, about the same capacity as the New South Wales coal fired generation capacity, again indicating the maturity of this technology.

Bioenergy systems normally consist of *primary* conversion technologies which convert the biomass into heat or gaseous and liquid products, together with *secondary* conversion technologies which convert these products into the more useful forms of energy being heat and electricity. An overview of the technologies is given in Figure 6-2. Alcohol liquid fuels are considered separately, later in this report.

Bioenergy systems covered in this section include only the thermo-chemical energy conversion technologies of combustion, gasification and pyrolysis, together with co-firing of solid biomass with coal or of gaseous biomass fuels with natural gas.

A wide range of technologies exists to convert the energy stored in biomass to more useful forms of energy. These technologies can be classified according to the principal energy carrier produced in the conversion process. Carriers are in the form of either heat, gas, liquid and/or solid products, depending on the extent to which oxygen is admitted to the conversion process (usually as air). The three principal methods of thermo-chemical conversion corresponding to each of these energy carriers are combustion in excess air, gasification in reduced air, and pyrolysis in the absence of air.

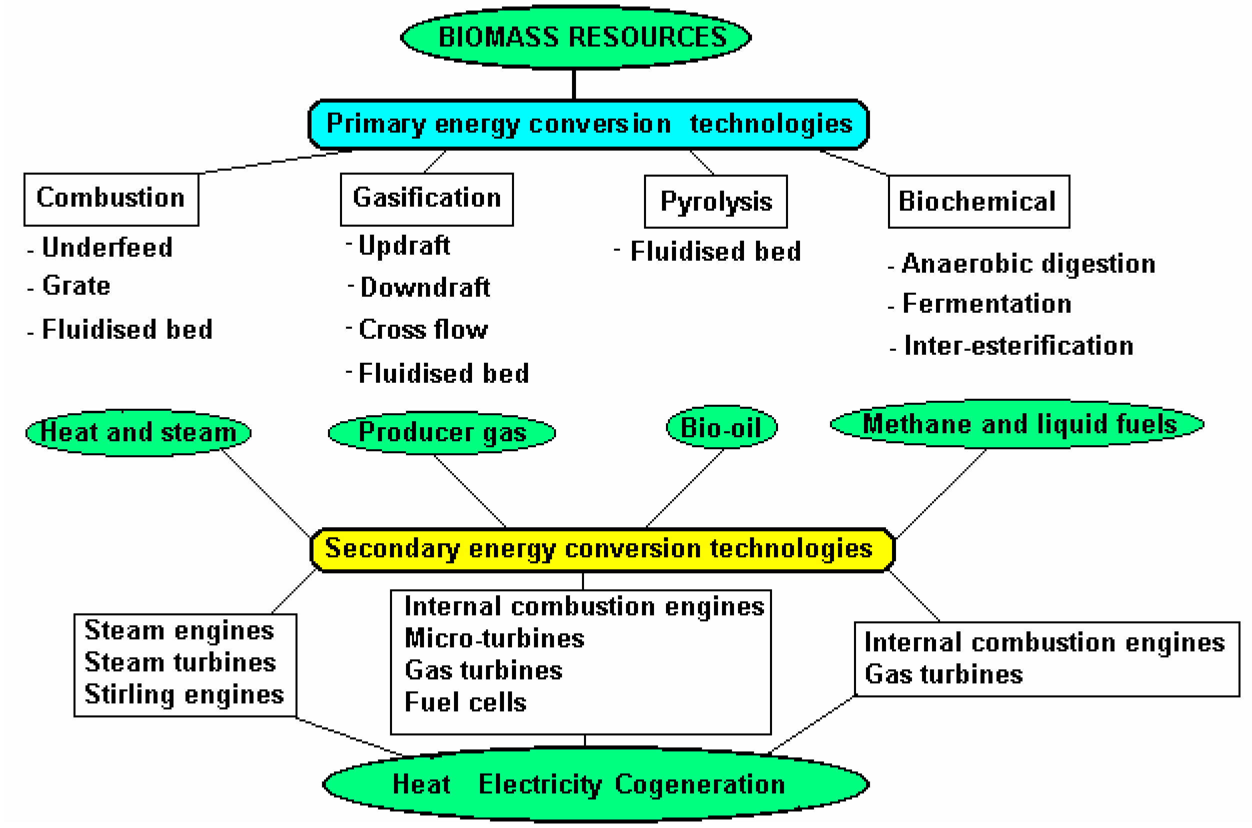


Figure 6-1: **Primary and secondary conversion technologies suited to biomass projects.**

6.3 Combustion

Direct combustion is the best established and most commonly used technology for converting biomass to heat. During combustion, biomass fuel is oxidised ("burnt") in excess air to produce heat. The first stage of combustion involves the evolution of combustible vapours from the biomass, which burn as flames. The residual material, in the form of charcoal, is burnt in a forced air supply to give more heat. The hot combustion gases are sometimes used directly for product drying, but more usually they are passed through a heat exchanger to produce hot air, hot water or steam (Figure 6-2). The combustion efficiency depends primarily on good contact between the oxygen in the air and the biomass fuel. The main products of efficient biomass combustion are carbon dioxide and water vapour, however tars, smoke and alkaline ash particles are also emitted. Minimisation of these emissions and accommodation of their possible effects are important concerns in the design of environmentally acceptable biomass combustion systems.

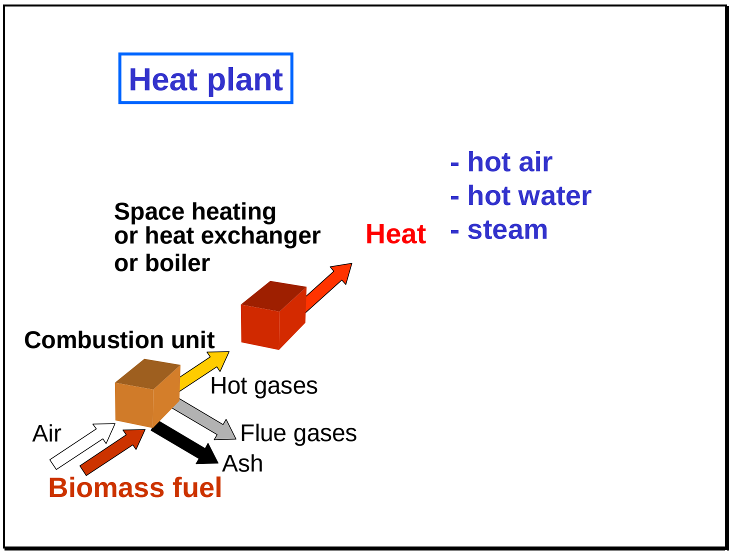


Figure 6-2: **Heat Plant**

Biomass combustion systems, based on a range of furnace designs, can be very efficient at producing hot gases, hot air, hot water or steam, typically recovering from 65-90% of the energy contained in the fuel. Lower efficiencies are generally associated with wetter fuels. For example forest residues (left in the forest after stemwood extraction) are between 50-60% moisture content (wet basis) soon after harvest.

The conventional technology for generating electricity from biomass is to use a combustion system to raise steam, and then to expand this steam in a turbine or engine used to drive a generator set to produce electricity. Whilst the production of steam using heat from the combustion of biomass is efficient, the conversion of steam to electricity is much less so.

To cope with a diversity of fuel characteristics and combustion requirements, a number of designs of combustion furnaces or combustors are routinely utilised around the world:

a) Underfeed stokers

Biomass is fed into the combustion zone from underneath a firing grate. These stoker designs are only suitable for small scale systems up to a nominal boiler capacity of $6MW_{th}$ and for biomass fuels with a low ash content, such as wood chips and sawdust. High ash content fuels such as bark, straw and cereals need more efficient ash removal systems. Sintered or melted ash particles covering the upper surface of the fuel bed can cause problems in underfeed stokers due to unstable combustion conditions when the fuel and the air are breaking through the ash covered surface.

b) Grate stokers

The most common type of biomass combustor is based on a grate to support a bed of fuel and to mix a controlled amount of combustion air, which often enters from beneath the grate. Biomass fuel is added at one end of the grate and is burned in a fuel bed which moves progressively down the grate, either via gravity or with mechanical assistance, to an ash removal system at the other end. In more sophisticated designs this allows the overall combustion process to be separated into its three main activities:

- initial fuel drying
- ignition and combustion of volatile constituents
- burning out of the char.

Separate control of the air conditions and the temperature for each activity are possible. Alternatively, for low ash fuels, the grate may be fixed and the fuel introduced by a spreader stoker which distributes the fuel so as to maintain an even fuel bed and provide optimum combustion conditions.

Grate stokers are available as:

- fixed grates for small scale combustion systems (typically less than 1MWth)
- reciprocating grates for larger scale
- newly developed designs that enable horizontal and vertical movement of the grate.

When the supply of primary air is controllable it is possible to operate grate firings efficiently even at partial loads down to a lower limit of 25% of the nominal maximum furnace load. Some newer designs of grate systems are water-cooled to avoid slagging and to extend the life time of the materials. Such attributes can increase the versatility of the combustion system, and could be considered if load or fuel requirements dictate.

Grate stokers are well proven and reliable and can tolerate wide variations in fuel quality (i.e. variations in moisture content and particle size) as well as fuels with a high ash content. They are also controllable and efficient. Advantages of grate stoker furnaces include:

- relatively low investment costs ($/kW)
- low operating costs
- good operation at partial load.

Disadvantages include:

- production of NOx emissions (reduction requiring special technology and greater costs)
- excess oxygen decreasing the efficiency
- combustion conditions not as homogeneous as in other combustor types.

Recent design developments have been driven by the desire to reduce emissions. This situation has also given rise to the development of the main alternative to grate based systems, namely the fluidised bed.

c) Fluidised bed combustors

Fuel is combusted in a bed of inert material (usually sand particles) suspended by air blown in from beneath the bed. This air is also used to combust or partially combust the biomass fuel. For plants with a nominal boiler capacity greater than $10MW_{th}$, bubbling fluidised bed (BFB) combustors start to be of interest. Circulating fluidised bed (CFB) combustors better suit plants larger than $30MW_{th}$. The minimum plant size below which CFB and BFB technologies are not economically competitive is considered to be around $5\text{-}10MW_{e}$.

Economic assessment

Technologies for using the heat of combustion to raise steam can generally be regarded as robust and well proven. Electricity production with conventional steam technologies of either steam engines or turbines have overall energy efficiencies starting at as low as 5% (typically for small systems) and generally being 20-25%. These figures are typically less that those achieved in large coal-fired power stations, generally because the latter can achieve better steam conditions than the smaller biomass plants.

Where there is a genuine demand for both electricity and heat, overall co-generation system efficiencies can be much higher, at around 50 to 80%.

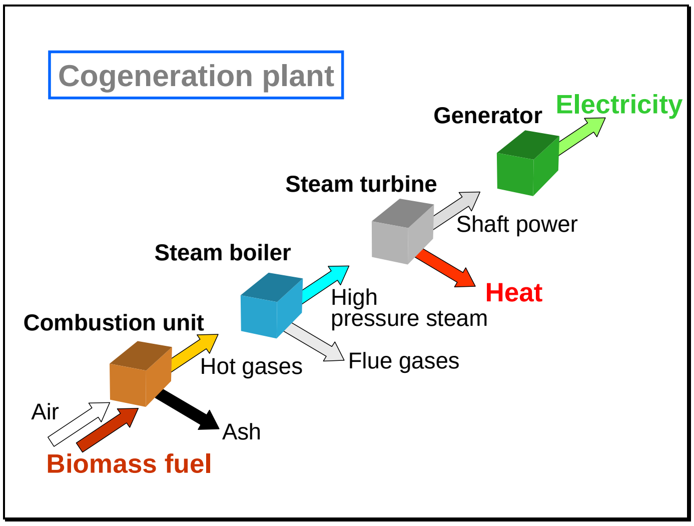


Figure 6-3: **Co-generation Plant**

Where biomass residues are available at low or zero cost, electricity and co-generation plants using steam technology may be competitive with electricity produced from fossil fuels (Figure 6-3). Where the biomass has to be purchased to cover costs of supply or opportunity costs, electricity prices will probably not be competitive without some form of subsidy or mandated market, such as MRET set up by the federal government. In these circumstances biomass to electricity schemes need other reasons for their existence and, where such reasons exist, electricity price structures should recognise this. Where supportive price structures exist, steam technology will continue to be a viable proposition for biomass to electricity plants. However, until the environmental benefits and other benefits from using biomass are fully internalised (to provide a level playing field compared with the use of fossil fuels), continuous price support mechanisms such as RECs (Renewable Energy Certificates) are often needed.

To improve the cost effectiveness of electricity generation from biomass, conversion efficiencies need to rise, capital costs need to fall, and transport and processing capacities (such as truck payloads) need to be maximised. Raising conversion efficiencies will also increase the displacement of fossil fuels, hence maximising environmental benefits and any associated environmental tax credits.

However, there is little scope for achieving significant efficiency improvements with steam technology over the next few years, because the technology is already relatively mature. The main problems with combustion technology that need comprehensive R&D concern the reactions taking place in the flue gas which cause corrosion and fouling in furnaces and boilers (especially when K, S and Cl rich biomass fuels such as straw, cereals and vegetative grasses are used). Ash melting behaviour and the variables which influence it also need further evaluation, particularly to allow better utilisation of biomass fuels that are relatively cheap but difficult to manage because of their composition and propensity to cause fouling or slagging in the bioenergy plant.

6.4 Gasification

The gasification of biomass takes place in a restricted supply of air or oxygen at temperatures up to 1200–1300°C. The basic gasification process comprises three distinct stages:

- **devolatilisation**; methane and higher hydrocarbons are evolved as volatile gases from the biomass by the action of heat, to leave a reactive char
- **combustion**; the volatiles and some of the char are partially burnt in air or oxygen to generate heat and carbon dioxide
- **reduction**; the carbon dioxide absorbs heat and reacts with the remaining char to produce carbon monoxide fuel gas. Due to the presence of water vapour in the gasifier, hydrogen is produced as a secondary component of the fuel gas.

This fuel gas may then be burnt to generate heat; alternatively it may be processed and then used as fuel for gas-fired engines or gas turbines to drive generators (Figure 6-4).

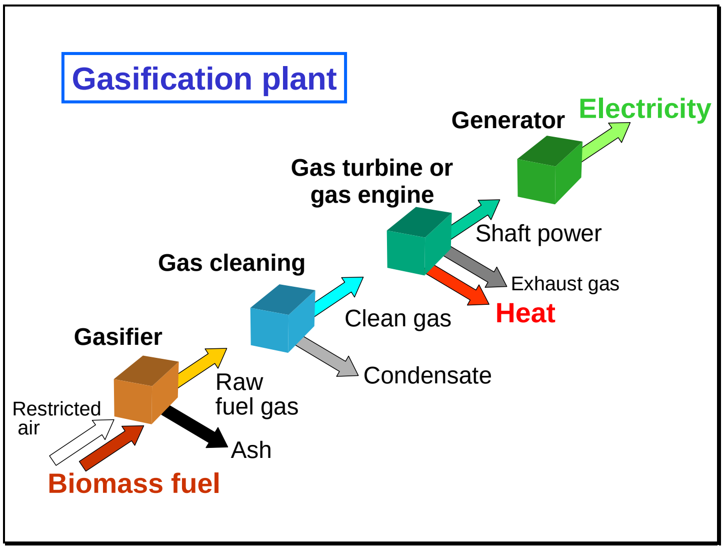


Figure 6-4: Gasification Plant

The variability of biomass fuels with respect to moisture content and particle size affects gas composition. Overall, the products are mostly gases of low to medium calorific values (4-6MJ/Nm^3). [This is the energy in an uncompressed or “normal” cubic metre of the gas.] There are also small amounts of unwanted by-products such as char particles, tars, oils and ash, which tend to be damaging to engines, turbines or fuel cells and which must therefore first be removed or processed into additional fuel gas. This can mean that gasifier operation is significantly more demanding than the operation of biomass combustion systems. Depending on the gasification system it can also mean that the biomass fuel must be of a consistent quality compared with combustion systems which are often more forgiving. Note that there are exceptions to this general rule.

The final fuel gas consists principally of carbon monoxide (CO), hydrogen (H_2) and methane (CH_4) with small amounts of higher hydrocarbons such as ethene (or ethylene, C_2H_4) and ethane (C_2H_6). When air is used to drive the gasification process, the combustible gases produced are diluted with carbon dioxide and nitrogen which have no energy value. For this reason the calorific value of the final fuel gas mixture is typically 4-6MJ/Nm3. This is only 10-14% of the calorific value of natural gas, for which commercial gas engines and gas turbines have been designed. The low calorific value makes the fuel gas less than ideal for these applications and it is also less suitable for transportation uses as higher storage costs are involved and vehicle range is restricted.

A large number of variables affect gasifier design, two important ones being the medium (air or oxygen) and the operating pressure.

a) Gasifiers which use air as the gasification medium (directly-heated gasifiers) use the exothermic reaction between oxygen in the air and the organic materials in the fuel to provide the heat necessary to devolatilise the biomass and convert it to residual carbon-rich chars. The heat to drive the process is generated within the gasifier.

   When pure oxygen is used as the medium instead of air, then, since no inert nitrogen is present, the calorific value of the gas is increased to 10-15MJ/Nm^3 which enables engines and turbines to be used to generate electricity with less modification. However, the cost of producing oxygen and the potential hazards associated with its use have generally made oxygen blown gasifiers unattractive, especially at smaller sizes. In addition biomass already contains an oxygen component which is not present in fossil fuels, so therefore it benefits less from oxygen addition.

   Indirectly-heated gasifiers accomplish heating of the biomass and its gasification through heat transfer from a hot solid through a heat transfer surface. Since air is not introduced into the gasifier, no nitrogen is present as a diluent and a gas of higher calorific value is produced.

b) A pressurised gasifier will produce gas at a pressure that is suitable for direct use in gas engine or gas turbine applications and provide the highest possible overall process efficiency. To take full advantage of operating at pressure however, a number of ancillary systems must be developed. Reliable, high pressure feed systems have not been commercially proven and hot gas clean-up systems are required (to remove from the gas stream any contaminants that would adversely affect turbine or engine operation). Alternatively, gasifiers can be operated at low pressure and the cleaned product gas can be compressed to the pressure required for use in a gas turbine. Pressurised gasifiers are smaller than atmospheric gasifiers for the same output, but they can also be more expensive to manufacture.

   For fuel to be provided to a pressurised gasifier, that fuel needs to be safely and efficiently brought from atmospheric pressure up to the operating pressure of the gasifier before it can be introduced to the vessel. The fuel feeding system of a pressurised gasifier is thus much more complicated as it involves pressure seals, and the fuel feed system would need purging with inert gas to prevent explosions. These factors increase both the capital and operating costs of such a system. Some research on small pressurised downdraft gasifiers has been undertaken in New Zealand (unpublished) but it does not currently appear to be a commercial proposition.

Cleaning the fuel gas produced can be difficult for all designs of gasifier, particularly at the small scale. If either the type of biomass fuel used, or the gasification process itself, leads to the production of dust or ash, it may well be possible to remove it with a hot gas cyclone. Before use in combustion engines or turbines however, the gas may also have to be cooled to intermediate or low temperatures due to temperature limitations of the fuel control systems of the engine or turbine. Reducing the gas temperature will increase the volumetric calorific value of the gas, and it will also increase the condensation of tars, making the gas even less suitable for practical use in engines and turbines. In these circumstances a gas cleaning system will be essential, possibly comprising cyclones, filters and wet scrubbers. Wet scrubbers are particularly effective as they capture tars, which are water soluble; inert dust being ash and mineral contaminants; and they also reduce the gas temperature in a single operation. However, this produces a contaminated liquid waste stream with potential toxic and carcinogenic properties. The need for treatment of such a waste stream can detract from the clean image of biomass fuels.

A number of gasification processes use high temperatures, which may be less suitable for fuels with low ash softening and melting temperatures (such as many annual crops and their residues). In such cases a gasification (or combustion) process may need to have suitable regard for water cooling internally and the possibility of vaporised salts carrying over into heat recovery equipment and causing slagging problems there.

6.4.1 Reactor design

A major variable for gasifier technology is the reactor design, and various types having been developed over many decades. Usually gasifiers are classified according to how fuel and air are fed into the gasification vessel.

*6.4.1.1 Fixed bed updraft gasifiers (Counter current moving bed - Figure 6-5*a*)*

Updraft (or counter-current flow) gasifiers have combustion air blown into the reaction chamber from below while the fuel is fed in from above. The great advantage of updraft gasifiers is their suitability for a large range of fuel moisture contents and particle sizes, and fuels with a low slag melting point such as straw. For heat applications up to 10MWth, updraft gasifiers are quite popular. Because the gas leaves the gasifier at relatively low temperatures, the thermal efficiency is high. This type of gasifier is not likely to be used for power generation applications due to the high tar production which would require extensive gas cleaning.

*6.4.1.2 Fixed bed downdraft gasifiers (Co-current moving bed- Figure 6-5*b*)*

Downdraft (or co-current flow) gasifiers have the fuel fed in from the top which then undergoes various gasification processes as it moves downwards under gravity. Air is injected either into the middle section of the gasifier or from the top and flows in the same direction as the fuel. In this design, downdraft gasifiers are not suitable for fuels with a low ash melting point, such as straw. They are popular for small scale power generation from biomass but in order to operate properly, fuel moisture content and particle size have to be within narrow limits. In the 1980s many gasifiers of this type were installed in developing countries where the problem of fully unattended operation was not an issue due to cheap and abundant labour. Up-scaling of this design of gasifier is difficult, and the maximum size is therefore probably limited to about 1MWe. Since the 1990s several projects have been executed in Europe to improve the downdraft gasifier design. The latest research trend is the development of small scale, fully automatic units fuelled by a single, well defined biomass fuel type in order to reduce problems due to size and moisture content variations.

*6.4.1.3 Fixed bed cross flow gasifiers (Cross current moving bed - Figure 6-5*c*)*

These are suitable for very small scale applications (smaller than or equal to 10kWe), and have been run on charcoal mainly in developing countries. Opportunities for up-scaling seem to be limited. However, in 1997 a project was commenced in Europe with the objective of developing a cross flow gasifier for co-generation applications in the 0.5MWe to 2.5MWe range. The gasifier operates at high temperatures (up to 1500°C) offering the possibility of thermal tar cracking to a level satisfactory for subsequent use of the fuel gas in an internal combustion gas engine without the need for extensive and costly gas cleaning.

*6.4.1.4 Fluidised bed gasifiers (Figure 6-5*d*)*

Fluidised bed technology for biomass gasification was implemented at a commercial scale in the 1980s. The major driving force that led to its development was the need for more efficient technologies at the larger scale for the utilisation of low-grade fuels such as biomass. Bubbling and circulating fluidised gasification reactors operate under much the same principles as comparable combustors.

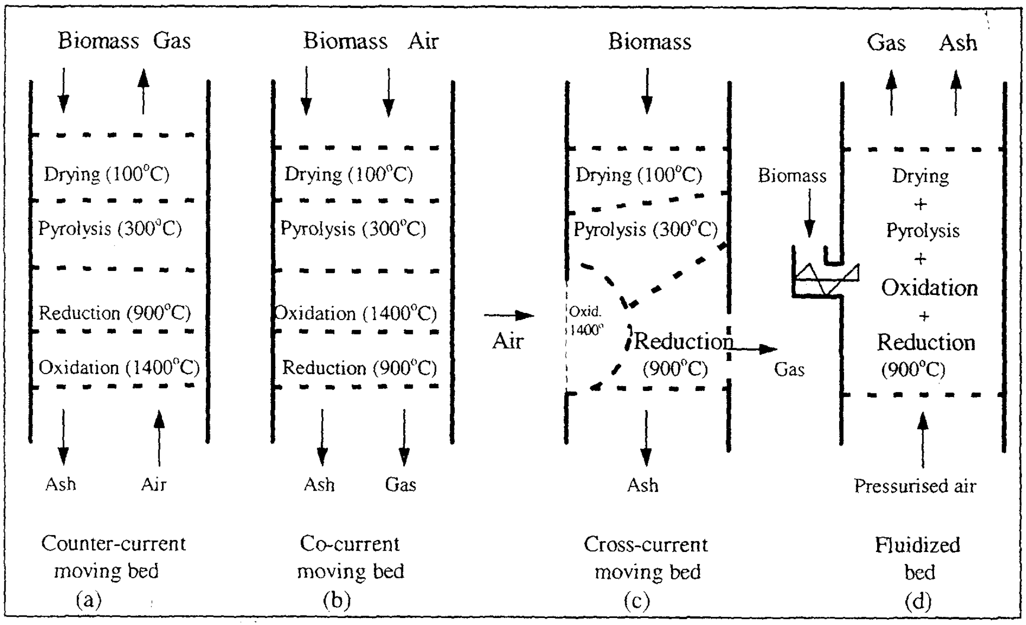


Figure 6-5: **Illustrative designs of gasification reactor designs showing areas of chemical activity and typical temperatures.**

6.5 Pyrolysis

During the pyrolysis process, biomass is heated either in the absence of air (i.e. indirectly), or by the partial combustion of some of the biomass in a restricted air or oxygen supply. This results in the thermal decomposition of the biomass to form a combination of a solid char, gas, and liquid bio-oil, which can be used as a liquid fuel or upgraded and further processed to value-added products.

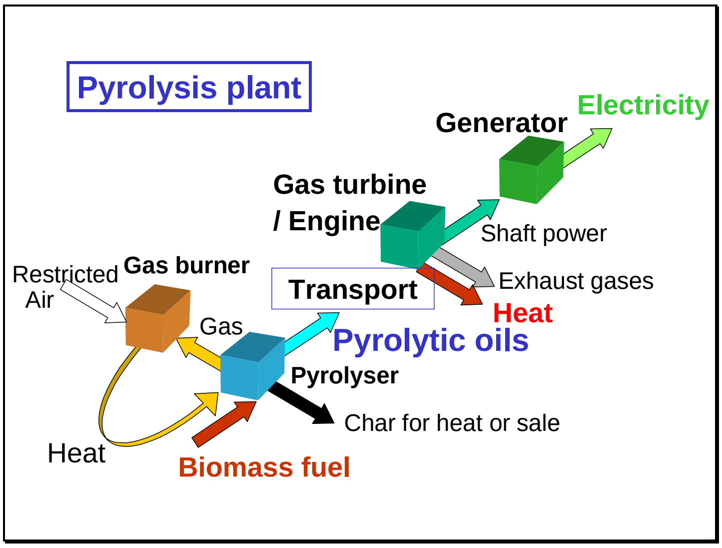


Figure 6-6: **Pyrolysis Plant**

A key focus and rationale for development of pyrolysis is the optimisation of the production of pyrolytic bio-oils which can be used as a chemical feedstock or as substitute for diesel fuel for stationary power generation. Bio-oil can theoretically be produced at one location and transported to a power plant at another location, as shown in Figure 6-6. As pyrolysis bio-oil has a higher energy density than solid biomass fuels such as wood chips, this offsets one of the inherent disadvantages of solid fuels; their low volumetric energy densities. The higher energy density of bio-oil (16-19 MJ/kg with a mass of 1,200 – 1,300 kg per cubic metre versus approximately 220 kg per cubic metre for wood chips) potentially allows a large reduction in the costs associated with the transportation and storage of this biomass derived fuel. An implication of remote fuel production is expansion of the region for economic supply of the bio-fuel, allowing greater flexibility in the location of bioenergy plants and lower costs. Storage of bio-oil requires special consideration, as bio-oil can be, subject to degradation as a fuel, and is highly acidic.

Figure 6-7 illustrates the range of biomass pyrolysis products and their general uses in addition to heat and power [1].

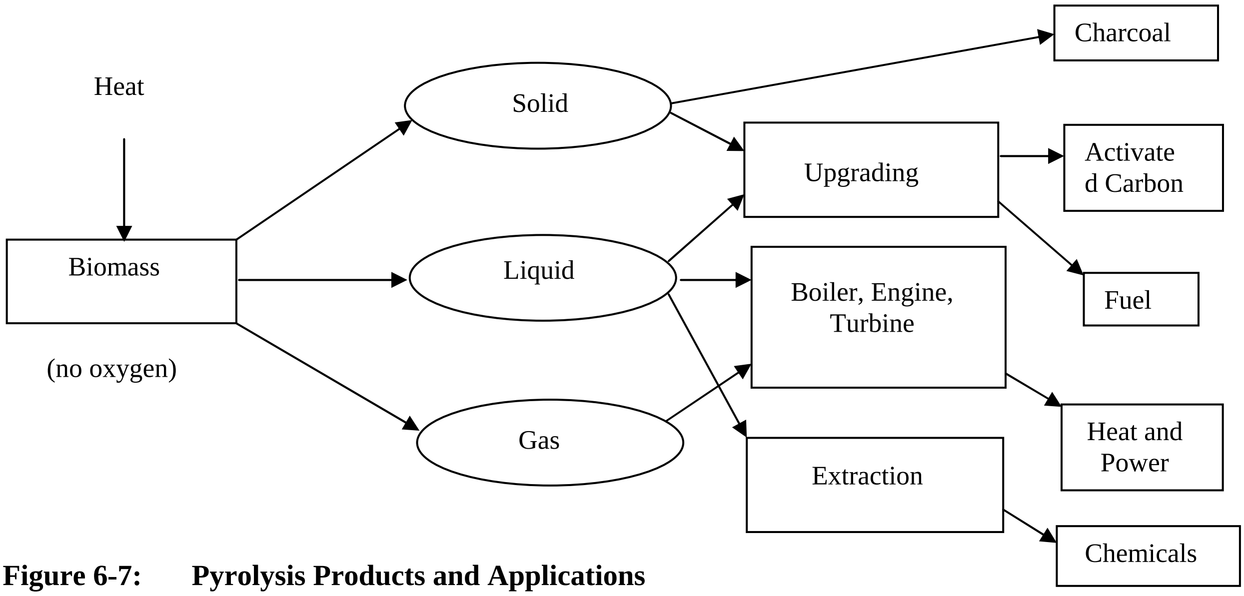


Figure 6-7: Pyrolysis Products and Applications

Control of the pyrolysis reaction parameters, such as temperature, heating rate and residence time allow control over the products of pyrolysis (solid, liquid or gas) to be achieved:

- **Conventional slow pyrolysis-** carbonisation at temperatures around 450°C with low heating rates and long vapour retention times gives approximately equal proportions of char, liquid and gas. This is well known and has been used for charcoal manufacture through the ages.
- **Fast (or flash) pyrolysis** – high liquid yields, typically 60-80% on a dry basis of the biomass. High heating rates, temperature approximately 500°C and short vapour residence time (<1 second).

This is summarised below in
Figure 6-8 :

Products	Slow Pyrolysis	Fast Pyrolysis
Liquid	30-35 %	60-80 %
Gas	25-30 %	12-20 %
Solid	20-35 %	5-15 %

Figure 6-8: Products of Slow and Fast Pyrolysis

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[1] *Biomass Conversion Technologies, Achievements and Prospects for Heat and Power Generation*, European Commission document EUR 18029 EN, November 1998.

Considerable research and development has been focused since the 1980's on fast pyrolysis to increase yields of organic liquid products. This is now leading to the emergence of new processes for the production and use of pyrolysis oils for renewable electricity and other value-added products. The remainder of this section focuses on fast pyrolysis of biomass.

Note that while pyrolysis appears to offer a number of advantages over combustion and gasification, these advantages have yet to be proven at a commercial scale. Attractive results from studies and laboratory scale equipment mean that there is now considerable R&D work underway around the world to better understand pyrolysis. But at present there are only a few pyrolysis plants operating at a large scale including:

- several plants in North America, designed by Ensyn of Canada and making food flavorings
- large scale pilot plant by Dynamotive, also of Canada

Fast Pyrolysis

Fast pyrolysis is a high temperature process that converts biomass into a liquid bio-oil which has a very similar chemical elemental composition to the original biomass. This bio-oil can theoretically be used as a fuel in a diesel engine, a gas turbine, or in a furnace, or it can be used as a renewable chemical feedstock. Bio-oil typically has a heating value, on a mass basis of about forty percent that of conventional fuel oil. Bio-oil has a specific gravity of 1.2 (compared to liquid petroleum fuels of approximately 0.85), resulting in the volumetric energy density of pyrolysis bio-oil being about 60 percent that of fuel oil.

Bio-oil can be pumped and poured at normal ambient temperatures, and its fluid nature allows it to be handled via pipes and pumps.

Other inherent advantages favouring the bio-oil route are:

- In general, liquid fuel combustion is much more efficient, controllable and cleaner than the combustion of solid fuels
- The costs to retrofit an existing gas- or oil-fired combustion system are much lower than replacement with a solid fuel combustor
- The production of liquid bio-oil can assist in the removal of ash from the biomass prior to combustion or other end-use applications. (Alkali metals in some biomass feedstocks such as agricultural straw are primary causes of slagging and fouling of combustion and heat transfer surfaces in biomass boilers). This potentially allows feedstocks that are contaminated with dirt and sand to be handled without problems.
- Can be used as a renewable replacement fuel for diesel engines and gas turbines.
- Some Northern hemisphere studies have suggested that bio-oil production plants can be cost-effective at as low as 100 tonnes per day feedstock capacity. This cost-effectiveness, combined with ease of transport, can make it more feasible to locate the processing plant close to the biomass raw materials and transport the bio-oil to one or more destinations rather than transport the raw materials over longer distances.
- The bio-oil can be fractionated into a number of higher value products. If suitable markets exist for these products the project economics will be improved.
- The fast pyrolysis technology is projected to have relatively low investment costs and high energy efficiencies compared to other processes, especially at a small scale. Bridgwater, as reported in Brem[1] indicates that fast pyrolysis bio-oil in combination with an engine, provides the highest energy conversion efficiency and the lowest capital and electricity costs for power plants up to 15 MW_e.

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[1] *Gasification, pyrolysis and liquefaction of biomass at TNO*, Gerrit Brem, Proceedings of the International conference on Efficiency, Cost, Optimisation, Simulation and Environmental Aspects of Energy and Process Systems, University of Twente, Enschede, The Netherland, 5-7 July 2000

6.5.1 Production Processes

The essential features of a fast pyrolysis process are[1]:

- Very high heating and heat transfer rates, which usually requires a finely ground biomass feed. Finely ground biomass feed has added cost implications.
- Carefully controlled pyrolysis reaction temperature of around 500 °C in the vapour phase, with short vapour residence times of typically less than two seconds.
- Rapid cooling of the pyrolysis vapours to give the bio-oil product.

The main product, bio-oil is obtained in yields up to 80 % (by weight on dry feed), together with by-products of char and gas (see Figure 6-8) which may be used within the process so there are no waste streams.

Fluid Bed Reactors

Fluid bed reactors are the most popular configuration due to their ease of operation and ready scale-up. A typical bubbling fluid bed configuration is presented in Figure 6-9. This illustrates the use of the byproduct gas and solid char to provide process heat, the drying of the incoming biomass feedstock to less than 10% moisture content to minimise the water content in the bio-oil, and the grinding of the feedstock to around 2 mm particle size to give sufficiently small particles to ensure rapid chemical reaction.

In fluid bed reactors approximately 90% of the heat is transferred by conduction and 10% by convection. The largest existing plants are based on this reactor design. The main advantages are limited char abrasion, high heat transfer rates, and a simple reactor configuration. Major disadvantages are related to economics, as these reactors require a small biomass particle size.

Bubbling fluid beds have been selected by several companies for further development, due to their ease and reliability of operation, and ease of scaling to commercial plant sizes. These include pilot scale plants by Union Fenosa who are reported to have a 200 kg/h pilot plant in Spain, DynaMotive who have been operating a 80 kg/h pilot plant in Canada based on a RTI design, and Wellman who have commissioned a 250 kg/h unit in the UK.[2]

Circulating fluid beds and transported bed reactors for fast pyrolysis of wood have been developed to commercial status. Several are used in the USA for manufacture of food flavourings and related products in plants with feed rates of 1 to 2 tonnes/h. Canadian company, Ensyn (www.ensyn.com) has developed transported bed reactor technology and has supplied a 650 kg/h unit to ENEL in Italy for fuel production and a 20 kg/h plant to VTT in Finland [3]. Liquid yields and quality of bio-oil are reportedly comparable to bubbling fluid beds. Circulating and transported beds are generally preferred for the largest systems in the process industries. However, their design increases the complexity of the technology as it necessitates solid material recirculation and solid/solid separation in the process.

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[1] *Fast Pyrolysis of Biomass: A Handbook*, IEA Bioenergy, CPL Press 1999, ISBN 1 872691 07 2

2 *Fast Pyrolysis of Biomass: A Handbook*, IEA Bioenergy, CPL Press 1999, ISBN 1 872691 07 2

3 The Contribution of Fast Pyrolysis to Bio-Energy, A.V. Bridgwater, p 45-48 *Proc. 1st World Conference on Biomass for Energy and Industry*, Seville, Spain, 5-9 June 2000

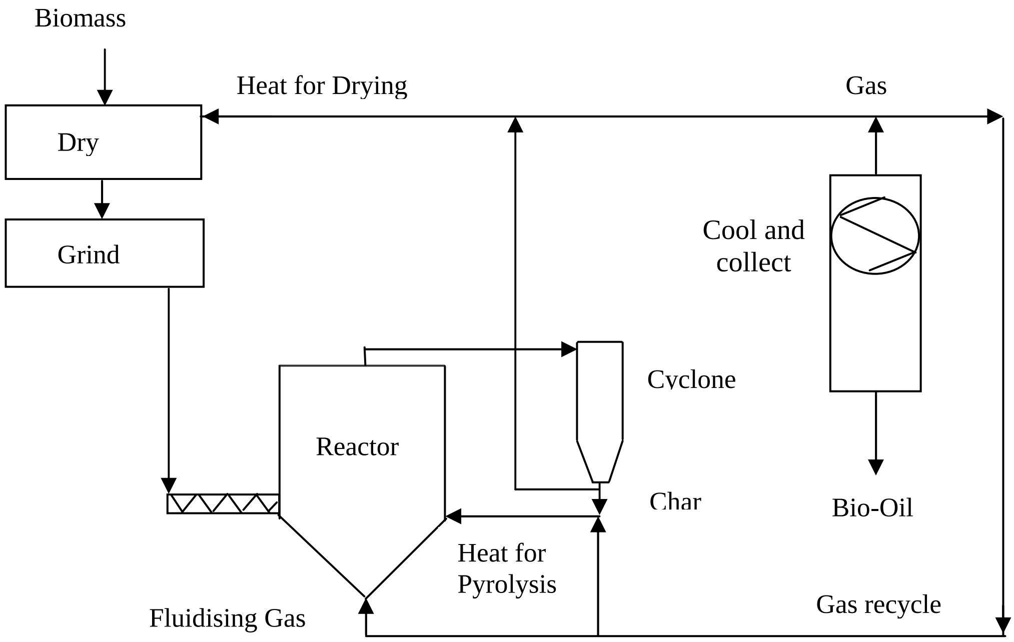

Figure 6-9: Conceptual Fluidised Bed Pyrolysis Process

Ablative Pyrolysis

This technology allows much larger biomass particle sizes to be employed than in other systems and the process is limited by the rate of heat supply to the reactor, rather than the rate of heat absorption by the pyrolysing biomass. Much of the pioneering work on ablative pyrolysis reactors has been carried out at the National Renewable Energy Laboratory (NREL) in the USA in their vortex reactor and more recently at Aston University in the UK.

The liquid yields are comparable to other fast pyrolysis processes at about 75% by mass on dry feed but the bio-oil has a lower viscosity and appearance of a more ‘cracked’ product. The key advantages of ablative pyrolysis are the ability to process much larger particles as the mechanism of heat transfer is different (it is akin to pressing down on melting butter in a frying pan with a spatula), and there is no requirement for a fluidising or transport gas. Both these factors contribute to a more compact and intensive reaction system. A disadvantage is that scaling-up to a commercial plant would be related to area of the pyrolysing reactor surface area, rather than volume as is usual in chemical reactors. Accordingly, the economy of scale opportunities for this technology are more limited.

Entrained Flow

In entrained flow reactors 95% of the heat transfer is performed by convection. This inhibits good heat transfer from the gaseous heat carrier to the solid biomass. ENGEMIN investigated this process with mixed results reported. They have ceased developing this technology.

Liquid bio-oil yields are reported as being lower than other fast pyrolysis processes, with a maximum of around 60% by mass on dry feed. There are significant design constraints as heat transfer is completely reliant on gas to solid limitations, which is unique to this particular configuration. Very small particles are therefore necessary to achieve the required heat transfer rates.

Rotating Cone Reactor
The rotating cone reactor is a recent development, invented at the University of Twente, and being developed by BTG in the Netherlands. This technology operates effectively as a transported bed reactor, but with the transport effected by centrifugal forces rather than by gas. A 200 kg/h unit is now operational which includes integrated heat recovery with a secondary char combustor.

Liquid yields are a little lower than other processes at typically 65% by mass, but the product quality is comparable to other fluid bed systems. An advantage is the minimal requirements for gas transport which leads to a more compact and more intensive reactor system as for ablative pyrolysis.

Vacuum Pyrolysis
In vacuum pyrolysis the rate of heating is very low compared to other systems described above. The merit of this technology is that condensable vapours are removed as soon as they form by operating under a vacuum. Pyrovac has operated a 3.5 t/h unit in Canada.

6.5.2 Properties of Bio-Oil

In theory, bio-oil can be substituted for conventional fuels in engines, turbines and boilers. However, the properties of bio-oil are very different to hydocarbon fuels and these two types of fuels do not readily mix. Bio-oil is acidic and corrosive, and is not as stable as fossil fuels. Exposure to air causes bio-oil degradation, requiring minimum exposure to oxygen to avoid polymerisation. However, bio-oil cannot be kept in a sealed vessel due to gas formation and the risk of pressure increase. There is also a tendency for the heaviest part of the bio-oil compounds to settle at the bottom of storage vessel, to form a sludge.

Typical properties and characteristics of wood derived pyrolysis bio-oils are summarised in Figure 6-10.

Physical Properties	**Typical Range**
Moisture	15 to 30 %
PH	2.5
Specific Gravity	1.2 to 1.3
Ultimate analysis (moisture free)	
C	56 %
H	6 %
N	0.1 to 0.3 %
O	37 %
S	-
Ash	0.1 %
HHV on dry basis (depends on moisture)	16 – 19 MJ/kg
Solid content	0.1 – 1 %
Viscosity (40°C)	40 – 100 cS
Viscosity (80°C)	3 – 24 cS
Pour Point	-12 to 33°C
Flash Point	50 to 70°C

Figure 6-10: Typical properties and characteristics of wood derived bio-oils

Figure 6-11 below compares bio-oil with diesel fuel, for which it is being developed as a substitute. [1]

Parameter	Bio-oil	Diesel
Heating Value MJ/kg	16 - 19	42
Kinematic Viscosity cS	3 – 24 @ 80°C	2 – 4 @ 20°C
Acidity pH	2.3 – 3.3	5
Water wt%	15 – 30	0.05 v%
Solids wt%	0.1 - 1	-
Ash wt%	0.1	0.01
Alkali (Na + K) ppm	5 – 100	<1

Figure 6-11: Typical Properties of Bio-oil Compared to Diesel Fuel

Combustion Properties of Bio-oil

Extensive tests have been carried out on bio-oil as a boiler liquid fuel. These tests show that combustion of bio-oil is feasible, notwithstanding:

- The high water content makes bio-oil difficult to ignite. The combination of high temperature required for ignition and the thermal degradation of the oil requires precise ignition chamber temperature control.
- The high water content of bio-oil results in higher water vapour content in the exhaust gases. The resulting higher dew point may limit the potential for energy recovery from exhaust gases in large boilers.
- Problems have been encountered with storage, pumping and keeping nozzles clean after plant shut down due to the bio-oil being very acidic, and containing suspended solid matter.

Appearance

Bio-oil is a generally a dark brown free flowing liquid. Colour varies depending on initial feedstock, mode of pyrolysis, and chemical composition. Hot vapour filtration of bio-oil gives bio-oil a more translucent red-brown appearance due to the removal of solid char.

Odour

Bio-oil has a distinctive acrid, smoky smell and can irritate the eyes after a prolonged exposure. The liquid contains several hundred different chemicals in widely varying proportions, ranging from low molecular weight and volatile formaldehyde and acetic acid to complex high molecular weight phenols and anhydrosugars.

Miscibility

Bio-oil contains varying quantities of water which forms a stable single phase mixture, ranging from about 15 % to an upper limit of about 40 % by weight water, depending on how it was produced and subsequently collected. The bio-oil is immiscible with petroleum derived fuels.

Density

The density of bio-oil is very high at around 1.2 kg/litre compared to fuel oil of around 0.85 kg/litre. This means that the liquid has about 42% the energy content of fuel oil on a mass basis, but 61% on a volumetric basis. This has implications on the design and specification of equipment such as pumps.

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[1] Adapted from Fast Pyrolysis of Biomass for Green Power Generation, K.W. Morris, W.L. Johson, R. Thamburaj, p1519-1524, *Proc 1st World Conference on Biomass for Energy and Industry*, Seville, Spain, 5-9 June, 2000.

Viscosity
The viscosity (ability to flow) of the bio-oil as produced can vary from as low as 25 cS to as high as 1000 cS or more depending on the water content, the amount of light fraction molecules and the extent to which the oil has aged. By contrast diesel is much less viscous at 2-4 cS (see Figure 6-11). Viscosity is important in many fuel applications.

Distillation
Bio-oil is inherently chemically unstable and cannot be completely vapourised once recovered from the vapour phase. If heated above 100°C to try to remove water or to distil off lighter fractions of molecules, it rapidly reacts and produces a char residue. The bio-oil can be stored at room temperature, where this degradation may be accommodated in a commercial application.

6.5.3 Upgrading of Bio-oil

The value of bio-oil as a fuel can be enhanced by further processing to improve its physical and chemical properties, depending on its intended application. This may take the form of physical processing to reduce the high percentage of water, solid, ash or alkali fraction in the bio-oil, or chemical/catalytic upgrading to address bio-oil's inherent high oxygen content of around 45% by weight, and low ratio of hydrogen to carbon, to improve its heating value.

Physical Upgrading
The most effective means of controlling the moisture content of bio-oil is by drying the incoming wood feedstock before pyrolysis. Water separation from bio-oil is to be avoided if possible, as the wastewater would be heavily contaminated with dissolved organics and would require potentially expensive treatment before disposal. Water evaporation or distillation is also difficult, as at elevated temperatures significant changes and losses occur in the bio-oil liquid.

The use of additives such as ethanol can lower bio-oil's viscosity. Bio-oil diluted with ethanol has been used with success in trials with diesel engines. Bio-oil and diesel are not miscible, and diesel cannot be used to improve the quality of the bio-crude as the emulsions are not stable and are costly to produce.

Hot gas filtration may remove fines and alkali metals in the bio-oil in a very effective way. Hot-gas filtration can reduce the ash content of the oil to less than 0.01% and the alkali content to less than 10 ppm. These systems are still experimental and no long-term test runs have been carried out.

Catalytic/Chemical Upgrading
Chemical/catalytic upgrading processes aim to reduce the oxygen content of the bio-oil, as this is the main cause of instability and unwanted characteristics of bio-oils. Catalytic upgrading is still at the experimental stage[1]. Two methods are being proposed; hydrotreatment using high pressure hydrogen and cobalt and nickel based catalysts, and catalytic cracking at atmospheric pressure where hydrogen is not required. These methods are not yet technically proven.

6.5.4 Environmental and Health Aspects

Fast pyrolysis is still an emerging technology, with very few commercial reactors, operating to date. As such the environmental aspects of fast pyrolysis oil production and utilisation have not been exhaustively investigated to date. During bio-oil production, gaseous, tar, ash, and soot particle pollutants are produced. Most often the bio-oil reactors are designed to recirculate gases and char to supply heat to the process. Gas emissions mainly consist of carbon monoxide, carbon dioxide, oxides of nitrogen, aerosols of organic compounds and water vapour.

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[1] IEA task 32 draft combustion handbook

Handling, storage and transportation of bio-oil is an important environmental consideration. Bio-oils contain numerous chemicals which, if in sufficient quantities, may be hazardous for both the environment and to human health.

It should be noted that health and safety issues are a major consideration in almost all chemical industries, and the issues raised above are not unique to pyrolysis bio-oil. Precautions such as using protective clothing, goggles, and safe operating procedures should enable the safe handling and use of bio-oils on a routine basis.

6.5.5 Bio-Oil Economics

Various studies of pyrolysis bio-oil energy plants have been conducted to gauge the likely costs and future prospects. A fully integrated bioenergy facility would incorporate biomass receival, storage and handling, biomass drying and grinding, product collection, storage and, when relevant, upgrading. The fast pyrolysis reactor would at most only represent about 10-15 percent of the total capital cost of an integrated system [1].

Bridgwater provides a formula for the projected cost of pyrolysis bio-oil as a function of feedstock cost and size of unit, based on detailed and comprehensive cost analysis studies as follows:

$$\text{Bio-oil cost, ECU/GJ (LHV)} = 9.31*(\text{wood capacity, dry t/h})^{-0.3407} + \frac{\text{Feed cost ECU/dry tonne}}{0.625*\text{wood LHV GJ/t}}$$

The bio-oil cost is expressed in LHV (lower heating value), with the bio-oil energy yield assumed to be 62.5% and the wood higher heating value taken as 19 GJ/tonne.

Diebold and Bridgwater[2]conducted a review of four independent studies on the economics of bio-oil, each with different assumptions yet similar conclusions. These studies all indicate that bio-oil can be produced for between US $0.13 and $0.16 per litre of wet oil (US$6.50-$7.00 /GJ- LHV), with feedstock costing between US$44 and US$60 per dry tonne. With co-generation, the cost drops to US$0.11 per litre (US$6.00/GJ) with a feedstock cost of US$44 per dry tonne. Assigning a zero cost for feedstock, as would be the case for waste biomass, the predicted cost drops to between $2.00 and $3.00/GJ.

Yet another report [3] claims that a complete 6.5 MWe Wartsila power plant would have a capital cost of US $7.8 million and could produce electricity for about US $0.072/kWh at zero feedstock cost and with no co-products from oil production. For every US$10 per bone dry ton price increase resulted in a electricity price increase of US $0.007/kWh. The co-production of products would significantly improve the economics of the integrated plant.

Brem illustrates that fast pyrolysis technology in combination with engines, for sizes up to 15 MW_e, results in the highest efficiency and lowest capital and electricity costs for all prospective forms of thermal bioenergy conversion.

Morris, Johnson and Thamburaj present the projected cost of electricity for various plant configurations based on the Orenda 2.5 MW_e gas turbine. Without assuming income from any charcoal or chemical products, and for a zero cost feedstock, the cost of electricity for a simple cycle gas turbine of 27% efficiency is approx. US$0.057/kWh, and for a 58% overall efficiency co-generation unit approx. US $0.041 c/kWh. For a feedstock cost of US $20 per tonne these costs are

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[1] Renewable Energy World, January-February 2001, *Towards the 'bio-refinery' – Fast Pyrolysis of Biomass*.

[2] Overview of Fast Pyrolysis of Biomass for the Production of Liquid Fuels, J.P. Diebold and A.V. Bridgwater, page 26 in 'Fast Pyrolysis of Biomass: a Handbook' cpl press

[3] Southeastern Regional Biomass Energy Program *Update* September/October 1998, page 3, 'Ensyn Bio-oil from Biomass'

indicated to be approx. US$0.088 and $0.072/kWh respectively. The authors conclude that with sale of co-products and carbon credits, such a plant would be more competitive than other bioenergy plants, and would be economically viable.

6.5.6 Development Activities

A number of research institutes and companies world-wide have been engaged in the development of fast pyrolysis as a source of renewable products and energy. Prime examples are:

BTG (Biomass Technology Group B.V.)
BTG of the Netherlands have developed the rotating cone technology described above and have demonstrated the technology on a 1 MW_{th} scale. Feedstocks tested have been wood waste, rice husks, straw, and other organic waste materials. Their existing reactor capacity is 260 kg/h bio-oil, with a 10 MW_{th} installation under construction.

Ensyn
The Ensyn group, headquartered in Massachusetts, USA and with design, engineering and R&D based in Canada, developed the first successful commercial fast pyrolysis plant in 1989[1]. Their core technology is the Rapid Thermal Processing or RTP™ process, a transported bed fluid reactor. Reference [2] provides a good overview of Ensyn's activities. Ensyn's business model in biomass activities is based on the ownership and operation of production facilities in which value is maximised by optimising multiple product streams from the pyrolysis of biomass feedstocks. This model is based on the extraction of higher value natural chemical products from RTP™ bio-oil, and the use of the remnant bio-oil for lower value energy purposes. Ensyn has four commercial RTP™ facilities currently in operation, three in Wisconsin, USA and one in Ottawa, Canada. The largest of these plants processes 75 green tons per day of hardwood wastes and has operated with a commercial availability of over 94%. Ensyn is reported to produce more than 800 tons of bio-oil per month in Wisconsin. Bio-oil from a RTP™ reactor has been co-fired commercially with coal at the 10% level in a one-month trial at the Manitowoc Generating Station (see above). Ensyn has also been working with Wartsila Diesel Oy of Finland to develop diesel engines fueled on bio-oil.

Ensyn has developed several commercial natural resin products from bio-oil that replace petroleum based chemicals in resin and polymer products. One of their products, *NR* is used in the manufacture of wood products, including orientated strand board and plywood. Ensyn bio-oil has also been used to produce a variety of natural chemicals, food flavourings and ingredients since 1990.

DynaMotive
Dynamotive, a Canadian headquartered company, with European business interests has been developing their BioTherm™ fast pyrolysis, bubbling bed fluid bed reactor technology for energy applications. They have teamed up with Orenda Aerospace to develop a 2.5 MW industrial gas turbine for electricity generation (see Section 7). Dynamotive is currently focusing on its first commercial scale plant, to be built in Ontario, Canada.

Pyrovac
Canadian company Pyrovac has operated a 3.5 tonne/hour industrial scale Pyrocycling™ plant in Quebec, Canada. This technology uses vacuum pyrolysis which is relatively complicated mechanically. This plant has been built to demonstrate the technology and to produce sizeable amounts of bio-oil and charcoal from various biomass sources.

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[1] Klass *Biomass for Renewable Energy, Fuels and Chemicals, Academic Press, 1998*

[2] *Commercial Bio-Oil Production via Rapid Thermal Processing*, by B Freel, and R Graham, in Proc. 1st World Conference on Biomass for energy and Industry, Seville, Spain, 5-9 June 2000, page 889-990

University of Melbourne School of Forestry

Dr Branko Hermescec of Melbourne University’s School of Forestry at Creswick, near Ballarat, Victoria has been developing fast pyrolysis technology which targets the production of furfural alcohol, furfural, alpha cellulose and a number of phenols. A key aspect has been treating radiata pine with furfural alcohol to produce ‘artificial ebony’. An innovative aspect of the technology is that it operates at a much lower temperature than conventional pyrolysis, and in fact uses ten times more oxygen than normally needed for combustion[1]. The process ‘unstacks’ wood into components of lignin, hemi-cellulose, and alpha-cellulose from which products of adhesives, plastics, medicines, food additives, heat resistant plastics, have been identified. It is reported that the research is being supported by a European company which is providing funding of $600,000 over two years to fund a production development unit and other support. Energy generation from the pyrolysis bio-oil has not been a feature of this research. It is believed the university has a commercial relationship with Carter Holt Harvey in the development of this technology.

PyNe

PyNe, the Biomass Pyrolysis Network (www.pyne.co.uk) is a global network of researchers and developers of fast pyrolysis of biomass. It has been established to discuss and exchange information on scientific and technological developments on biomass pyrolysis and related technologies for the production of liquid fuels, electricity and chemicals. PyNe is co-ordinated by Aston University in the UK with Professor Tony Bridgwater being the co-ordinator. Eighteen countries are represented on PyNe, which has been sponsored by the European Commission’s FAIR Programme in DGXII (Directorate General 12) and IEA Bioenergy. Scientific subject groups of PyNe are: Environment, Health and Safety; Implementation; Stabilisation and Upgrading; Analysis, Characterisation & Test Methods; and Science and Fundamentals.

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[1] Ascent Technology Magazine, Issue No. 37, June-August 2000, page 21-22, on the Web at http://www.isr.gov.au/pubs/mags/ascent/ascent37.pdf.

7. Secondary Energy Conversion Technologies

7.1 Summary

Secondary energy conversion of biomass fuels (solid, gas or liquid form) to electricity can be achieved using well established technologies. These include internal combustion engines, steam turbines, steam engines and co-firing with fossil fuels in existing fossil fuel based power plants. Simultaneously, many modular and advanced secondary energy conversion technologies are under development to improve energy conversion efficiencies and to provide more flexible energy supply options.

Steam turbines coupled to electrical alternators convert steam energy from biomass boilers to electricity. This is a mature technology, similar to that used in coal fired power stations world-wide. Overall energy conversion efficiencies are in the range 15-30 percent, depending on scale and engineering complexity. At small scale, steam turbines tend to be less efficient. Overall steam cycle efficiency is a function of steam temperatures and pressures. Operating efficiency is a trade off, with plant capital cost increasing to achieve more efficient design.

Steam engines are proven, robust technology and are mainly suited to constant speed operation in industrial environments. Steam engines are only produced in small sizes and are therefore relatively expensive.

Gasified biomass, composed mainly of carbon monoxide and hydrogen gases, can provide the fuel for internal combustion engines. Overall conversion of biomass energy to electricity is typically in the range 25-30%, with the higher value for larger units. A key issue is removing tar and particulate matter from the gas to allow trouble free engine operation. Several commercial small scale biomass gasification-engine projects have been built, with equipment available from companies in Europe, the USA and India.

Biomass co-firing with fossil fuels is also well established and allows biomass to be converted to electricity at low cost, and at high overall energy conversion efficiency. It utilises existing infrastructure and saves the need for dedicated components such as turbines and generators for bioenergy production. Co-firing may take several forms. In *direct co-firing,* biomass and fossil fuels are co-mingled and enter the boiler together. Occasionally a dedicated biomass burner is provided. The advantage of direct co-firing is simplicity and low investment cost, as low as an eighth that of a dedicated bioenergy plant of the same capacity. A disadvantage is mixing of biomass and coal ash, which complicates its subsequent sale and use. *Indirect co-firing* uses separate thermal energy conversion plants to keep the ash separate. *Parallel co-firing* uses totally separate combustion plants and boilers, with the steam from the biomass boiler then being fed into the main power plant. This helps to manage corrosion and fouling problems that may exist with biomass fuels such as agricultural straw.

There are many energy conversion technologies that are not yet commercial but are being investigated by research groups world-wide. These emerging technologies include Stirling engines, indirectly fired gas turbines, directly fired pressurised gas turbines, micro-turbines, advanced combined cycle gasification technologies, pyrolysis bio-oil fuelled plants, and fuel cells.

Stirling engines are ‘external combustion’ engines which operate through the expansion of a gas. There is no contact between the biomass generated heat and the moving parts of the Stirling engine. Stirling engines are available in small sizes up to 150 kW_e, making them suitable for distributed generation. World-wide a number of Stirling engines have been developed, although they are yet to be commercially proven.

Indirectly fired gas turbines use a heat exchanger to reduce the requirement for cleaning gasified biomass. Several large scale developments with indirectly fired gas turbines have occurred in recent times, mainly in Europe. Directly fired pressurised gas turbines in the range 5-20 MW_e are under development. In this system hot combustion gas from a pressurised gasifier is fed into a standard gas turbine. An example of this technology is the 6.2 MW Bioten project in the USA, which was recently put up for sale.

Micro-turbines are a variant on conventional gas turbines, except most designs incorporate a recuperator to recover exhaust energy to attain an improved efficiency of around 20-30 percent. Sizes are in the 25-250 kW_e range. They operate at high speeds and use sophisticated electronics to generate standard alternating current electricity. Currently there are no commercially operating gasifier/micro-turbine systems. The CSIRO is working on the development of such a system with AGO support. This “green gasifier generator” will use a gasifier designed by CSIRO and coupled to a Capstone micro turbine.

Biomass Integrated Gasification Combined Cycle (BIGCC) systems achieve increased overall thermal efficiencies by simultaneously using a gas turbine and a steam turbine. Gas cooling and recovered exhaust heat from the gas turbine are used to raise steam for the steam turbine. A number of BIGCC projects have been commissioned to prove this concept in anticipation of commercial deployment. These include the ARBRE project in York, UK and the Bioflow project in Varnamo in Sweden.

This section also covers the use of pyrolysis bio-oil in engines and gas turbines. Wartsila of Finland has conducted trials with a 1.5 MW_e engine with 95 percent bio-oil, and Orenda Aerospace of Canada has conducted trials with a 2.5 MW_e industrial gas turbine fueled by bio-oil.

Fuel cells are electrochemical devices in which hydrogen-rich fuel produces heat and power. They can operate at high overall energy conversion efficiencies and are now entering the market in selected applications for stationary power. They can also be used in for distributed heat and power production. It is anticipated that fuel cells could operate using fuels derived from biomass.

7.2 Introduction

Other than the direct use of heat produced during the primary biomass conversion stage, energy carriers produced (air, gas, solid or liquid) have to be converted into a useful form of energy (space heating, hot water, electricity or process steam) in the secondary conversion stage. There are several secondary energy conversion technologies for generating electricity at a range of scales, and in some cases they are also used in co-generation heat systems. They include:

- internal combustion engines
- steam turbines
- steam engines
- co-firing with fossil fuel
- Stirling engines
- indirectly fired gas turbines
- directly fired pressurised gas turbines
- micro-turbines
- fuel cells
- advanced power cycle technologies.

The first four items in the list above are mature, commercially available technologies, while other items in the list are at various stages of demonstration or development. The state of technology development with respect to commercialisation is discussed here, and for each technology some project examples are provided.

7.3 Internal Combustion Engines

Reciprocating or internal combustion engines (ICEs) are among the most widely used prime movers to power small electricity generators. Advantages include large variations in the size range available, fast start-up, good efficiencies under partial load efficiency, reliability, and long life. Typical electricity conversion efficiencies (fuel energy to electricity) of 25-30% help to make ICEs an economic option in many generation applications. Several types are commercially available but those of most significance to stationary power applications are four-cycle spark-ignition (Otto cycle) and compression-ignition (Diesel cycle) engines. The primary difference between Otto and Diesel cycles is the method of fuel combustion. The Otto cycle uses a timed spark to ignite a pre-mixed fuel-air mixture whereas the Diesel engine compresses the air introduced into the cylinder, thereby raising its temperature to the ignition temperature of the fuel which is then injected at high pressure.

The essential mechanical parts of both engine designs are similar in that they use cylindrical combustion chambers, close fitting pistons and a crankshaft to transform linear motion into rotary motion to drive the generator. Large, modern, compression ignition engine generating sets can attain electrical efficiencies up to 30% and operate on a variety of fuels. They can provide higher partial load efficiencies than spark-ignition engines because of their leaner fuel-air ratios at reduced loads.

Gas cleaning for tar and particle removal is the key issue for successful application of wood gas from fixed bed biomass gasifiers using ICEs. Few of the current gas cleaning systems have demonstrated long term compliance with the gas quality requirements for satisfactory ICE application and few engine manufacturers are prepared to maintain their warranties for limited applications using biomass gasifiers. Commercial gasifier suppliers such as Martezo and B9 tend to recommend engines from manufacturers with which they have built up experience.

Several small scale biomass projects have been evaluated linking gasifiers with ICEs. In the UK for example a Fluidyne 60kWth downdraft gasifier (Figure 7-1) was connected to an internal combustion engine generator set of 30kW$_e$ output. The gasifier was fuelled by shredded short cycle willow stems. The system was to supply electricity and heat to a single farm or a co-operative of two to three small adjacent farms. The waste heat that the process produced was to be used for drying the fuelwood chips or dumped. Energetically the system proved feasible, but the technical reliability was questionable at the time the study was reported. Problems encountered included supplying the biofuel through a hopper without bridging, poor flow of charcoal/ash through the bottom of the reduction zone, and inefficient operation of the gas cleaning unit. The economic feasibility of the system was not evaluated but is probably at a high cost as small scale gasifiers are usually individually manufactured rather than mass produced.

Fluidyne downdraft gasifier from cold takes just 2 to 3 minutes before the ICE (in this case for research undertaken at Massey University a 1200cc Datsun engine driving a 30kW generator) can be run on the gas.

Figure 7-1: **Small scale batch fed gasifier fueling Internal Combustion Engine**

7.4 Steam Turbines

Traditionally steam turbines have been used in large scale power generation and co-generation plants. The basic steam cycle is based on a “closed cycle”. Water is heated, evaporated and superheated in a boiler (known as the Rankine cycle). Some of the energy contained in the steam is converted into rotational motion by expanding it through a turbine connected to an electric generator (Figure 7-2). The steam is then lead through a condensor, cooled and turned into water again, which is recycled to the boiler to complete the cycle. A steam turbine is particularly suited for very large power outputs which, combined with the cost and reasonably high efficiency at this scale, is the reason for its wide use in large scale power plants (Figure 7-3). System efficiencies can vary between 15 and 35% depending on the steam parameters.

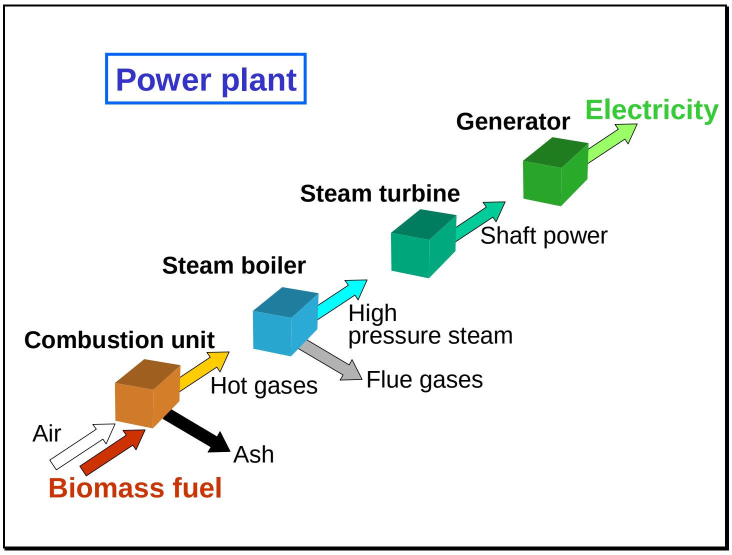

Figure 7-2: **Power Plant**

Higher efficiencies are generally found in larger plants, where more energy may be "captured" by the steam and released in the turbine. This helps make cofiring of biomass attractive, as the biomass used in a large coal-fired power station may well provide significantly more electricity than an equivalent amount of biomass burnt in a small, dedicated bioenergy plant.

Figure 7-3: Steam turbine driving a 25 MW$_e$ generator in a wood-fired power plant in Canada

Where the production of electricity is to be maximised, the steam turbine will exhaust into a vacuum condenser. System conversion efficiencies are likely to be in the range 10-20% for plants 1 - 5MW$_e$, and 15-30% for plants greater than 5 MW$_e$. Higher efficiency turbines usually come at higher cost, which can lead to a trade off between plant capital cost and operating efficiency.

Heat available from the condenser will be at low temperatures, usually below 50°C, which is insufficient for most heating applications even for low grade heat, so this heat is normally wasted by dispersal to the atmosphere or a large water course. Where there is need for heat as well as electricity, the plant can be configured to provide higher temperature steam or process heat by:

- taking some steam directly from the boiler
- extracting partially expanded steam from a turbine designed for that purpose
- arranging for the steam engine or turbine to produce exhaust steam at the required temperature.

All three options greatly reduce the amount of electricity available from the plant although the overall recovery of useful energy from the biomass feed may be much higher, 50-80% being possible for well designed co-generation systems.

Specific capital costs of a steam turbine alone are much smaller for large units than for small units. At the small scale (below 2MW$_e$), capital cost is often a significant obstacle for their uptake compared with ICEs. However the main advantages of a steam turbine system are that it is a mature technology with no technical barriers; it can withstand high pressures and temperatures; and the forces exerted on the foundations are low due to no oscillating masses as with an ICE. Disadvantages other than the high comparative investment costs can include low efficiency at the small scale, poor partial load efficiency, relative complexity for maintenance, and low suitability if the steam is of poor quality (i.e. low pressure and high water content).

7.5 Steam Engines

Steam engines are also proven technology but suited mainly for constant speed operation in industrial environments. Steam engines are only produced in small numbers, and are relatively expensive per unit in terms of $/kW. The efficiency of steam engines largely depends on the quality of the steam, which means that boilers with good steam pressures and temperatures are needed. Steam engines need steam with a pressure of at least 10 bar and a temperature of at least 180°C. Traditional steam engines are reliable and have low maintenance costs. The principle of a steam engine is similar to that of an ICE, the main difference being that in a steam engine the working fluid is steam, as opposed to fuel combustion products in an ICE. Most steam engines are double acting in that steam expands during both the forward and backward stroke of the piston. As a result a steam engine is lighter and smaller than an internal combustion engine for a given power output. Steam engines can be divided into traditional steam engines, modified steam engines, and systems which use diesel engine components thus reducing the production cost. The main market for traditional steam engines in biomass systems would be as co-generation units in quantities which are too small for the economic operation of a steam turbine. Some small steam engines (several kW output) are already in use privately in Australia to drive small generators with battery backup in Remote Area Power Supplies. Strathsteam in South Australia is one company that has provided units for this purpose.

Steam engines are available in different sizes ranging from a few kW to more than 1 MW_e. Specific investment costs for the steam engine alone vary significantly, with small units having a much higher cost per kW than large units. Other than for applications of several kW, capital and maintenance costs of steam engines are generally too high and efficiencies too low to be cost competitive against gasifiers and ICES. Advantages of a traditional steam engine include:

- it is a proven, robust technology (at least for traditional steam engine designs)
- able to withstand constant operation in an industrial environment
- has no internal corrosion of components as opposed to an internal combustion engine or gas engine
- needs steam to operate, not clean gas from a suitable gasifier
- can have reasonably good efficiency for small engines if well designed and when used in connection with standard industrial boilers.

Disadvantages include the low efficiency when used with steam of poor quality (usually as low pressure) and the poor image of old design and outdated technology.

7.6 Co-firing

Co-firing or co-combustion of biomass with coal and other fossil fuels can provide a near term, low risk, low cost option for producing renewable energy while simultaneously reducing the use of fossil fuels. Co-firing involves utilising existing power generating plants that are fired with fossil fuel (generally coal), and displacing a small proportion of the fossil fuel with renewable biomass fuels. Biomass can typically provide between 3 and 15 percent of the input energy into the power plant. Co-firing has been accepted as a complying source of renewable energy by the Federal Government for producing Renewable Energy Certificates under the *Renewable Energy (Electricity) Act 2000* and its *Regulation*, and also within New South Wales under the *Electricity Supply Act 1995*.

Co-firing has the major advantage of avoiding the construction of new, dedicated, bioenergy plant. An existing power station is modified to accept the biofuel and produce a minor proportion of its electricity from that biomass. No new generating plant is needed. Besides requiring a low capital investment cost, co-fired biomass is converted into renewable energy at a conversion efficiency essentially the same as a large, coal fired power plant, which could be more efficient than a small dedicated bioenergy plant.

A range of biomass fuels have been trialled or are in commercial use for co-firing around the world in power plants ranging in size up to 900 MW_e. These biomass fuels include wood and wood residues, straw, agricultural residues and also pyrolysis bio-oil. The most common power plants used for co-firing are those with pulverised coal boilers (such as are used at major Australian power stations), with fluidised bed combustors, cyclone boilers and grate boilers also being used. Co-firing in cement kilns is also common with a range of waste materials including tyres being co-fired.

Co-firing has already been embraced in Australia, with application in several cement kilns and also as a source of renewable electricity for a number of generating organisations. Macquarie Generation has co-fired biomass with coal at its Liddell Power Station in the Hunter Valley, NSW for several years. Delta Electricity has trialed co-firing of plantation and other wood waste and is now moving to commercial operation. Western Power Corporation and CS Energy, amongst others, are both investigating co-firing at their Muja and Swanbank power stations, respectively. Overseas, co-firing is ongoing in Europe and the USA, with several hundred megawatts of biomass co-fired power being produced on a commercial basis at various power plants.

7.6.1 Co-firing Configurations

Co-firing may be implemented using different types and percentages of biomass in a range of combustion and gasification technologies. The fuel preparation requirements, issues associated with combustion such as corrosion and fouling of boiler tubes, and characteristics of residual ash dictate the co-firing configuration appropriate for a particular plant and biofuel. These configurations may be categorised into direct, indirect and parallel firing.

7.6.1.1 Direct Co-firing

In direct co-firing the biomass fuel and the primary fuel (generally coal) enter the combustion chamber of the boiler together. This is the most common form of biomass co-firing. The cheapest and simplest form of direct co-firing for a pulverised coal power plant is through mixing prepared biomass and coal in the coal yard or on the coal conveyor belt, before the combined fuel is fed into the power station boiler. In some instances, such as at the Gelderland power plant in the Netherlands, wood waste is pulverised separately and directly co-fired in the pulverised coal furnace using a separate burner. An option that has been implemented at the St Andra Power Plant in Austria is to install a biomass grate in an existing pulverised coal boiler. In this instance the biomass provides 10 MW_{th}. Sludge-types of biomass can be directly co-fired using an oil lance.

Bio-oil has been used for co-firing at the Manitowoc Generating Station in Wisconsin, USA, where five percent of the energy was provided in a trial at a 20 MW coal fired power station unit. In this project, bio-oil was fed into the furnace of a grate boiler (see www.ensyn.com) through oil injectors installed above the grate.

The advantage of direct co-firing is the low investment cost and simplicity. The typical capital cost for direct co-firing can be as low as $200/kW of bioenergy capacity; about an eighth that of a dedicated bioenergy plant of the same capacity. A disadvantage of direct co-firing is that the biomass ash is mixed with the coal ash, which can complicate its subsequent sale and use.

7.6.1.2 Indirect Co-firing

It must be remembered that the use of biomass fuel in a large power station potentially means that the operation of the whole station may be influenced by the characteristics of the biomass fuel. If the biomass fuel has different attributes to the normal fossil fuel, then it may be prudent to partially segregate the biomass fuel rather than risk damage to the complete station. This caution has led to the use of biomass via indirect co-firing at a number of sites.

For indirect co-firing, the ash of the biofuel and the main fuel are kept separate from one another as the thermal conversion is partially carried out in separate processing plants. An example of this is at the AMER Central Unit 9 power plant, Geertruidenberg in the Netherlands where biomass is gasified, and the gas cooled and cleaned before it enters the main coal furnace, where it supplies 85 MW_{th} of energy. The ash produced during gasification of the biomass may be dealt with independently of the ash produced in the main coal-fired boiler. This separation of the ash allows problematic biomass fuels to still be co-fired with coal, but with specific design features to cope with any unique properties and handling requirements. The AMER gasification co-firing plant's biomass fuel consists mainly of building demolition timber which is prone to contamination with paint and other substances which require special processing. Indirect co-firing has also been demonstrated at the Zeltweg plant in Austria, and at Lahti in Finland.

As indirect co-firing requires a separate bioenergy conversion plant, it has a relatively high investment cost compared with direct co-firing. However the common use of large, high efficiency steam boilers and turbines in the existing power station still allows this approach to be achieved with a significantly lower capital cost than for a stand alone biomass power plant.

7.6.1.3 Parallel Firing

For parallel firing, totally separate combustion plants and boilers are used for the biomass/waste and the coal fired power plants. The steam produced is fed into the main power plant where it is upgraded to higher temperatures and pressures, to give resulting higher energy conversion efficiencies. This allows the use of problematic fuels with high alkali and chlorine contents (such as wheat straw) and the separation of the ashes. An example of parallel firing is at the Enstedværket power station in Denmark, where a straw fired power plant provides 40 MW_e and the coal fired plant provides 630 MW_e of the total output. Parallel firing requires relatively very high investment costs, with savings over a dedicated bioenergy plant being obtained from the dual use of the coal fired power station's turbo-generator and steam circuit. This additional cost is to an extent offset by the higher energy efficiencies obtained.

7.6.2 Fuel Handling and Preparation

The characteristics and energy densities of biomass fuels vary significantly from that of coal, the main fossil fuel with which biomass is co-fired. This results in the need for different sized equipment for fuel receiving, storage, and reclaiming. As with any fuel, suitable precautions need to be taken with biomass fuels to prevent spontaneous combustion and dust explosions.

The biomass fuel delivered to a power station may vary from whole chips 5 cm in size, to fine, dry sawdust. For combustion in a pulverised coal power station, maximum sized particles of approximately 5 mm with moisture content below 25% are generally required. This may be achieved by milling the biomass with the coal in the power station coal mills, or by providing dedicated grinding mills to achieve the fuel specification. In the 150 MW_e pulverised coal plant in Studstrupvæket, Denmark, up to 20% of straw is co-fired[1]. Here the delivered straw bales are first shredded.

Fuel preparation may also require metal detectors and magnetic separation to locate and remove ferrous metals from waste wood. Oversized biomass fuel may be screened and returned to a grinder for further treatment. Fuel drying using boiler exhaust gases may sometimes prove to be cost effective. Dirt may be excluded from the fuel (at a cost) by storing the biomass on paved storage areas.

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[1] IEA Bioenergy Task 32 draft combustion handbook

A much wider range of fuel sizes, composition and moisture contents are acceptable in grate and fluidised bed combustors. Biomass pellets and cubes made from organic wastes, tree thinnings and paper waste may also be used as the fuel for co-firing, although it must be remembered that pelletising processes add cost to the biomass feed.

7.6.3 Plant Operation and Emissions

Biomass and coal have very different characteristics, with coal having a very high proportion of pure carbon and biomass containing up to 72% volatile material[1]. Accordingly, co-firing biomass in an existing installation increases the amount of the flue gases per unit of energy. This alters the flow patterns of combustion gases through the boiler and temperature profiles can be dramatically modified. This results in slightly lower energy conversion efficiencies and increased amount of unburned carbon in fly ashes. The decrease in boiler energy efficiency due to co-firing is generally in the range of 0.3 to 0.6 percentage points out of 85 to 88 percentage points[2]. Though plant design modifications can be implemented, these factors limit the percentage of biomass that can be co-fired in an existing installation. Indirect or parallel co-firing is a way of overcoming these limitations.

Major technical challenges related to co-firing are the potential for slagging, fouling, sintering and high temperature chlorine-induced corrosion in the boiler. Slagging and fouling problems arise from some biomass fuels, such as straw, which have high alkali content. Ash deposition rates generally decline when co-firing involves wood or similar low-ash, low-alkali, low chlorine fuels and increase when co-firing involves high-chlorine, high-alkali, high-ash fuels such as straw and many other herbaceous materials. Deposition rates may also depend on individual fuel properties and interactions between the co-fired fuels.

Chlorine contained in herbaceous or intensely cultivated fuels, such as wheat straw, may cause severe corrosion on boiler tubes. High-temperature corrosion of superheater tubes induced by chlorine-containing biomass in particular can be of concern. A solution to this corrosion problem, applied in the latest straw combustion installations in Denmark, is to use the controlled formation of a slag layer on the superheater tubes to protect the underlying metal from chlorine-induced corrosion. Sulphur in the coal has been found to ameliorate this corrosion potential by interacting with the alkali chlorides. By maintaining the fuel chlorine and alkali concentrations below one fifth of the total fuel sulphur (on a molar basis), corrosion problems can be avoided[3].

Biomass contains very low levels of sulphur, and the formation of sulphur dioxide when co-firing will be reduced by an amount proportional to the co-firing rate (through the reduction in coal use). Emissions of sulphur dioxide from the burning of fossil fuels lead to ‘acid rain’. This has been a major environmental issue, particularly in the northern hemisphere where coals have intrinsically higher sulphur content.

The formation of nitrogen oxides (NOx) may also be reduced, due to co-firing of biomass with coal. Reduction in NOx formation has been reported to be in a greater proportion than the co-firing rate. This reduction in NOx formation is traced to lower fuel nitrogen content and higher volatile yields from biomass. Mann and Spath [4] indicate in a study, that for co-firing rates of 5% and 15%, NOx emissions are reduced by as much as 9.8% and 26.4% respectively.

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[1] Addressing the Constraints for Successful Replication of Demonstrated Technologies for Co-Combustion of biomass/waste, Report of the Final Seminar, Ir. J. Koppejan, page 2119-2123, Proc. of 1st World Conference on Biomass for Energy and Industry, Seville, Spain, 5-9 June 2000

[2] *Biomass Cofiring – A Renewable Alternative for Utilities and Their Customers*, USA Dept of Energy pamphlet, May 1999, DOE/GO-10099-758

[3] IEA Task 32 draft combustion handbook

[4] A Life Cycle Assessment of Biomass Cofiring in a Coal-Fired Power Plant, by Margaret Mann and Pamela Spath, NREL, spring 2001 issue of Clean Products and Processes – pre-publication version

Spath and Mann also report that on a life cycle basis for co-firing rates of 5% and 15%, greenhouse gas emissions on a CO_2-equivalent basis are reduced by 5.4% and 18.2% respectively.

7.6.4 Ash Marketability

A barrier that needs to be overcome for more widespread introduction of biomass co-firing is related to the marketability of fly ash. The existing Standards for the use of fly ash in cement and concrete are written exclusively for coal-derived fly ash, and preclude the use of co-mingled biomass and coal ashes. Indirect co-firing and parallel firing overcome this barrier, but at an expense. It has been shown that concrete produced from a co-firing installation does not necessarily have to be of lesser quality than normal concrete. It is anticipated that the Australian Standard for fly ash in concrete (AS 3582) will be modified to cater for biomass co-firing[1]

7.6.5 Plant Operating Experience

Within the USA as of mid 2000[2] co-firing experience included 11 direct co-firing applications with pulverised coal totalling 74 MW, seven separate feed systems into pulverised coal power stations providing 48 MW, eight blended fuel applications using cyclone burners totalling 132 MW, and 55MW using fluidised bed and stoker grate boilers.

A series of EU-THERMIE case studies promoting the commercial application of co-firing biomass and waste also report experiences at:

- Slough Trading Estate CHP plant, UK (waste derived fuel and coal)
- Tekniska Verken CHP plant, Sweden (biofuel, rubber and coal)
- Stora Fors Paper Mill, Sweden (biomass and coal)
- Stora Hylte Paper Mill, Sweden (biomass and coal)
- Idbacksverket CHP Plant, Sweden (biofuel and coal)
- Kymijarvi CHP Power Plant, Finland (wet biomass and coal)
- Rauhalhti Power Plant, Finland (peat, wood fuels and coal).

Within Australia, Macquarie Generation has been co-firing wood waste at their Liddell Power Station in the upper Hunter Valley for a number of years. More recently Delta Electricity have conducted trials on direct co-firing of wood waste at Wallerawang Power Station, near Lithgow, NSW, and Western Power Corporation and CS Energy are also known to be conducting trials on co-firing.

7.7 Emerging Technologies

There are a range of new and emerging bioenergy conversion technologies at various stages of development and demonstration. Some of these are being developed for small scale applications, while others are being developed at a larger scale (30 MW_e), with emphasis being placed on improved energy efficiency, environmental performance and lower cost.

7.7.1 Stirling engines

Stirling engines can utilise any source of heat provided that it is of sufficiently high temperature. They differ from ICEs in being external combustion engines, fuel being combusted outside the engine and the heat then transferred into the cylinder by a heat exchanger or via the cylinder wall. There is no contact between the moving parts of the Stirling engine and the biomass generated heat or gas or its contaminants. As a result the lifetime is relatively long and maintenance intervals are large. The principle of a Stirling engine is that a working gas, enclosed by two pistons in a vessel,

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[1] Personal communication with Peter Coombes, Delta Electricity November 2001

[2] Seminar presentation, Evan Hughes, EPRI, 6 June 2000 at 1st World Conference and Exhibition on Biomass for Energy and Industry, Seville, Spain, 'Addressing the Constraints for Successful Replication of Demonstrated Technologies for Co-Combustion of Biomass/Waste', part of the EU-DG XVII Thermie B Project DIS/1743/98-NL

moves continuously back and forth between hot and cold spaces in a regenerator and is therefore continuously heated or cooled (Figure 7-4). The pistons are driven by expansion of the gas caused by differences in volumes due to the temperature differences. Typically, Stirling engines are single-acting with one cylinder containing two pistons. Double-acting engines with four cylinders and one piston in each cylinder are mechanically more simple and compact, and this design is suitable for bigger engines. Even more simple are Stirling engines where springs control the piston movements without a kinematic crank mechanism.

In the late 19th and early 20th century several thousand Stirling engines with a maximum output of around 4kW were in operation in Europe and the USA. However the Stirling engine was later replaced by the more efficient and lighter internal combustion engine. Due to the low emissions and noise levels, the Stirling engine was revived by Philips Company in the 1930s. Finding materials suitable for simple manufacture and operation at high pressures has been a limitation until recently.

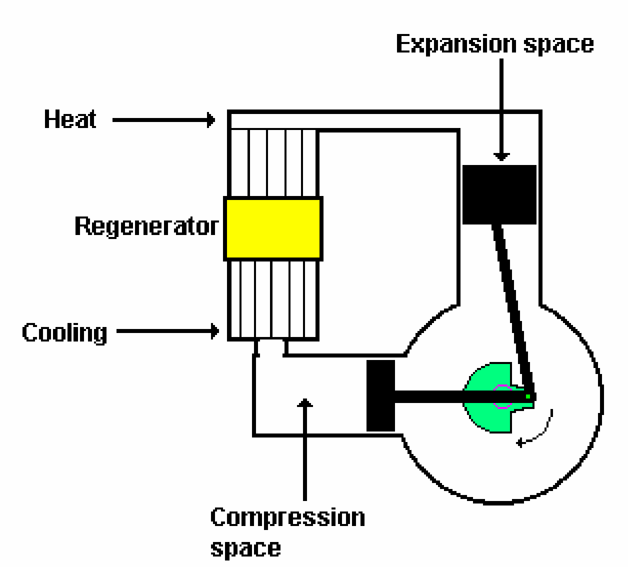

Figure 7-4: The Stirling engine uses a closed thermodynamic cycle
(Which repeatedly expands and compresses a fixed mass of gas)

Stirling engines are available in the 0.5 to 150kW$_e$ range and a number of companies are working on its further development. However, only a few engines have been introduced to the market and only one or two have proven to be commercially viable to date. Currently the specific cost of, for example, the V160 Stirling engine is high, at around \$9,000/kW$_e$. However, if future sales of up to several thousand annually can be realised, specific costs are anticipated to reduce significantly. For Stirling engines specifically developed for biomass firing, overall efficiencies of fuel energy to shaft output are around 30%.

Advantages of Stirling engines include relatively high efficiency; good partial load efficiency; low noise level, safe operation, low expected maintenance costs, suitability for a wide range of fuels, and long engine life time (25,000 hrs).

Disadvantages include:

- limited testing on fuels to date
- only very small engines have been built so experience with larger engines is lacking
- there is little data on reliability and expected life times from commercial use
- high heat exchange temperatures may cause corrosion
- sealing of the engine working under high internal pressures is a technical problem yet to be resolved.

Prospects for Stirling engines are very good but they are yet to be commercially proven. Considerable R D & D work is in progress on developing Stirling engines for use with biomass fuels. Several designs are under development and one or two have recently reached the near commercial stage.

- In Denmark two Stirling engines were under development for running on biomass giving maximum electric power outputs of 36 and 150kW$_e$.
- In the UK, the CRE Group Ltd in collaboration with Gamos Ltd designed a novel form of low pressure, nitrogen charged Stirling engine of 150kW$_e$ with 600 kW$_{th}$ heat output specifically for stationary applications.
- A 10kW$_e$ Stirling engine has been coupled to a 1MW$_{th}$ biomass atmospheric fluidised bed combustion unit utilising pine chips. The SPS V160 Stirling engine was specifically designed for stationary use, low cost production and long running time.
- In the USA, the STM Corporation has developed a small modular biomass-powered system based on their 25kW$_e$ Stirling engine (STM4-120) coupled to a sub-atmospheric updraft gasifier fired with sawdust. This “BioStirling” system was equipped with an induction generator to produce grid-connected electric power.
- Sunpower Inc. has undertaken studies of a gasifier coupled to a Stirling engine with a capacity of 1 to 18kW$_e$ for residential, small commercial building and agricultural markets.

7.8 Indirectly Fired Gas Turbines

Gas turbines based on conventional designs but with the combustion chamber replaced by a heat exchanger are termed “indirectly-fired”. Heat produced by external combustion in a standard combustor is transferred by clean air as the working fluid through the close coupled heat exchanger, so that the need for clean gas is less crucial. However before hot combustion gas enters the heat exchanger, some gas cleaning is still necessary. Research is currently focused mainly on the heat exchange system because all other components are mass produced. In a Canadian project, specific investment cost was estimated at $8,000/kW$_e$ for a 530kW$_e$ system.

Advantages of the indirectly fired gas turbine are that many components are mass produced which should ultimately allow reduced costs, and a high efficiency is possible if the inlet temperature in the gas turbine can be increased to that of directly fired gas turbines. Disadvantages include:

- low efficiencies if using standard metal heat exchangers
- the large size required for the heat exchanger
- the need for a particle cleaning system which must work reliably at high temperatures
- the heat exchanger complicating the control and regulation of the turbine.

Basically there are no technical barriers, but extensive testing has yet to be done to prove that the system works well and is cost effective.

Projects

Several commercial scale developments have occurred in recent times.

1. In Belgium a fluidised bed gasifier designed to run on sawdust was coupled to an indirectly fired gas turbine. The gas turbine was fired externally through a high temperature metallic air heater. To enhance power output and to allow flexible power to heat ratios, water injection into the air heater was included. Capacity of the gas turbine and available heat was 300kW$_e$/1200kW$_{th}$. Expected investment costs were $9,000/kW$_e$ however, on a scale of 1.8MW$_e$, a replicated design was estimated to cost $5,500/kW$_e$. The targeted maximum electric efficiency is 24%.

2. In the Netherlands a demonstration project was planned for small scale stationary power generation under 500kW$_e$ for co-generation applications. The indirectly fired gas turbine used clean air as a working fluid. The combination of low temperatures and pressures resulted in specifications for the turbine construction materials being met by stainless steel instead of ceramics. A two-stage combustor was chosen as the most promising system coupled to the gas turbine. The system had an electrical efficiency of 20% and investment costs were estimated to be $5,000/kW$_e$, mainly due to the high costs of the heat exchanger which was 50% of the total investment.

7.9 Directly Fired Pressurised Gas Turbines

In this system hot combustion gas from a pressurised gasifier is lead into a directly fired pressurised gas turbine. As the gas temperature is usually higher than the maximum allowable inlet temperature of the gas turbine, it is mixed with cooler air. The operation of gas turbines with biomass derived fuels is promising in the range of 5 and 20MW$_e$ plant sizes and several demonstration plants have been built in the USA, UK and Scandinavian countries.

Economical and technical data are sparse. Specific costs are expected to be around $2,400/kW$_e$ for a complete plant or $1,100/kW$_e$ for just a 6MW$_e$ gas turbine. Advantages of the directly fired pressurised gas turbine are that:

- no steam ducting system is required thus reducing costs
- a standard gas turbine design can be used
- relatively little erosion, corrosion or deposition occurs on turbine blades due to effective hot gas clean-up
- residual ash from the cyclone can be used as fertiliser.

Disadvantages are that only white wood and low sulphur containing coal have been tested and that part-load efficiency of the turbine is low.

The concept of a pressurised air-blown fluid bed gasifier coupled to a gas turbine of capacity 225kW$_e$ was evaluated in North Carolina. The gas from the gasifier was passed through a hot gas clean up system followed by injection into the combustor chamber of a gas turbine. Electricity was produced from a generator which was powered by the output shaft of the gas turbine. Problems experienced with this system were the biomass feed system, ineffective hot gas clean up, and a relatively low conversion efficiency. Major engineering challenges yet to be resolved are the design of a gas turbine fuel supply and combustion system that will accept and burn the hot gas. The system is still under development.

It is of interest to note, the ‘Bioten’ biomass-fueled electrical power plant in Red Boiling Springs, Tennessee USA has been liquidated due to the lack of a green power purchase agreement with local and regional utility agencies. The plant, which was constructed at a cost of over US$25 million dollars, was designed to produce up to 6.2 MW of electricity from waste wood products as well as a waste heat stream suitable for process heat and/or generation of low level steam.

7.10 Micro-turbines

A micro-turbine is similar to a gas turbine, except that most designs incorporate a recuperator to recover part of the exhaust heat for preheating the combustion air and hence increase overall efficiency to around 20-30%. Air is drawn through a compressor section, mixed with a gaseous fuel and ignited to power the turbine section that drives the generator. Several competing manufacturers are developing units in the 25-250kW$_e$ range. Multiple units can be integrated to produce higher electrical output while providing additional reliability should one need repair or maintenance. Most manufacturers are pursuing a design where the compressor, turbine and generator are mounted on a single shaft supported on lubrication-free air bearings and operating at speeds of up to 120,000rpm. The high frequency power that is generated is converted to grid compatible power through power conditioning electronics. However for some single shaft machine designs, either a standard induction or synchronous generator can be used without any power conditioning electronics needed. Micro-turbines are a relatively new development and therefore many of the performance characteristics provided are still only estimates based on demonstration projects and laboratory testing.

Advantages of micro-turbines include compact and light weight design, a fairly wide size range due to modularity, and low noise levels. Groups investigating gasifier /micro-turbine systems are targeting lower electricity costs than may currently be achieved by gasifier /ICE systems within the next few years. To our knowledge there are currently no commercially operating gasifier/micro-turbine systems anywhere in the world.

1. Reflective Energies, an American company, is developing a small, robust micro-turbine electric power plant, the Flex-Microturbine™. It will be run on fuel gases from gasification of biomass, biogas from landfills and animal wastes, and waste gases from petroleum and coal production operations. No further details have been reported.

2. Another American company, Capstone is a world leader in micro-turbines. One application of its products is at a Los Angeles landfill, where 50 micro-turbines operate on landfill gas, a mixture of methane and carbon dioxide. A Capstone micro-turbine is also to be used in a project that includes CSIRO Forestry and Forest Products in Australia which seeks to couple a small gasifier to a micro-turbine for electricity generation. This project is currently underway in Melbourne with financial support from the Renewable Energy Commercialisation Program of the Australian Greenhouse Office.

7.11 Advanced Combined Cycle Gasification Technologies

Since 1990 there has been a lot of interest in demonstrating advanced power generating cycles based on biomass gasification technologies, mainly biomass integrated gasification combined cycle (BIGCC or IGCC) systems (Figure 7-5).

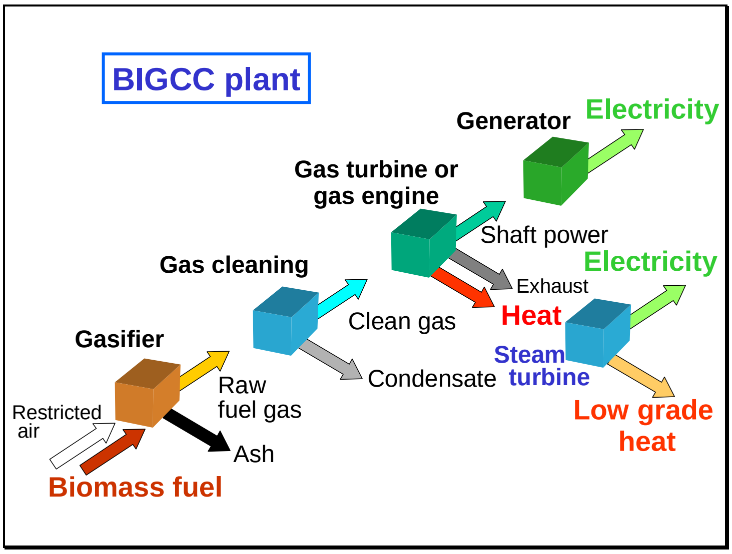

Figure 7-5: BIGCC Plant

In these cycles a gas turbine is fuelled by synthesis gas (mainly CO and H_2) from the gasification of biomass. In addition, surplus heat from the flue gas from the turbine is used to generate steam, which is then fed into a steam turbine to generate additional power. The combined use of gas and steam turbines is referred to as "combined cycle". Electrical efficiencies significantly above those of conventional bioenergy systems are possible. Several large demonstration projects have been developed in the range of 7-10MW$_e$ and developers are keen to move up to larger plants to achieve economy of scale for future, commercial operations.

The benefits of advanced power cycles utilising gasification technology include increased conversion efficiency, which results in reduced feedstock consumption per unit of electricity produced, and thus reduced operational costs, reduced environmental impacts and the possibility of co-firing biomass with fossil fuel and wastes. Investment costs for the first fully commercial plant of its kind are estimated to be \$4,300-\$5,000/kW$_e$ for plants in the power range of 8 - 30MW$_e$ for atmospheric IGCC, and \$4,000-6,000/kW$_e$ for pressurised IGCC plants up to 60MW$_e$. IGCC cycles are considered to have most potential in medium to large scale gasification projects in the range of 30 to 100MW$_e$.

The most recent BIGCC development is the ARable Biomass Renewable Energy "ARBRE" project in Yorkshire, England, led by First Renewables Ltd and supported by a 15 year NFFO contract from the UK government that was awarded in 1996. The project is to be a fully integrated development including:

- contracting biomass supplies from dedicated crops of short cycle Salix crops from local growers
- applying domestic treated sewage sludge for land treatment and for use as a fertiliser, with Yorkshire Water being a project partner
- contracting for other sources of woody biomass
- constructing a high efficiency combined cycle power station supplied by these fuels
- recycling of nutrients from the ash to the land
- electricity generation and sale, being the main business objective.

Planning approval was obtained in 1997 following widespread consultation with local residents, the local District Council, the Department of the Environment, and many others, together with the production of an environmental impact statement.

The plant requires 43,000odt/y of fuelwood, much of which will be sourced from short cycle crops (SCC) willow. Other woody biomass supplies will be sourced as a supplement fuel initially but over 1,500ha of willow has been established by local farmers within a 60km radius and contracts for long term supply up to 10 years are anticipated. The ecological benefits of SCC willow have created much interest and after a slow start, the encouragement of woodland grants of around \$2000/ha to plant SCC led to a greater rate of uptake. Several willow varieties have been grown to reduce risk of yield loss from pests and diseases and also to increase visual diversity. Treated sewage sludge is applied to give increased yields but also to provide an environmentally acceptable method of sludge disposal.

The SCC will be harvested on a three year rotation in late winter/early spring before leaf growth, either directly as chips or as stems and stored on-farm. Stems are later chipped after they drop below 30% m.c.w.b. Nearby, 10,000t of forest residues sourced from forests up to 100km away are stored as a strategic reserve, but this resource is expected to continue to provide 20% of the fuelwood supply after the willow crops have matured. Fuel is delivered to the power plant by road and tipped into the reception area, which holds supply for three days and where the residual heat in the exhaust flue gas is used to dry it.

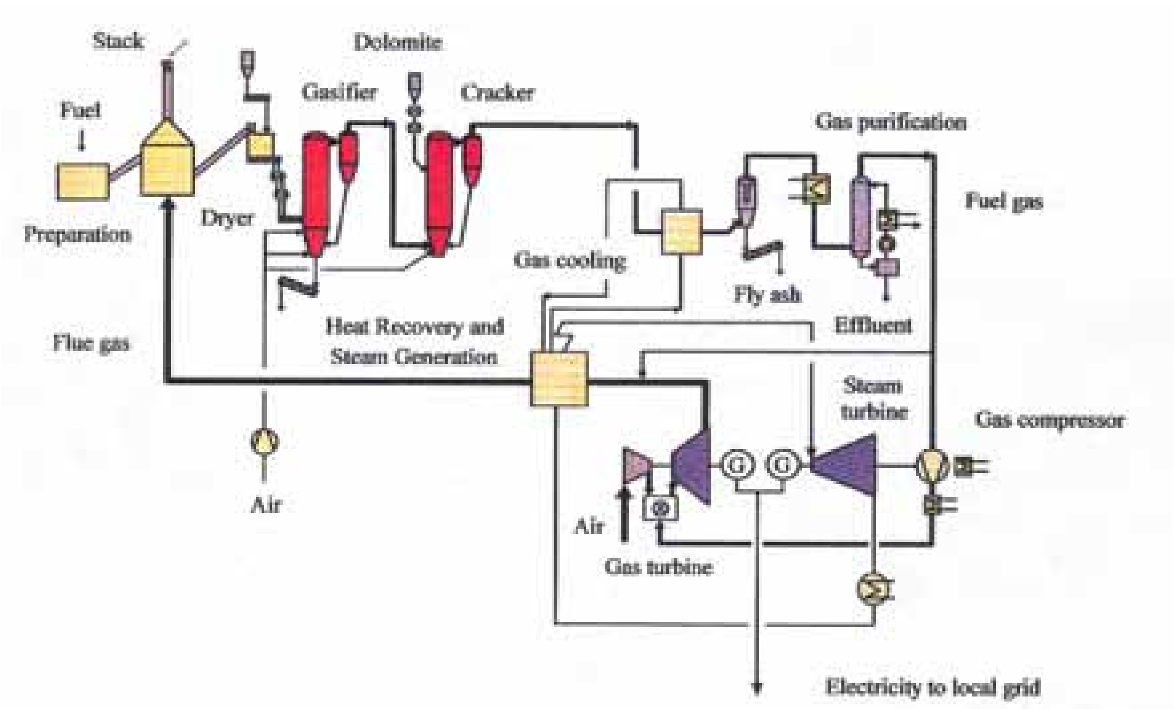

Figure 7-6: The Yorkshire Arbre process for a willow coppice and wood process residue fuelled gasification combined-cycle plant.
Source: First Renewables Ltd.

The plant design is a BIGCC (Figure 7-6) which improves the overall power generation efficiency compared with traditional combustion plants and is expected to give reduced atmospheric emissions. A Swedish Termiska Processor AB (TPS) atmospheric circulating fluidised bed (CFB) gasifier had been successfully tested using a range of fuels, including those sourced from SCC *Salix,* and this was selected as the heart of the process. Two other plants by TPS (www.tps.se/egen/egen_en.htm) are operating commercially using RDF-fuelled (refuse derived fuel) in Greve-in Chianti, Italy. TPS technology has also been selected for opportunities being evaluated in Brazil.

The circulating fluidised bed (CFB) gasifier design is air-blown and allows for a catalytic tar cracking system. Chipped fuelwood is fed continuously into the lower part of the gasifier along with secondary air. Primary air enters the bottom of the vessel at high pressure to fluidise the bed. Gas leaving the gasifier contains ash, wood char and sand particles which are separated out in cyclones and returned to the bottom of the gasifier. The raw gas passes to the tar cracker which is similar in design to the CFB combustor except with dolomite as the bed rather than sand. Here the hydrocarbons are broken down. The final gas stream consists of CO, H_2, CO_2, N2, CH_4, H_2O and some traces of residual hydrocarbons and particulates that escape the cyclones. This stream then enters a gas cooling process followed by cleaning using bag filters, a second cooling process and then to a wet scrubber to condense the water vapour and remove ammonia and traces of alkali compounds and tars.

Most of the cool, clean gas is then compressed ready for combustion in an Alstom Power ‘Typhoon’ gas turbine designed to operate on low heat value gas. Heat is recovered from the exhaust leaving the gas turbine by the waste heat boiler. In addition a portion of the gas produced is fired into this exhaust stream to maintain temperature in order to produce superheated steam for a steam turbine. Residual heat in the flue gases is used to dry the biomass fuel in the covered storage area. Generators coupled to the steam and gas turbines produce $10MW_e$ of power of which the plant requires $2MW_e$ to run the process, leaving $8MW_e$ to be exported to the grid and sold.

Ash is removed from the bottom of the gasifier and from the filters and discharged into sealed containers for disposal or recycling. The plant components are modular so future projects of similar design will have a relatively short construction period.

The ARBRE project has been a showcase for BIGCC and SCC over recent years, combining a number of innovative technologies and practices into a single project. Regrettably in 2003 the project appears to have been abandoned. The gas turbine had been run for short periods. Problems were encountered with feed handling, gas clean-up and the evaporator cooler. These were being addressed at a time when the project was one of several sold to Energy Power Resources Ltd, who decided to terminate the project. It is not clear whether the project was terminated for technical, commercial or policy related reasons.

7.12 Conversion of Pyrolysis Bio-oil

Bio-oil is a possible substitute for heavy and light fuel oil (including diesel) in many stationary applications including in boilers, furnaces, engines and turbines for electricity and co-generation applications. In addition, a range of chemicals can potentially be extracted or derived from bio-oil including food flavourings, specialty chemicals, resins, agri-chemicals, fertilisers, and emission control agents 1114. Upgrading bio-oil to transportation fuel is feasible, but currently not economic. Figure 7-7 illustrates the applications of pyrolysis bio-oil.

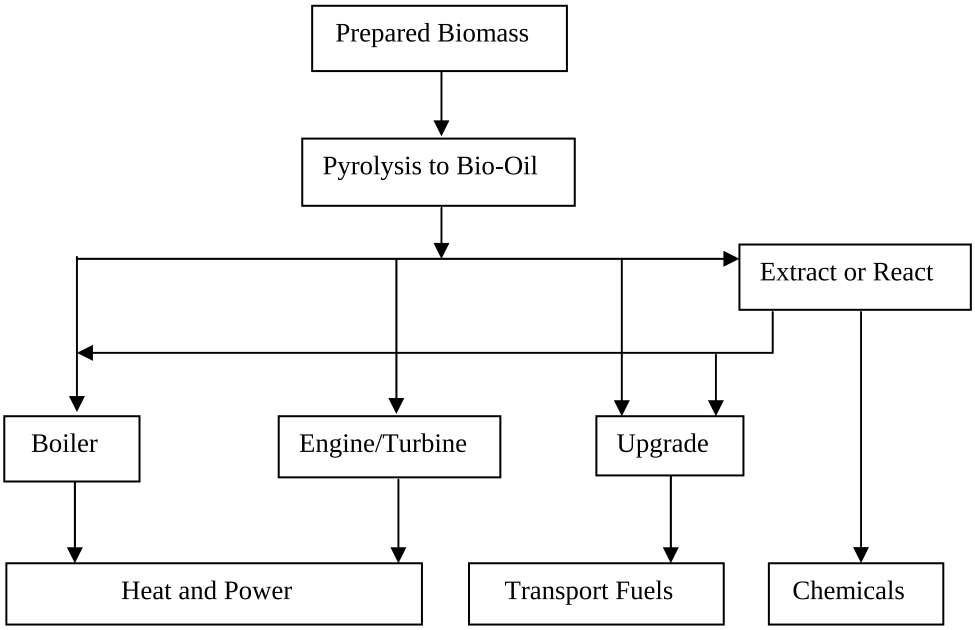

Figure 7-7: Applications of pyrolysis bio-oil

7.12.1 Heat and Power Production

A promising application of bio-oil is in electricity production in boilers, engines and combustion turbines. As has been noted in Section 6.4, bio-oil can be produced in one location and transported to a power plant located elsewhere. Bio-oil has a number of environmental advantages over fossil fuels such as diesel:

- Reduced carbon dioxide emissions. Bio-oil is derived from biomass, which when sustainably produced emits no net greenhouse gases.
- No SOx (oxides of sulphur) emissions, as biomass contains virtually no sulphur.
- Potential for low NOx (oxides of nitrogen) emissions. Bio-oil fuels are reported to generate under half the NOx emissions of diesel oil in gas turbines.

7.12.1.1 Engines

Bio-oil has been successfully demonstrated in short and medium term trials, with in excess of 500 hours operation reported on various engines, ranging in size from laboratory test units to 1.5 MW_e modified dual fuel diesel engines. Ormrod of the UK has operated a low speed, dual fuel, 250 kW_e engine for over 400 hours, including several test runs over 9 hours, with electricity generated for 320 hours. This includes running exclusively on bio-oil. Wartsila of Finland has also run a pilot injection diesel 1.5 MW_e engine on 95% bio-oil fuel with no deterioration in rating. Long term test runs are now on-going to confirm performance and obtain emission data.

7.12.1.2 Gas Turbines

Orenda Aerospace Corporation, a Magellan Aerospace company based in Canada has been developing and demonstrating a 2.5 MW industrial gas turbine fueled on bio-oil. They have demonstrated the feasibility of using bio-oil and also that similar performance can be achieved for bio-oil and diesel. Over 13,000 litres of bio-oil have been combusted in this gas turbine, with development of a second generation gas turbine system under way.

7.13 Fuel Cells

Fuel cells are electrochemical devices in which a hydrogen-rich fuel reacts chemically with oxygen to produce electricity and heat. Fuel cells have some similarities to batteries, except that the energy source (fuel supply) is continuously replenished during operation. During the past 10 years in particular, progress on fuel cells has been immense, primarily due to the development of new catalysts and materials. Their market entry is now considered by many to be imminent, with fuel cell proponents considering them to be the most likely future alternative to internal combustion engines for both vehicle and stationary power and heat applications.

A fuel cell system consists of several major components including:

- a hydrogen fuel supply or, if hydrogen is not used directly, a fuel reformer to generate hydrogen-rich gas from the chosen fuel
- a power section where the electro-chemical process occurs
- a power conditioner to convert the direct current (DC) generated in the fuel cell into alternating current (AC).

The power section consists of the actual stack of fuel cells linked in series. Each cell consists of an anode and a cathode in contact with an electrolyte and operates essentially by reverse electrolysis. When the anode and cathode are supplied with hydrogen fuel and air respectively, the fuel cell generates a voltage between the two electrodes of less than 1V peak. When the electrodes are connected to an external circuit the fuel cell generates electric power (Figure 7-8). The chemical equation:

$$\mathbf{2H_2 + O_2 \longrightarrow 2H_2O + energy}$$

is the same for when hydrogen is combusted in air but instead of light and heat being produced, electrical energy is generated, together with varying degrees of heat.

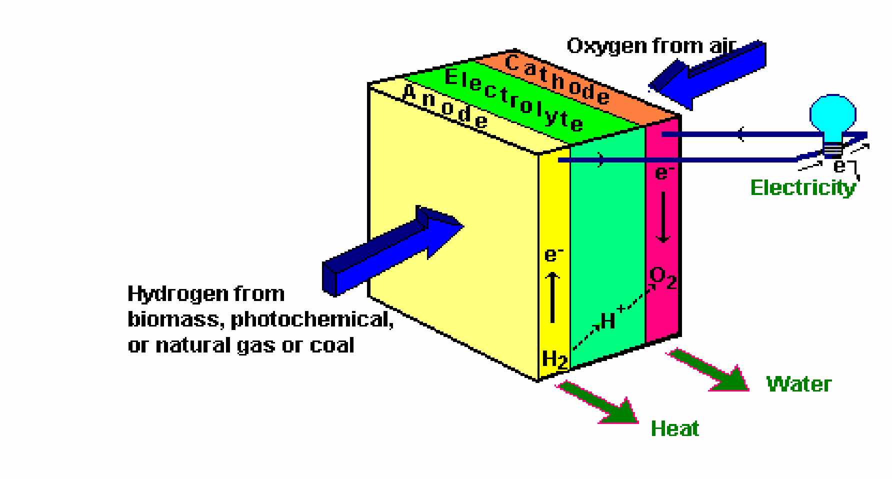

Figure 7-8: Operating principle of a fuel cell.
(Source: Energy Wise News, EECA)

Individual fuel cells produce only between 0.5-0.9 volts of DC electricity so they are combined into stacks like cells in a battery to obtain more usable voltage and power outputs.

Advantages of fuel cells include:
- high energy efficiency, even in the lower power range
- modular design, enabling different power ranges to be obtained
- very low emissions
- low maintenance and high reliability, as there are no moving parts
- no noise from the fuel cell.

Fuel cell technologies differ with respect to their electro-chemical reactions, materials of construction, tolerance to contaminants, fuel flexibility, and operational characteristics. These characteristics vary with the application and the cost. For applications in transport, fuel cells are required with high performance, but moderate lifetimes are acceptable since vehicles have a relatively short life. Stationary applications are more demanding on lifetime, but less so on power density.

The efficiency of fuel cells remains essentially the same irrespective of power plant size. Due to flexibility in plant size, both small and large power plants can be installed in either congested urban dwellings directly connected to the grid or in relatively small or isolated villages, islands and utility centres as ‘stand alone’ systems. Fuel cells are currently considerably more expensive than ICEs. However it is claimed that, in the long term, the cost of electricity generated from fuel cells will become less than from other competing energy conversion systems such as ICEs. This will in part be due to flexibility of the fuel source, and increased efficiency. Fuel cells also offer the benefits of decentralised power supply when compared with grid supply due to reductions in the transmission and distribution costs of electricity.

7.13.1 Stationary applications

One large potential market world-wide for fuel cells is for distributed electricity generation. Several types of fuel cell are competing for early entry into a variety of prospective uses in this market. Proton exchange membrane, phosphoric acid, molten carbonate and solid oxide fuel cells are the prime technology options. Each type has its own distinctive characteristics, such as operating temperatures, efficiency ranges, fuel use, markets and cost. The potential advantages of fuel cells over gas turbines include smaller unit sizes at similar efficiencies, the potential of a zero GHG emission technology if appropriate fuels are selected, lower maintenance costs, less noise and, importantly, better economic performance, initially in particular applications and eventually in a more general role.

In a unique innovation currently under consideration, high temperature solid oxide fuel cells and gas turbines could potentially be integrated to boost electric generating efficiencies. The hot, fuel rich exhaust from the fuel cell is combusted and used to drive the gas turbine. Energy recovered from the turbine's exhaust is used in a recuperator that preheats air from the turbine's compressor section. The heated air is then directed to the fuel cell and the gas turbine. Any remaining energy from the turbine exhaust can be recovered for steam in a combined cycle or for other heat demand. Such hybrid SOFC/CCGT systems have projected efficiencies of 72 to 74%, and would represent a very high overall efficiency for electricity generation. Typical plant sizes would be 1 to 100MW_e and fuelled with natural gas would produce the lowest emissions of all fossil fuel electricity generating options of about 75 –80gC/kWh.

7.13.2 Biomass as a fuel source for fuel cells

Hydrogen, the ideal fuel for fuel cells, can be produced from a wide range of renewable and non-renewable sources. The thermo-chemical gasification of many biomass feedstocks, such as municipal waste, agricultural or forest wastes, or wood chips from short cycle crop plantations can be used to produce hydrogen. Hydrogen so produced is attractive from an environmental point of view because the carbon cycle would be closed. Typically hydrogen makes up about 6% by weight of dry biomass. To obtain hydrogen from biomass, a process of pyrolysis or gasification must be applied, which produces a gas containing approximately 20% hydrogen by volume. The challenge is to overcome the economic barriers that current technology presents for converting biomass to hydrogen for use in clean, efficient energy conversion devices.

7.14 Discussion

At present approximately 90 percent of bioenergy world-wide is produced in combustion units. Electricity producing units raise steam to power steam turbines which in turn drive turbo-alternators. The maturity of this technology may be gauged by the level of deployment, where for instance, in the USA alone there is some 12,000 MW of installed bioenergy capacity. An Australian example of this technology is the newly commissioned 30 MW_e Rocky Point Sugar Mill Co-generation plant, which operates on bagasse for part of the year and wood wastes in the non-cane crushing season.

At a smaller scale, there are many examples around the world of gasifiers supplying gas feed to internal combustion engines, driving small generators. An example of this technology is the commercially available French Martezo gasifier fuelling spark ignition engines up to the 0.5 MW scale.

The quest for more efficient, industrial scale bioenergy has led to the development of biomass integrated gasification combined cycle plants, aiming to achieve improved overall thermal conversion efficiencies. Other developments are small modular generation units ranging from 1-50 kW. These include the use of wood pellets to fuel small Stirling engines and work by the CSIRO with a biomass gasifier providing gas feed for a micro-turbine.

To overcome a thermodynamic limitation to the efficiency of conventional 'heat engines', fuel cells are being developed to achieve greater energy conversion of the fuel. There are several variants of fuel cells, with the most prospective being the solid oxide fuel cell. Such technology is being developed by a number of groups, including Ceramic Fuel Cells Limited in Victoria, Australia building on earlier CSIRO expertise in electrically conducting ceramics. It is surmised that once this type of technology is commercialised for use with natural gas, it will also be adapted to run off purified biogas and syngas derived from the gasification of biomass.

8. Energy Technologies – Ethanol

8.1 Summary

Ethanol, a renewable transport fuel, can be produced through the fermentation of the sugars found in biomass. The best known feed is the hexose (six-carbon or ‘C6’) sugar, naturally occurring in sugar cane and its by-product molasses. This sugar can be fermented with yeasts and the resulting dilute ethanol stream can be concentrated to recover pure ethanol. Sugar for fermentation can also be recovered from starch, a polymer of hexose sugars (or ‘polysaccharide’). This route is common in the USA where corn starch provides the feedstock for a major fuel ethanol industry.

Biomass in the form of wood or agricultural residues such as wheat straw is viewed as a low cost alternative feedstock for ethanol production. Like starch, wood and agricultural residues contain polysaccharides. However, these alternative ‘lignocellulosic’ feedstocks are more complex chemically. They contain a cellulose fraction, principally a polymer of easily fermentable C6 sugars, a hemicellulose fraction, principally a polymer of C5 sugars, and a non-fermentable lignin fraction which provides the structural strength of the lignocellulosic biomass. Organisms such as yeast that ferment C6 sugars do not naturally ferment C5 sugars. C5 sugars fermentation can be achieved using different micro-organisms or by modifying C6 fermenting organisms.

Work around the world for using these lignocellulosic feedstocks is concentrated on the difficult process of releasing the majority of the sugar (via hydrolysis), and then fermenting both the C5 and C6 sugars. Major hydrolysis paths being developed are: concentrated sulphuric acid, dilute sulphuric acid, and acid pre-treatment followed by enzymatic hydrolysis.

Proponents and developers of sulphuric acid technologies include Agrol Biotechnologies Ltd, the Austrian Institute for Agrobiotechnology, Arkenol, BC International, Iogen, Lund University, Masada Resource Group, the US National Renewable Energy Research Laboratory (NREL), and TVA. A variety of hydrolysis and fermentation approaches are being taken which are covered in this section. For instance Agrol is reportedly developing thermophylic (high temperature) micro-organisms that ferment both C6 and C5 sugars. JGC, an Arkenol associate, is constructing a demonstration plant in Japan. BCI intends modifying an existing commercial scale ethanol plant in Jennings, Louisiana to operate on biomass feed using dilute acid hydrolysis. Masada is targeting the cellulose fraction of municipal solid waste for its concentrated sulphuric acid route. NREL’s development is largely based on dilute acid hydrolysis followed by enzymatic saccharification and simultaneous fermentation. One approach of NREL, and the University of NSW, is to use a genetically modified organism *Zymomonas mobilis* for simultaneous fermention of C5 and C6 sugars. In Europe and North America at least seven pilot plants have been built and operated, with research and development expenditure to date estimated to total more than A$200 million.

Future directions and developments include the development of more active cellulase enzymes, more robust and stable fermentation organisms and other yield improvements through improved technologies and processes. NREL in particular believes that if a number of aspects of the biomass-to-ethanol process can be improved through research over the next ten or so years, the cost of ethanol produced from biomass could be reduced by as much as 50% from the present (hypothetical) best case estimates. This would place ethanol from wood in a very competitive position compared with ethanol made from sugar or starch industry by-products.

In parallel with work to produce ethanol from biomass, a number of groups are looking at biomass-derived sugars as feedstock for other fermentation industries. Renewable and biodegradable plastics and other industrial chemicals can be produced via fermentation pathways. Lignin, which cannot be used directly to make ethanol can still be used as fuel for heat and power generation. It also has potential for use to make other industrial chemicals and bio-based products. In the future, a large scale biomass to ethanol plant may be part of a larger complex that makes ethanol, electricity and one or more renewable industrial chemicals.

Conversion of biomass to ethanol and other products offers huge potential for the future. This is reflected in the scale of research and development underway for this development.

8.2 Introduction

Ethanol may be produced by fermentation, using yeasts or other micro-organisms to convert sugars into ethanol with CO_2 as a by-product. There is little difference between the processes in fermentations for potable alcohol (beers, wines) and those for industrial or fuel grade ethanol.

The feed for all ethanol fermentations is sugar; traditionally a hexose (a six-carbon or “C6” sugar) such as those present naturally in sugar cane in Australia and sugar beet in Europe. Thus in Queensland ethanol is already made from molasses, the low-value, sugar-containing by-product of crystal sugar manufacture.

Sugar for fermentation can also be recovered from starch, which is actually a polymer of hexose sugars (or “polysaccharide”). The corn to ethanol industry in the USA is based around the treatment of corn starch to break the starch polysaccharide into its component sugar molecules (using enzymes), which may then be fermented to produce ethanol.

Cane sugar and corn are both food crops. Their use for ethanol production is limited by their opportunity costs as human and animal feeds, and it is typically the by-products of the manufacture of food grade products that are used for ethanol production. Even then, much of the cost of ethanol from these materials is made up of the cost of the feedstock.

Biomass, in the form of wood and agricultural residues such as wheat straw, is viewed as a low cost alternative feed to sugar and starch. It is also potentially available in far greater quantities than sugar and starch feeds. As such it receives significant attention as a feed material for ethanol production.

Like starch, wood and agricultural residues contain polysaccharides. However, unlike starch:

- while the cellulose fraction of biomass is principally a polymer of easily fermented C6 sugars, the hemicellulose fraction is principally a polymer of C5 sugars, with quite different characteristics for recovery and fermentation
- the cellulose and hemicellulose in biomass are bound together in a complex framework of crystalline organic material known as lignin.

These differences mean that recovery of these biomass sugars is more complex than recovery of sugars from a starch feed. Once recovered, fermentation is also more complex than a simple fermentation of C6 sugars. Work around the world on producing ethanol from biomass feeds centres on these issues of releasing the sugars (hydrolysis) and then fermenting as much of the C6 and C5 sugars as possible to produce ethanol.

There are several different methods of hydrolysis under active investigation in the northern hemisphere:

- concentrated sulphuric acid
- dilute sulphuric acid
- use of nitric acid
- acid pretreatment followed by enzymatic hydrolysis.

Work by many of the groups investigating these technologies is summarised below, followed by a discussion of ethanol production costs.

8.3 Sulphuric Acid Technologies

A number of groups have investigated ethanol hydrolysis via sulphuric acid. Some of these are presented below, in alphabetical order. Most of the information has been gathered though meetings with the relevant groups during a study tour to North America in May 2001 by Colin Stucley of Enecon and subsequent communications.

8.3.1 AGROL and Institute for Agrobiotechnology

8.3.1.1 Organisations

Agrol Biotechnologies Ltd (Agrol) is a private company that is based in the UK and has significant shareholding by Hong Kong groups. It was formed in 1993 as a research and development organisation to utilise a range of thermophilic micro-organisms isolated by researchers at Imperial College in London.

The Institute for Agrobiotechnology (IFA) is a government research organisation based in Tulln, Austria. IFA conducts wide ranging research at the laboratory and pilot scale into a range of agricultural and environmental issues.

8.3.1.2 Technology

Agrol reports that it has developed thermophilic micro-organisms that ferment both C6 and C5 sugars to produce ethanol, and that these organisms are efficient, fast and stable. It claims that the ability to ferment at thermophilic temperatures (higher temperatures than the mesophilic yeasts and bacteria used by most other groups) helps prevent contamination of the fermentation process and thus facilitates continuous fermentation.

IFA has recently co-ordinated a Euro 1 million project aimed at developing an efficient handling and hydrolysis process for wheat straw [1]. This development includes Agrol and several other European technical and consulting companies and has been partially funded by the European Union. The project commenced in 1999.

8.3.1.3 Status

Agrol reports that it has carried out extensive successful laboratory and pilot scale fermentation of a range of feeds. Feed hydrolysis has generally been by others. Agrol is now seeking funds for a showcase (15 ML) ethanol plant in Europe.

8.3.2 APACE Research

8.3.2.1 Organisation

APACE Research is an organisation based at Dungog, NSW. It chief scientist, Dr Russell Reeves conducts research into renewable fuels, looking at ethanol from biomass and also developing emulsifying agents to stabilise ethanol/diesel fuel blends.

8.3.2.2 Technology

The APACE process for biomass to ethanol is based on three main elements:

- Concentrated, single stage acid hydrolysis technology, provided by University of Southern Mississippi and Tennessee Valley Authority (TVA). USM/TVA technology is also used for subsequent ion exclusion to recover the sugars.
- Zymomonas mobilis bacterium for simultaneous fermentation of C6 and C5 sugars, reportedly jointly developed with the University of NSW (The UNSW biotechnology team led by Associate Professor Peter Rogers has been working with *Z. mobilis* for at least two decades).

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[1] Danner H *et al* - Co-production of Electricity and Ethanol from Biomass, Publishable Final Report for Contract JOR3-CT97-7049, 2001

- Following fermentation, ethanol is extracted via a two stage process involving potassium carbonate salts. The principal aims of using salts for phase separation and ethanol extraction are to reduce the energy and waste treatment requirements for ethanol recovery by avoiding the conventional distillation step. This potassium salt technology has been developed by APACE.

8.3.2.3 Status

APACE reports [1] that all of its work to date has been carried out at the laboratory scale, using batch fermentations. APACE has been working for some time to develop funds for a pilot plant to examine the above technologies, and has had partial funding commitment of $2 million on offer from the Federal government since 1994. State Forests of NSW is also interested in supporting the pilot plant. A study in 2000 by Manildra Energy [2] has indicated that the capital cost of a pilot plant to produce 160,000 litres per year is approximately A$16 million.

8.3.3 Arkenol

8.3.3.1 Organisation

Arkenol Inc. is a privately owned company based in Mission Viejo, just south of Los Angeles in California. It was formed in 1992 as a subsidiary of ARK Energy, an independent US developer of gas-fired co-generation facilities. Initially, ethanol production was seen by ARK Energy as a mechanism to help develop new co-generation plants (via the PURPA legislation in the USA). However the concept of stand-alone plants for ethanol from biomass has subsequently been expanded by Arkenol, and also used as a basis for investigating renewable plastics and other products from biomass feeds.

Arkenol has an agreement in place with the JGC Corporation of Japan to develop opportunities for their technology in Asia and the Pacific Rim. This includes production of ethanol and also lactic acid as a feedstock for renewable, biodegradable plastics such as polylactide (PLA).

8.3.3.2 Technology

Arkenol's process for biomass to ethanol is as follows:

a) Hydrolysis of feed is conducted in two stages using concentrated acid. By using two stages, separate extraction of C5 and C6 sugars is possible. Solution is filtered after each stage to remove lignin and other insoluble components.
b) Industrial scale chromatography (resins developed by Arkenol in association with Dow) is used to separate sugars and most of the acid, with the latter being reconcentrated and reused.
c) Residual acid in the sugar solution is neutralised with lime, and the resultant gypsum is removed via centrifugation.
d) Fermentation - Arkenol uses *Z.mobilis* from NREL, modified to suit Arkenol's hydrolysate. With research collaborators Applied Power Concepts (APC), they have also developed yeast and bacteria in-house.

8.3.3.3 Status

At a meeting in May 2001 Arnold Klann, President of Arkenol noted the following:

a) Arkenol has spent US$35 million to date on ethanol and related biomass technologies.
b) Pilot plants have been operated in collaboration with Californian company Applied Power Concepts (APC) under contract for approximately 8 years.
c) The main pilot plant was operated by APC on a 16 hour/day, 7 day/week basis for extended periods, and was ultimately shut down in 2000.
d) Arkenol has been working for several years to finalise funding for its first full scale ethanol plant, near Sacramento in California and based on straw feed. Licences and permits are in place.

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[1] personal communication 1/6/2001

[2] Manildra Energy (Australia) Pty Ltd - Ethanol from Cellulosics Pilot Plant Project, Milestone No. 1 Feasibility Study, October 2000.

Through the association with JGC, a demonstration scale biomass to ethanol plant is under construction in Japan in 2002. This plant is several times larger than the pilot plant operated by Arkenol in the USA.

8.3.4 BC International

8.3.4.1 Organisation

BC International (BCI) is a private company based in Massachusetts, USA. BCI was formerly BIONOL Corporation and in the early 1990s investigated the development of a paper mill sludge to ethanol project in New York State. Another participant in that project was BioEnergy International, which held the rights to technology developed by the University of Florida for the conversion of C5 and C6 sugars to ethanol. When BioEnergy went bankrupt in 1995, BCI acquired exclusive licence rights to the technology. BCI maintains close links to the University of Florida, and has recently established a research facility close to the laboratories of Dr Lonnie Ingram, who is responsible for the University's work on ethanol-producing micro-organisms.

8.3.4.2 Technology

BCI achieves feed hydrolysis in two stages using dilute sulphuric acid. The first stage hydrolyses hemicellulose and the second stage hydrolyses cellulose. Both stages use elevated temperatures and pressures and short residence times. This approach allows separate conditions for the release of C5 and C6 sugars, which is reported as being useful to avoid the degradation of C5 sugars during the release of the C6 material. BCI notes that using dilute acid also avoids acid loss and costly acid recovery equipment associated with concentrated acid hydrolysis, and also loss of sugar that may be carbonised in a concentrated acid process.

Fermentation uses micro-organisms developed by Dr Lonnie Ingram's team at the University of Florida, principally based on genetically modified *E.coli*. It is possible for BCI to operate C5 and C6 fermentations separately but typically with the same organism.

In addition to the dual dilute acid hydrolysis approach, BCI is investigating enzymatic hydrolysis at its research facility in Florida. BCI noted that this route may be more cost effective in the longer term.

8.3.4.3 Status

Most of BCI's industrial work takes place at a site in Jennings, Lousiana. This site is an existing ethanol manufacturing facility that was purchased second hand by BCI several years ago. The facility was originally established to produce ethanol from molasses feed, and was subsequently modified so that it could also use starch (via waste grains from nearby grain handling facilities). This starch was saccharified with enzymes to produce a sugar feed for fermentation in a manner similar to the corn-to-ethanol plants in the US mid west.

The site no longer has a distillation train but does have extensive feed handling, saccharification, fermentation and product storage facilities, as well as a production plant for the yeast required. BCI has:

- retained key staff from the original facility, giving them a personnel resource with considerable full scale ethanol experience working alongside their research and pilot plant teams
- upgraded the laboratory
- modified the yeast production facility to make a small pilot plant
- built a new, larger pilot plant on the site. This plant has operated since April 2000, testing a variety of feeds including rice hulls, bagasse and wood
- purchased (second hand) equipment from a furfural plant that may be modified to provide much of the acid hydrolysis section of a large biomass to ethanol facility.

BCI intends installing a new distillation plant based on distillation columns and molecular sieves. Much of the second hand, full scale plant was purchased several years ago and it appears that its integration has been held up by lack of project funding. It is intended that much of the output of the completed plant be sold as industrial alcohol.

BCI also has plans to build full scale plants in other parts of the USA and in Spain.

8.3.5 Iogen

8.3.5.1 Organisation

Based in Ottawa Canada, Iogen is a privately owned Canadian company that manufactures and markets a range of industrial enzymes into the pulp and paper, textiles and animal feed industries. Iogen has been in operation for approximately twenty years and has been researching ethanol production for much of this time.

8.3.5.2 Technology

Iogen's process for converting biomass to fermentable sugars has been developed in-house and involves:

- pretreatment - to improve feed surface area or "accessibility". Via acid soak and heat, or modified steam explosion. Iogen notes that improvements to pretreatment over time have greatly reduced the quantity of enzyme required for hydrolysis. Pretreatment varies according to the biomass being used.
- enzymatic hydrolysis - multistage, sequential hydrolysis using enzymes to convert cellulose and hemicellulose to C6 and C5 sugars
- fermentation - occurs after hydrolysis and in separate vessels (not in parallel with hydrolysis as per some of NREL's work). Iogen's fermentation is based on yeasts, modified in-house to utilise C5 in addition to C6 sugars.

Iogen has not provided details of current conversion rates achieved, but has quoted a target of 300 litre ethanol per dry tonne of feed. It was noted that the type of feedstocks (principally agricultural residues) had an impact on conversion rates.

8.3.5.3 Status

Iogen has built and operated two pilot scale facilities. It has recently completed a demonstration scale (or" semi-works") facility at its Ottawa site. This facility uses wheat straw as feed and enzymatic hydrolysis to produce sugars. The sugars are then used for fermentation to produce ethanol, and also in separate fermentations to produce Iogen's industrial enzyme products.

Iogen has a stated focus on straws as feed material, and is working towards full scale plant opportunities in the USA and the UK. The oil company Shell has recently become a major shareholder in Iogen.

8.3.6 Lund University

Lund University is based in the city of Lund in Sweden. Its departments of Chemical Engineering and Applied Microbiology are involved in a range of relevant work, including:

- biomass pretreatment strategies
- techno-economic modelling
- microorganism selection and development.

The University has recently built a pilot scale ethanol process unit [1]. The University appears to have no affiliations with industry for ongoing development of in-house technology.

8.3.7 Masada

8.3.7.1 Organisation

The Masada Resource Group LLC (Masada) is based in Birmingham, Alabama, USA. Masada was formed in the 1980's and originally worked in areas unrelated to ethanol:

- cable television and telecommunications
- cellular phone and personal communications
- home and business security.

Masada has been actively developing its ethanol technology since 1991. Whilst other groups have focused on agricultural and forestry biomass as feedstocks, Masada has developed its ethanol business as part of an integrated approach to management of municipal solid waste (MSW).

8.3.7.2 Technology

Masada's ethanol technology has been labelled the CES OxyNol^{TM} process. It has been developed by Masada over 9 years of collaboration with the Tennessee Valley Authority at Muscle Shoals in Alabama. In the context of ethanol from municipal waste, the process may be summarised as follows:

a) Cellulosic materials are separated from MSW. Masada reports that proposed garbage feed is up to 50% cellulose on a dry weight basis.
b) These materials, plus some sewage sludge, are hydrolysed with concentrated sulphuric acid to break the cellulose down into its component sugars. Justifying the choice of the concentrated acid route, Masada noted that the use of concentrated acid for hydrolysis gave good sugar yields and avoided the expensive materials of construction needed to use dilute acid at elevated temperatures. Masada also noted that enzymatic hydrolysis was considered too expensive and too prone to inhibition by contaminants that might be found in an MSW feed.
c) Lignin is separated from the hydrolysis liquid and is used as feed to a gasifier for process steam generation.
d) The solution of sugar and acid in water is processed for sugar/acid separation and the acid is concentrated for reuse.
e) The sugar solution is neutralised (producing gypsum). It is then a feedstock for a conventional yeast fermentation step, followed by distillation of the ethanol produced.

Masada advises that most of the suitable feed material in MSW is cellulose-based, with lower amounts of hemicellulose than are normally found in green biomass feeds. Therefore, for MSW feed, Masada is fermenting only C6 sugars, and not the C5 sugars that would be released via hemicellulose hydrolysis. Masada advises that for alternative feeds (such as wood) they would provide a process capable of fermenting both C6 and C5 sugars. They are currently working on such a process in collaboration with NREL.

8.3.7.3 Status

The patented technology used in Masada's process has been under development since 1979. Masada has worked with the Tennessee Valley Authority (TVA) to develop its ethanol process and Masada does not have a laboratory or pilot plant of its own.

Masada's present focus is on its first full scale ethanol facility, to be built at Middletown in the state of New York, USA. The contract for the Middletown waste to ethanol plant was awarded in 1995.

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[1] Professor Bärbel Hahn-Hägerdal, Presentation at IEA Bioethanol meeting, Breckenridge CO, May 2001

Final permitting was completed in July 2000 but it would appear that ongoing community consultations and other issues have slowed the project. The current project status is not known.

The Middletown plant is based on receival of some 230,000 tons per year of MSW (plus more than 250,000 tonne per year of sewage sludge cake) from a total of 24 area municipalities. The plant has a planned output of approximately 9.5 million US gallons (36 ML) of ethanol per year.

8.3.8 NREL

8.3.8.1 Organisation

The National Renewable Energy Laboratory (NREL) is part of the United States Department of Energy. Based in Golden, Colorado (just out of Denver) NREL is the DOE's principal organisation for the management and implementation of research into renewable energy, including liquid transport fuels such as ethanol. NREL activities include work in-house, liaison with other US government groups (such as the Oak Ridge National Laboratory in Tennessee, which focuses on biomass feedstocks), work with specialist sub-consultants and the management of independent work by other, private groups that are funded by the US government. NREL's activities in relation to ethanol include:

- development of micro-organisms. This includes work looking at introducing the capability to ferment C5 sugars into genetically modified bacteria and also into yeasts.
- laboratory work
- process trials and optimisations using its biomass to ethanol pilot plant. The plant comprises a number of sections which may be operated independently. For example, feed pretreatment work can be carried out in isolation from the need to conduct pilot scale fermentation or distillation work.
- costing studies for full scale facilities, typically using simulation models such as ASPEN and working in conjunction with specialised engineering consultants[1].

NREL can work with companies seeking to develop biomass to ethanol plants. They can license their micro-organisms and technology, or carry out work on a fee for service basis.

8.3.8.2 Technology

NREL has investigated several different technologies. Their current work is generally based on dilute acid hydrolysis followed by enzymatic saccharification and simultaneous fermentation. Principal process steps and indicative conditions are as follow:

1. Dilute acid (0.5% sulphuric) hydrolysis at high temperature (190 ^{0}C) is used to convert most of the hemicellulose to soluble C5 sugars and "exposes" the cellulose for subsequent enzymatic hydrolysis.
2. The solution is flash cooled, which also helps remove degradation products that are detrimental to the fermentation step. If acetic acid is present it is removed, for example via ion exchange. If necessary, pH is balanced via over-liming.
3. Simultaneous saccharification and fermentation (SSF) then takes place. Two principles are at work here:
    a) enzymatic saccharification of cellulose is "product inhibited". This means that as the concentration of C6 sugars (released from the cellulose) increases in the solution, the cellulase enzyme is inhibited from further action on the cellulose feed. Continuous removal of the C6 sugars allows the cellulase to work more effectively. This may be

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[1] NREL Report No. NREL/TP-580-26157 - *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-current Dilute Acid Pre-hydrolysis and Enzymatic Hydrolysis. Current and Futuristic Scenarios.* July 1999

achieved by fermenting the sugars as soon as they are available, conducting the fermentation in the same vessel as the hydrolysis is occurring.

b) Organisms such as yeast naturally ferment C6 sugars, however they do not naturally ferment C5 sugars and need to be modified to achieve this. The fermentation of a mixture of C6 and C5 sugars may therefore be carried out in separate fermenters using organisms that can ferment each of the C6 and C5 sugar feedstocks. Alternatively, co-fermentation can take place using a genetically modified organism that can utilise both C6 and C5 sugars. The NREL model assumes co-fermentation of glucose (C6) and xylose (the major C5 present) via *Z.mobilis* bacteria that have been genetically modified for this task.

4. The fermented broth is then sent to distillation for ethanol recovery.

8.3.8.3 Status

Pilot plant - NREL opened its biomass to ethanol pilot plant in 1994, and has made equipment additions and modifications since then. This plant is sized to process up to 1 ton of biomass per day, and uses four 9000 litre fermenters. Collaborative work with the pilot plant has included programs with Amoco, Arkenol, BC International, Sealaska and others. Investigations have considered hydrolysis and fermentation with yeasts and bacteria. The plant is now used on an as required basis by NREL for in-house or collaborative work.

Modelling - In 1999 NREL published an extensive report on the anticipated costs of a full scale ethanol production facility based on dilute acid hydrolysis and simultaneous saccharification and fermentation (SSF). This report also included a range of short term and long term projections for cost savings in ethanol technology and the resultant impact on ethanol production costs. Additional information focusing on corn stover feed was published in 2002. [1]

Feed stocks - NREL's in-house work on biomass to ethanol has included work with hardwood feeds, such as yellow poplar used in their 1999 costing report. More recently they have focused on agricultural residues as feed, particularly corn-stover - the lignocellulosic material left behind in the field after corn is harvested. Agricultural residues are perceived to be a large, relatively low cost feed for ethanol in the United States and corn-stover has the added advantage that it is available to an industry already very familiar with technology and liquid fuels. The corn (starch) to ethanol industry provides most of the current US supply of fuel ethanol.

Enzymatic hydrolysis - NREL has identified cellulase enzymes and SSF as the technology with the most potential for cost effective ethanol production in the future. NREL is conducting work in-house to create suitable yeasts or bacteria capable of efficiently fermenting both C6 and C5 sugars. It has also placed significant contracts (totalling almost $30 million) for work by US enzyme companies Genentech and Novozyme to develop more cost effective cellulase enzymes over the next few years. The reported target is to bring down the cost of these enzymes tenfold per unit of activity. There is some debate as to the baseline levels of activity. (Current costs for the enzymatic hydrolysis step are variously reported as between US$0.45 and US$0.60 per gallon.)

Note that cellulase enzymes often work best at temperatures higher than optimal for fermenting organisms. Thus there needs to be successful collaboration between groups for both enzymes and fermenting organisms to perform optimally in a combined vessel. For this reason, some other groups are investigating organisms that are capable of producing ethanol at higher temperatures than typical yeasts.

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[1] NREL Report No. 6483 may be downloaded from NREL website

8.3.9 Sealaska

Sealaska is an Alaskan group interested in providing ethanol for the Alaskan market via a small wood to ethanol plant in that state. No direct contact has been made with Sealaska by this study team. A literature search has indicated that a feasibility study was carried out in 2000 by Merrick Consulting Engineers, however no study reports were found. No indication of funding or timing could be found. It appears that the process technology would be provided by a group such as NREL.

8.3.10 TVA

8.3.10.1 Organisation

The Tennessee Valley Authority (TVA) is the largest public power company in the United States, with generating capacity of almost 30 GW from fossil fuel, hydro-electricity and nuclear powered facilities across seven states.

TVA has run a biomass research and development program for almost twenty years. This work has included energy crop production, co-firing trials and work on biomass to renewable energy alongside TVA's other renewable energy work. TVA established the Public Power Institute (PPI) in 1999 to be responsible for these activities. The PPI biomass facilities are based in Muscle Shoals, Alabama.

8.3.10.2 Technology

TVA has investigated a range of biomass to ethanol process pathways, including work with both dilute and concentrated acid hydrolysis. They have conducted work with a number of companies seeking to develop biomass to ethanol facilities. They have also collaborated with specialist equipment vendors.

8.3.10.3 Status

TVA has reportedly spent more than US$50 million on facilities and research in the time it has investigated biomass to ethanol. At Muscle Shoals it can provide laboratory and pilot scale equipment for collaborative work using a range of pretreatment equipment, acid concentrations and micro-organisms. TVA has worked with US hardwood feeds, both as single species and mixed species feeds. TVA has also modelled full scale ethanol processes using the alternatives of concentrated and dilute acid and enzymatic hydrolysis.

8.3.11 Summary

There is considerable existing and planned activity to develop biomass to ethanol technologies:

- at least seven pilot scale facilities already built and operated in North America and Europe
- probably well in excess of A$200 million spent overseas to date on facilities and research
- several demonstration-scale and full-scale facilities at advanced stages of project development
- more than US$30 million allocated in the USA alone for development of cellulase enzymes over the next few years
- other research programs in place to investigate improvements to processes and micro-organisms.

The general impression given by interviewees during a May 2001 study tour by Colin Stucley was that several different technologies for biomass to ethanol are available now, but are capable of significant technical/cost improvements over coming years. The major hurdle to construction of full scale plants was generally noted by US groups as finalisation of suitable project funds for first-time plants. Almost without exception, the organisations contacted were interested in collaboration, and utilisation of their work in Australia.

The status of various technologies is summarised in Figure 8-1 below.

	Arkenol	**BCI**	**Iogen**	**Masada**	**NREL**	**TVA**
Current feed priority	Seem flexible, driven by low cost.	Bagasse, rice straw (but have also tested hardwoods)	Cereal straw	Municipal Solid Waste (but have also tested hardwoods)	Corn stover (crop residues), but have also tested hardwoods.	Variety of feeds, no preferences.
Pretreatment			Hot, dilute acid soak		several options	several options
Hydrolysis to release sugars	Concentrated acid	Two stage dilute sulphuric. Research on enzymic hydrolysis.	Enzymatic	Concentrated sulphuric	C5 - dil. sulphuric C6 - enzymes	Concentrated & dilute sulphuric
Fermentation	Modified NREL *Z.mobilis*	Uni of Florida engineered organism for C5 and C6.	Yeast, modified for C5 and C6.	Conventional yeast, for C6 only. Also have organism available for use of both C5 & C6.	Engineered bacteria, but are now moving to yeast with introduced C5 pathway.	
Pilot plant work	Shared plant used over several years then dismantled. New JGC pilot plant in Japan.	Two pilot plants at Jennings, currently in use.	Two plants built and operated in-house.	Used the TVA plant	Pilot plant in place, used on assignment.	Range of pilot plant facilities, available on assignment.
Commercial status	Sacramento CA project appears to have faltered. Small full scale plant being built in Asia with JGC.	Closing finance to complete full scale plant at Jennings, LA, based mainly on 2nd hand equipment.	Small full scale plant already in operation in Ottawa.	Closing finance for first plant, Middletown NY	No plans	No plans

Figure 8-1: **Summary of Major Technology Providers**

8.4 Other Technologies

8.4.1 Nitric Acid Hydrolysis - HFTA/University of California

8.4.1.1 Organisation

HFTA is a company formed to commercialise technology developed at the University of California (UC). It is based in Oakland, California and has ongoing personnel and laboratory links with UC.

8.4.1.2 Technology

The HFTA technology is based on nitric acid for biomass hydrolysis instead of sulphuric acid. The process was developed at the University of California. No further details have been found in any general literature search.

8.4.1.3 Status

HFTA report[1] that work test work has been carried out using a 2 litre batch reactor at the UC laboratory to investigate sugar yields.

HFTA note that Pro-Forma Systems of Colorado have conducted an economic comparison of dilute sulphuric and dilute nitric acid processes and concluded that the installed cost of ethanol plant per gallon was significantly lower for the nitric acid process. However it is important to view these data in the light of the limited extent of nitric acid hydrolysis laboratory work that has taken place.

8.4.2 Gasification/Bioconversion

As an alternative to the hydrolysis of biomass to release sugars, it is possible to gasify the biomass to produce a syngas rich in CO, CO_2 and H_2, which may then be metabolised by selected micro-organisms to produce ethanol.

In contrast to the acid hydrolysis route, there appear to be no activities towards full scale plants using this process route and it is presented here only for information. Two proponents of this process are introduced below.

8.4.2.1 Bioengineering Resources

Bioengineering Resources Inc. (BEI) is based in Fayetteville in Arkansas. BEI offers a process route that is different from the other fuel ethanol organisations described in this report. BEI reports that it has developed a process that first gasifies the biomass and then uses the syngas produced as feed for organisms that can ferment the syngas to produce ethanol. They reportedly have laboratory and pilot scale facilities. BEI will provide details if confidentiality agreements are put in place.

8.4.2.2 Oklahoma State University

The 23rd Symposium on Biotechnology for Fuels and Chemicals at Breckenridge Colorado[2] included a presentation by Randy Lewis of the Oklahoma State University on gasification/bioconversion. Lewis spoke of the University's work in isolating organisms capable of conversion of syngas to ethanol, butanol and acetate. The University has reportedly investigated this process at the laboratory scale.

It was also suggested at that symposium that a catalytic approach for converting syngas to methanol will be more cost effective. Groups such as CE-CERT at the University of California Riverside are investigating methanol production via this catalytic pathway.

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[1] G.A. Craig, HFTA - *What's new with nitric acid hydrolysis.* Paper presented at the Western Biomass Conference, Sacramento California, September 2000

[2] 23rd Symposium on Biotechnology for Fuels and Chemicals, Breckenridge Colorado 6-9 May, 2001 - conference proceedings in print

8.5 Costs of Production

8.5.1 Example: Ethanol from Molasses

In order to understand some of the influences on costs for wood to ethanol plants it is helpful to first consider the costs of plants to manufacture ethanol from molasses. Molasses to ethanol plants are widely used around the world.

In late 2000, European ethanol plant manufacturer Vogelbusch provided Enecon with capital cost estimates for ethanol plants using molasses as feed material (ie. no hydrolysis step and no C5 fermentation). The prices were provided for plants built in Europe, and for reporting below have been converted to Australian costs by estimating the local and imported components and likely labour and material rates in Australia as compared with Europe (refer Attachment 4). The prices included approximately 10% for equipment to handle dunder (the liquid residue from the distillation process).

These prices compare well with cost data from the Energy Research and Development Corporation (ERDC) report *Biomass in the Energy Cycle* 1994[1], inflated by 20% to reflect current prices. They are somewhat higher than cost estimates for molasses-based plants provided by the Praj group of South East Asia.

Plant capital costs were estimated for three plant sizes: 10 ML/year, 30 ML/yr; and 100 ML/yr are shown below (Figure 8-2).

10 ML / yr	**30 ML / yr** *(prices in A$ million)*	**100 ML / yr**	**Notes:**
18	35	72	from ERDC report (updated from 1994)
27	39	64	from Vogelbusch (corrected to Aust pricing)
22	37	68	Average capital cost figures (A$M)
2.2	1.2	0.7	Capital cost (A$M) per annual ML of capacity

Figure 8-2: Ethanol Plant Costs - Molasses Feed

If operating costs, feed purchase and a profit margin are considered, total costs for production of ethanol from molasses can be developed. These are summarised in Figure 8-3 below:

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[1] Energy Research & Development Corporation - *Biomass in the Energy Cycle*. Report by Strategic Industry research Foundation, September 1994.

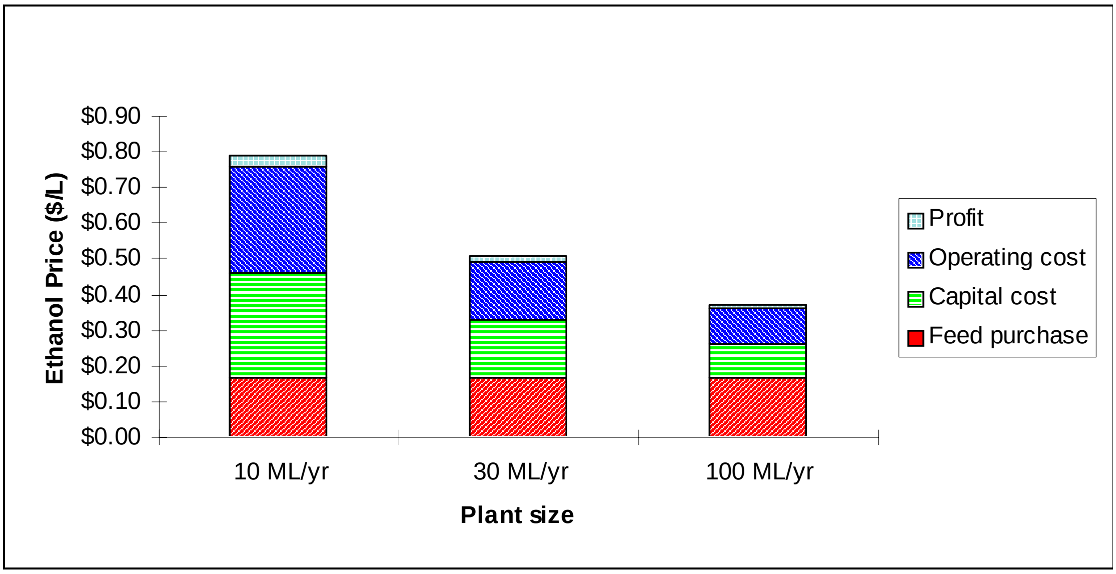

Figure 8-3: Ethanol Price Break-down - Molasses Feed

For these three plant sizes, with feed material at constant price, the production cost of ethanol varies from 37 to 79 cent/litre. For all plants, molasses feed is assumed to be available at $45 /tonne, with 270 litre ethanol produced per tonne of molasses.

Note that constant feed price is assumed above to demonstrate the effect of increased plant size with other factors held constant. If feed is derived from forestry or agricultural operations feed costs may be influenced by the transport distance from feed source to processing facility. Larger facilities may need to gather feed from greater distances, and the larger transport costs may ultimately offset the benefits achieved through plant economies of scale. The impact of feed supply and cost need to be considered on a case by case basis.

8.5.2 Cost Estimates - Wood to Ethanol

Of the organisations contacted during this study, only NREL provided significant data on the costs for ethanol from woody biomass. A literature search was also conducted at the start of this study. The most comprehensive recent data found on the costs of biomass to ethanol plants is that by the NREL from July 1999.

The NREL report develops capital and operating cost estimates for a hypothetical plant sized to produce 200 ML ethanol per year. All costs provided in the report relate to construction and operation in the USA.

a) The total production cost at such a plant, including feed costs, is US$1.44/US gallon.
b) Feed cost (US$ 25 per dry ton, for 68 gallon ethanol per dry ton of feed) contributes US 37 cents per gallon. If this is removed from costing, the ethanol price reduces to US$1.07/gal.

A <u>very preliminary</u> conversion of this cost to an Australian plant can be made as follows:

a) The conversion of capital cost to an Australian location is estimated to be on the basis US$1.00 = A$1.4 (See 17.3 Attachment 3).
b) Operating cost will be a mix of labour, consumables, and financing charges. Assume that these costs "convert" directly on a dollar for dollar basis.

c) A biomass-to-ethanol plant is more capital intensive plant than the molasses plant above, so the impact of capital cost on product price may be greater than operating cost. Thus revised capital and operating cost might be 1.07 by 1.25 = A$ 1.34/gal
d) Assume plantation feed available at A$60 per dry tonne (approx. $35 per green tonne). This will contribute Aust. 88 cent/gal
e) Total cost will be A$2.22/gal, or 59 cent/litre.

This estimate is extremely simplistic and should be used merely as a guide to the worth in undertaking further, more detailed costing work. Another estimate, using different feed costs and project parameters, is provided in Section 11.

Notes:

1. The NREL estimate is based on costs for the "nth" plant, reflecting a situation where several plants are already in operation and this nth plant does not have costs that may be expected for early full scale plants involving new technology. While no full scale wood-to-ethanol plants are in operation, considerable work is currently underway to finalise funding of several full scale plants in the USA and Europe.

2. The NREL model is based on dilute acid hydrolysis followed by simultaneous saccharification and fermentation.

3. The NREL model assumes a large plant (200 ML), however plants of this size are now being built in the US corn-ethanol industry. The benefits of such scale are shown clearly by the three costs for molasses-ethanol plants above.

8.6 Future Developments

8.6.1 Process Improvements

There is scope for significant improvements to the current technology for producing ethanol from wood. If achieved these improvements will reduce the cost of ethanol produced. The US Department of Energy (DOE) has identified several areas for particular attention, which are described below:

Cellulase Enzyme Development
For processing technologies that include cellulase enzymes, the enzyme (including its preparation) represents a significant component of the final ethanol cost. Improvements in enzymes are therefore one method of reducing the ethanol cost over coming years. DOE enzyme programs are focused on the following attributes in particular:

- Increased thermal stability
- Improved cellulase binding domain
- Improved active site
- Reduced non-specific binding.

DOE is funding work by two major US enzyme companies (Novozyme, Genencor) over several years, with the aim of reducing the cost of using cellulase enzymes ten-fold.

Fermentation Organism Development

Micro-organisms have been developed for industrial use that are capable of fermenting some hexose and pentose sugars. Work by DOE and others is addressing improvements to these organisms, including:

- the ability to ferment a wider range of pentose sugars (such as arabinose and galactose as well as xylose), thereby increasing the overall conversion of wood to ethanol
- the ability to ferment at higher temperatures, allowing more synergy between hydrolysis and fermentation in simultaneous systems
- greater fermentation rates and better ethanol tolerance.

Process Development and Integration

Advances in cellulase enzymes and fermentation organisms must be suitable for integration with industrial processes if their benefits are to be reflected in reduced costs at the industrial scale. Effective use of new cellulases can be enhanced if physical pretreatment of the biomass (eg. steam, hot water, acid, pressure extrusion) is developed with an understanding of the requirements for optimal enzyme performance.

For those technologies that do not use enzymes for hydrolysis, improvements to acid hydrolysis are also possible to recover the maximum amount of sugars in a cost effective manner. Developments include the operating conditions for hydrolysis, which influence capital cost (eg. materials of construction, equipment sizing) and operating costs (eg. acid utilisation and recovery). Improvements to hydrolysates from an acid-based system may be integrated with organism selection that is best suited to the final mix of sugars and other components in the hydrolysed feed.

8.6.2 Yield and Cost Improvements

The potential impact of the process improvements described above are demonstrated in the yield improvements that would follow. Based on its model for a large plant using simultaneous saccharification and fermentation, DOE has estimated that if all process improvements are realised in the time frame envisaged, the following yield and cost benefits should occur (Figure 8-4):

Year	**Model/Improvement**	**Yield** (US gallon per dry ton of feed)	**Cost** (US$/gal)
1999	DOE/NREL process estimate - wood feedstock with co-saccharification (hydrolysis using enzymes) and fermentation.	68[1]	1.44
1999	“Best of industry” assuming improved hemicellulose conversion, enzyme production and ethanol fermentation.	76	1.16
2005	Higher xylose sugar yield at pretreatment. Cellulase enzymes improved three-fold. Improved fermentation kinetics.	81	0.94
2010	Optimised pentose sugar recovery. Cellulase enzymes improved ten-fold.	94	0.82
2015	Plant biotechnology provides 20% more carbohydrate in feed.	112	0.76

Figure 8-4: Summary of Projected Improvements in Ethanol Processing

Note that these estimates are for a large scale plant in the USA, not Australia, with feed provided at US$25 per dry ton.

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[1] This equates to approximately 140 litres per green tonne of feed.

Achieving all of these targets will require a concentrated and well funded program of RD&D, by a number of groups, over a fifteen year period. The cost reductions identified assume not only that these programs will all proceed but that all of their targets are achievable and that all programs will be successful. Nevertheless, the reductions identified represent an ethanol cost in fifteen years that is approximately half the likely cost today.

8.7 Co-production of Electricity

When biomass is hydrolysed to break down cellulose and hemicellulose into component sugars there is residual matter that includes un-hydrolysed cellulose and hemicellulose and other material such as lignin. This hydrolysis "residue" can be used as fuel for combustion or gasification to raise steam and generate electricity. The steam and electricity can be used on-site for the energy requirements of the ethanol facility, thus improving the life cycle analysis of the ethanol. The electricity that is generated may also be considered as a significant product in its own right. In this way the economics of hydrolysis may be considered differently; instead of maximising the production of sugars for ethanol, the sugar production is undertaken until it is more cost effective to use un-hydrolysed material as fuel for electricity generation

Several groups have studied systems for the co-production of ethanol and electricity. For example, researchers at IFA-Tulln report that the process they have investigated for hydrolysis of wood converts approximately 25% of the dry matter to sugars, leaving 75% for boiler fuel.

The balance between production of ethanol and electricity may be decided on economic grounds. Each product will have a known market value. Variation in the processing steps will allow some variation in the relative amounts of each product to be made. If ethanol is the higher value product, optimising for ethanol recovery will be sensible until the additional cost of process improvements to increase recovery are a greater cost than the revenue received for the additional ethanol produced.

As part of an assessment of process improvements anticipated in coming years, NREL note that increased ethanol recovery will be at the expense of reduced biomass residue for electricity generation. In fact it is possible that the balance will move to the point where, even with on-site power generation from residue, there will be a need for additional power from outside the plant to provide the plant's requirements. There will be no export of renewable electricity in these circumstances.

8.8 Discussion

8.8.1 Process Selection

8.8.1.1 Hydrolysis

The study has identified a range of techniques for processing biomass to produce sugars via hydrolysis, using:

- concentrated acid
- dilute acid
- enzymes.

Each process has been demonstrated for a range of feed stocks and each appears to have its own strengths and weaknesses:

- Concentrated acid hydrolysis requires the separation of sugars from an acid-rich solution, via industrial chromatography. The acid stream is then reconcentrated for reuse. Both Masada and Arkenol have noted their efforts, and success, in developing systems for this process step.

However, TVA has suggested that acid losses in the separation step may still be a significant operating cost.

- In the work conducted in the USA it appears that concentrated acid is favoured where there is greater variability in feed characteristics, for example Masada's work with MSW feed. While dilute acid work has been undertaken with multiple feeds, it appears that there is a preference for only one feed stock at any time. With respect to enzymatic hydrolysis, Iogen noted that enzymes may be adversely influenced by contaminants found in MSW.

- Dilute acid hydrolysis does not require the acid separation and reconcentration needed in concentrated acid hydrolysis. However dilute acid hydrolysis is carried out at temperatures of approximately 200 deg C and materials of construction for hydrolysis vessels are relatively expensive. The conditions are such that careful control is required for optimal hydrolysis of hemicellulose and cellulose. Hemicellulose hydrolyses more easily than cellulose, and the pentose sugars released in hemicellulose hydrolysis may be degraded (and thus lost as fermentation feed) if subjected to a more rigorous cellulose hydrolysis.

- Both dilute and concentrated acid systems appear well developed relative to enzymic hydrolysis. Current enzyme systems are hampered by the high costs and low activities of the hydrolysis enzymes or "cellulases". Enzymic hydrolysis is more complex than acid hydrolysis if one considers that there may be a range of enzymes working in parallel at any time. For example, there are enzymes that remove sugar molecules one at a time from the end of the cellulose and hemicellulose polysaccharides. There are also enzymes that break the long chain polysaccharides into shorter chains (oligosaccharides and disaccharides). Each enzyme may be inhibited by the products it creates. It is this point that leads to interest in simultaneous hydrolysis (or saccharification) and fermentation (SSF), so that the sugars produced by the various cellulase enzymes are quickly fermented to ethanol and do not have the chance to inhibit the production of more sugars. NREL favours SSF, whereas Iogen favours separate hydrolysis and fermentation.

When advances to hydrolysis technologies are considered, they are generally discussed as improvements to cellulase enzymes, hopefully bringing the cost of enzymic hydrolysis down so that it is preferred over acid hydrolysis. As noted above, NREL has recently awarded contracts totalling almost US$30 million to two US enzyme companies to work on this problem. BCI, while currently using the dilute acid approach, is also conducting work to improve enzymic hydrolysis as a possible alternative technology in the future.

8.8.1.2 Fermentation

The principal difference between ethanol from biomass (wood, agricultural residues) and ethanol from starch and cane sugar/molasses feeds is the need to ferment significant quantities of pentose (C5) sugars released via hydrolysis of the hemicellulose present in the biomass. Hemicellulose is not similarly present in starch or cane sugar/molasses feeds.

Thus while yeast, or a bacterium such as *Zymomonas mobilis*, may be used successfully in fermentation of a C6 feed from hydrolysed starch (as in the corn to ethanol industry) or cane sugar/molasses, these same organisms are not immediately suitable for fermentation of biomass sugars to ethanol unless they are first successfully modified to allow their metabolic processes to use C5 sugars as a feed.

Thus most of the work on biomass to ethanol fermentation around the world focuses on development (naturally or via genetic manipulation) of micro-organisms that will metabolise both C6 and C5 sugars to ethanol, quickly, with high yields, and with an organism that is stable and robust enough to thrive in an industrial environment.

Development of suitable micro-organisms includes the following:

- Some groups work with the well understood brewing yeasts, such as *Saccharomyces cerevisiae*, and modify them to metabolise C5 sugars.
- Others (including the University of NSW) work with the bacterium *Zymomonas mobilis* to achieve similar results.
- The University of Florida has carried out extensive genetic manipulation work with *E.coli*.
- The British based group Agrol is working with different micro-organisms, thermophilic bacteria that apparently naturally ferment both C5 and C6 sugars.
- Work at Melbourne University includes research with organisms from other groups and fundamental work to better understand the metabolic pathways involved in ethanol production.

8.8.2 Lignin

Lignin is a complex crystalline material that acts as a framework to hold the cellulosic components of wood together. It is a physical barrier to effective softening and hydrolysis of wood by acid, steam etc. Lignin can not be converted to fermentable sugars, however it can be burnt or gasified for a combination of waste disposal and energy recovery for steam and power.

There will be significant quantities of lignin available from any large scale ethanol plant. For example, a 100 ML plant producing 250 litre of ethanol per dry tonne of wood will require 400,000 dry tonne/year of feed and potentially generate some 80,000 tonne/year of lignin.

In the paper industry, lignin is a byproduct of the pulping process. Much is burnt as fuel, but there are also many products routinely made from lignin. These vary according to whether the lignin is a byproduct of a sulphite or Kraft pulping process and include:

- dispersants, used in the manufacture of concrete, ceramics, gypsum etc
- binders, for animal feed, bricks, dust suppression etc
- dyes
- additives to agrochemicals, asphalt and other products
- resins.

Several companies in Europe and North America specialise in the manufacture of products based on lignin sourced from the paper industry. Recent presentations on lignin products[1] highlighted the multitude of products that are already made from lignin, but stressed that economics on many products were only slightly above use of the lignin as boiler fuel. It was noted that of some 50 million tonnes of lignin material generated annually in the pulp and paper industry around the world, approximately 1 million tonnes were used in a range of chemical applications, with the balance being used as boiler fuel.

In many studies of wood to ethanol plants, the lignin produced is considered as boiler fuel, partly to improve the greenhouse gas balance for the fuel ethanol to be produced. Use of a renewable fuel to generate plant steam and electricity will assist the life cycle analysis for the project. However the establishment of a relatively small scale boiler and steam turbine to generate power from lignin combustion will often be more costly than to use grid-supplied power, even if the latter is from fossil fuels.

There is some work underway to develop value added opportunities for lignin in the transport fuel industry. The oxygen present in lignin means that it has the potential to be used as feedstock for the

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[1] Presentation at the lignin utilisation session of the 23rd Symposium on Biotechnology for Fuels and Chemicals, Breckenridge CO, May 2001

production of fuel oxygenates. Personnel at the University of Utah are investigating the possibility of "cracking" lignin and processing it into chemicals that can be used as octane boosters in liquid fuels.

In Australia, CSIRO's Molecular Biology group has initiated work to investigate biotransformation of lignin, with the aim of developing higher value products from lignin feed and thus improving the overall economics of an integrated plant producing ethanol and other products.

8.8.3 Feedstock Selection

The biomass feed chosen for ethanol manufacture influences the selection and optimisation of processing technology. Feed characteristics will impact on the costs of pretreatment and hydrolysis, as well as optimisation of fermentable sugars and the final balance between ethanol recovery and use of residues for generation of electricity and process heat. Several general observations can be made:

- Feeds that involve supply of mixed species appear to be too complex for efficient hydrolysis by dilute acid or enzymes. So, if the greatest range of processing options is desirable, particularly the potential to use the anticipated improvements in enzymes over coming years, a feed with relatively constant physical and chemical characteristics would appear to be preferable.

- Pretreatment of the feed is useful to make cellulose and hemicellulose "accessible" for hydrolysis. Feeds that are more easily treated by techniques such as acid, steam explosion, hot water soaking may offer a cost advantage.

- At present hexose sugars are more easily fermented than pentose sugars. Also, some pentose sugars (eg. xylose) are easier to ferment than others. If these preferences remain, there could be an economic incentive to select feeds that maximise the production of these sugars.

The opportunities for cost reduction through improvements to feed composition are interlinked with the costs for feed supply and for feed processing based on a selected technology. Greater understanding of:

- the most likely pathways for hydrolysis in 10 -15 years
- likely fermentation developments
- the impact of feed supply and ease of processing on the final ethanol cost

will assist in the design of a suitable program for development of Australian wood feeds.

9. Energy Technologies – Methanol

9.1 Summary

Methanol is one of the most commonly used chemicals in the world, with global production estimated at 32,000 billion litres per year, overwhelmingly produced from natural gas. Over a quarter of the methanol produced world wide is presently directed towards the production of methyl tertiary butyl ether (MTBE), a petrol additive which is now falling out of favour for environmental and health reasons. A future market for methanol is possible as a fuel for vehicles using fuel cells.

Modern production of methanol involves three steps. These are:

- Generation of a synthesis gas from the natural gas feedstock to produce carbon monoxide and hydrogen via steam reforming.
- Upgrading the synthesis gas, primarily to remove carbon dioxide and contaminants.
- Methanol synthesis and purification. This is achieved by reacting the hydrogen and carbon monoxide gases with steam over a catalyst in the presence of a small amount of carbon dioxide at elevated temperature and pressure.

Methanol production from biomass would be similar to production from natural gas. The main difference would be producing the synthesis gas through gasification of biomass. The requirements and steps for synthesising methanol are well determined: pre-treatment and conditioning of the biomass, gasification (indirect or oxygen blown preferred to minimise nitrogen in the feed gas), purification of the gas, conditioning of the gas to attain correct ratios of constituents, methanol synthesis (usually over a copper-zinc catalyst), followed by purification of the methanol through multistage distillation. Gasification of biomass is still a relatively immature technology and gasification for subsequent synthesis is somewhat different to gasification for heat and power use. To our knowledge there are no integrated test facilities or commercial plants for gasification and methanol synthesis in operation or being planned.

Engineering and costing studies have been conducted for a 390 ML/a methanol plant in Sweden, requiring some 1.3 million tonnes of green biomass feed per year. The energy efficiency of this plant was estimated at 57 percent, i.e. the percentage of energy in the methanol as a proportion of the input energy in the biomass. The estimated capital cost for this plant was estimated at US$417 million. Interestingly, this Swedish study notes there is little scope for major technical or cost improvements, as the processing steps are well known and mature through the natural gas-to-methanol industry.

There is some merit in using dual feeds of natural gas and biomass for methanol production. Such dual use would overcome the disadvantage of the low hydrogen/carbon ratio of biomass and the excess hydrogen occurring through use of natural gas. The Swedish report also notes a possible benefit of co-producing electricity with methanol. Such co-production in the Australian context would need to carefully assessed to account for the relative selling prices for electricity and methanol.

9.2 Introduction

Methanol is a colourless, odourless and nearly tasteless alcohol, with the simplest chemical structure of all the alcohols: CH_3OH. It is also one of the most commonly used chemicals in the world today, with total world production estimated to be 32,000 billion litres per year.[1] Much of this production is in the USA and Europe, where methanol is used as the feedstock for the production of methyl tertiary butyl ether (MTBE), a widely used additive to boost octane levels in petrol (acting as an "oxygenate"). In 1997 27% of the world's methanol production was used to make MTBE [2]. However, recent problems with contamination of groundwater by MTBE in the USA have led to reductions in its use and expanded production of ethanol in that country as an alternative oxygenate for petrol [3].

9.2.1 Early Recovery from Biomass

Methanol and other chemicals were routinely extracted from wood in the 19th and early 20th centuries. However, the original route for methanol recovery from biomass was quite different to the route proposed today. Methanol was originally recovered from wood as a by-product of charcoal manufacture, and was often called "wood alcohol". Pyrolysis (heating wood in the absence of air) to above 270 ^{O}C in a retort causes thermal cracking or breakdown of the wood and allows much of the wood to be recovered as charcoal. The watery condensate leaving the retort contained methanol, amongst other compounds. Typically, approximately 16kg of methanol could be recovered per 1000 kg of air-dried wood that was carbonised. [4]

9.2.2 Modern Production from Natural Gas

In 1923, BASF started commercial production of methanol from synthesis gas (a mixture of H_2, CO and CO_2) by a catalytic process[5]. Now almost all the methanol used world-wide comes from the processing of natural gas. In general, methanol production from natural gas feed consists of three steps.

a) synthesis gas (syngas) generation - in the case of natural gas feed, syngas production consists of converting methane (CH_4) into carbon monoxide (CO) and hydrogen (H_2) via steam reforming.

b) syngas upgrading - primarily removal of CO_2, plus any contaminants such as sulphur.

c) methanol synthesis and purification - reacting the CO, H_2 and steam over a catalyst in the presence of a small amount of CO_2 and at elevated temperature and pressure. The methanol synthesis is an equilibrium reaction and excess reactants must be recycled to optimise yields.

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[1] Governors' Ethanol Coalition, USA - http://www.ethanol-gec.org/clean/cf05.htm

[2] *Methanol supply and its role in the commercialisation of fuel cell vehicles* - ETSU F/02/00142/REP - 1999 Report for the Energy Technology Support Unit of the UK Department of Trade and Industry

[3] CRC for Water Quality and Treatment - Health Stream, Issue 23, September 2001

[4] FAO Forestry Paper No. 63, 1985 - Industrial Charcoal Making. ISBN 92-5-102307-7. http://www.fao.org/docrep/X5555E/x5555e00.htm

[5] De Boer AJ, Den Uil H - *An evaluation of three routes for the production of liquid fuels from biomass* - ECN-R-97-001, January 1997

9.3 Methanol from Biomass

Modern methods proposed for the production of methanol from biomass involve the conversion of the biomass to a suitable synthesis gas, after which processing steps are very similar to those developed for methanol from natural gas. Note that:

- The gasification techniques proposed are still at an early stage of development using biomass feed, with no units operating commercially yet to make gas optimised for methanol production.
- The proposed methanol synthesis techniques are based on similar techniques used widely already with natural gas as feed.
- No group has yet combined all stages in an integrated test facility or commercial production unit to make methanol from biomass feed.

Proposed processing steps are described in some detail by De Boer and Den Uil (see footnote 5), which has been summarised below.

1. Pretreatment

Before biomass can be gasified it must be pre-treated to meet the processing constraints of the gasifier. This typically involves size reduction, and drying to keep moisture content below specific levels.

2. Gasification

Biomass gasification involves heating biomass in the presence of low levels of oxygen (ie. less than required for combustion). Above certain temperatures the biomass will break down into a gas stream and a solid residue. The composition of the gas stream is influenced by the operating conditions for the gasifier, with some gasification processes more suited than others to producing a gas for methanol production. In particular, simple gasification with air creates a synthesis gas stream that is diluted with large quantities of nitrogen. This nitrogen is detrimental to subsequent processing to methanol and so techniques using indirect gasification or an oxygen feed are preferred. For large scale gasification, pressurised systems are considered to be more economic than atmospheric systems. Two technologies are generally considered in recent studies of biomass to methanol:

- The IGT/Renugas technology that was tested at full scale in Hawaii last decade. IGT technology is now licensed to Carbona in Finland.

- The Battelle-Columbus indirect gasification technology, that is licensed to Future Energy Resources Corporation (FERCO) in Georgia. The first full scale plant is currently being tested in Vermont, USA.

In addition to these units, other groups such as Lurgi, Framatome and MTCI have reportedly investigated suitable gasification technologies. De Boer and Den Uil[1] summarise the gas streams from these technologies as follows (Figure 9-1):

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[1] De Boer AJ, Den Uil H - *An evaluation of three routes for the production of liquid fuels from biomass* - ECN-R-97-001, January 1997

Gas component	Range produced from biomass gasifiers (Vol %)	Steam reformed Natural gas (Vol %)
H_2	14.9 - 48.1	72.1
CO	16.0 - 46.5	14.8
CO_2	14.6 - 40.4	8.8
N_2	0 - 13.6	0.1
CH_4	0 - 17.8	4.3
C_2	0 - 6.2	-

Figure 9-1: Composition of dry synthesis gas produced by different biomass gasifiers

A typical composition for steam-reformed natural gas is also shown above, as an indication of the change in composition that is needed from the initial biomass synthesis gas before it is optimised for methanol production. Different data for gas composition and predicted performance of the Carbona/IGT and FERCO/ BCL gasifiers are provided in Johansson *et al*[1] and Faaij *et al*[2], suggesting there is some flexibility in the composition of the gas output from each gasifier.

3. Gas Clean-up

The synthesis gas produced by biomass gasification contains a range of contaminants, depending on feed and gasification process. Gas clean-up is required to prevent mechanical problems and deactivation of the methanol catalyst. Clean-up steps may include particulate removal, sulphur removal and scrubbing for chlorine compounds.

4. Synthesis Gas Conditioning

For optimal production of methanol, three parameters are of particular importance:

a) The ratio of CO_2 to CO should be optimised for methanol production, similar to the ratio in steam-reformed natural gas
b) The synthesis of methanol is most efficient when the feed gas contains the correct ratio of components. Ideally the stoichiometry number (SN) = $H_2/(2CO + 3CO_2)$ will be approximately 1.
c) The concentration of inert materials (eg. N_2, CH_4) should be minimised.

The CO_2/CO ratio and the stoichiometry number can be adjusted by the water-gas-shift reaction and then CO_2 removal. Inert materials such as CH_4 may be reduced by additional steam reforming.

The water-gas-shift reaction is a catalytic process operating at 200-475 ^{0}C to convert CO and steam to H_2 and CO_2, via the reaction:

$$CO + H_2O \rightarrow H_2 + CO_2$$

For the production of methanol from biomass only partial conversion is required. Excess CO_2 may then be removed by one of several commercially available processes.

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[1] Johansson TB *et al* - Renewable Energy - *Sources for fuels and electricity.* - Earthscan Publications Ltd, London, 1993. ISBN 1-85383-155-7 (Paperback).

[2] Faaij A *et al - Production of methanol and hydrogen from biomass via advanced conversion concepts - preliminary results.* 1st World Conf. & Exhibition on Biomass for Energy and Industry, Sevilla, Spain, June 2000.

If the raw gas from the gasifier contains significant quantities of CH_4, steam reforming may also be used, as follows:

$CH_4 + H_2O \rightarrow 3H_2 + CO$

5. Methanol Synthesis
Once the economic optimum synthesis gas is available the methanol synthesis takes place. This typically uses a copper-zinc catalyst at temperatures of 200 - 280 ^{0}C and pressures of 50 - 100 bar.

6. Methanol Purification
The crude methanol from the synthesis loop contains water produced during synthesis as well as other minor by-products. Purification is achieved in multistage distillation, with the complexity of distillation dictated by the final methanol purity required.

9.4 Engineering and Costing Studies

With no integrated research or demonstration facilities to investigate methanol from biomass, recent studies to date have been based on data available from independent work on the various steps outlined above. Some of these are well-defined commercial processes, while others are still at the pre-commercial stage of development.

The Swedish Altener “BAL-Fuels Project” by Ecotraffic R&D AB and Nykomb Synergetics AB investigated biomass-derived methanol in some detail and issued its final report in 1997[1]. The report presents a cost estimate for a 1,000 tonne per day methanol facility, requiring some 1.3 million tonnes of green feed per year to produce 390 million litres per year of methanol.

Total capital cost for this plant constructed in Sweden was estimated at US$ 417 million.

Energy efficiency may be defined as the quantity of energy in the wood feed that is recovered in the renewable energy products. For the BAL Fuels Project, the above plant was estimated to have an energy efficiency of 57% if methanol production was maximised; that is 57% of the energy coming into the plant in the wood feed was recovered in the methanol produced. This efficiency assumed that the power requirements of the plant would be met by using external (ie. fossil fuel) sources of electricity. Alternatively, part of the biomass feed to the plant may be diverted to production of steam and electricity so that the plant does not import any energy. In this case, the methanol produced would represent recovery of only 49% of the incoming biomass energy. For the Swedish plant it is suggested that other, low grade energy from the plant could be recovered as hot water for district heating. While this use is quite common in the cold climate of Scandinavia there are no parallel uses envisaged in Australia.

The Swedish report notes that, with the current maturity of much of the methanol plant processing steps, there is little scope for major improvements to the biomass-to-methanol plant. Gains in gasification technology are possible and energy savings around the plant may also be possible as the integration of the various process elements is developed.

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[1] Ecotraffic R&D AB & Nykomb Synergetics AB - *Altener “BAL-Fuels project” - Feasibility phase project for biomass-derived alcohols for automotive and industrial uses*, 1997 - Contract No. XVII/4

9.5 Methanol from Dual Feeds

The opportunity for methanol production from a combined natural gas and biomass feed is described generally as follows by Borgwardt[1].

A methanol yield of 0.782 mol could be obtained from 1 mol of natural gas by the conventional steam reforming process. The Battelle Columbus gasifier (licensed to FERCO) is expected to produce 1.477 mol of methanol from 100 kg of biomass. By comparison, process simulations indicate that a combined system using both natural gas and biomass can improve the methanol yield from the same amounts of feedstocks by 10-13%. The improvement can be explained as follows:

- The ratio of hydrogen to carbon (H/C) in biomass is too low to produce methanol without consuming part of the gasified carbon to react with steam (by the water-gas shift reaction) to produce the extra hydrogen needed and the resulting CO_2 is lost. By adding natural gas, the gas leaving the reformer has the proper H_2/CO ratio for methanol synthesis; no shift reaction is required and all carbon goes into the methanol.

- When natural gas alone is used to make methanol by the conventional route, excess H_2 is produced beyond that required for methanol synthesis and can only be used as reformer fuel.

9.5.1 Hynol Process

The Hynol process is being developed to produce methanol from biomass with a methane stream (such as natural gas) as a co-feedstock. There are three steps to methanol production via this process[2]:

- Biomass and methane (via natural gas, or other sources such as landfill gas) are introduced into the hydrogen pyrolysis reactor (HPR) in the presence of hydrogen. The HPR produces primarily hydrogen, methane and water.
- The methane gas mixture is then converted with steam and added natural gas to hydrogen and carbon monoxide in the steam pyrolysis reactor (SPR).
- The output from the SPR is then cooled and introduced to the methanol synthesis reactor (MSR), which produces the methanol. The unreacted hydrogen and methane are recirculated from the MSR back into the HPR.

9.6 Co-production of Electricity

In the Altener BAL Fuels Project[1] it was noted that there was flexibility in the use of the gasified biomass feed to produce gas streams suitable for methanol synthesis and also for generation of steam and power. Subsequent work by Ecotraffic and Nykomb Synergetics has investigated the development of a "Biomass based Methanol energy combine - Trollhatten region" or BioMeeT project[3]. This study considers synergies between the co-production of electricity and methanol. Note that the prices paid for renewable electricity vary from country to country and are influenced by government policy and costs for fossil-fuel based generation. In an Australian context, as with co-production in an ethanol/electricity plant, the relative product selling prices will determine whether such an approach is warranted and then what split of products is most favourable.

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[1] Borgwardt RH – Methanol Production from Biomass and Natural Gas as Transportation Fuel – Industrial & Engineering Chemistry Research Vol. 37 No. 9 pp 3760-3767, 1998

[2] Ecotraffic R&D AB & Nykomb Synergetics AB - *Altener "BAL-Fuels project" - Feasibility phase project for biomass-derived alcohols for automotive and industrial uses*, 1997 - Contract No. XVII/4 http://cert.ucr.edu/~kjohnson/biomass.htm

[3] Ecotraffic R&D AB & Nykomb Synergetics AB - *BioMeeT - Planning of biomass based methanol energy combine - Trollhätten region,* 2000

10. Costs for Electricity

10.1 Summary

Key determinants for the cost of electricity from a biomass plant are: the economy of scale of the plant, impact of biomass fuel costs, and maximising the running time of the power plant.

To illustrate these concepts, this section considers three plants of different scale and configuration. These are a 1 MW gasification plant fuelling a reciprocating gas engine, a 5 MW gasification plant with a waste heat boiler and steam turbine, and a 30 MW conventional boiler and steam turbine plant producing electricity. An assessment of the feed requirements, capital costs and operating costs per year are summarised as follows (Figure 10-1):

	1 MW	**5 MW**	**30 MW**
Gross Electrical Output (MWe)	1.0	5.0	30.0
Feed Requirements (green kt/yr)	13.7	91.2	375.3
Capital Cost (M$)	$5.3	$12.5	$47.4
Operation & Maintenance Cost (M$/yr)	$0.3	$0.8	$2.9
Unit Capital Cost ($M/MW)	5.3	2.5	1.6

Figure 10-1: Assessment of costs per year

This table illustrates the significant benefits of economy of scale in larger plants, with the per-megawatt capital cost for a 30 MW plant only 30 percent that of the cost for a 1 MW plant. Smaller plant projects generally have a proportionately higher fixed development cost, and for a 1 MW project the basic plant and equipment cost may comprise only two-thirds of the completed project cost.

A simple costing model is used to assess the required electricity selling price to make a bioenergy project economically viable. The model uses a set of baseline assumptions, such as project life, construction period, inflation rates for costs and revenues, depreciation, financing rates for debt, feed purchase price (assumed to be $30 per green tonne at the plant), operating time per year and the required internal rate of return (IRR) to attract investment.

Under these assumptions the required electricity selling price for various plant sizes are: 1MW: 20 c/kWh; 5 MW: 15c/kWh; 30 MW: 10c/kWh.

The cost components attributed to feed purchase, operating cost, capital cost and required return for the base case are shown in Figure 10-2:

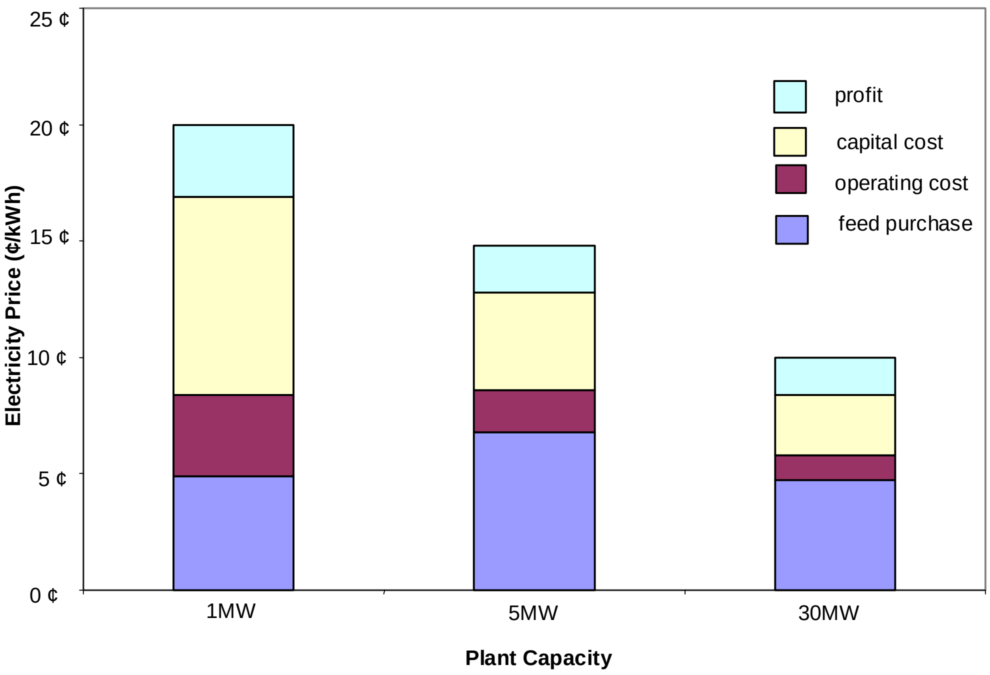

Figure 10-2 Electricity Price as a function of Plant Capacity

For small projects capital cost is the major cost component, making it important that use of the plant is maximised to improve fixed cost recovery. For large projects, the unit capital cost has dropped and the major cost can be feed purchase. Low feed costs (via use of low value residues, or via revenue or subsidies due to feed co-values) could be a major opportunity for commercially viable large scale projects.

A sensitivity study was conducted to gauge the impact of project parameters on the electricity selling price. Varied parameters were: feed cost, plant utilisation, plant capital cost, operating and maintenance costs, and the portion of equity finance. Graphs are presented in the section, which show these variations. As expected, the required price rises linearly with increasing feed cost, drops with increased utilisation of the plant, rises with increases to capital, operating and maintenance costs, and rises with increased levels of equity as opposed to debt finance.

10.2 Introduction

This section provides an introduction to the costs of electricity that is generated by different sized bioenergy plants. It highlights key issues that can have a major impact on the electricity cost, including:

- The economy of scale that the plant offers
- The impact of the feed cost
- The importance of running the plant for as many hours per year as possible.

Remember that this data can only be a guide. It includes assumptions as to equipment, site, feed characteristics, labour requirements and so on which, while selected here to be broadly representative, will probably vary significantly from project to project. The information presented below can help to identify:

- Whether an opportunity is worthy of more detailed analysis
- The areas that show greatest sensitivity to variations, and thus warrant the most attention in any investigations.

To show the variability of costs and sensitivities with project size, three plant size options are presented in this section for comparison. These have been selected arbitrarily and have electrical outputs of:

- 1 MW, utilising gasification and gas engine technology
- 5 MW, utilising gasification, waste heat boiler and steam turbine technology
- 30 MW, utilising conventional boiler and steam turbine technology

The main parameters for each of these options are shown in Figure 10-3.

	1 MW	**5 MW**	**30 MW**
Gross Electrical Output (MWe)	1.0	5.0	30.0
Feed Requirements (green kt/yr)	13.7	91.2	429.0
Capital Cost (M$)	$5.3	$12.5	$47.4
Operation & Maintenance Cost (M$/yr)	$0.3	$0.8	$2.9

Figure 10-3: Electricity Plant Parameters

These costs are analysed later in this section to develop prices for electricity.

10.3 Capital Costs

The capital cost breakdown for each option is shown in Figure 10-4.

Electrical output:-	**1 MW**	**5 MW**	**30 MW**
Cost estimate for:			
• Gasifier	$3,460,000	$ 2,910,000	-
• Boiler	-	$ 2,550,000	$ 9,580,000
• Steam Turbine	-	$ 1,940,000	$ 9,990,000
• Auxiliary Equipment	$ 200,000	$ 1,520,000	$11,820,000
• Grid Connection	$ 260,000	$ 660,000	$ 2,900,000
• Civils and Infrastructure	$ 260,000	$ 260,000	$ 4,210,000
• Design and Proj. M’ment	$ 640,000	$ 1,490,000	$ 4,630,000
• Contingency	$ 480,000	$ 1,130,000	$ 4,310,000
Total	**$5,300,000**	**$12,460,000**	**$47,440,000**
Unit cost ($M/MW):	5.3	2.5	1.6

Figure 10-4: Breakdown of Capital Costs

Notes to accompany table:

1. The cost shown for a 1 MW gasifier is for a package plant comprising feed drying, gasification and engine/generator set.

2. Auxiliary equipment includes such items as feed handling and drying equipment, steam condensing equipment and others.

3. Design and Project Management includes owners engineering costs, commissioning costs and permitting costs.

4. The contingency allowance is calculated as being 10% of all other costs.

The economy of scale achieved with larger plants is clearly seen from these three examples, with the unit capital cost at 30MW only 30% of the cost for a 1 MW plant

Also, the difference between equipment costs and a completed, installed project may be quite significant. For example, the basic equipment for a straightforward 1 MW project may only comprise two thirds of the completed project cost.

10.4 Operating Costs

Apart from the purchase of biomass feed, the principal operating costs for a bioenergy plant are for operating labour, maintenance and consumable items. A typical operating cost breakdown for each of the three plant sizes is shown in Figure 10-5.

	1 MW	**5 MW**	**30 MW**
Operational Labour	$110,000	$300,000	$ 960,000
Maintenance	$160,000	$370,000	$1,420,000
Consumables	$ 50,000	$120,000	$ 470,000
Total	**$320,000**	**$790,000**	**$2,850,000**

Figure 10-5: Breakdown of Operating Costs

The job roles and numbers that have been assumed for each option are shown in Figure 10-6.

Position	**$/person /annum**	**Number of Positions**		
		1 MW	**5 MW**	**30 MW**
Gate Guard	$ 60,000			1.0
Clerk	$ 50,000		0.2	1.0
Plant Manager	$100,000		1.0	1.0
Plant Engineer	$ 80,000			1.0
Tradesman	$ 60,000	0.5	1.0	
Plant Operator	$ 60,000	1.0	1.0	5.0
Boiler Attendant	$ 60,000		1.0	4.0
Shift Relief	$ 70,000			1.1
Head Office Costs	$ 80,000	$20,000		
Total		**$110,000**	**$300,000**	**$960,000**

Figure 10-6: Labour Cost Breakdown

Labour costs include all general overheads, superannuation, taxation, leave allowance etc.

The Plant Operator and Boiler Attendant positions for the 30 MW plant option are shift positions and therefore require shift relief. All other positions are day positions. Note that the number of personnel required can vary significantly with different feed characteristics and handling requirements and opportunities to "share" personnel with other, adjacent processing facilities. Modern plants tend to favour low labour usage and a high level of automation.

Maintenance costs are estimated as 3% of the total capital cost. Recommended allowances from individual suppliers can vary considerably both in scope and amount. In many cases routine maintenance may be undertaken by plant personnel. In others they need to be completed by specialists.

Consumable costs are estimated as 1% of the total capital cost, and cover such items as boiler and domestic make up water, effluent disposal, and workshop and office consumables.

10.5 Costing Model

The commercial decision to build a bioenergy plant is made on a similar basis to a decision on any other large industrial project. When a company or investor is asked to provide money to enable a bioenergy plant to be built, it is essential that they can understand the way that the project will be developed and the time expected for their investment to be recovered and profit made. Figure 10-7 shows typical assumptions used for basic economic analysis of the bioenergy plants described above.

Item	Value Used
Project life	15 years from first investment
Residual value of plant	Assumed to be nil
Construction period for the plant	• 6 months for 1 MW option • 12 months for 5 MW option • 18 months for 30 MW option
Commissioning period	included in construction period
Production ramp up	Immediate full production and full product purchase
Inflation of costs and revenue each year	• 3% for costs • 3% for revenue
Depreciation	straight line over 15 years
Company tax rate	30%
Interest on any borrowings	10%, with all loans repaid by the end of the 5th year
Financing	100% equity financing
Feed purchase price	$30 per green tonne delivered to site
Plant operation	8,000 hours per annum (leaving time for scheduled shutdowns and maintenance)
Required project IRR	15%

Figure 10-7: Assumptions Used for the Economic Analysis of Bioenergy Systems

10.6 Price of Electricity

Using assumptions such as those above described above, and knowing typical capital and operating costs for each bioenergy plant, allows calculation of the necessary price for sale of electricity to allow the project to proceed. These are shown according to plant output in Figure 10-8.

Plant Size	Required Electricity Sales Price
1 MW	20.0 ¢/kWh
5 MW	14.4 ¢/kWh
30 MW	10.7 ¢/kWh

Figure 10-8: Results of Economic Analysis

The profit, capital cost, operating cost and feed purchase cost components of the above mentioned electricity sales prices are shown in

Figure 10-9 to demonstrate how these component portions change with increasing plant size.

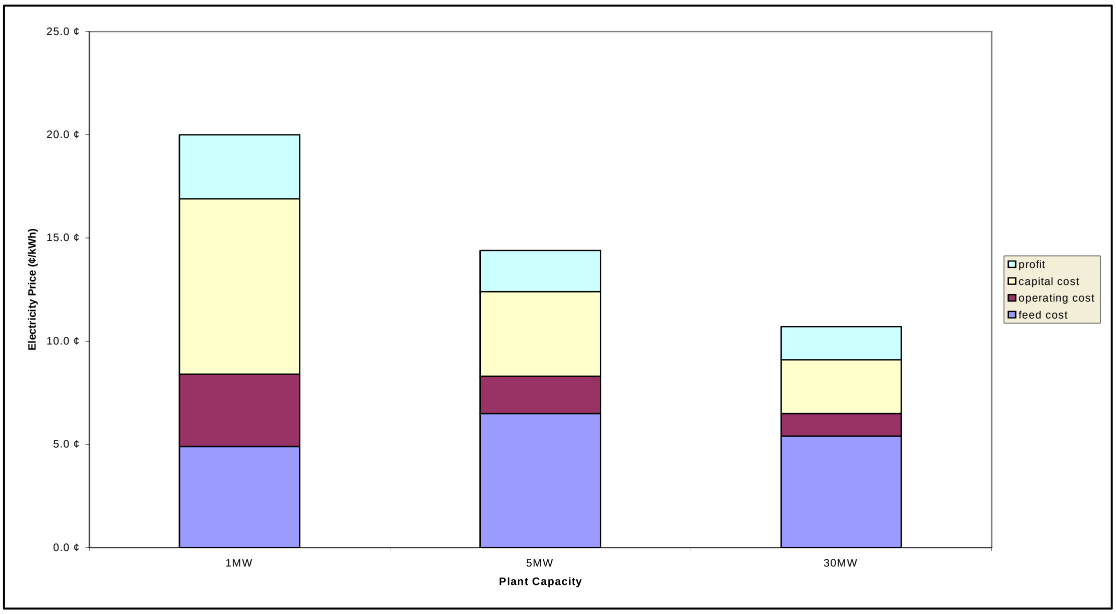

Figure 10-9: Electricity Price Breakdown

This process will allow an investor to achieve a certain internal rate of return on his investment (set at 15% for this example). An alternative way to assess the project is to consider the price for electricity that is acceptable in the marketplace and determine what IRR that will provide. If the IRR is high enough an investor may finance the plant.

While prices paid to generators for renewable electricity are usually confidential to those involved, it is understood that renewable electricity, with Renewable Energy Certificates, is currently typically purchased at 7 ¢/kWh. Thus, none of the above projects would be deemed economically viable for any investor seeking a return of 15% or greater. To determine what may be changed about a project to improve its viability involves an examination of the sensitivity of the financial performance to changes in the major project variables. Several of these are considered below.

10.7 Electricity - Sensitivity Analysis

The figures shown above for bioenergy projects represent one set of conditions for each example. It is quite likely that conditions will vary considerably from project to project, or even within a project over time. Equally, in the early stages of development it is understandable that there will be some uncertainty over the costs being used to determine project viability and the organization developing the project will wish to understand the effect of changes that might occur to the financial data as the project progresses. For these reasons it is useful to conduct sensitivity analyses, looking at the impact of changes to key project parameters. These changes may be examined singly or in combination.

To illustrate this aspect of project appraisal, a number of sensitivity analyses were performed on the bioenergy plants described above. In each case a single major parameter was varied and the effect of the change was plotted against electricity selling price. Variables examined were:

- feed cost
- plant utilisation

- plant capital cost
- operating and maintenance costs
- portion of equity financing

The results of these sensitivities are shown in Figure 10-10 to Figure 10-14 following.

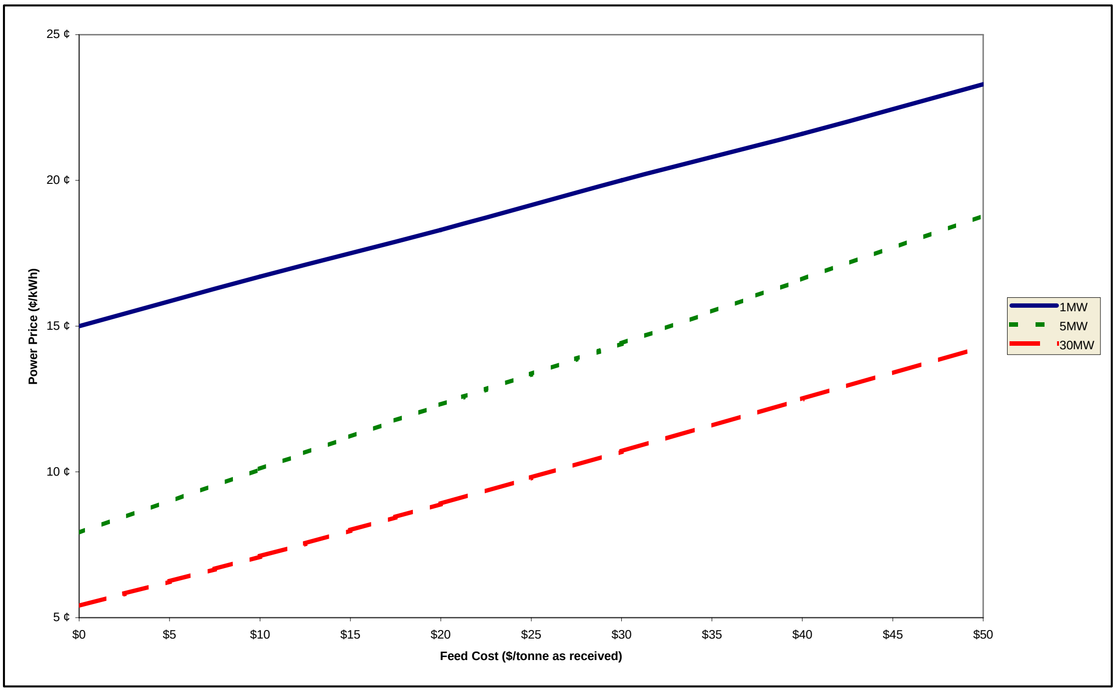

Figure 10-10: Power Price Variation due to Feed Cost Changes

Changes in feed cost create proportional changes in electricity selling price. A $10 change in feed price is reflected in a change to the required electricity selling price of 1.5 – 2.5 c/kWh, depending on the system efficiency. These curves are developed for fresh (i.e. green) wood feed. It is encouraging to observe that, for low feed costs, many of these hypothetical bioenergy projects could offer electricity that is quite competitive with other sources of renewable power. An understanding of feed cost (and all of its elements) is therefore central to both the development and implementation of a bioenergy project. In many cases the variability in feed cost may be more significant to assessing viability than all other costs for the project.

When bioenergy projects are discussed, there is often talk of “free” feed, in the form of agricultural, forestry or processing residues. Note that the economic viability of a bioenergy project is based on the cost of feed actually delivered to the bioenergy plant. This includes any cost of feed purchase, plus collection, transport and possibly intermediate storage. Thus feed with nil value at its source (e.g. saw mill residues) may have a cost of $20/tonne by the time handling and transport are included.

Note also that bioenergy projects can only be seriously considered when feed supply is secure for the economic life of the project. No sensible developer will commit millions of dollars to a power plant if there is too much uncertainty about cost and/or availability of feed once the project is built. But when the initial cost of the feed is close to zero, there is little incentive for the producer of that feed to enter into long term supply agreements. The dynamics of feed supply and project risk need to be well understood before any project can proceed.

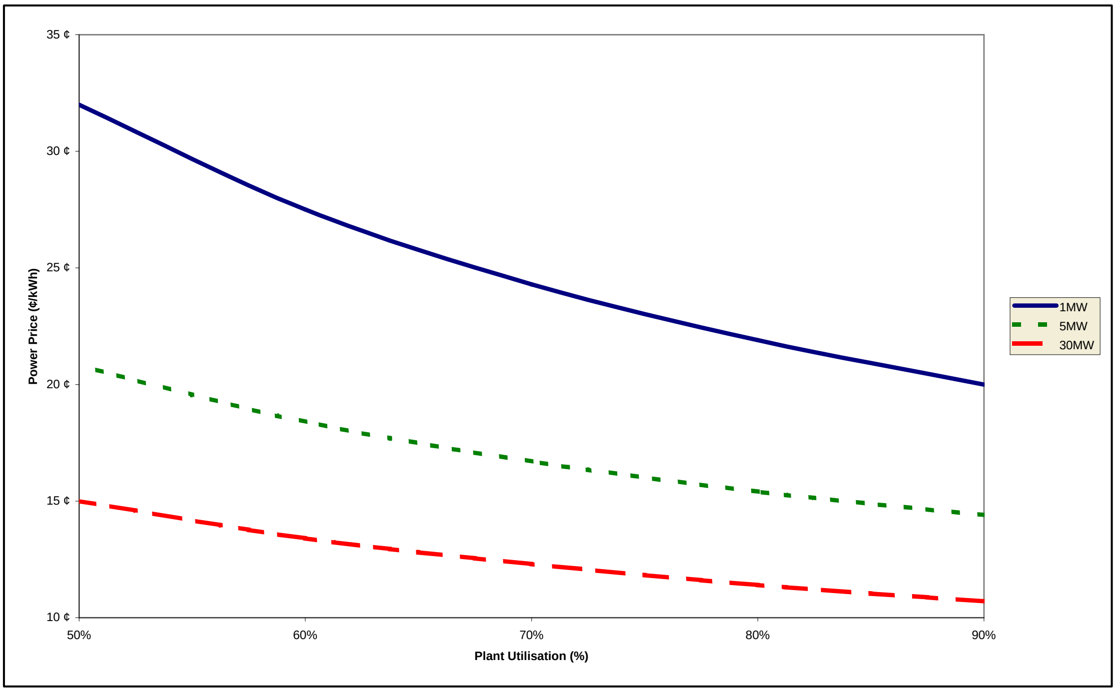

Figure 10-11: Power Price Variation due to Plant Utilisation Changes

Plant utilisation is the amount of time over a given period that the plant will be fully utilised. No plant can operate for 24 hours per day and 365 days per year; there is a need for maintenance and repairs, both scheduled and unforeseen. Thus many large fossil fuel power stations operate for approximately 90% of the total time available each year. Many bioenergy plants are capable of similar levels of performance. In the base case described above it was assumed that a bioenergy plant would be operational and provide maximum electricity for sale for 8,000 of the 8,760 hours available each year, representing 90% utilisation.

If a power plant is connected to a large grid it is likely that the full output of the plant can be utilised whenever the plant can operate. However, if a power plant is isolated from a large grid its output may be restricted by the changing needs of the particular users it supplies. This may mean that there are times where it is required to operate at less than full output or even go offline. Reducing the overall utilisation can have a major effect on the cost of electricity needed to maintain a certain IRR. As the graph above shows, a drop from 90% to 50% utilisation will force the price of electricity up by 40-60%.

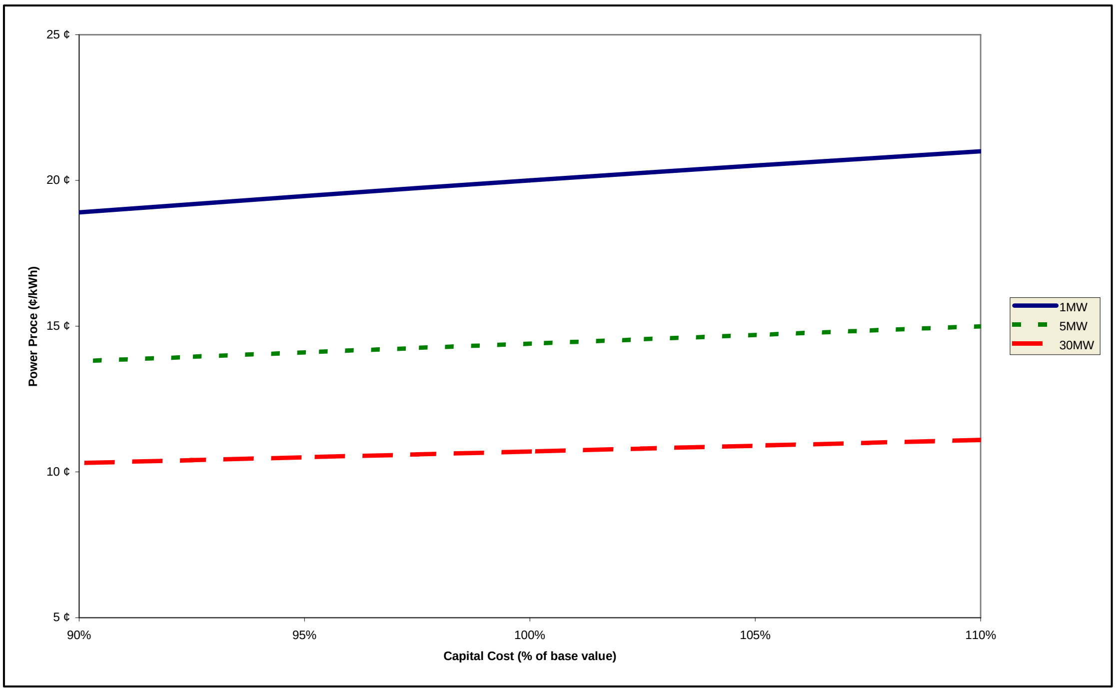

Figure 10-12: Power Price Variation due to Capital Cost Changes

There are many factors that will cause variations in capital cost between one plant and another.

These can include:

- Location difference, requiring different site preparation and civil works, or different labour rates for construction
- Access to electricity grid requiring new lines, more or less grid protection, etc
- Feed storage and preparation requirements
- Combustion or gasification equipment to manage different feed conditions, or expected variation in feed parameters
- Emission control, by the design and installation of equipment to keep gaseous, liquid, solid and noise emissions to acceptable levels
- Synergies in co-location alongside existing plant – share personnel, equipment, infrastructure etc
- Co-generation requirements
- Selection of equipment configuration that increases reliability or decreases risk of down time but is more costly to build (for example using dual fuels or installing multiple engines instead of just one).

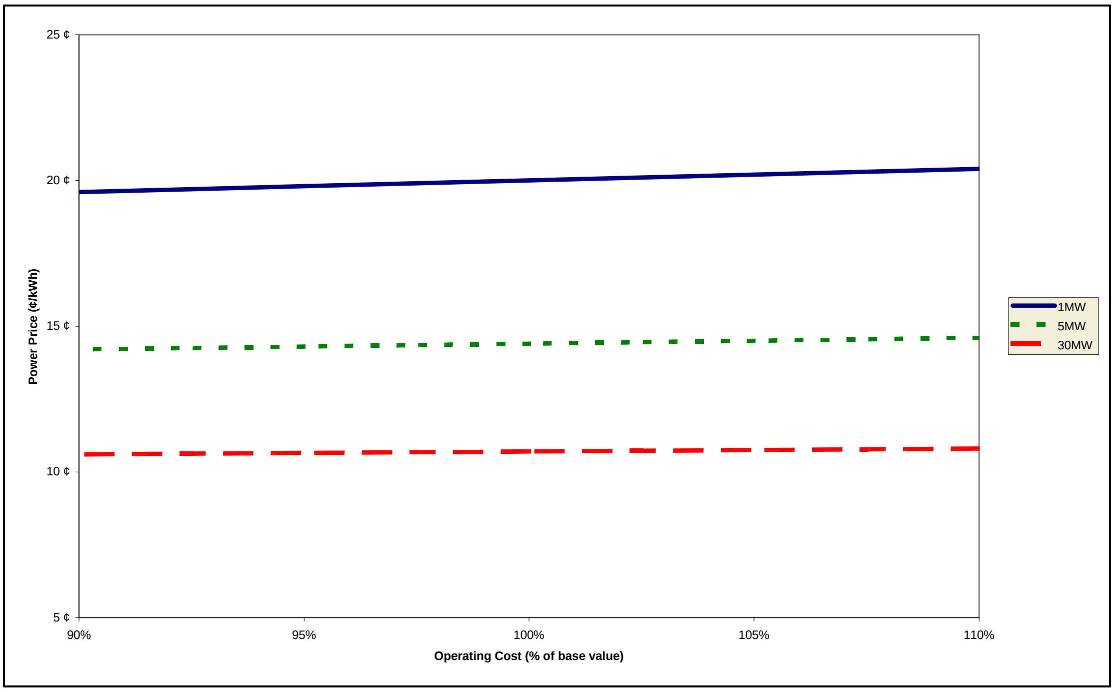

Figure 10-13: Power Price Variation due to Operation and Maintenance Cost Changes

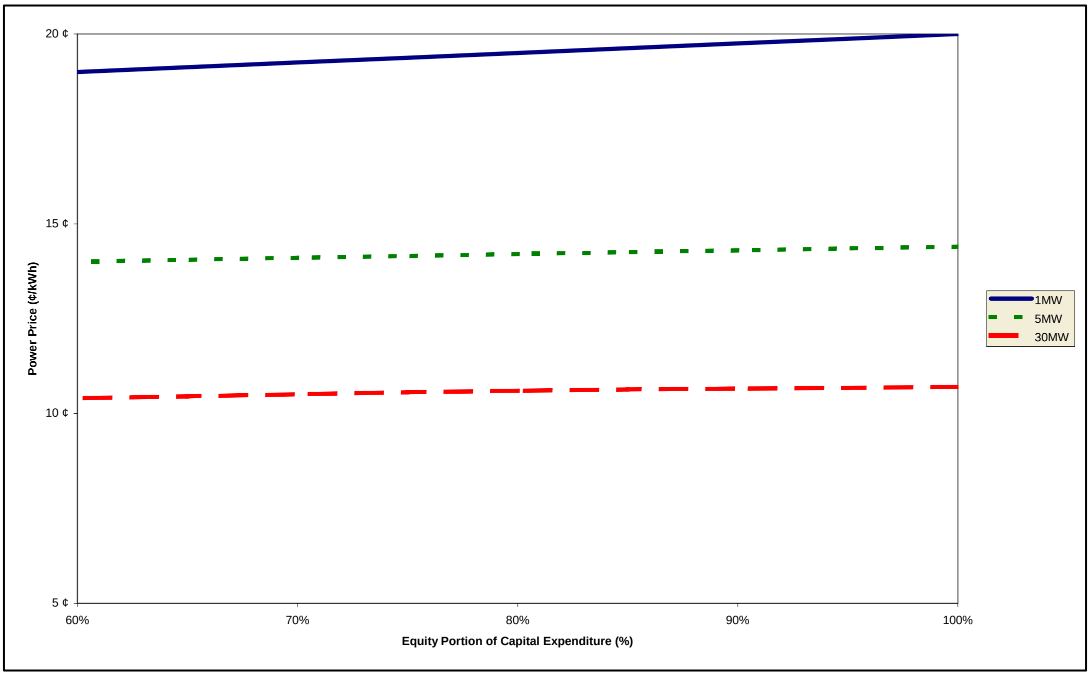

Figure 10-14: Power Price Variation due to Equity Portion of Capital Changes

10.8 Discussion

There are other project parameters that may be varied, for example the rate of return for project investors. Projects with secure feed supply and long term (>5 years) power purchase agreements may be able to attract equity at lower returns and debt over longer periods, both of which will assist project economics.

Even with funding at competitive rates, good plant utilisation and low cost feed, it is clear from the above data that many potential projects will not be financially viable. This will be particularly true for smaller projects (with higher unit capital costs) and projects with significant costs for delivered feed (for example where transport over long distances adds to the delivered cost).

Against these difficulties niche opportunities may be possible, for example in locations where a premium may be paid for electricity due to difficulties in grid supply.

The difficulty in achieving financial viability based on electricity alone also points to the importance of finding co-products and being able to recover value for additional environmental and/or social benefits. These issues are discussed further in a later section.

11. Plant Costs - Liquid Fuels

11.1 Summary

The results of costing studies for ethanol (Figure 11-1) and methanol plants (Figure 11-2) at both large and small scale attempt to identify the capital and ongoing operating costs under a common set of conditions. Some allowance has been made for the relative costs of plants to be constructed in Australia as opposed to construction in the USA or Sweden.

Parameter:	**Large plant**	**Small plant**
Ethanol output of plant (megalitre/year)	**200**	**100**
Conversion (litre ethanol per tonne green feed)	140	140
Green feed required (tonne/year)	1,430,000	715,000
Conceptual estimate of capital cost (A$ million)	470	310
Operating costs:		
• Unit cost of green feed	30	30
• Total cost of green feed	42,900,000	21,450,000
• Cost of feed per litre of ethanol (cents per litre)	21.45	21.45
• Other variable operating costs at 6 cents per litre	12,000,000	6,000,000
• Labour and on costs	3,632,000	2,900,000
• Maintenance at 1% of capex	4,700,000	3,100,000
Insurance and taxes at 1.5% of capex	7,050,000	4,650,000
Total of operating costs ($)	70,282,000	38,100,000
Estimated product selling price ($/L)	0.82	0.99

Figure 11-1: Ethanol Project Cost Parameters

Parameter	**Large plant**	**Small plant**
Methanol output of plant (megalitre/year)	**390**	**200**
Conversion (litre methanol per tonne green feed)	290	290
Green feed required (tonne/year)	1,340,000	690,000
Estimated cost in Sweden in 1997 (US$)	417	-
Conceptual estimate of capital cost (A$ million)	830	560
Operating costs:		
• Unit cost of green feed	30	30
• Total cost of green feed	40,200,000	20,700,000
• Cost of feed per litre of methanol (cents per litre)	10.34	10.34
• Labour costs	3,500,000	2,800,000
• Catalyst	2,000,000	1,000,000
• Insurances, taxes	8,300,000	5,600,000
• Maintenance at 3% of capex	24,900,000	16,800,000
Total of operating costs ($)	78,900,000	46,900,000
Estimated product selling price ($/L)	0.62	0.79

Figure 11-2: Methanol Project Cost Parameters

These estimates are conceptual only, and reflect costs estimated for plants built now using world's best practice. A number of potential improvements to the ethanol pathway have been identified, leading NREL to suggest that significant cost reductions could be achieved over the next 10-15 years. The methanol pathway is based on more mature technology and similar cost reductions are not envisaged.

11.2 Estimated Costs

The literature reviewed during this study offers a number of cost estimates for ethanol and methanol from biomass. These estimates are produced by a range of organisations around the world and they vary in many respects, including:

- Year of estimate
- Country
- Plant size
- Estimate basis (conceptual, feasibility, detailed)
- Feedstock cost
- Financial parameters

To better allow financial comparisons in this study between ethanol, methanol and electricity, attention has been focussed on capital and operating cost estimates to reflect a common set of conditions, using data from two recent overseas studies. These studies show considerably more detail in preparation of estimates than some other references. Costs have been converted to Australian conditions and current dollars. Common feed prices are used, as well as common financial parameters. Data are summarised in the tables below.

Parameter:	**Large plant**	**Small plant**
Ethanol output of plant (megalitre/year)	**200**[1]	**100**
Conversion (litre ethanol per tonne green feed)[2]	140	140
Green feed required (tonne/year)[3]	1,430,000	715,000
Conceptual estimate of capital cost (A$ million)	470[4]	310[5]
Operating costs:		
• Unit cost of green feed	30	30
• Total cost of green feed	42,900,000	21,450,000
• Cost of feed per litre of ethanol (cents per litre)	21.45	21.45
• Other variable operating costs at 6 cents per litre[6]	12,000,000	6,000,000
• Labour and on costs	3,632,000[7]	2,900,000[8]
• Maintenance at 1% of capex[9]	4,700,000	3,100,000
• Insurance and taxes at 1.5% of capex[10]	7,050,000	4,650,000
Total of operating costs ($)	70,282,000	38,100,000
Product selling price ($/L)	0.82	0.99

Figure 11-3: Ethanol Project Cost Parameters

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[1] Plant size in 1999 study by NREL

[2] Conversion based on NREL figure of 68 US gal/dry US ton of feed

[3] Assuming feed at 50% moisture, wet basis

[4] NREL figure of US$ 234 million, multiplied by 2 to cover exchange rate and small allowance for inflation. Refer attachment for more detailed discussion of cost conversions.

[5] Figure for 200 ML plant, varied by exponent of 0.6

[6] Based on direct conversion of NREL costs - for chemicals, utilities etc

[7] NREL labour requirements and proportion of on costs, using assumed salaries in Australia

[8] Assume 80% of labour for larger plant, as most functions will still be needed in smaller plant

[9] Similar to NREL at 1% of total capital as opposed to 2% of equipment (which is around half of capital cost)

[10] Same as NREL

Parameter	**Large plant**	**Small plant**
Methanol output of plant (megalitre/year)	**390**[1]	**200**
Conversion (litre methanol per tonne green feed)[2]	290	290
Green feed required (tonne/year)[3]	1,340,000	690,000
Estimated cost in Sweden in 1997 (US$)	417	-
Conceptual estimate of capital cost (A$ million)	830[4]	560[5]
Operating costs:		
• Unit cost of green feed	30	30
• Total cost of green feed	40,200,000	20,700,000
• Cost of feed per litre of methanol (cents per litre)	10.34	10.34
• Labour costs[6]	3,500,000	2,800,000[7]
• Catalyst[8]	2,000,000	1,000,000
• Insurances, taxes[9]	8,300,000	5,600,000
• Maintenance at 3% of capex[10]	24,900,000	16,800,000
Total of operating costs ($)	78,900,000	46,900,000
Product selling price ($/L)	0.62	0.79

Figure 11-4: Methanol Project Cost Parameters

The product selling prices indicated above were each developed via project financial analysis according to the following parameters:

Item	**Value used**
Project life	15 years from first investment
Residual value of plant	Nil
Construction period	18 months
Commissioning period	Included in construction period.
Production ramp up	Immediate full production and full product purchase
Inflation	Costs and revenues: 3%
Depreciation	Straight line over 15 years
Company tax rate	30% [11]
Interest on borrowings	10%, all loans repaid by end of 5th year.
Financing	40% debt financing
Required project IRR	15%

Figure 11-5: Project Financial Assumptions

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[1] Plant size in 1997 BAL study in Sweden

[2] Conversion based on BAL figure of 390 ML methanol from 1.33 million tonne green feed

[3] Assuming feed at 50% moisture, wet basis

[4] Swedish price by 2, comprising currency change and small allowance for inflation. Refer attachment for further discussion.

[5] Figure for 390 ML plant, varied by exponent of 0.6

[6] BAL labour requirements at 63 staff but average Australian rate, plus 40% on costs.

[7] 80% of larger plant

[8] BAL price - Catalyst at A$2 M/year

[9] BAL estimate is 1% of total investment

[10] BAL and NREL maintenance estimates vary by 300%.

[11] Recommendation of "Ralph report". If the current figure of 36% is used, accelerated depreciation (straight line over 8 years) could be used, providing an even better return. NOW 30%

12. The Project Development Pathway

12.1 Summary

The development of a successful project will generally involve a number of groups with a diverse range of interests. For instance the feedstock providers may be interested in long term supply agreements at a good price and on-farm environmental benefits. The plant engineer will be interested in reliable, flexible and proven technology, and consistent feed. The project investors will be interested in minimised risks and good and secure returns. Government bodies will require environmental benefits and a professionally run project in return for RECs, and community groups may look for environmental and community benefits.

When one considers this range of requirements it is easy to understand that the development of a successful project can be complicated and time consuming. This requires sound and methodical planning, especially to understand and address project risks, demonstrate acceptable financial returns and engage all stakeholders throughout the process. From a technical and financial perspective this is generally achieved through a staged process involving conceptualising the project, conducting prefeasibility and then more detailed feasibility studies, followed by ‘front end engineering development’ (FEED) to reach an implementation decision. After reaching the decision to proceed, other elements of the project need to be implemented, such as securing feed supplies, equipment procurement contracts, obtaining all the necessary approvals and entering into contracts for sale of the products of the plant. Environmental assessments and approvals, eligibility for RECs, and community consultation will all proceed in parallel with technical and cost estimating activities.

Prefeasibility studies will address feed supply and cost, markets for products and likely prices, technology selection, rough plant costings and financial analysis. Feasibility studies will go into more depth. For instance feed supply would be characterised through combustion testing, seasonality, cost of setting up the fuel supply chain, its sustainability and compliance with regulations, and developing the proposed plan of management and sales. The feasibility studies will also focus on the bioenergy plant, investigating issues such as mass and energy balances, site selection and layout, emissions and their control, and plant cost estimates typically to +/-20 percent accuracy. Sale of electricity and other products would be investigated. At this stage a detailed financial analysis would be conducted.

The front end engineering development (FEED) comprises technical activities to take the project through to finalisation of a document suitable for raising capital for the detailed design, equipment procurement and construction of the plant. It goes into details such as assessment of the site, equipment lists, piping specifications, health safety and environmental management plans and noise studies.

After completion of FEED, the biomass supply agreements, equipment supply contacts, approvals and product purchase agreements would need to be finalised. It is generally at this point that full project funding may be finalised and implementation of the project can proceed.

12.2 Introduction

How is a successful bioenergy project defined? A successful outcome may be described quite differently by different people, depending on their interest in the project. Here is how a range of different participants might gauge success for a bioenergy project:

Feedstock provider – long term supply contract for feed material at a good price, environmental benefits on-farm.

Plant engineer – consistent feedstock, reliable technology, good plant utilisation, straightforward interaction with the grid.

Project financier – all risks understood and minimised or quantified. Credit for all environmental benefits in financial equations to improve project security and returns. Ability to duplicate the project elsewhere.

Company shareholder – return on investment.

Government body – cost-effective environmental benefits from a reliable, professionally run project.

Community groups – environmental benefits captured, broadening of farm income, long term jobs in the region.

All of these different groups will be involved in most bioenergy projects. The perspective of each group is quite valid, and the outcome of a well developed and operated project should be success for all participants. However, when one considers the range of participants and their various interests and involvement, it is easy to see that the definition and then development of a successful project can be a complicated and time-consuming process.

The costs of planting feed material, establishing optimal harvest and transport procedures and equipment, designing and building a bioenergy plant, and establishing safe and reliable grid connections, all mean that most bioenergy projects will require many millions of dollars to implement. To secure this money and to ensure that it is invested sensibly, it is imperative that bioenergy projects are based on sound planning and comprehensive data for every stage of the operation. In particular there are two key points common to all participants that will enable projects to proceed successfully:

- Understanding risk – knowing where risk or uncertainty occurs at every stage of the operations, and minimising and/or quantifying it. For example, a project may look attractive on initial financial appraisal, but may be based on feed material that has not yet been successfully grown, or on technology that has never been used outside a laboratory. A site may be very suitable for grid connection or other reasons, but result in difficult noise levels for a rural environment. Power utilisation may be variable and lead to a plant that is often under-utilised and incapable of providing a proper return on investment.

- Demonstrating that the project will make an acceptable financial return. All projects (be they bioenergy or anything else) need to compete for funds, and even the best understood and most environmentally beneficial project will not proceed if it is going to lose money.

12.3 Selecting Technology

In earlier sections of this report many options for primary and secondary conversion of biomass to energy were discussed. The selection of a particular mix of equipment for each project is a complex task that includes recognition of factors such as:

- Characteristics of the feed, and feed variability on daily, monthly and yearly bases
- The number of different biomass feeds to be utilised over the life of the project
- Harvest period for feed, and hence a possible need for dual fuel capability to ensure continuous output, or to store feed for extended periods when harvesting is not possible
- The size of the project
- Importance of, or interest in, co-products to help make the project financially attractive

- Whether or not the project is linked to another energy, forestry or agricultural enterprise and the long term stability of that enterprise
- The preferred investment strategy of the financiers
- The reliability required by the energy purchaser (for example, is a bioenergy plant supplying electricity in to a large electricity grid or as the sole provider of power at a remote location)
- The timing of the project and returns on investment for forestry and plant
- Whether the project is a "showcase" project of new technology that is unproven at commercial scale but has great potential that may only be developed via a full scale prototype.

In many situations the most important determinants for selection of technology (and its supplier) may be an understanding of the skills within the project development group and the expectations of funding bodies:

- While there is great interest in attractive new technologies, it is also possible that these technologies will increase the difficulty of raising capital for the project because of the risk that they will not work as expected, or at all. Also, while a technology may look very attractive at the laboratory scale, taking it from the laboratory, through a pilot stage, to a full scale prototype can involve millions of dollars and years of hard work. This cost and effort may be well worth it, but it must be identified and accepted from the outset when commercially unproven technology is being considered.

- Some project teams will have the experience to analyse feeds and make strong judgements about particular aspects of the technology (e.g. grate design, ash handling or noise control). Most, however, will have little experience in these matters. There are many consultants and equipment suppliers in Australia and overseas that are experts in particular technologies. It is often far easier (and more acceptable to funding bodies) for these experts to be brought into the project early in its development, as designers skilled in particular situations and problems, or perhaps as equipment suppliers that can take total responsibility for the construction and performance of the bioenergy plant.

12.4 Staged Development

The standard method of assessing bioenergy projects is much the same as that for any other large processing plant. Information is gathered and assessed at a certain level of accuracy and cost. A favourable result leads to more detailed assessment and greater accuracy, also at greater cost. Gradually the project is brought to a stage where information is adequate for a commitment of funds and the project may proceed.

The various stages to reach project approval are outlined below. Details will vary from project to project. The common purpose is to understand and assess the project, working initially with limited funds for this task and progressively spending more on assessment as the project is better understood and remains financially attractive.

12.4.1 Project Conceptualisation

Each project starts with an idea. This may be based on an existing or anticipated feed supply, a need for power or energy at a particular location, or energy as a co-product from the processing of biomass for other activities and products. Such an idea is the genesis of a bioenergy project. Using data such as that presented in this report, the proponents can review their idea and add quantities to it. Preliminary discussions with representatives of each major group involved (feed supply, plant construction and operation, product purchase, funding) can test whether the idea is robust enough to progress to the next stage.

12.4.2 Prefeasibility studies

Evaluation of projects that pass the initial criteria for further examination will be subject to a pre-feasibility study, addressing inter alia:

- Feed supply and cost
- Markets for products and likely prices
- Technology selection
- Plant costing to “order of magnitude” accuracy (± 40%), often based on plant costs from other projects then factored as necessary
- Financial analysis.

12.4.3 Feasibility studies

Feasibility studies will examine each opportunity in sufficient detail to be able to allow a decision by project developers on whether to proceed with engineering development and project financing. Work will address inter alia:

Feed supply

- Characterisation of each feed, including combustion tests if necessary
- Quantification of each feed, including seasonal availability and changing availability over the life of the proposed project
- Sustainability of the feed (including its compliance with any relevant government legislation if Renewable Energy Certificates are to be sought.)
- Cost of establishment, harvesting, and transport for each feed
- Availability of equipment and personnel for the supply chain
- Proposed plan for management and sales.

Bioenergy plant

- Interaction with other projects (supplier of feed or user of energy, such as a saw mill)
- Site selection and discussion of reasons behind it
- Preliminary plant layout (site specific)
- Preliminary process flow sheets
- Mass and energy balances sufficient to size most equipment, quantify major emissions, and quantify major requirements for water, gas, electricity, and other bought-in utilities
- Preliminary emissions study
- Preliminary motor list, with sizes
- Preliminary I/O and instrument lists
- Assessment of alternative options for plant development
- Preliminary plant costing, preferably to ±20% accuracy, based on budget prices for most plant items, with estimated costs for equipment installation, civil works, piping, electrical and control, engineering and project management.

Products

- Electricity - supply to grid and sales
- Genuine markets for any co-products.

Analysis and reporting

- Detailed description of each aspect of the proposed project
- Financial analysis, including sensitivity analysis
- Program, estimated costs and timetable for further work.

12.4.4 Front End Engineering Development (FEED)

Also known as a Basic Engineering Package (BEP), the FEED typically comprises the technical activities that take the project through to finalisation of a document suitable for raising capital for the detailed design, equipment procurement and construction of the plant. It gives the project proponents much of the information they require to allow a decision to proceed.

- Design basis
- Process plant description
- Piping and Instrumentation Diagrams (P&IDs)
- Material and energy balances
- Detailed site survey
- Soil study
- Design climatic conditions
- Plot plans and plant layouts
- Equipment list
- Equipment data sheets (preliminary)
- Sufficient specification of key items for cost estimation by others. Such items might include equipment for handling feed or capturing emissions.
- Emission design limits and preliminary estimates
- Piping specifications
- Piping line list
- Control strategy
- Preliminary motor list including kW
- Preliminary I/O and instrumentation list
- Details of off site services
- Interconnection application
- Health, Safety and Environment (H,S & E) management plan requirements
- Environmental referral documentation
- Atmospheric emissions modeling report, and emissions control strategy
- Preliminary noise study
- Fire protection management plan
- List and definition of required items outside battery limits (OBL) of the process plant, including buildings, equipment, mobile plant, infrastructure upgrades, etc., sufficient to complete detailed design
- General project specifications
- Contract management plan
- Tender documents for next stage
- Preliminary plant costing, preferably to ±10% accuracy, based on accurate prices for all major plant items, with quotes or detailed estimates for equipment installation, civil works, piping, electrical and control, engineering and project management.

12.4.5 Implementation Decision

The completion of a FEED package should provide the project developer with capital and operating cost estimates that are of sufficient accuracy to support a decision to proceed with project financing and implementation. There are a number of other elements to the project that must also be suitably developed before project implementation. These can include:

Feed supply – a draft agreement for supply of feed, which may include quantities, physical characteristics and composition, delivery arrangements, timing etc.

Equipment supply – it may be appropriate to enter into an agreement with a contractor or an equipment supplier for a "turnkey" package. This could involve the supplier taking responsibility for most of the equipment on the site, including feed handling, energy conversion, grid connection and waste management. One of the key benefits of such an approach is that the supplier may then offer a "performance guarantee" such that for an agreed feed the plant will produce an agreed energy output with agreed operating costs, emissions, availability (hours of operation per year) and so on. Such guarantees are useful in fundraising.

Alternatively the project developers may decide to place several orders for packages of equipment, or even purchase individual items and assemble the plant independently.

Approvals – A variety of approvals are required for the construction and operation of large processing facilities, and bioenergy plants are no exception. While some of these approvals may not be finalised until well into the process of detailed design, they must be understood and examined during the time leading up to an implementation decision. These approvals will vary from project to project but may include liaison with:

- local council
- environment protection authority
- fire department
- water supply authority
- state government
- electricity supply authority.

Product purchase agreement – The project can not expect funding and implementation without a clear indication of who will buy the product (e.g. electricity) and under what conditions the purchase will take place. It is expected that a product purchase agreement will be developed and signed (perhaps with conditions precedent) at this stage.

13. Case Studies – Production of Biomass

13.1 Summary

To help identify opportunities and barriers to bioenergy production from new tree planting, case studies have been undertaken that investigate two important potential sources of biomass fuels: tree plantation crops and short cycle crops.

Tree plantations have as their main products sawlogs, veneer logs and material for engineered wood products. Tree plantation crops are typically planted around 1,100 saplings per hectare, and thinned at intervals to around 300/ha. The thinnings and wood processing residues can provide biomass fuel.

Short cycle crops are grown in short rotations of less than 5 years and in this case study, are harvested specifically for bioenergy. Trees are coppiced (cut at ground level) and then allowed to resprout from the stump and regrow before harvesting again on regular cycles.

Case studies for both tree plantations and short cycle crops are presented for two contrasting localities; subtropical South East Queensland (SEQ) and in the dry, temperate setting of the Murray Darling Basin (MDB). The median rainfall in SEQ is 1,065 mm with 70 percent of precipitation occurring in summer and autumn, in contrast to an average annual rainfall of just 580 mm for the MDB, where rainfall is also less seasonal. The study notes the high probability of frosts in the MDB, and for both locations there are periods when harvesting is not possible due wet soil conditions.

The case studies consider other variables related to biomass yields, such as land fertility within various transportation distances and road infrastructure for access to suitable land. Modelling parameters included land lease rates, survey and planning costs, establishment and recurrent costs.

Case studies for **short cycle crops** estimated biomass yield in SEQ at 35 tonnes dry matter per hectare per annum, and in the MDB at 10 tonnes dry matter per hectare per annum. In **SEQ** a stumpage price for biomass of $20.30 per tonne fresh weight provides growers with an internal rate of return (IRR) of 10 percent before tax. To provide 300,000 t/a biomass would require 4,629 ha total planted area. For 700,000 t/a 10,800 ha would be required. In the **MDB** slower growing rates translate into biomass being available for $51.80 per tonne to achieve similar grower returns. 300,000 t/a in the MDB requires 16,200 ha and 700,000 t/a requires 31,500 ha to achieve the IRR of 10 percent.

Case studies for **tree plantation crops** are conducted for both SEQ and MDB under assumptions of land lease costs ($200 and $107 $/ha), Mean Annual Increment (25 and 10 cubic metres per hectare per annum) and rotation lengths (25 and 10 years respectively). For **SEQ**, setting the biomass price at $20.30 for comparison with plantation energy crops, provided an IRR of 8.4 percent (before tax), taking into account sale of the primary timber products (87 percent of total revenue to growers). In the **MDB** an area 60 percent larger than in SEQ is required to source the same amount of biomass, due mainly to the effect of lower rainfall on biomass growth rates. To maintain the same 8.4 percent IRR, and taking into account the revenue from sawlogs, a price of $239 per tonne of fresh biomass for bioenergy is required.

A sensitivity study is conducted to gauge the variation in biomass cost for changes in major parameters. For instance in SEQ for tree plantation crops, a 10 percent increase in tree growth rate results in a reduction in the required price for biomass of almost 50 percent

These case studies conclude that, if bioenergy production provides a market for fuel, short cycle crops produce a much greater return to growers than long rotation tree plantation crops despite both having similar outlays and the plantations having more than one product. Consequently, growers are more likely to opt for short cycle crops that produce only biomass for renewable energy than plantations which take longer to mature and to produce a monetary return from conventional forest products. This is highlighted in the MDB where the income from biomass would be over four times higher for short cycle crops. The price differential for biomass will make it more difficult to initiate projects in the drier areas. However the possible price for biomass from deep rooted tree crops in drier regions of the MDB may ultimately be more than for biomass in wetter regions if appropriate values can be placed on dryland environmental benefits such as salinity mitigation, soil conservation, catchment protection, carbon sequestration and biodiversity enhancement.

13.2 Background

The production of renewable energy from biomass is largely dependent on two factors:

1. a sustainable source of biomass to use as fuel over the life of the project
2. a suitable process for converting the biomass into useful forms of energy such as heat, power or transport fuels.

One of the main driving forces to the production of renewable energy from biomass at a commercially acceptable price is the cost effective supply of sufficient biomass to the gate of the renewable energy plant in a form that can be readily used by the plant. In addition to this, the ideal production of biomass will consider:

- environmental sustainability
- socially acceptable outcomes.

There is a wide range of cropping systems that could potentially be used to produce biomass for supplying fuel to renewable energy projects. One cropping system that has more to offer than simply producing biomass involves tree plantations, which can produce a variety of beneficial outcomes. These include:

a) wood-based products, including:
    i. sawlogs
    ii. feed for engineered wood products, such as medium density fibreboard
    iii. biomass from thinnings
    iv. charcoal or activated carbon
    v. essential oils

b) environmental services including:
    i. salinity mitigation
    ii. soil conservation
    iii. catchment protection
    iv. carbon sequestration
    v. biodiversity enhancement.

To investigate the feasibility of supplying biomass from tree plantations, a modelling platform was developed and an exercise undertaken to assess the cost of growing biomass in two different plantation forest production systems across two contrasting sites in Australia. The forest plantation cropping systems modelled were:

1. Plantation energy crops (or short cycle crops) – Trees are planted at a density of 5,000/ha and grown in short cycles of less than 5 years for the specific purpose of supplying biomass for renewable energy projects. The trees are harvested and then allowed to coppice before being harvested again on a regular basis.

2. Tree plantation crops – Trees are planted around 1,100/ha, thinned at suitable intervals to around 300/ha, and grown in long rotations (generally greater than 20 years) for sawlogs and other wood products. The thinnings and wood process residues created in producing the wood products can be used as fuel in bioenergy projects. Once the final crop is harvested the site is replanted and the cropping cycle restarted.

The modelling in this study has used information from a variety of sources and research literature to arrive at the results below. There is a general lack of information available on the growth of tree plantations in many parts of Australia, including the two regions selected. In particular there is little information available on growing short cycle tree crops in Australia, including field machinery technologies from planting to harvesting. Consequently basic methodology was used to evaluate what equipment is available in various agricultural industries and to take an informed guess at the adaptability of this equipment to a short or long cycle plantation forestry situation.

13.3 Locations

In order to show the impact of location, two sites with contrasting climates were chosen for this review. These were a wet site in sub-tropical, South East Queensland (SEQ) and a dry site with temperate climate in the Murray Darling Basin (MDB). The key climatic features of each site and their soil and infrastructure characteristics are described below.

13.4 Climate

13.4.1 Sub-tropical Queensland

The SEQ site has a typical sub-tropical climate with the following dominant features:

- Distinct wet/dry season (Figure 13-2)
- High intensity rainfall
- High pan evaporation in summer, which is the wet season
- Low frost probability.

The median rainfall for the area selected is 1,065 mm; however the annual rainfall varies dramatically, with the lowest recorded annual rainfall being 379 mm and the highest 1,810 mm (Figure 13-1)[1]. Approximately 70% of the rainfall occurs in the summer and autumn months, with winter and spring generally being very dry (Figure 13-2). In general the site has a water deficit during the winter and spring months, as evaporation exceeds rainfall, while the summer and autumn months are not in deficit. The annual range from the minimum to the maximum temperature is approximately 20°C, which is an indication of the sub-tropical influence and proximity of the site to the coast.

Climate for SEQ (1890-2002)	Mean/Median	Minimum	Maximum
Median annual rainfall (mm)	1,054/1,065	379	1,810
Maximum temperature ºC	27	21.8	30.1
Minimum temperature ºC	21	10.5	21.6
Pan Evaporation (mm)	4.2	2.8	6

Figure 13-1: Average climate data for typical sub-tropical location in SE Queensland

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[1] Clewett JF, Smith PG, Partridge IJ, George DA, Peacock DA (1999) Australian Rainman Version 3: An integrated software package of Rainfall Information for Better Management. *QI98071, Department of Primary Industries Queensland*

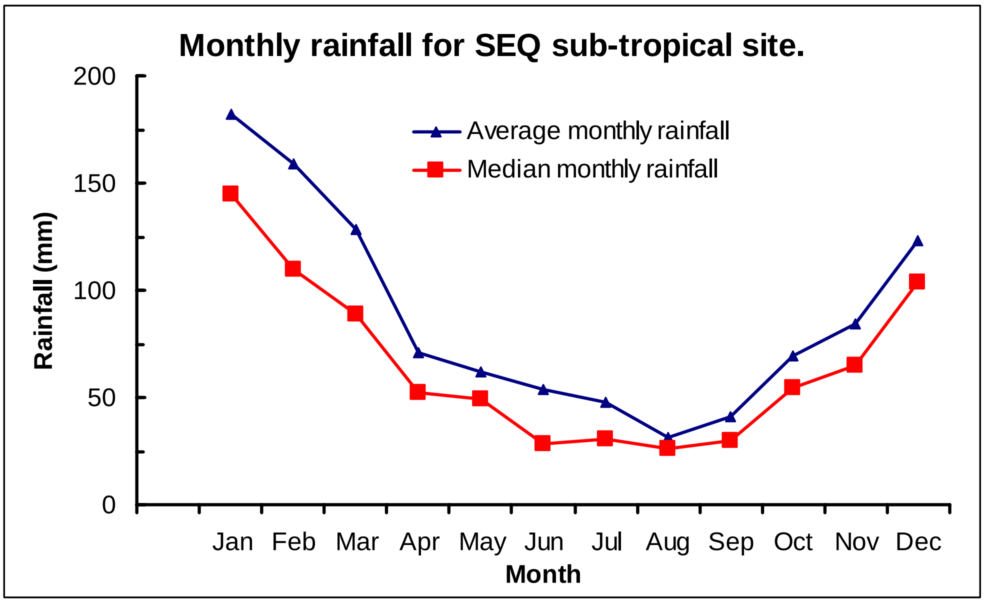

Figure 13-2: Monthly rainfall for a sub-tropical location in SEQ

There is a high probability of rainfall preventing harvesting during parts of the year, especially during the wet summer months. Rainfall events in excess of 50mm at a time will limit harvesting equipment access to paddocks for up to 2 days. Using this knowledge the following probability chart (Figure 13-3) was produced that shows that for 1 in 20 years harvesting will be prevented for up to 12 days in January and February. However, more generally, rainfall will only prevent biomass harvesting for 8 days maximum during January in 2 years out of 10.

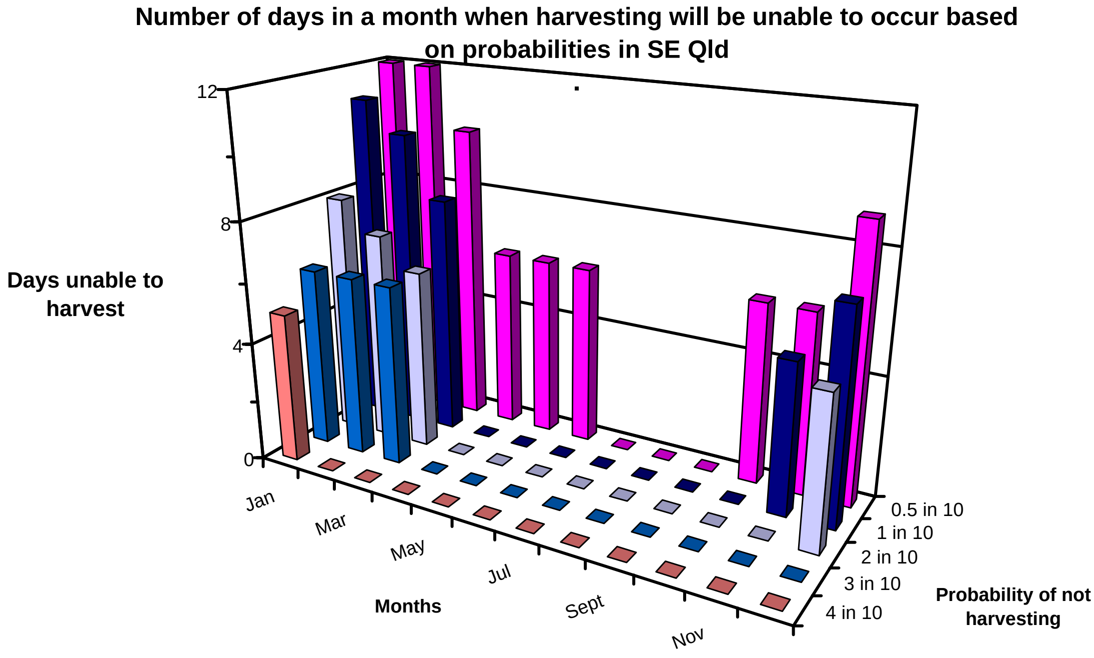

Figure 13-3: Probability of not harvesting over the year for plantation crops grown in SEQ (Also showing the number of continuous days unable to harvest.)

13.4.2 Temperate Murray Darling Basin

The location chosen for biomass production modelling in the MDB has the following climatic characteristics:

- Relatively uniform distribution of rainfall through the year (Figure 13-5)
- High probability of frosts
- Distinct winter/summer temperature regimes.

The average rainfall for the MDB location is 580 mm per annum and the variation around this average is large, with a minimum recorded annual rainfall of 264 mm and a maximum annual rainfall of 1,206 mm (Figure 13-4)[1]. The annual variation in temperature ranges by approximately 28ºC, which is an indication of the temperate climate and the inland nature of the site.

Climate for MDB (1900-2002)	Mean/median	Minimum	Maximum
Median annual rainfall (mm)	581/ 580	264	1,206
Maximum temperature ºC	24	16	32
Minimum temperature ºC	12	4.4	19
Pan Evaporation (mm)	5.4	2.3	9.1

Figure 13-4: Average climate data for typical temperate location in MDB

Approximately 57% of the rain falls during the summer and autumn months, demonstrating the uniform distribution of rainfall through the year (Figure 13-5). In general the site has a moisture deficit in summer as evaporation exceeds rainfall during this period.

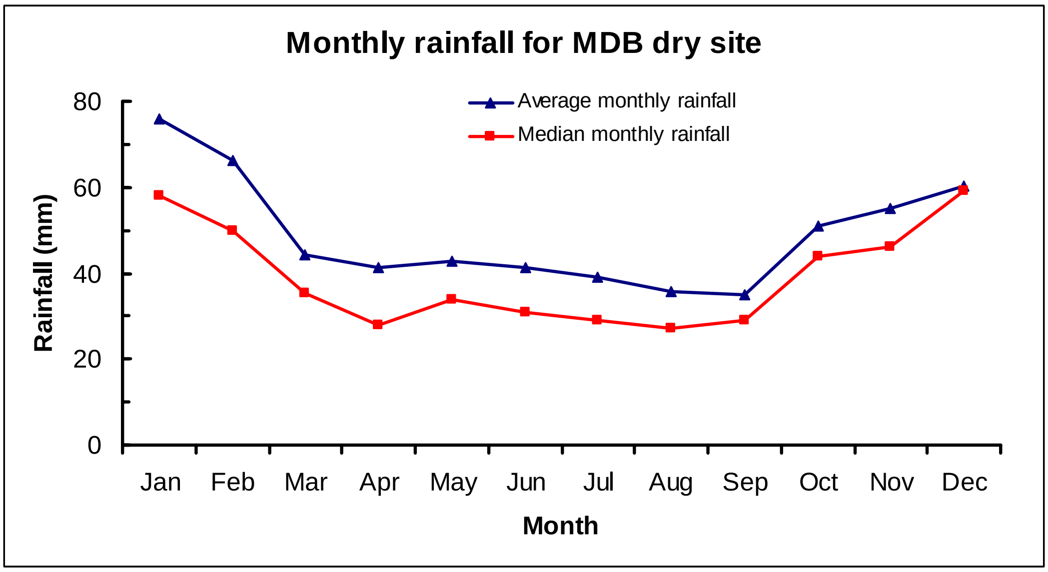

Figure 13-5: Monthly rainfall for a temperate location in the MDB
(An area which receives approximately 580 mm rainfall per annum.)

There is a 1 in 20 year chance that rain will prevent harvesting during the year at the MDB site. During this period, rain will prevent harvesting for a maximum of 9 days during January (Figure 13-6), and all months except June, August and September will potentially have periods when harvesters will not be able to access the paddocks. To avoid lost energy production, storage would need to be built to supply biomass to the plant for up to 9 days.

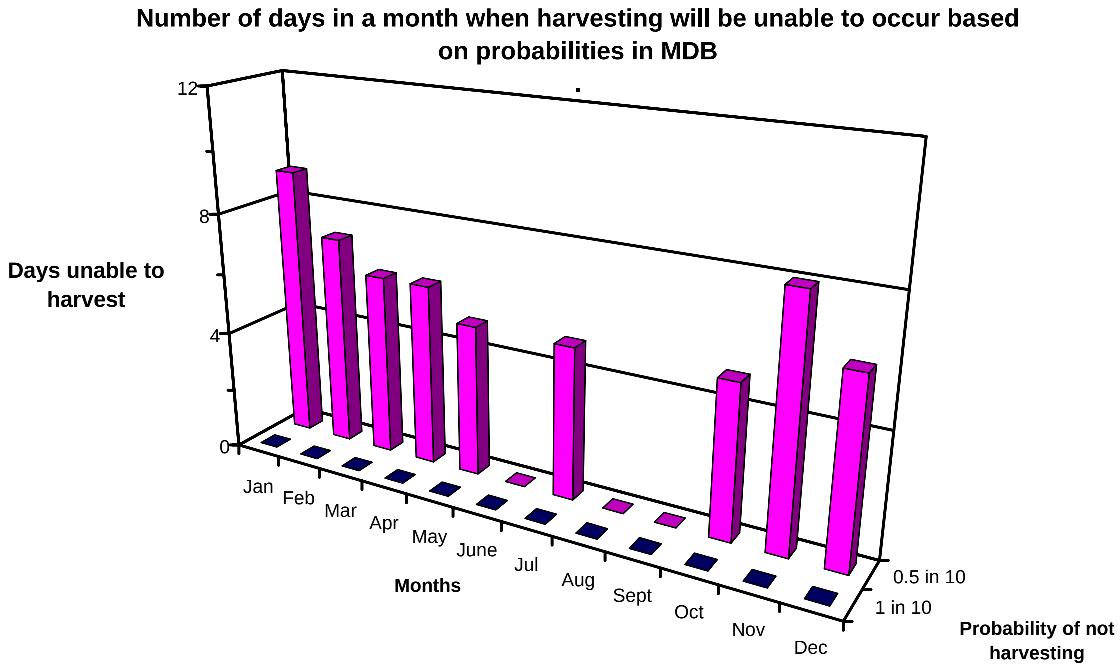

Figure 13-6: Probability of not harvesting in a year for the MDB.
(Also showing the number of continuous days per month when harvesting can not occur.)

13.5 Land suitability

A typical site in each region was selected as the location of the bioenergy plant. The suitability of the land for growing biomass within a 100 km radius of each site was then determined based on soil fertility. Three land suitability classes[1] were developed, with Class 1 land having the best soil fertility and Class 3 land having the lowest soil fertility (Figure 13-7).

Land suitability class	Description
Class 1 – High fertility	Soils with clay-loam to clay textures having high cation exchange capacity and nutrient status
Class 2 – Medium fertility	Soils with mainly loam to clay-loam textures and moderate cation exchange capacity
Class 3 – Low fertility	Soils that mainly have sand and sandy-loam textures, consequently they have low organic matter status and low cation exchange capacity, resulting in overall low nutrient status

Figure 13-7: Land suitability classes for biomass production.

The total area of land within each land suitability class for each site was determined across a range of distances using a Geographic Information System[1] (Figure 13-8). It was then assumed that only a portion of each land suitability class would be available for forest plantation development as detailed below:

- 1% of Class 1 land will be available for purchase
- 5% of Class 2 land will be available for purchase
- 10% of Class 3 land will be available for purchase.

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[1] Kilgour B, Wyborn LAI (1998) National Digital Geoscience Data Set Version 1.1. Australian Geological Survey Organisation.

Using these assumptions it was determined that the total area of land available of all three classes within 100 km of the bioenergy conversion plant for plantation development was 212,000 ha in SEQ and 230,000 ha in MDB (Figure 13-8).

SEQ

Distance from processor	Number of towns	Road length	Land Suitability Class			Total Area	Land area available for development
			1	2	3		
(km)		(km)		(ha)		(ha)	(ha)
25	10	225	26,444	-	168,664	195,108	17,395
50	34	876	145,216	-	623,298	768,514	65,234
75	49	1,642	257,170	-	1,225,022	1,482,192	127,646
100	77	2,849	423,851	-	2,037,121	2,460,972	212,189

MDB

Distance from processor	Number of towns	Road length	Land Suitability Class			Total Area	Land area available for development
			1	2	3		
(km)		(km)		(ha)		(ha)	(ha)
25	1	228	-	182,404	12,787	195,191	10,399
50	10	1,044	-	557,927	224,230	782,157	50,319
75	27	2,275	4,806	930,527	824,629	1,759,962	129,085
100	55	4,034	83,180	1,560,000	1,505,000	3,148,180	230,164

Figure 13-8: Infrastructure and Land Suitability Class within 25, 50, 75 and 100 km arcs of the bioenergy conversion plant for each site.

13.6 Infrastructure

The capacity of the roading infrastructure in the region to allow efficient transport biomass to the renewable energy site was assessed by determining the length of roads in arcs of 25 km radius out to 100 km from the renewable energy plant (Figure 13-8). There are approximately 2,800 km of roads in SEQ within a 100 km radius of the renewable energy plant and 4,000 km of roads in the MDB. It was assumed that the average transport distance from forest site to bioenergy plant would be on a mix of spur roads in the forest, arterial roads and class 1 roads.

13.7 Biomass Productivity

The capacity of a site to accumulate biomass is a function of the climate, soil fertility and genetics; however, every site has a maximum biomass threshold that it can carry. The maximum quantity of biomass that each of the two sites was capable of growing was assessed by referring to research literature and then discounting the potential maximum biomass grown to take into account the commercialisation of research yields (Figure 13-9).

Site	Crop grown	Maximum biomass produced (tDM/ha/year)	Potential biomass produced (tDM/ha/year)
SEQ	Sugar cane for 12 months	50-75[1]	35-53
MDB	Wheat (only one crop/year)	15-20[2]	10-14

Figure 13-9: Potential biomass production rates in SEQ and MDB.

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[1] Bull TA, Bull JK (2000) High density planting as an economic production strategy: (a) Overview and potential benefits. *Proceedings of the Australian Society of Sugarcane Technologists*. **22,** 9-15.

[2] Lund R (2002) Increasing the adoption of conservation farming in Central West NSW. http://www.grdc.com.au/growers/res_upd/north/02/trangie_conservation.htm

The production of biomass within a site, where rainfall is relatively uniform, will be a function of the fertility of the soils on which the biomass crop is grown. This is demonstrated in Figure 13-9 where maximum biomass yields varied across both sites accordingly. In this modelling exercise, it was assumed that the biomass production capacity of the different soils within a site will be the same and the lowest recorded in Figure 13-9.

13.8 Growing Biomass for Renewable Energy

A modelling package (developed by the authors on other work) was used to assess the economics of growing biomass for renewable energy generation from the two tree plantation systems. Two scenarios requiring different quantities of biomass were considered, *viz.* 300,000 tonnes fresh weight and 700,000 tonnes fresh weight of biomass per year. The energy plants that will be operated using these feeds are described in Section 17 below.

13.9 Biomass from Short Cycle Crops

For this study, short cycle crops (SCC) are defined as tree crops planted and grown in short rotations of less than 5 years length for the specific purpose of supplying biomass for renewable energy projects. The trees are grown to harvestable size, harvested and allowed to coppice before being harvested again. These SCC are grown at high stocking densities, in excess of 5,000 stems per hectare, using agricultural cropping technologies to plant, fertilise, apply pesticides and harvest. The general assumptions used in the SCC modelling platform are detailed in Figure 13-10.

Assumption*	**Unit**	**SEQ**	**MDB**
Biomass yield	tDM/ha/yr	35	10
Moisture content of biomass	% mc (Wet Basis)	55%	55%
Calorific value	GJ/tFW	8.9	8.9
Rotation length	Years	2	4
Number of rotations before replant		4	4
Land lease rate	$/ha/yr	150	80
Plantation costs			
Survey and planning	$/ha	52	52
Total fixed establishment costs	$/ha	1,707	1,707
Total recurring establishment costs	$/ha/harvest	520	520
Total seedling costs	$/ha	1,457	1,457
Annual maintenance costs	$/ha/yr	129	129

*Costs and revenues over time are net of inflations.

Figure 13-10: Assumptions assessing the economics of short cycle crops in SEQ and MDB. (Assumptions are based on GRO[1] and AUSNEWZ[2] publications.)

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[1] Greenfield Resource Options Pty Ltd (1999) *Silviculture, management and infrastructure requirements for hardwood plantations in South East Queensland.* Main Report, June 1999. Bureau of Rural Sciences: Canberra, Australia

[2] AUSNEWZ (2000) *Maximising Value from Blue Gum Investments.* URS Forestry:Hobart, Australia

13.10 Short Cycle Crops SEQ

“Stumpage price” is the price forest growers receive for their unharvested trees. The purchaser of the trees is responsible for harvesting and transporting of the trees.

Using the assumptions listed in Figure 13-10 the stumpage price of biomass grown in SCC in SEQ is $20.30 per tonne fresh weight. This stumpage price will provide the grower with an IRR of 10% (real) before tax. Figure 13-11shows the impact on stumpage price when changing the:

- SCC establishment costs
- biomass accumulated in the SCC

while maintaining the IRR at 10% before tax. The price growers require for the biomass grown in SCC is far more sensitive to the rate of biomass accumulated than it is to the cost in establishing the SCC. A 25% decrease in the rate of biomass accumulation results in a 33% increase in the stumpage price for the biomass, whereas a 50% increase in the cost of establishing the SCC is required to achieve the same increase in biomass stumpage price.

SEQ Biomass stumpage price ($/t FW)	**Change in establishment costs**				
Change in biomass accumulated	**-20%**	**-10%**	**0**	**25%**	**50%**
-50%	35.0	37.6	40.2	42.7	53.0
-25%	23.5	25.2	26.9	28.7	35.5
0%	17.8	19.1	20.3	21.6	26.7
10%	16.2	17.4	18.5	19.7	24.4
20%	14.9	16.0	17.0	18.1	22.4

Figure 13-11: Sensitivity analysis of stumpage price for biomass grown in SCC in SEQ (Assuming the grower is to receive an IRR of 10% (real) before tax.)

13.10.1 Supply 300,000 tonnes of wet biomass in SEQ

Approximately 4,629 hectares in total need to be established to supply an average of 300,000 tonnes per annum of wet biomass over a nominal 8 year period (Figure 13-12). However, it will take two years from planting to harvest before the first biomass is available for use.

Based on the land available from land classes 1 and 3, an average transport distance of 10kms to cart the biomass from the forest site to the bioenergy plant was assumed

13.10.2 Supply 700,000 tonnes of wet biomass in SEQ

Approximately 10,800 hectares will need to be planted to SCC in SEQ to supply an average of 700,000 tonnes of wet biomass per year (Figure 13-13). There are minor savings in production costs by increasing the size of the plantation area; however these cost savings are offset by reduced yields associated with moving onto poorer quality sites due to the requirement for a larger plantation area. The nett effect is that the price for biomass to achieve a 10% IRR from small and large SCC areas is roughly equivalent.

In this instance, based on the land available (Figure 13-8) an average transport distance of 20km radius was assumed.

Years		0	1	2	3	4	5	6	7	8	9
Area established per year	ha	2,315	2,315	0	0	0	0	0	0	0	0
Area under SCC	ha	2,315	4,629	4,629	4,629	4,629	4,629	4,629	4,629	4,629	2,315
Biomass Wet	tFW	-	-	324,000	324,000	307,800	307,800	292,410	292,410	277,790	277,790
Biomass Dry	tDM	-	-	145,800	145,800	138,510	138,510	131,585	131,585	125,005	125,005
Total energy delivered	GJ	-	-	2,878,902	2,878,902	2,734,957	2,734,957	2,598,209	2,598,209	2,468,299	2,468,299

Figure 13-12: Area required to supply an average of 300,000 t FW p.a. from SCC in SEQ

Years		0	1	2	3	4	5	6	7	8	9
Area established per year	ha	5,393	5,393	0	0	0	0	0	0	0	0
Area under SCC	ha	5,393	10,786	10,786	10,786	10,786	10,786	10,786	10,786	10,786	5,393
Biomass Wet	tFW	-	-	755,000	755,000	717,250	717,250	681,388	681,388	647,318	647,318
Biomass Dry	tDM	-	-	339,750	339,750	322,763	322,763	306,624	306,624	291,293	291,293
Total energy delivered	GJ	-	-	6,708,553	6,708,553	6,373,125	6,373,125	6,054,469	6,054,469	5,751,745	5,751,745

Figure 13-13: Area required to supply an average of 700,000 t FW p.a. from SCC in SEQ

13.11 Short Cycle Crops MDB

The slower rates of biomass accumulation at the MDB site (Figure 13-9) result in the stumpage price received for biomass grown in SCC being $51.80 per tonne fresh weight if growers are to receive an IRR before tax of 10% (real). A 20% increase in the biomass accumulation rate to 12 tonnes of dry matter per annum and a 20% reduction in the establishment costs will result in the stumpage price for biomass reducing to $38.10 per tonne fresh weight (Figure 13-14).

MDB biomass stumpage price ($/t FW)	**Change in establishment costs**				
Change in biomass accumulated	**-20%**	**-10%**	**0**	**25%**	**50%**
-50%	90.7	96.9	103.1	118.6	134.0
-25%	60.6	64.8	68.9	79.2	89.5
0%	45.6	48.7	51.8	59.5	67.3
10%	41.5	44.3	47.1	54.2	61.2
20%	38.1	40.7	43.3	49.7	56.1

Figure 13-14: Sensitivity analysis of stumpage price for biomass grown in SCC in MDB (Assuming the grower is to receive an IRR of 10% (real) before tax.)

13.11.1 Supply 300,000 tonnes of wet biomass in MDB

Approximately 16,200 hectares of land will need to be established to SCC in the MDB area to supply an average of 300,000 tonnes of wet biomass per annum (Figure 13-15).

Hence based on the land available and the various land classes and their yield potential, an average transport distance of 30km from paddock to power plant was assumed.

13.11.2 Supply 700,000 tonnes of wet biomass in MDB

Approximately 31,500 hectares of land will need to be established to SCC in the MDB area to supply an average of 300,000 tonnes of wet biomass per annum (Figure 13-16).

Years	Units	0	1	2	3	4	5	6	7	8	9
Area established per year	ha	4,050	4,050	4,050	4,050	-	-	-	-	-	-
Cumulative area established	ha	4,050	8,100	12,150	16,200	16,200	16,200	16,200	16,200	16,200	16,200
Biomass Wet	tFW	-	-	-	-	324,000	324,000	324,000	324,000	307,800	307,800
Biomass Dry	tDM	-	-	-	-	145,800	145,800	145,800	145,800	138,510	138,510
Total energy delivered	GJ	-	-	-	-	2,878,902	2,878,902	2,878,902	2,878,902	2,734,957	2,734,957

Years		10	11	12	13	14	15	16	17	18	19
Area established per year	ha	-	-	-	-	-	-	-	-	-	-
Cumulative area established	ha	16,200	16,200	16,200	16,200	16,200	16,200	16,200	12,150	8,100	4,050
Biomass Wet	tFW	307,800	307,800	292,410	292,410	292,410	292,410	277,790	277,790	277,790	277,790
Biomass Dry	tDM	138,510	138,510	131,584	131,584	131,584	131,584	125,006	125,006	125,006	125,006
Total energy delivered	GJ	2,734,957	2,734,957	2,598,209	2,598,209	2,598,209	2,598,209	2,468,299	2,468,299	2,468,299	2,468,299

Figure 13-15: Area of land required to be established to supply 300,000 t FW p.a. to a renewable energy plant in the MDB.

Year	Year	0	1	2	3	4	5	6	7	8
Area established per year	ha	7,865	7,865	7,865	7,865	-	-	-	-	-
Cumulative area established	ha	7,865	15,729	23,594	31,458	31,458	31,458	31,458	31,458	31,458
Biomass Wet	tFW	-	-	-	-	755,000	755,000	755,000	755,000	717,250
Biomass Dry	tDM	-	-	-	-	339,750	339,750	339,750	339,750	322,762
Total energy delivered	GJ	-	-	-	-	6,708,553	6,708,553	6,708,553	6,708,553	6,373,125

Year	Year	9	10	11	12	13	14	15	16	17	18	19
Area established per year	ha	-	-	-	-	-	-	-	-	-	-	-
Cumulative area established	ha	31,458	31,458	31,458	31,458	31,458	31,458	31,458	31,458	23,594	15,729	7,865
Biomass Wet	tFW	717,250	717,250	717,250	681,388	681,388	681,388	681,388	647,318	647,318	647,318	647,318
Biomass Dry	tDM	322,762	322,762	322,762	306,625	306,625	306,625	306,625	291,293	291,293	291,293	291,293
Total energy delivered	GJ	6,373,125	6,373,125	6,373,125	6,054,469	6,054,469	6,054,469	6,054,469	5,751,745	5,751,745	5,751,745	5,751,745

Figure 13-16: Area of land required to be established to supply 700,000 t FW per annum to a renewable energy plant in the MDB.

Based on available land in the area, it was assumed the average transport distance was 40 km.

13.12 Biomass from Tree Plantation Crops

Tree plantation crops (TPC) are traditionally planted and grown in long rotations to supply logs to mills for processing. Generally the rotation lengths are greater than 20 years length. In growing the log crop there are thinnings from silvicultural operations. After harvest of the stemwood there will be residues from milling operations that could be used as fuel for bioenergy production.

The modelling scenario run to supply biomass from TPC in both SEQ and MDB was limited to supplying 300,000 tonnes of fresh weight per annum from the first thinning; as the area of land required to be planted to establish the plantation was in excess of the land area considered available within 100 km of the renewable energy plant in the MDB scenario (Figure 13-8 and Figure 13-17).

The base assumptions used in the TPC model are listed in Figure 13-17 and Figure 13-18. Different land lease rates were used compared to the SCC model (Figure 13-10) due to the land being under the forest for greater periods of time in TPC.

Assumptions[*]	**Unit**	**SEQ**	**MDB**
Land lease rate	$/ha	200	107
Plantation costs			
Survey and planning	$/ha	52	52
Total establishment costs	$/ha	1,852	1,852
Average annual maintenance costs	$/ha	182	177
Average cost for harvest preparation	$/m^3 harvested	4.55	9.92
Revenue from sale of solid wood			
Veneer logs	$/m^3	110	110
Thinning logs	$/m^3	30	30
Poles	$/m^3	90	90
Sawlogs	$/m^3	70	70
Mean Annual Increment for rotation length	m^3/ha/year	25	10
Biomass moisture content	% FW	55%	55%
Rotation length	Years	25	40
Area established each year for 300,000 t biomass	ha	6,378	6,378
Total area established for 300,000 t biomass	ha	159,439	255,102

[*] Costs and revenues over time are net of inflations.

Figure 13-17: Assumptions used to assess the economics of using biomass from tree plantation crops in SEQ and MDB
(Assumptions are based on GRO[1] and AUSNEWZ[2] publications.)

			Products			
Harvest age (years)	**Stems removed**	**Volume** (m^3/ha)	**Veneer logs**	**Poles**	**Sawlogs**	**Biomass** (tFW/ha)
			---------------(m^3/ha)---------------			
			SEQ			
8	444	53	0	0	0	47
18	367	234	23	0	105	117
25	300	326	98	65	98	87
			MDB			
17	444	53	0	0	0	47
30	367	157	16	0	71	78
40	300	182	55	36	55	41

Figure 13-18: Product table for tree plantation crops grown in SEQ and MDB.
(Assumptions are based on GRO[1] and AUSNEWZ[2] publications.)

13.12.1 Biomass from TPC in SEQ

The biomass from the TPC production system will first be available eight years after establishing the first area of approximately 6,400 hectares when the first thinning occurs. If a similar area is planted each year of the rotation it will supply approximately 300,000 tonnes of wet biomass for renewable energy production from year eight to year 18 (Figure 13-20), after which the quantity of biomass available for bioenergy production will increase to approximately 1.0 million tonnes of wet woody biomass due to biomass coming from first and second thinning operations. The total area that will need to be established over the 25 year rotation of the TPC in SEQ will be approximately 159,500 hectares and this will result in a maximum total of 1.6 million tonnes of wet woody biomass being available 25 years after establishment (Figure 13-20). In addition to biomass available for energy purposes from the plantation, there will be a substantial volume of solid wood available from the harvest of the plantation, with approximately 1.7 million cubic metres of solid wood products being harvested from year 25 onwards.

The price to be paid for the biomass produced in TPC in SEQ was set at $20.30 per tonne of fresh weight so it could be directly compared with SCC in this area; this resulted in the growers receiving an IRR of 8.4% (real) before tax, as opposed to the 10% IRR achieved from SCC. The revenue from the biomass in the TPC makes up approximately 13% of the total revenue received and 87% of the total revenue comes from the sale of solid wood products such as veneer logs, sawlogs and poles.

The price required to be received for the biomass to ensure an 8.4% IRR return before tax to growers is highly sensitive to changes in the growth rate of the trees, and a 10% increase in tree growth rate results in close to a 50% reduction in the required price for biomass, while a 25% reduction in tree growth more than doubles the biomass price required by growers (Figure 13-19).

SEQ TPC Biomass price ($/t FW)	**Change in establishment costs**				
Change in biomass accumulation rate	**-20%**	**-10%**	**0%**	**25%**	**50%**
-50%	110.4	116.5	122.5	137.6	152.7
-25%	46.4	50.4	54.4	64.5	74.5
0%	14.3	17.3	**20.3**	27.9	35.4
10%	5.6	8.3	11.1	17.9	24.8
20%	-1.7	0.8	3.3	9.6	15.9

Figure 13-19: Sensitivity analysis of price for biomass grown in TPC in SEQ
(Assuming the grower is to receive an IRR of 8.4% (real) before tax.)

Based on the available land (Figure 13-8) an average transport distance of 80 km was assumed to supply biomass from the forest delivered to the bioenergy plant.

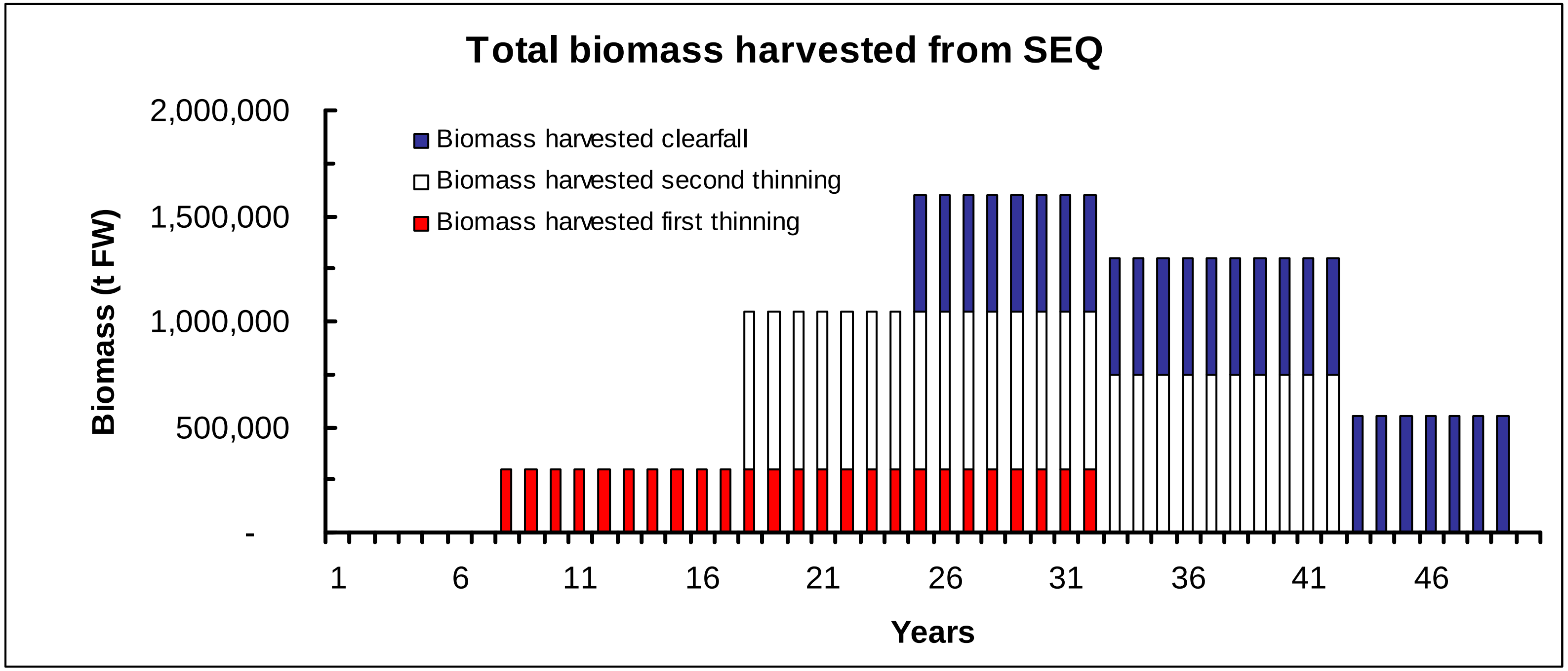

Figure 13-20: Quantity of biomass produced from first and second thinning and clearfall harvest of TPC in SEQ that is available for bioenergy production.

13.12.2 Biomass from TPC in MDB

Slower tree growth rates have numerous effects on the production of biomass from TPC for renewable energy generation in the MDB. The first effect is that the biomass from the first thinning will not be available until approximately 17 years after the TPC is established. The second effect is that the area of land to be utilised for TPC to supply 300,000 tonnes of wet biomass at the first harvest period is 6,378 hectares (Figure 13-17). Over a 40 year rotation period the total area of TPC to be established will be approximately 255,000 hectares, which is 60% larger than the total area required for TPC in SEQ. The maximum quantity of biomass produced in the 40 year rotation period will be approximately 1.1 million tonnes from 40 years on (Figure 13-22).

The price growers will need to receive to ensure an IRR before tax of 8.4% is approximately $239 per tonne of wet biomass. This high price is required to be paid for the biomass to offset the slow rate of growth of the trees in this dry area. The revenue from the sale of trees at thinnings and final harvest for biomass makes up approximately 67% of total revenue, while the revenue from the solid wood products produced at thinnings and harvest is only 33% of the total revenue received from TPC grown in the MDB. This is in contrast to the figures of 13% and 87% respectively for TPC grown in SEQ. Similar to the scenario in SEQ the price paid for the biomass in the TPC scenario is highly sensitive to tree growth rates, as demonstrated in Figure 13-21. However, under none of these sensitivity options does the price of biomass achieve anything close to a price that would support a financially viable bioenergy project.

MDB TPC Biomass price ($/t FW)	**Change in establishment costs**				
Change in biomass accumulation	**-20%**	**-10%**	**0%**	**25%**	**50%**
-50%	486	504	523	570	617
-25%	308	321	334	365	396
0%	220	229	239	262	286
10%	196	204	213	234	255
20%	175	183	191	211	230

Figure 13-21: Sensitivity analysis of price for biomass grown in TPC in MD
(Assuming the grower is to receive an IRR of 8.4% (real) before tax.)

Based on available land area (Figure 13-8) a transport distance of 100km on average was assumed.

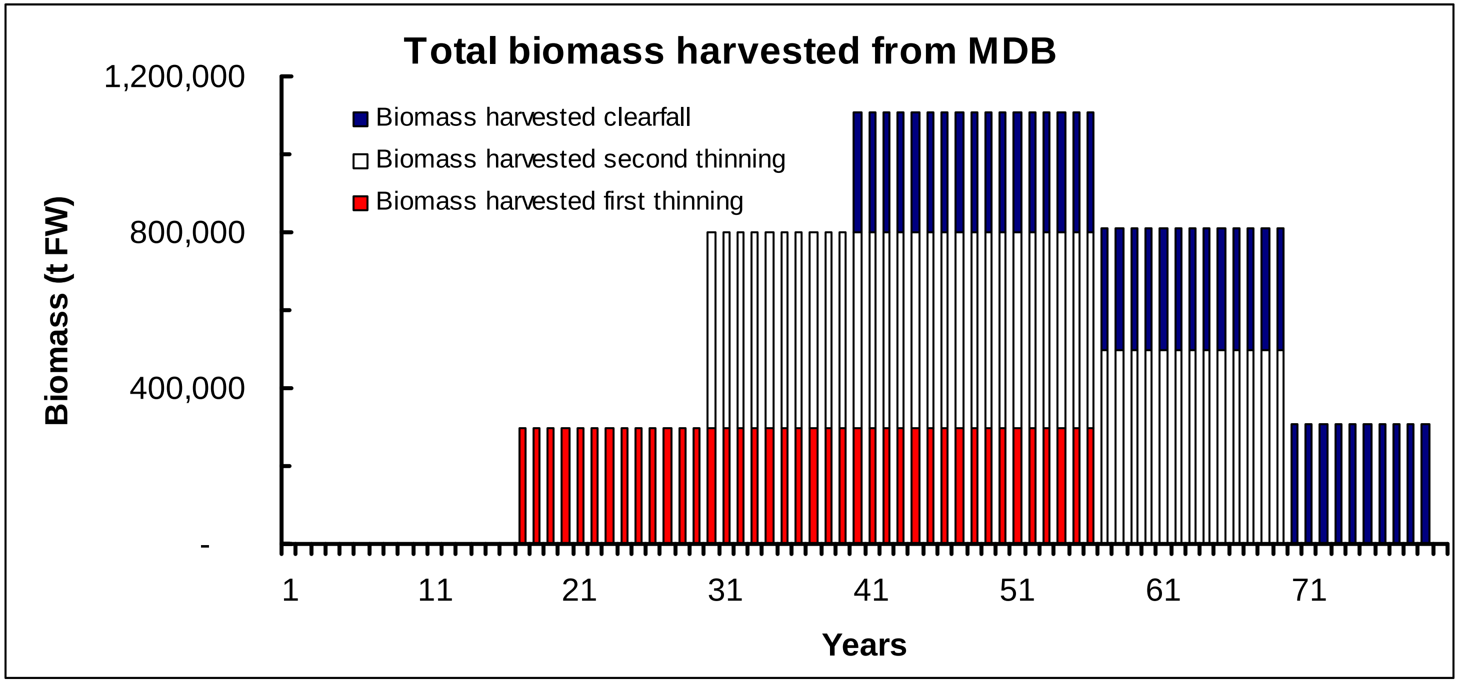

Figure 13-22: Quantity of biomass harvested from first and second thinning and clearfall harvest of TPC in MDB that is available for bioenergy production.

13.13 Comparison of Biomass Costs

The cost of biomass paid at the stump from SCC and TPC in SEQ was set at a value of $20.30 per tonne fresh weight. This price returned an IRR before tax of 10% and 8.4% for the SCC and TPC production systems, respectively. Moving to the drier climate of the MDB area resulted in much slower biomass accumulation rates due to slower tree growth rates and consequently an increase in the price growers would need to be paid for their biomass to achieve equivalent IRR to growers in SEQ (Figure 13-23).

Biomass price ($/tFW)	**SCC (IRR 10% before tax)**	**TPC (IRR 8.4% before tax)**
SEQ	20.30	20.30
MDB	51.80	239.00

Figure 13-23: Comparison of the price paid for biomass produced in SCC and TPC production systems in SEQ and MDB.

The biomass production system based on short cycle tree crops produces a greater return to growers when compared to long rotation TPC despite both production systems having similar outlays, and the TPC producing more than one product. Consequently, growers are more likely to establish SCC that only produce biomass for a renewable energy project, than plant TPC that take longer to mature and longer to produce any monetary return. This is highlighted in the drier MDB area where growers achieve an IRR greater than 8% before tax when they receive $51.80 per tonne fresh weight of biomass from the SCC and a price of $239 per tonne fresh weight is required for biomass from the TPC. Consequently, under the scenarios tested here, growers in drier regions of Australia would be better off establishing short cycle tree crops dedicated to energy than long rotation TPC, to achieve better financial return.

It is anticipated that the differential in price paid for biomass from either SCC or TPC between wetter (SEQ) and drier (MDB) areas will make it harder for renewable energy projects in drier areas. However, the price that is able to be paid for biomass from deep rooted semi-permanent tree crops, such as mallee, planted in these drier regions of the MDB may ultimately be more than that for biomass in wetter areas, if appropriate values can also be placed against a range of other benefits provided by these crops. These other benefits include environmental services such as:

i. salinity mitigation
ii. soil conservation
iii. catchment protection
iv. carbon sequestration
v. biodiversity enhancement.

Many of these benefits are hard to quantify in monetary terms. Consequently, before the establishment of either SCC or TPC in drier areas is ruled out due to the apparent cost of the biomass to the renewable energy plant, a comprehensive analysis of the additional values of these crops needs to be undertaken.

14. Case Studies – Harvest and Transport

14.1 Summary

For each of the biomass production systems considered in the preceding section, case studies are conducted below to assess the cost of harvesting, handling, storing, processing and transporting the biomass to an energy conversion plant.

Modelling was conducted using a spreadsheet computer model (BIOTRANZ). The model takes into account elements such as biomass dry matter losses during harvest, storage and processing, and changes to the moisture content over time. For each system, various transport routes are configured to include forest tracks, spur roads, arterial roads and ‘class one’ roads. Modelling assumptions are made, in part using the biomass costs from the case studies of the preceding section. Recognising that the very high price of $239/t (fresh weight) for thinning in the MDB is unrealistic, a price of $150/t dry matter is used. The model assumes two alternative harvesting and transport systems appropriate for short cycle crop and forest thinnings extraction. Operating shifts in the field and at the bioenergy plants are assumed. The truck payloads are constrained to 25 tonnes to comply with possible road regulations. Other assumptions are made at the various points of the biomass supply chain. The methodology again applies a sensitivity analysis to assess the impact of some assumptions on the delivered feedstock price.

For South East Queensland the fuel purchase cost is approximately half the overall delivered fuel cost. In the MDB the biomass purchase price dominates the delivered biomass cost and is around 75 percent of the delivered cost.

These case studies conclude that the supply chain cost of biomass from short cycle crops, (i.e. excluding purchase price), range from between $36 per tonne (dry matter) ($1.80/GJ) over a 10 km transport distance in a region with a two year rotation to around $46/t (dry matter) ($2.30/GJ) over 40 km in a drier region with a four year rotation. Thinnings can be harvested and delivered for between $38/t ($1.90/GJ) where forest yields are good and average transport distances are below 80 km, but can reach over $75/t ($3.60/GJ) in slower growing regions where the collection distance is up to 150 km. When the purchase price of the biomass is included, the total costs of biomass delivered to a bioenergy plant can be doubled in higher rainfall areas (SEQ) and trebled in drier areas such as the Murray Darling Basin.

A major consideration for biomass fuel supply is the short lead time to establish short cycle crop biomass (2-4 years) compared with 8-17 years after planting trees, when forest thinnings would first become available.

14.2 Transport of the Biomass to a Conversion Plant

The objective of this part of the case study was to determine the cost of harvesting, handling, storing, processing and transporting the biomass material to deliver it to the bioenergy power plant. A spreadsheet model, BIOTRANZ, (developed in the UK but adapted for Australasian conditions) was used to calculate the delivered costs. Details of the model appear elsewhere and the specific assumptions used in this study are outlined below.

The BIOTRANZ model (BIOmass TRAnsport model for New Zealand), programmed in Excel (version 97), consists of several worksheets for product and machinery input data, a comprehensive analysis datasheet and a summary sheet. In this study separate worksheets were assigned for calculating the overall transport costs of the two delivery systems for each of the two regions. Graphs were generated to depict resulting delivery costs for all 4 systems compared in each region, in terms of $ per tonne dry matter and $ per GJ delivered, and also taking the different moisture contents as delivered into account. Using linked input worksheets minimised the risk of mistakes because all systems and sites used the same input data. The program contains a module which selects the transport vehicle type with the lowest costs. Dry matter losses during harvest, storage and processing, and changes of the moisture content over time during storage are incorporated into the model.

Previous studies using the BIOTRANZ model have compared various handling and transport systems for a given situation[1]. For this study, a single system was selected and assumed to be the optimum to supply each of the two biomass resources under consideration:

1) short cycle crops (SCC) and
2) the forest thinnings extracted from tree plantation crops (TPC).

An overview of the various locations, biomass feedstocks and system options evaluated in this project is outlined in Figure 14-1.

The larger capacity plants in terms of tonnes processed per year require greater volumes of feedstock which has to be collected from a wider radius, thereby giving a greater average transport distance.

In the real world it is likely that a range of feedstocks will be available under several supply contracts to meet the total biomass demand of a large bioenergy power plant. For example a central wood-fired combustion steam turbine power plant could utilise sawdust from local sawmills, bark, wood process residues and offcuts, forest arisings, purpose grown energy crops, orchard prunings, municipal green waste, straw, bagasse etc. and thereby reduce the collection radius and average transport distance. In this hypothetical study however, only one of the two chosen single sources of biomass was analysed for each proposed bioenergy power plant.

S E Queensland				**Murray Darling Basin**			
Power plant 300,000t/yr		**Power plant** 700,000t/yr		**Power plant** 300,000t/yr		**Power plant** 700,000t/yr	
System A	System B	System C	System D	System E	System F	System G	System H
SCC	TPC	SCC	TPC	SCC	TPC	SCC	TPC
Machinery:							
Austoft Trac/ trailer Truck	Feller bunch Chip Truck	Austoft Trac/ trailer Truck	Feller bunch Chip Truck	Austoft Trac/ trailer Truck	Feller bunch Chip Truck	Austoft Trac/ trailer Truck	Feller bunch Chip Truck
Av distance							
10km	80km	20km	120km	30km	100km	40km	150km
F 0.2	F 0.15	F 0.2	F 0.15	F 0.2	F 0.15	F 0.2	F 0.15
S 2.0	S 2.00	S 2.0	S 2.00	S 4.0	S 4.00	S 4.0	S 4.00
A 3.0	A 30.00	A 5.0	A 50.00	A 8.0	A 40.00	A 12.0	A 60.00
C1 4.8	C1 47.85	C1 12.8	C1 67.85	C1 17.8	C1 55.85	C1 23.8	C1 85.85

F= forest tracks S= spur roads A= arterial roads C1= class one roads

Figure 14-1: Overview of locations, feedstocks and system options

Comparison of selected systems to deliver biomass over various average distances from either short cycle crops short cycle crops (SCC) or forest thinnings from tree plantation crops (TPC) to bioenergy power plants to be constructed in the two study locations.

Additional analysis is required to evaluate how the biomass supply for a proposed new conversion plant might best be provided for a specific plant location based in each of the two regions so that the

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[1] Sims & Culshaw, 1998; Hall et al, 2001; Sims & Venturi, 2003

volume and locations of the existing biomass resource could then be identified. A different feedstock mix would result in each region since the Murray Darling Basin is currently mainly arable/pastoral with little forest area whereas S E Queensland has some existing plantation forests, some of which are already mature and being processed for timber products. In this case the fuelwood demand for a new plant could possibly be largely met from forest thinnings and wood process residues immediately and then supplemented with short cycle crops as necessary as bioenergy demand grows and new plants are built. Assuming the existing plantation forests are replanted after harvest but the total forestry land use area remains constant, then any increase in demand for bioenergy over time would have to be met from purpose grown short cycle crops (or perhaps from vegetative crops). Conversely in the Murray Darling Basin where growth is slower and few plantation forests exist, short cycle crops would need to be established first to provide biomass within four years or so which would then be supplemented after around 18 to 20 years as new forest plantings matured and the thinnings, and later wood process residues became available.

14.3 Model Assumptions

The purchase or stumpage price, as calculated in the section above, was converted to $/t dry matter assuming the moisture content at harvest was 55% for both short cycle crops and forest thinnings. However the very high price of $239/t fresh weight paid for the thinnings in Murray Darling Basin would eliminate the option to use this material for biomass completely, so it was assumed a much lower price of $150/t dry matter could be negotiated with the growers.

Two handling and delivery systems were evaluated for each forest site based on existing systems as used by forest contractors (Figure 14-2). The machine capacities are shown along with the hourly costs based on detailed analysis of purchase price, annual hourly use, labour, fuel, depreciation, repairs and maintenance etc. A modified Austoft sugar cane harvester was used to cut and billet the short cycle crops crop into short 150-200mm lengths which were conveyed into one of two tractor-pulled trailers running alongside. These were used to transport the biomass an average of 200m to the headland where it was tipped on to the ground, then after an average of 7 days, was loaded into a truck/trailer unit by front loader to be transported to the bioenergy plant. Here it was tipped and stock-piled on a concrete standing before feeding on to the plant conveyor by front loader.

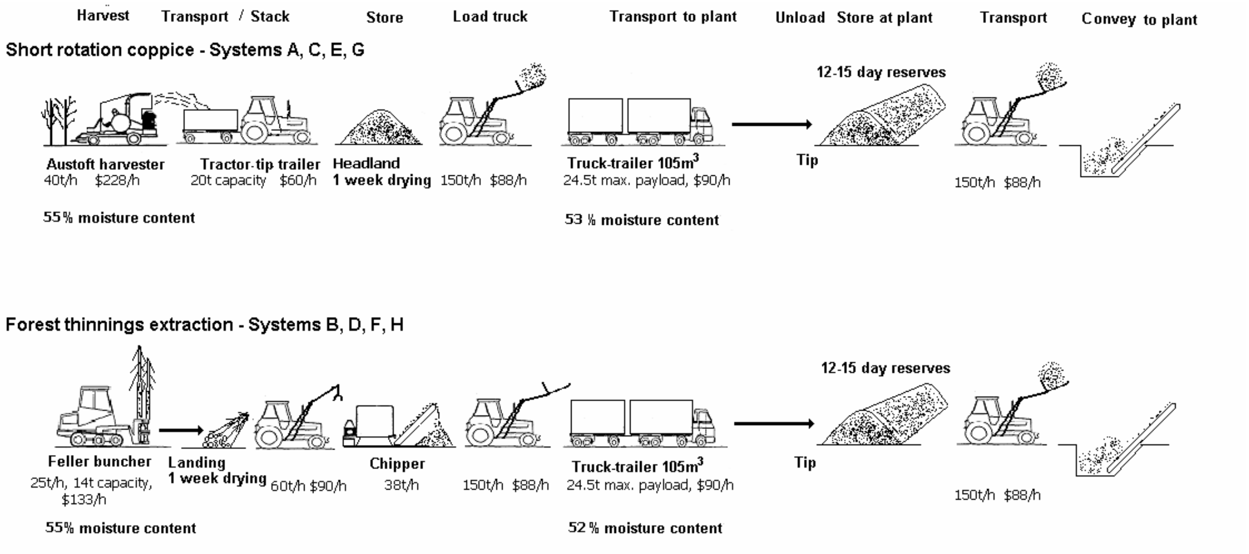

Figure 14-2: Alternative Harvest and Transport Systems

The forest thinnings were cut using a feller buncher which accumulated 10 or so trees before taking them the 200m average distance to the landing. Here they were left for around 1 week on average before chipping and loading by front loader into a truck/trailer unit. However there was a slightly faster drying rate assumed for the whole trees (5% per month; 1% dry matter loss per month) than for the billets (3% per month; 2% dry matter loss per month) due to transpirational drying. The figures used are only indicative, the model calculating exact moisture change over time and consequential dry matter losses. To compensate for dry matter loss additional material needs to be purchased and the model adjusts the purchase price accordingly. The chipped biomass was then handled in exactly the same way as for the short cycle crops billets but it was assumed that at the bioenergy plant the drying rate for the short cycle crop billets would be 2.5% per month and 1% per month dry matter losses whereas the smaller chips from the thinnings would dry at only 1% per month and have 2% per month dry matter loss.

The common assumptions used for all systems were: discount rate 9%; in-forest equipment working one shift per day; equipment at the power plant working two shifts per day; 235 working days per annum. Specifications and costs of the harvest, handling and processing equipment used as shown in Figure 14-2 were derived from research[1]since there was no comparable cost data available for such machines currently operating in Australia. Machine productivities and truck capacities may differ when handling chips rather than billets due to the nature of the material, but for simplicity in this exercise they were assumed to be similar.

Specifications of the transport vehicles considered in the analysis are based on relevant legislation. On forest roads, a higher maximum gross vehicle weight (GVW) and therefore payload is allowed for most vehicles. When transporting on public roads however the maximum gross vehicle weight is restricted by legislation giving payloads of approximately 25 tonnes for the chosen truck configuration. At the relatively high moisture contents envisaged it was assumed the load would be weight limited rather than volume limited. An option not evaluated would be to allow longer storage periods at the headlands or landing to enable some natural drying to occur in order to maximise transport in terms of GJ/load.

For each road type, different average speeds were assumed, based on practical experience. The average one-way transport distances assumed for travelling on in-forest tracks (F), spur roads (S), arterial roads (A) and class 1 (C1) roads are given in Figure 14-1 for each system, partly based on the roading network in each of the two regions. The average vehicle speeds on these road types were assumed to be:

- 3 km/h for the tractor-trailer (SCC) or feller buncher (TPC) when operating on the forest track to transport the biomass to the headland ready for loading on to trucks or, for the thinnings, after chipping
- 10 km/h on the spur roads for the truck-trailer unit
- 70km/h on arterial or “B” roads
- 80km/h on class 1 highways.

The return journey over the same route (but not loaded) was assumed and is accounted for in the model.

Storage at the headland for the short cycle crop, or at the landing for the forest thinnings, was assumed to be no more than one week on average. A cost for the land rental was included. At the bioenergy plant a concrete pad was costed in to account for a rolling stockpile of a 15 days in S E Queensland based on the probability of not harvesting for a period due to higher rainfall than in the Murray Darling Basin where only 12 days of reserves are needed. The drier conditions also

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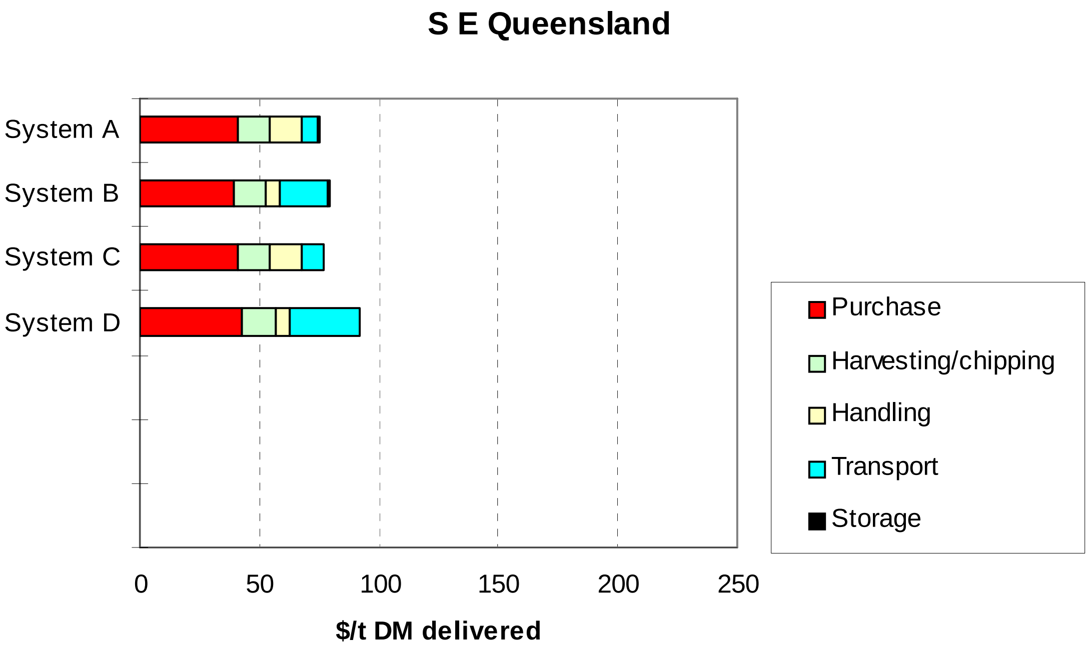
[1] Hall (1995a, 1995b, 1997) and Hall & Wyllie (1996)

accounted for a drying rate of 3% moisture content per month storage versus 2.5% assumed for S E Queensland.

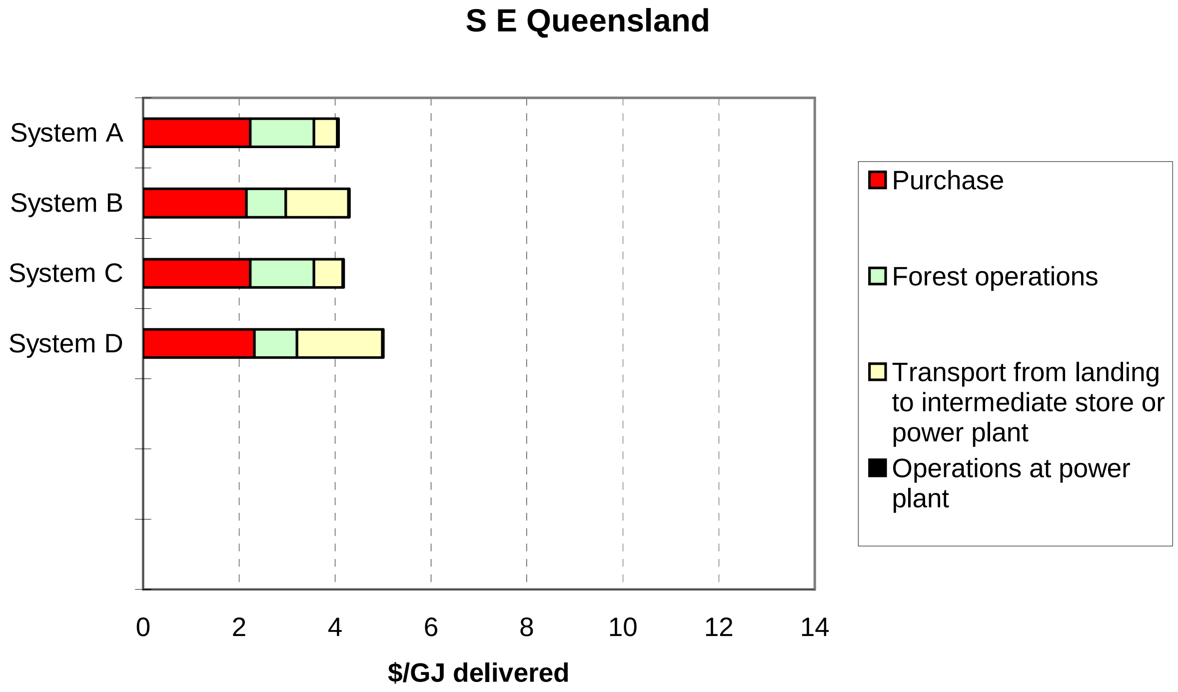
14.4 Results

The base case delivered costs of biomass feedstock for Systems A, B, C and D (Figure 14-1) in S E Queensland are illustrated in Figure 14-3*a* (in terms of $/t dry matter delivered and categorised into purchase price, harvest/chipping, handling, transport and storage costs) and also in Figure 14-3*b* (in terms of $/GJ delivered and categorised into purchase price, forest operations, transport and power plant operations). Storage costs are considered to be negligible as only 1 week storage was contemplated. Similar results are given in Figure 14-3*c* and Figure 14-3*d* for the Murray Darling Basin where forest growth is slower due to soil and climatic differences.

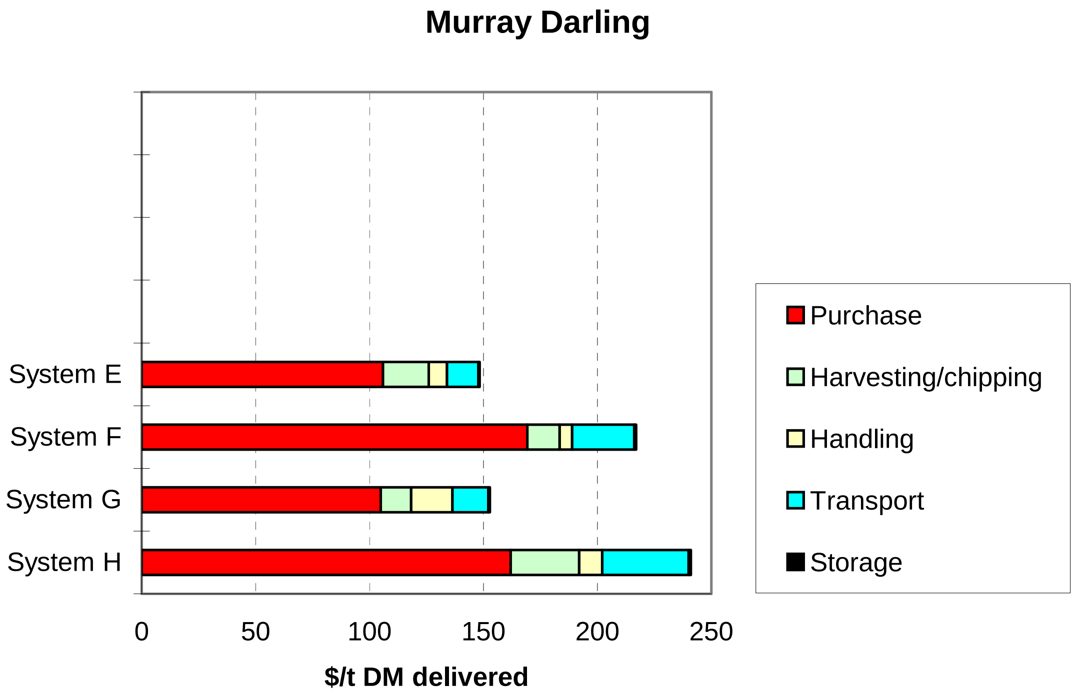
***a*)**



b)


S E Queensland
System A
System B
System C
System D
0
2
4
6
8
10
12
14
$/GJ delivered
Purchase
Forest operations
Transport from landing to intermediate store or power plant
Operations at power plant

c)


Murray Darling
System E
System F
System G
System H
0
50
100
150
200
250
$/t DM delivered
Purchase
Harvesting/chipping
Handling
Transport
Storage

d)

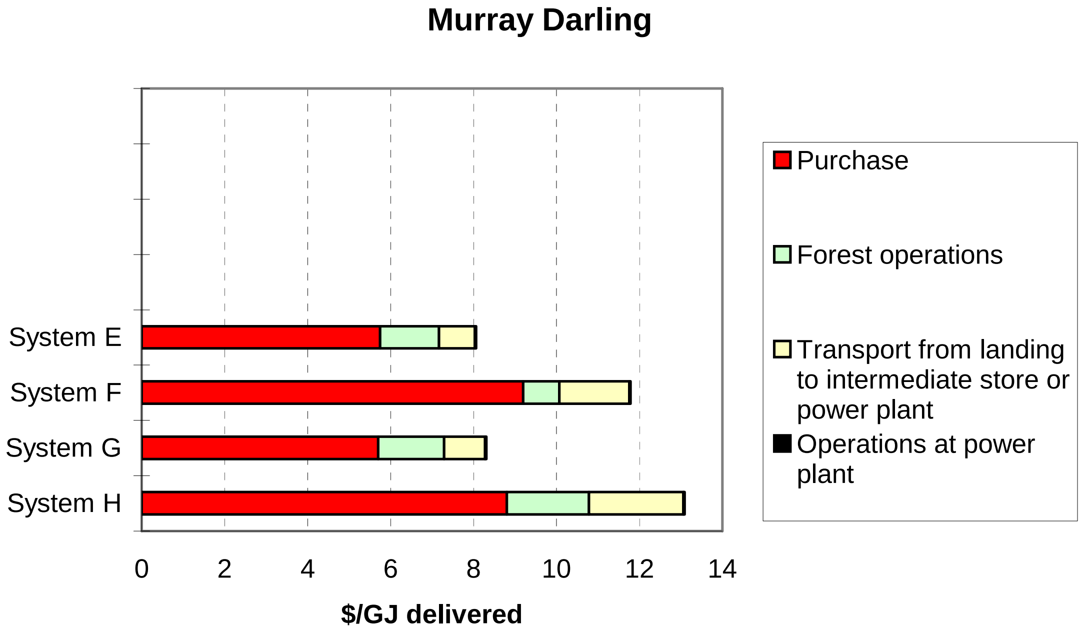


Figure 14-3: Delivered costs of biomass from short cycle crops
(Systems A, C, E and G) and forest thinnings (Systems B, D, F and H) to provide a cogeneration or power plant with 300,000t/yr (Systems A, B, E and F) or 700,000t/yr (Systems C, D, G and H) in either S E Queensland or the Murray Darling Basin).

The dominance of the purchase price, particularly in the Murray Darling Basin is evident. For S E Queensland, from the sensitivity tables below, it is shown that if the biomass accumulation rate was 10% higher than estimated and the establishment costs could be 10% less following greater experience from growing the crops, a significant reduction in the negotiated stumpage purchase price becomes possible (from $36.90/t dry matter to $31.60/tDM for short cycle crops (SCC, systems A and C) and to $15.90/tDM for the thinnings (TPC, systems B and D). This change in purchase price alone results in a total cost reduction of around 8% for short rotation systems and over 25% for thinnings (Figure 14-4).

Base case (Figure 14-3)	**System $/t DM**	**A 74.98**	**B 79.11**	**C 77.06**	**D 92.17**
Purchase price: –10% establishment costs and +10% yield	10% changes	-8.0	-28.6	-7.7	-26.4
Harvest costs: reduce from $12/tDM for SCC and $10/tDM for TPC.	50% lower	-8.9	-6.8	-8.7	-6.3
Moisture content at harvest: increase from 55%	Up to 60% mc	+3.3	+4.4	+3.6	+5.0
Transport distance: reduced due to greater concentration of resources	10% less	-0.7	-2.6	-0.9	-3.2
	50% less	-3.3	-12.8	-4.5	-15.7
Yield increase: + 10% Establishment costs: –10% Harvest costs: –10% Transport distance: -10% Field storage time: 6days to 3 days average Storage at plant: 9 days from 15 days		-10.7	-32.3	-10.6	-31.4
As above, but assuming no change to purchase price due to any yield increase or establishment cost reduction.		-2.8	-5.0	-2.9	-5.3

Figure 14-4: Sensitivity analysis for delivered costs

Reducing harvesting costs using the Austoft harvester for the short cycle crops (calculated to be $12/t dry matter) or the feller buncher for the thinnings ($10/tDM) can result in an overall cost reduction of around 6-9%.

The moisture content at harvest and the assumptions made on the changes to it throughout the overall handling and storage process, together with assumed dry matter losses over time when the biomass is in the form of whole trees, billets or chips is complex. Basically the longer the period of storage up to around 3-4 months the lower the moisture content becomes. This affects the payload in terms of GJ per truck load transported and hence the system costs but this is partly counteracted by the additional losses of dry matter that result from longer storage periods. In the base case the assumptions used are listed in Figure 14-5. Changing the storage time at the headland from 6 to 3 days for the short cycle crops billets very slightly (+0.006 - +0.008%) raised the overall delivered costs but slightly lowered it for the thinnings (-0.7 – -2.3%). Further work is needed to evaluate moisture content changes and dry matter losses with greater accuracy but the results are unlikely to have a significant effect on the final delivered costs.

	Short rotation coppice	**Thinnings**
Fresh material density	0.51t/m^3 - billets	0.68t/m^3 - chips
Moisture content at harvest	55% wet basis	55% wet basis
Drying rate at headland	3% /month - billets	5% - whole trees
Drying rate at conversion plant	2.5% /month - billets	1% - chips
Dry matter losses at harvest	10% of total biomass	4% of total
at headland storage	1% /month - billets	2% /month - chips
at conversion plant	1% / month - billets	2% /month - chips

Figure 14-5: Base case assumptions used for moisture contents and dry matter losses.

Reducing the average transport distance by 10% as a result of a greater concentration of biomass resources, resulted in a delivered cost reduction of only around 1 to 3 % in this case study where the purchase price accounts for around 50% of the total costs in S E Queensland and around 75% in the Murray Darling Basin.

Significant overall cost reductions of around 10 to 30% may be possible if several parameters can all be improved in terms of cost reductions or yield increases (Figure 14-4). However most of this cost reduction results from a lower stumpage purchase price. An analysis was also conducted on just reducing several parameters by a small but realistic amount (harvest costs –10%; transport distance -10%; field storage time cut to 3 days average; and storage at the plant reduced to 9 days from 15 days). These factors resulted in overall delivered cost reductions between 3 to 5%.

If production costs can be reduced and result in lower purchase prices and transport and handling systems can be improved and costs reduced, then in S E Queensland it appears that billets from short cycle crops can be delivered for around $4/GJ and chips from forest thinnings for $3/GJ. The relatively slow crop and forest growth rates of the Murray Darling Basin would be a significant constraint to developing a bioenergy industry there.

14.5 Conclusions

The delivered costs of short cycle crops, excluding the biomass purchase price, range between $36/tDM ($1.8/GJ) over a 10km transport distance in a region with a 2 year rotation to around $46/tDM ($2.3/GJ) at 40kms in a drier region with a 4 year rotation. Thinnings can be harvested and delivered for between $38/tDM ($1.9/GJ) where forest yields are good and average transport distances are below 80kms but can reach over $75/tDM ($3.6/GJ) in slower growing regions where the collection radius is closer to 150kms. When the purchase price for the biomass as paid to the growers is included, then these delivered costs may be doubled in higher rainfall areas (e.g. S E Queensland) and trebled in dry areas (e.g. the Murray Darling Basin).

It is possible that in some regions biomass from forest thinnings can be delivered to a conversion plant cheaper than can biomass from purpose grown short cycle crops. However in this simple case study, the discounted costs for the delay in providing the material from forests as they mature needs to be taken into account. The short lead time to provide biomass feedstock from short cycle crops within 2 to 4 years after establishment, compared with 8 to 17 years after planting for forest thinnings, is a major advantage when planning feedstock supplies for new conversion plants in regions where plantation forests do not currently exist.

14.6 Further Reading

Hall P, Gigler J K and Sims R E H. 2001. *Delivery systems of forest arisings for energy production in New Zealand*. Biomass and Bioenergy 21 (6), 391-399

Hall P. 1995a. *Collection and transportation of logging residues*. LIRO Report, Vol. 20, No. 16. Logging Industry Research Organisation, Rotorua, New Zealand.

Hall P. 1995b. *A system for collecting, transporting and processing logging residue*. Fibre Recovery Limited. LIRO Technical Note TN-23. Logging Industry Research Organisation Rotorua, New Zealand.

Hall P. 1997. *Utilisation of logging residue from a hauler landing*. LIRO Technical Note TN-33. Logging Industry Research Organisation, Rotorua, New Zealand.

Hall P. and Wyllie N., 1996. *Harvesting and transportation of logging residues. In: Applications of bioenergy technologies*. Conference papers. EECA and Forest Research Institute, 12-14 March 1996. Forest Research Institute, Rotorua, New Zealand.

Sims R E H, 2001. *The Brilliance of Bioenergy – the Business and the Practice*. James and James, (Science Publishers) London. 316 pages. ISBN 1-902916-28-X.

Sims R E H and Culshaw D, 1998. *Fuel mix supply reliability for biomass-fired heat and power plants*. Proc. 10th European conference "Biomass for Energy and Industry", Wurzburg. June. pp 188-191. CARMEN.

Sims R E H and Venturi P, 2003. *All-year-round harvesting of short cycle crops eucalyptus compared with the delivered costs of biomass from more conventional short season, harvesting systems*. Biomass and Bioenergy. In press.

15. Case Studies – Production of Electricity

15.1 Background

Eight case studies have been investigated for the production of electricity. A summary of the key parameters for each option is shown in the following figure (Figure 15-2).

Crop types, locations and biomass productivity correspond to the options discussed for the harvesting and transport case studies.

Power plant size was estimated by applying a known overall power plant efficiency to total energy delivered from the various biomass production options as presented in Figure 13-12, Figure 13-13, Figure 13-15 and Figure 13-16.

Capital costs were estimated by scaling up or down from capital cost for a 30MW plant as shown in Section 10.3 using a scaling exponent of 0.6 on equipment costs as discussed in Section 17.3.

Annual operating and maintenance costs were estimated by assuming the same labour costs as shown in Section 10.4 and applying 3% of capital cost for maintenance and 1% for consumables, also discussed in Section 10.4.

Feed costs for each option are as per the findings and assumptions of the case studies for the production, harvesting and transport of biomass as discussed and presented in Sections 13 and 14.

15.2 Economic Analysis

15.2.1 Costing Model

Economic analysis of each case study option was conducted using the assumptions as shown in Figure 15-1.

Item	**Value Used**
Project life	15 years from first investment
Residual value of plant	Assumed to be nil
Construction period for the plant	18 months
Commissioning period	included in construction period
Production ramp up	Immediate full production and full product purchase
Inflation of costs and revenue each year	• 3% for costs • 3% for revenue
Depreciation	straight line over 15 years
Company tax rate	30%
Interest on any borrowings	10%, with all loans repaid by the end of the 5th year
Financing	100% equity financing
Feed purchase price	as shown in Figure 15-2
Plant operation	8,000 hours per annum (leaving time for scheduled shutdowns and maintenance)
Required project IRR	15%

Figure 15-1: Assumptions Used for the Economic Analyses

Crop Type	**Short Cycle Crop (SCC)**				**Tree Plantation Crop (TPC)**			
Crop Location	South-East Queensland (SEQ)		Murray Darling Basin (MDB)		South-East Queensland (SEQ)		Murray Darling Basin (MDB)	
Biomass productivity (t/yr fresh weight)	300,000	700,000	300,000	700,000	300,000	700,000	300,000	700,000
Power Plant Size (MWe)	20	50	20	50	20	50	20	50
Capital Cost ($M)	$39.3	$61.0	$39.3	$61.0	$39.3	$61.0	$39.3	$61.0
Annual Operating & Maintenance Cost ($M)	$2.5	$3.4	$2.5	$3.4	$2.5	$3.4	$2.5	$3.4
Feed Cost ($/t fresh weight)	$39.00		$70.00		$46.00		$93.00	

Figure 15-2: Key Parameters for Case Study Options

15.2.2 Price of Electricity

Each case study was evaluated using the costing model to determine the electricity sale price from the generation to the grid. The results of this evaluation are shown in Figure 15-3.

Crop Type	Crop Location	Plant Size	Electricity Sales Price
Short Cycle Crop	South East Queensland	20 MW	13.9¢/kWh
		50 MW	10.8¢/kWh
	Murray Darling Basin	20 MW	19.7¢/kWh
		50 MW	16.2¢/kWh
Tree Plantation Crop	South East Queensland	20 MW	15.2¢/kWh
		50 MW	12.0¢/kWh
	Murray Darling Basin	20 MW	24.0¢/kWh
		50 MW	20.2¢/kWh

Figure 15-3: Results of Economic Analysis

The profit, capital cost, operating cost and feed cost components of the electricity sales prices are shown in Figure 15-4 and Figure 15-5.

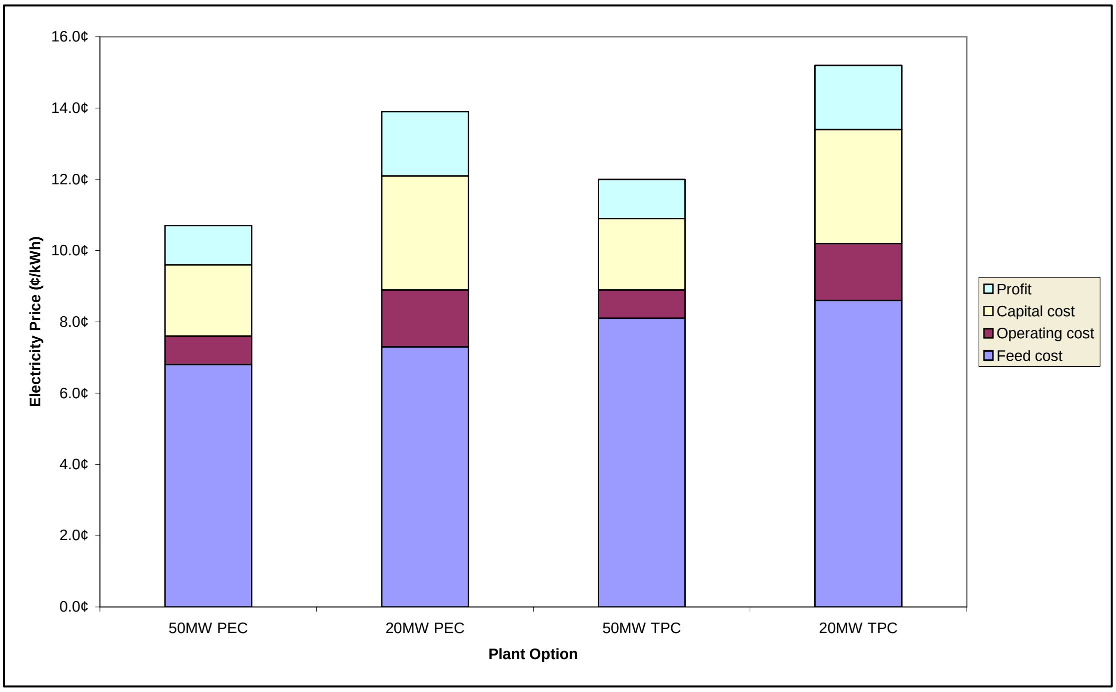


Figure 15-4: Electricity Price Breakdown for Power Plants Located in South-East Queensland

Note: PEC is an abbreviation for Plantation Energy Crop, which is identical in this example to a Short Cycle Crop (SCC).

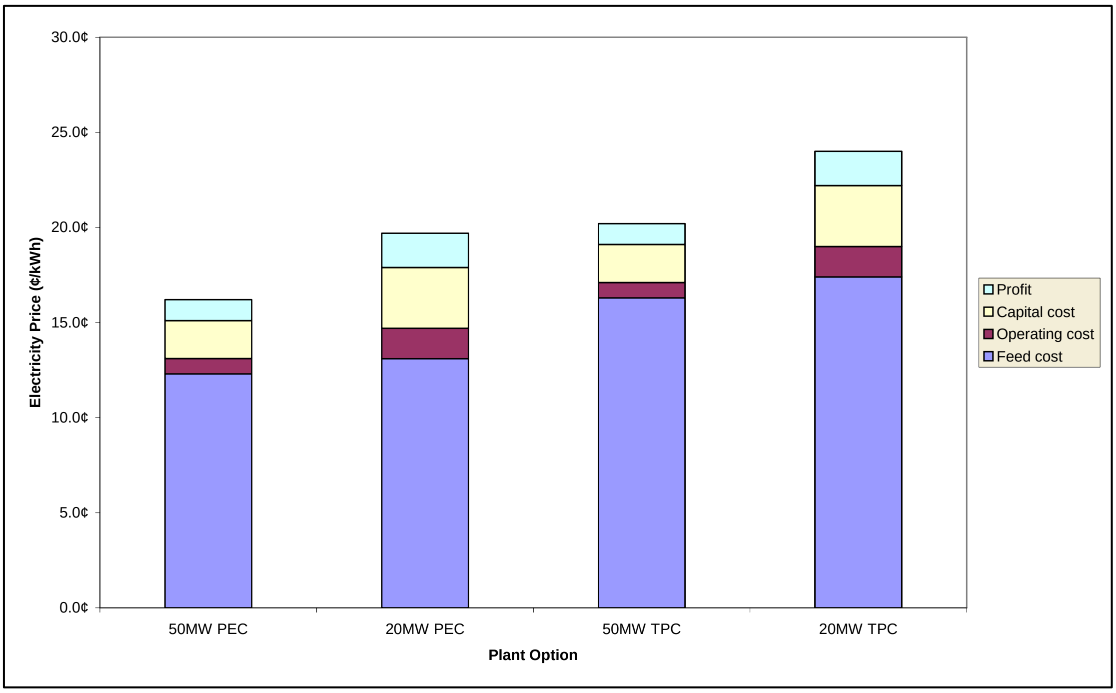


Figure 15-5: Electricity Price Breakdown for Power Plants located in the Murray Darling Basin

These graphs clearly demonstrate that feed cost is the major component of the total electricity sales price. For the South-East Queensland options, it ranges between 53% and 68% of the total, and for Murray Darling Basin between 66% and 81%.

As plant size increases unit costs for the plant decline and so the feed cost portion as a percentage of the total electricity price becomes larger.

15.2.3 Sensitivity Analysis

Sensitivity analyses were performed to determine the effect of variations in feed cost and capital cost on electricity price.

Figure 15-6 shows the effect of varying feed cost on the required electricity sales price for both plant size options. The various feed costs selected correspond to that required by each crop location and type investigated for the biomass case studies.

The graph demonstrates that in order to achieve a typical renewable electricity sales price of 7-8¢/kWh or less (which includes the value of Renewable Energy Certificates), and with project financing as above a 50MW plant would require a feed cost of approximately $18/green tonne, and a 20MW plant would require feed to be provided to the plant at no cost.

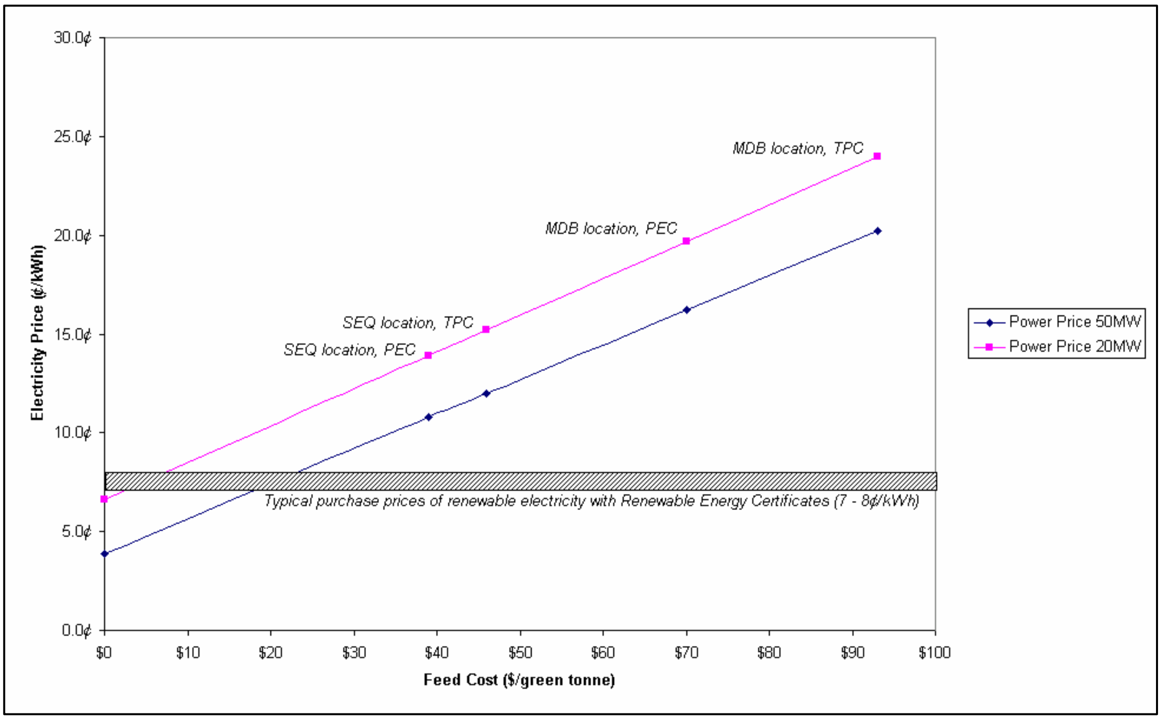


Figure 15-6: Impact of Feed Cost on Electricity Price

Figure 15-7 shows the effect of plant capital cost by plus or minus 20% on the required electricity sales price for both plant size options. A $39/green tonne feed price was used for this sensitivity which corresponds to South-East Queensland plant location employing a plantation energy cropping method. This option was selected as it has the lowest feed cost of all options investigated, and therefore will be most sensitive to changes in capital cost.

The graph demonstrates that project economics are not highly sensitive to changes in plant capital cost. For the 20MW option, electricity price varies approximately ± 7% for plant capital cost changes of ± 20%. The 50MW option is less sensitive, with the same percentage change in capital cost resulting in an approximate ± 6% change in electricity price.

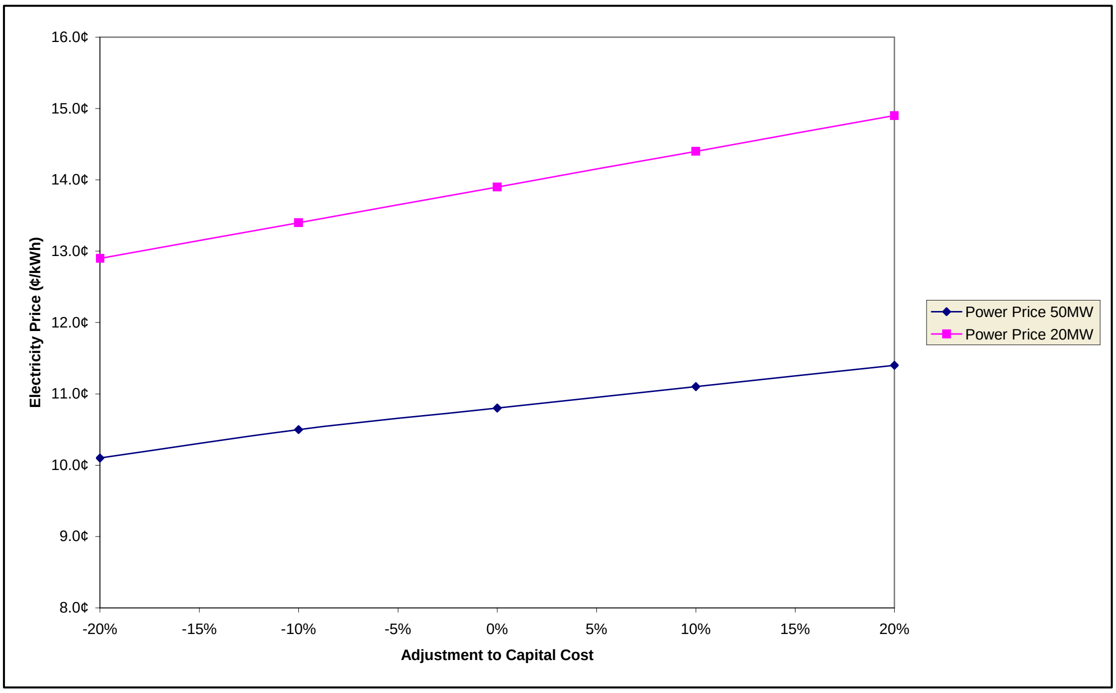


Figure 15-7: Impact of Capital Cost on Electricity Price

The examples above assume 100% equity funding with an internal rate of return (IRR) of 15% for investors. A stable low risk project may be able to attract finance at a lower IRR and may also be able to finance much of the plant via debt. Financing the project on a more attractive basis will reduce the cost of electricity. For example, running the financial model for a 50MW plant using SCC (or PEC) from S.E.Queensland indicated an electricity price of 10.8c/kWh. Reducing equity IRR from 15% to 12% and allowing for 40 % of the plant to be funded on debt at 10%, reduces the electricity selling price to 10.2c/kWh. This is a reduction of some 5% overall and a reduction of almost 20% of the non-feed component of the cost. In a situation where a project is marginally viable with the original financial conditions, such a change could allow that project to proceed.

16. Co-products and Co-values

16.1 Summary

Bioenergy invariably has many dimensions to it, resulting in a variety of interfaces and interactions with the environment, society and the economy, the three pillars of the sustainability paradigm. These have been broadly considered as:

- "co-products" – where the product or attribute has a value that can be sold or traded. As such, co-products fit well with production of bioenergy to meet market needs; multiple products from a plant producing bioenergy will presumably help to make the more bioenergy cost competitive.

- "co-values" – where the product or attribute clearly exists but is not well quantified or has no mechanism whereby it can be given a monetary value that allows it to be incorporated in market based financial decisions for projects to go ahead.

16.1.1 Co-products

A variety of biobased products can be produced in conjunction with biomass energy to the overall economic viability of a project. Examples that have been in operation for many years include energy production from saw mill and sugar mill residues. There is a world-wide push to increase the use of renewable resources for a variety of products, particularly those that are currently derived from the petro-chemical industry. There is large potential in this area and it is of interest that the USA has a national target of tripling bioenergy and biobased products by 2010. The US Vision in this area sets a goal of providing ten percent of basic chemical building blocks from plant derived matter by 2020.

Co-products that may be associated with bioenergy production are:

Renewable Energy Certificates. Not a product in itself but still a tradable item that facilitates the competitive position of some bioenergy. Provides an incentive for compliant forms of renewable energy (including certain forms of bioenergy) driven by federal government policy.

Greenpower. Voluntary electricity marketing scheme across most of Australia that provides a premium price for certain forms of renewable electricity. Certain forms of bioenergy comply with the requirements of this scheme.

Other environmental instruments. Not yet in place other than isolated test cases. It is possible that carbon and salinity trading mechanisms will evolve in Australia, providing financial benefits for biomass that should assist bioenergy projects.

Charcoal and activated carbon. Charcoal is used for cooking or metallurgical applications. Activated carbon has many uses, including adsorption of contaminants and odours, water purification, and minerals processing. The integrated tree processing project under construction in Western Australia is an example of activated carbon and energy co-production.

Oils and other natural products. Eucalyptus oil can be recovered from the leaves of eucalypts grown as short cycle crops, such as the mallee trees grown for salinity mitigation in WA. Recent programs such as Search and Florasearch have been implemented with assistance from the Joint Venture Agroforestry Program. These programs have sought to identify Australian native flora that can offer opportunities for farmers that wish to plant trees on their farms for environmental benefits but with commercial returns to cover the costs of planting and land use during the time required for environmental benefits to develop.

Bio-based products. Innovative techniques for fermentation and biotechnology are being used in Australia and overseas to seek and develop new products from biomass, including plastics, pesticides and other high value chemicals. It is likely that processes developed for these products will benefit from co-location with large scale energy plants.

Methanol and ethanol. These alcohol fuels can be jointly produced with electricity. Non fermentable lignin from ethanol production can be used for electricity generation.

Saleable ash. Wood fly ash can be used as a soil amendment. Bottom ash can be used as road base. Ash from a chicken litter fired power plant in the UK fetches a premium price.

Pyrolysis oil products. A variety of chemical products may be derived from bio-oil. These include ethanol, slow release fertilisers, NOx and SOx reduction agents, fuel enhancers, flavouring agents, adhesives, boiler fuel, syngas and hydrogen. A few such products are already produced commercially.

16.1.2 Co-values

Bioenergy can have a number of positive impacts at various levels. Environmental benefits can accrue if bioenergy supports new tree planting in rural areas. Socio-economic benefits of bioenergy can broadly accrue through: support for rural and regional development, macroeconomic effects (such as increased security of energy supply), supply-side effects (such as improved infrastructure), and demand-side effects (such as increased regional employment and incomes).

Some of these effects are broad and long term, and are difficult to quantify, for example improved competitive position and sustainability for a region. Some relate to bioenergy but also to other forms of renewable energy. Others relate specifically to bioenergy, particularly through any large scale tree planting using bioenergy as one of its commercial drivers. Such tree planting can offer multiple environmental benefits and also sustainable employment and cash flow opportunities in rural areas that are simply not possible through the use of other forms of renewable energy.

Co-values from bioenergy include:

Salinity mitigation. Strategic planting of deep rooted perennial crops is generally regarded as one of the best ways to avoid and manage dryland salinity, particularly in south west Western Australia. Benefits accrue on-farm through such sustainable agricultural practice, and also off-farm in the protection of rivers and other water supplies, wetlands and other areas of native vegetation, roads and other infrastructure.

Carbon sequestration. Bioenergy is essentially carbon dioxide neutral and its ability to reduce greenhouse gases is reflected in its inclusion as an energy source that may be eligible for Renewable Energy Certificates. The planting of new trees to provide fuel for bioenergy plants also provides an opportunity for carbon sequestration in the average standing biomass developed in the new short cycle crops or plantations.

Regional development and employment. Bioenergy is most often a regional activity, creating jobs and stimulating the local economy. Fuel supply is a permanent, ongoing activity. Various studies have shown bioenergy to have a significant economic multiplier effect, with many indirect and induced jobs created.

Weed control. The Mandatory Renewable Energy Target legislation makes provision for using certain woody weeds for bioenergy. A project is currently being developed in the Northern Territory using *Mimosa pigra*, and it is estimated that some 100 MW of capacity could be fuelled by another noxious weed, *Acacia nilotica* in Queensland. Work in NSW has examined the use of the woody weed camphor laurel as a fuel supply for any bioenergy plants located at the northern NSW mills. Commercial incentives for collecting these weeds helps to stop them spreading and allows the return of infested land to productive use.

Biodiversity and animal habitat enhancement. Establishing sustainably managed bioenergy crops could restore land and provide a net increase in animal habitat. This would lead to improved biodiversity outcomes. Native tree species should require less fertilisers, pesticides and herbicides compared to arable food and feed crops grown on the same land. Salinity mitigation through sustainable bioenergy tree crops can also help to preserve remnant areas of native vegetation and biodiversity from damage by saline water.

Infrastructure implications. Bioenergy projects could result in upgrading local roads, bridges and other infrastructure works to the benefit of the local community. A bioenergy plant could obviate the need for new transmission lines to an area. These aspects will be site specific and need to be considered on a case-by-case basis.

Waste management. Bioenergy could be linked to waste management and reduction of landfills. Several types of biomass from the agricultural and forestry sectors, which for some time have been burned or landfilled for disposal, could be used beneficially for bioenergy.

Security of energy supply. Bioenergy is generally a distributed source of energy, providing security and diversification of energy supply for either electricity or liquid fuels.

Fire hazard reduction. An alternative to prescribed burning for fire hazard reduction could be carefully planned removal of some biomass to reduce the potential for catastrophic bush fires. This concept is yet to receive close environmental and economic assessment.

Exports and services. Potential exists for export of bioenergy products and services. A robust bioenergy industry will also require various environmental and other professional services in its support.

16.2 Introduction

It should be clear from the previous sections of this study that producing electricity or liquid fuels from biomass generally involves direct costs which are greater than processes that use non-renewable energy sources to produce these products. This situation is not expected to change over the short to medium term. It must therefore be remembered that renewable energy from biomass also serves other purposes, with its current consideration by Australia and many other countries based on its ability to reduce the production of carbon dioxide, a major contributor to climate change via the greenhouse effect. In this regard it may be considered along with other forms of renewable energy, such as electricity from wind, solar and hydro.

The greenhouse gas benefits are implicit in the support provided to renewable electricity via the Mandatory Renewable Electricity Target (MRET) established by the federal government to increase renewable electricity generation over this decade. It is possible that legislation will also be developed to provide a stable framework of incentives for renewable alcohol fuels.

While renewable energy from biomass allows the reduction of greenhouse gases, it may also provide a number of other benefits that can help to offset any perceived cost disadvantages. These include other environmental benefits, social benefits, and improvements in various indicators of economic performance. How valuable and desirable these benefits will be will depend on what policy objectives are being targeted and the appropriateness of these objectives for the welfare of society as a whole. Some of these issues are examined further below.

Bioenergy is invariably multi-faceted with a variety of interfaces and interactions with the environment, society, and the economy. The value derived from a bioenergy project would seldom be based on one single product, but rather from the range of products, and values, flowing from the project.

The multi-value, multi-product nature of bioenergy is most relevant to many organisations' strategic and corporate thinking and plans, where the 'triple bottom line' of not only maximising financial returns, but also placing an emphasis on environmental and social aspects has become important. This triple-bottom-line consideration is also closely related to Ecologically Sustainable Development, which embraces the concepts of economic development, environment and social benefits. Ecologically sustainable development is based on two basic aspirations of society:

- to achieve economic development, to secure rising standards of living both now and in the future
- to protect and enhance the environment now and for the future.

Accordingly, renewable energy technologies such as bioenergy assume an important role within the sustainability paradigm.

This section addresses co-products and co-values associated with bioenergy, especially as they relate to economic, social and environmental values. Co-products essentially refer to physical products and services, while co-values refer mainly to co-incident values from an overall bioenergy project. There is often no clear boundary between co-values and co-products.

Broadly, the socio-economic benefits of bioenergy are dependent on the nature and scale of the applicable technology and regional economic setting, but would be likely to include some or all of the following:

- Support for rural and regional development, stemming rural depopulation and diversification of the local economy.
- Macroeconomic implications, including security of energy supply, increased rate of growth, risk diversification, export capability.
- Supply-side effects, including increased productivity, enhanced competitiveness, labour and population mobility, improved infrastructure, and economies of supply.
- Demand-side effects, including employment, income, induced investment, and support for related industries. Demand-side effects embrace direct effects, such as plant construction jobs; indirect effects, such as increased activity in the supply chain which provides materials and services to build the plant; induced effects stemming from successive expenditure linked to the construction and operation of the plant; and displacement effects which reduce the demand for competing activities.

The emphasis of this section is on woody biomass for energy production, recognising that co-production could refer to growing biomass feedstocks on adjacent land for a range of biobased, non-energy applications using common resources.

16.3 Co-Values from Bioenergy

There are potentially several co-values which would be linked to a bioenergy development. Many of these benefits would be project specific, and are thus difficult to quantify in this general coverage. Some projects may be justified on the grounds that they have significant long-term supply-side effects, even though these effects may be difficult to quantify. Many of these supply-side effects are usually deemed to be broad impacts such as improved competitive position of a region, including inward investment, or the growth of eco-tourism arising from the novelty of a broad scale bioenergy production system and an energy conversion plant. As such, broad socio-economic benefits may not be able to be incorporated into traditional economic assessments, such as cost-benefit studies.

The following are regarded as some of the more important co-values from bioenergy:

16.3.1 Greenhouse Gas Reduction

Bioenergy from sustainably managed biomass is recognised internationally as a renewable energy source with no net emission of carbon dioxide, the main greenhouse gas associated with human-induced global warming. The carbon dioxide emitted from combustion, gasification, pyrolysis, or fermentation of the biomass during the energy conversion process is captured during the regrowth of an equivalent amount of biomass by photosynthesis. In fact, biomass can be thought of as a form of solar energy stored in the chemical bonds within the cell structure of biomass. Under the Kyoto Protocol bioenergy is regarded as carbon dioxide neutral.

A more comprehensive assessment of the greenhouse gas balances of bioenergy systems requires a life cycle analysis, accounting for the greenhouse gas balances associated with the construction of the bioenergy plant and up-stream processes such as production and harvesting of the biomass, its transportation, storage and usage, as well as down-stream processes such as decommissioning of the plant. This approach captures emissions from fossil fuels used during harvesting operations, fertiliser use, and embedded energy in the materials used to create the equipment.

A key group analysing such greenhouse gas balances of bioenergy systems is ‘Task 38’ of the International Energy Agency’s (IEA) Bioenergy Program, in which Australia participates though Bioenergy Australia[1]. Studies and modelling through Task 38 have shown the greenhouse gas merits of bioenergy systems. One case study of note conducted by the US participant from the National Renewable Energy Laboratory, and presented at a Task 38 meeting in Canberra in March 2001, showed that for bioenergy systems using wood waste, that would otherwise be disposed of to landfill, the net emissions of greenhouse gases would be –410 grams carbon dioxide-equivalent per kilowatt-hour of electricity produced. This study took into account the methane, a potent greenhouse gas that would otherwise be emitted to the atmosphere, if it were not used for bioenergy. This study showed 134% carbon closure in the biomass-energy conversion system.

A UK Department of Trade and Industry study [2] compared the life cycle carbon dioxide emissions of various conventional and renewable energy technologies. The findings of this study, comparing fossil fuel and various bioenergy and other renewable energy technologies are summarised below (Figure 16-1). On a life cycle basis, greenhouse gas emissions of bioenergy systems are project specific, but typically in the range 10-50 grams CO_2 equivalent/kWh.

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[1] See http://www.joanneum.ac.at/iea-bioenergy-task38

[2] *New and Renewable Energy: Prospects in the UK for the 21st Century, Supporting Analysis,* March 1999

Technology	**g/kWh CO_2**
Coal: Best Practice	955
Natural gas: in combined cycle plant	446
Onshore wind	9
Hydro - existing large	32
Hydro – small-scale	5
Decentralised photovoltaic (PV)- retrofit	160
Decentralised PV – new houses	178
Decentralised PV – new commercial	154
Bioenergy – poultry litter - gasification	8
Bioenergy – poultry litter – steam cycle	10
Bioenergy – straw – steam cycle	13
Bioenergy – straw - pyrolysis	11
Bioenergy – energy crops - gasification	14
Bioenergy – Forestry residues – steam cycle	29
Bioenergy – Forestry residues - gasification	24
Bioenergy – animal slurry – anaerobic digestion	31
MSW incineration	364
Landfill gas	49
Sewage gas	4

Figure 16-1: Life Cycle Carbon Dioxide Equivalent Emissions for various technologies (g/kWh)

It may come as a surprise that bioenergy offers lower greenhouse gas emissions than photovoltaic (PV) systems; as PV is considered by some to be the “ultimate” source of renewable energy. While the *operation* of photovoltaics offers substantial greenhouse benefits, the full lifecycle analysis also includes the very real and substantial amounts of energy that go into the production of photovoltaic equipment, such as the fossil fuels used to produce silicon for cells and aluminium for structural requirements. When all these energy needs are considered, the carbon dioxide emissions associated with the full cycle of PV are in the ranges shown above.

16.3.2 Salinity Mitigation and Landcare

Dryland salinity is one of the most severe environmental problems facing Australia. Widescale planting of deep-rooted perennial crops such as mallee eucalypts has been recognised as being able to reduce dryland salinity through strategic planting in recharge areas and in other targeted locations. It is generally recognised that economic drivers are needed to justify such plantings, with bioenergy and various bio-based industries seen as highly prospective.

Additional trees in the landscape grown for biomass are expected to reduce surface run-off and add to transpiration, potentially mitigating flooding. Trees will also better bind the soil, preventing erosion.

Strategically planted biomass can also be used for bioremediation of effluent streams. This particularly applies to planting buffer zones adjacent to wetlands and riparian plantings.

Dryland salinity will affect the farms where it occurs and will also have off-farm effects. These effects vary significantly from region to region, and the quantum and timing of benefits from extensive tree planting will depend upon many different factors. As more work is undertaken to understand and assess the nature of salinity damage, it should be possible to identify areas where the total salinity benefits gained from tree planting for renewable energy will be maximised, and/or achieved in a timely fashion.

The recent National Salinity Audit [1] considered the total on farm and off farm costs attributable to dryland salinity in various regions. The table below summarises costs attributable to issues of water and salinity in Western Australia (Figure 16-2).

From this data it appears that the best guess for total off farm costs across WA puts them at some seven times the estimated on farm costs, largely because of the costs attributed to road maintenance. This is a state-wide average, and certain areas may be expected to realise even greater savings through management of water and salinity. Whether some or all of this management is achieved with trees (with or without assistance from drainage and evaporation works) in a timely manner can only be learnt through more detailed assessments.

	Best guess	**Possible range**
Agricultural land: opportunity cost of lost operating profit	80	80-261
Rural towns: annuity of a 50 year discounted present value	5	2-16
Roads: additional repair and maintenance costs	505	Not tested
Railways: additional repair and maintenance costs	11	Not tested
Vegetation: imputed cost of protection of 10% of affected areas	63	63-626
Total	**664**	

Figure 16-2: Annual costs due to water tables/salinity ($m) in Western Australia

16.3.3 Regional Development

Bioenergy based on forestry and agricultural residues, purpose grown energy crops, or based on animal residues such as chicken litter, wool scourings, cotton ginning trash, rice wastes and animal manure, is essentially a rural activity. Establishment of a bioenergy plant results in direct construction jobs, purchase of materials, need for transportation, hire of equipment, housing of workers, purchase of land, and the requirement for a variety of other goods and services.

Operation of the power plant requires a steady and reliable fuel supply over the life of the power plant, which could be in excess of 25 years. For instance, a 20 MW bioenergy plant will require at least 200,000 tonnes of biomass fuel per annum. The fuel bill alone will inject several million dollars into the local economy where the fuel is grown and harvested. Operation of the plant will also require labour, various materials, and maintenance services. The power plant will also require water and the disposal of ash. Besides the direct and indirect jobs associated with the power plant, there will be induced economic activity through local expenditure stemming from the bioenergy plant.

This regional development aspect of bioenergy has been recognised around the world. For instance the Austrian Government recently funded a 30 million Euro innovative gasification-combustion bioenergy plant at Güssing, near the Hungarian border to stimulate the local economy in an economically depressed area. The UN Food and Agriculture Organisation (FAO) is also supporting bioenergy for economic development, mainly in developing countries.

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[1] http://audit.ea.gov.au/anra/land/docs/national/Salinity_WA.html

Task 29 of IEA Bioenergy ‘Socio-Economic Aspects of Bioenergy Systems’ has explored the BIOSEM model based on economic Keynesian Multiplier Theory to capture both the employment and income impacts from the installation of a bioenergy project [1]. A study based on a 3 MW bioenergy plant in the UK showed a 2.13 multiplier for the local economy over direct and indirect expenditure from the power plant.

Similarly, a study by the Centre for Environmental Strategy, University of Surrey, UK entitled ‘The Use of Biomass Energy – in a regional context’ [2] examined the factors that made bioenergy viable in Växjö, Sweden, a community of 70,000 and the social acceptability of biomass energy in that community. Växjö municipality owns the local district heating and electricity plant which is fueled 95% by biomass. The plant has a thermal capacity of 210 MW and an electricity capacity of 30 MW. This plant created more than 100 new jobs from using biomass as the primary energy supply.

16.3.4 Employment

Employment and regional development are closely linked. As noted above, direct and indirect jobs will be created during the construction of a bioenergy plant. Then, for the duration of the plant’s operation, long term employment will be created in the fuel supply chain, operation and maintenance of the power plant, and in indirect jobs via the injection of expenditure into the local economy.

For the 3 MW bioenergy plant case study in the section above (from IEA Bioenergy Task 29), modelling indicates that the project would generate 3.5 direct jobs, 7.4 indirect jobs, and 4.9 induced jobs, totalling 15.7 permanent jobs.

A German study [3] assessed the value of bioenergy for addressing unemployment in Germany by the adoption of an additional 140 PJ/a using an economic ‘input-output’ model. This study showed positive annual employment effects occurring in mainly rural areas in the agricultural and forestry sector which more than compensated for losses in other sectors. The study also showed that the direct employment effects only represent one third of the total employment effects. Most of the positive employment effects occur in the agricultural and forestry sector. An important negative employment effect in this study was caused by the reduction in purchasing power, as heat energy from biomass was assumed to be 20-25% more expensive than from heating oil, and power from biomass 80-100% more expensive than power from coal. The study notes the sensitivity of the findings to whether the technology is imported or locally produced.

An Australian study ‘Employment and Regional Development Opportunities with the Australian Renewable Energy Industry ‘ by MacGill, Watt, and Passey, conducted for the Australian Co-operative Research Centre for Renewable Energy (ACRE)[4] examined the employment implications of three biomass projects: the Narrogin, WA Integrated Wood Processing (IWP) project using plantation mallee eucalypts, the Rocky Point Sugar Mill co-generation plant using bagasse and wood-waste, and Brightstar Environmental’s SWERF technology being demonstrated near Wollongong, NSW, as well as the Albany, WA wind farm, a gas turbine power plant, and the Tarong North coal fired Power Station in Queensland. The study found that all three bioenergy plants provided more Australian content and greater employment creation per dollar invested, per MW installed and per MWh generated than the wind and two fossil fuel generation options. The mallee project provided the most employment of the three bioenergy case studies. For a 5 MW IWP plant,

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[1] Task 29, Proceedings of the Workshop *Socio-economic aspects of bioenergy systems: Challenges and opportunities*, 28-31 May 2001, Rocky Mountains Region, Alberta, Canada.

[2] (Policy Report 1995:1, by Dr Ragnar E Lofstedt, ‘The Use of Biomass Energy – in a regional context’

[3] ‘Employment Effects of an Increased Use of Biomass in Germany’, S. Beerbaum and K.-H. Kappelmann, Proceedings of the 1st World Conference on Biomass for Energy and Industry, Seville, Spain, 5-9 June 2000, page 88

[4] http://alpha400.ee.unsw.edu.au/acre

an estimated 135 job-years would be generated during manufacture and construction, and 32 ongoing jobs. The plant would have an estimated 90% local content.

An IEA Bioenergy Task 12 report [1] collates various estimates of employment effects. These range between 160 and 500 person-years/TWh (fuel heating value) for a variety of settings. The ACRE study indicates in excess of 1000 person-years/TWh (electricity) for the IWP project, which is consistent with the IEA Bioenergy reported studies.

16.3.5 Security of Energy Supply

At a macro level, bioenergy is an indigenous energy source, independent of energy imports. Biomass can be converted into gaseous or liquid fuels, or can be used for the production of heat and/or electricity. Biodiesel, ethanol and methanol can be manufactured from renewable biological sources and used as liquid transportation fuels. Other biomass fuels can be used for the production of heat and power.

At a regional level, bioenergy plants can be distributed throughout a power system, lessening dependency for power from a few, large centralised power stations. Failure of transmission connections would allow parts of the power system connected to regional bioenergy plants to operate as an ‘islanded’ power system, maintaining the power supply to the local area.

At a small scale, bioenergy can be used in remote area power supplies, and can even be installed as small modular mobile units. The US National Renewable Energy Laboratory has initiated a small modular biopower development program to develop this opportunity.

This diversity of supply solutions lessens susceptibility to major power system events. It also lessens exposure to possible terrorism threats.

As biomass has inherent energy storage, power generated by bioenergy can generally be dispatched, adding to its value on a power system. Distributed generation also is important at maintaining the voltage profile on the power system and assuring quality of supply.

Bioenergy plants will typically generate electricity 24h/day and 7 days/week. As such it should be possible to incorporate this electricity into the development and operation of stable transmission grids. As a contrast to this continuous supply, electricity generated from wind is unfortunately dependent on that wind and is by nature intermittant. It may be possible for bioenergy to play a role in the cost-effective supply of base load power and grid management that is not possible with wind farms. Whether any such advantages can be incorporated into the decision process for bioenergy remains to be seen.

16.3.6 Weed Control

Parts of Australia are subject to severe woody weed infestations from exotic species. The Mandatory Renewable Energy Target (MRET) makes provision for using certain woody weeds as a biomass fuel subject to the Renewable Energy (Electricity) Regulations 2001.

State Forests of New South Wales in collaboration with Delta Electricity and the NSW Sugar Milling Co-operative [2] have been investigating using *Camphor laurel* in northern NSW as part of the fuel supply for the mooted Condong and Broadwater co-generation power projects.

A NSW Agriculture report, ‘Economic Analysis of the Use of Cotton Wastes and Other Agricultural Residues as Feedstocks for Ethanol Fuel Production’ for the then NSW Office of Energy (1995)

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[1] ‘Forest Management for Bioenergy’, 9&10 September 1996 by Bengt-Olof Danielsson, Department of Operational Efficiency, Swedish University of Agricultural Sciences, Garpenberg

[2] http://www.nswsugar.com.au/PAGES/PressReleases/24Feb2000.htm

identified at that time some 220 million tonnes of woody weeds in northern NSW that could potentially be used as a bioenergy feedstock. As much of this would be native species, it is unclear whether these weed species would qualify under the current MRET legislation for Renewable Energy Certificates.

The Power and Water Authority in the Northern Territory has been granted Australian Greenhouse Office funding for a project to use *Mimosa pigra* as a fuel for a small gasifier driving an internal combustion engine [1]. Another woody weed that is under investigation for power generation is *Acacia nilotica*, which infests thousands of hectares in central Queensland. An assessment has indicated that 100 MW of bioenergy capacity could be fuelled on this weed in parts of Queensland.

The use of woody weeds for bioenergy may assist in their control and eradication. A number of issues must be satisfactorily resolved before large scale harvest and transport of woody weeds is possible, including:

- The ability to harvest weeds from many different sources on public and private land and involving legal issues and also equipment issues for satisfactory access.
- Regular road transport of harvested weed material (to a central bioenergy plant) without spreading the infestation
- Integration with state or federal weed eradication programs.

16.3.7 Fire Hazard Reduction

The concept of removing excess biomass from plantations, woodlands and forests to reduce the amount of combustible material has been raised in various forums. It is argued that fires are inevitable, and when a fire does occur, if fuel levels are high, a catastrophic fire could occur, killing even fire hardy species such as eucalypts. An alternative to prescribed burning could be to remove some biomass to reduce fuel levels and hence the fire hazard. This concept is yet to be subject to close environmental and economic analysis. A similar debate is underway in California.

A similar alternative of using understory vegetation for biomass as opposed to prescribed burning is raised in an American authored IEA Bioenergy Task 29 ‘Socio-economic aspects of bioenergy systems’ paper by Thomas M. Williams[2]. The Red Cockaded Woodpecker’s preferred habitat is fire dependent longleaf pine ecosystems. Prescribed burning is used as the primary method of habitat enhancement. Rising costs of prescribed burning from US$10 per hectare in 1990 to US$40 per hectare in 1999, and the US Clean Air Act compliance which limits the area that may be burnt have raised the alternative of using understory vegetation for bioenergy.

16.3.8 Biodiversity and Animal Habitat

Establishment and sustainable management of bioenergy crops, especially short cycle tree crops on marginal agricultural land using native species would provide additional habitats for animals. This would assist with revegetation of the landscape, as only a small proportion of the crop would be coppiced in any one year.

Native tree species established for bioenergy should also require less or no fertilisers, pesticides and herbicides compared to arable food and feed crops grown on the same land.

A major problem that can be caused by dryland salinity is the effect of saline water flow on remaining biodiverse areas. In Western Australia for example, many of the remaining biodiverse

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[1] http://www.greenhouse.gov.au/ago/newsletter/spring2001/renewables.html

[2] Utilisation of understory hardwoods from Red Cockaded Woodpecker Habitat, Thomas M. Williams, Baruch Institute of Coastal Ecology and Forest Science, Clemson University, SC, USA, in Proceedings of the Workshop, Socio-economic aspects of bioenergy systems: Challenges and opportunities, 28-31 May 2001, Rocky Mountain Region, Alberta, Canada

areas are fragile lakes systems or areas of remnant vegetation in river valleys. The influx of saline water as run off from farming areas is already causing significant damage to many of these areas, poisoning vegetation and thus upsetting the ecological balance and adversely affecting bird, animal and aquatic life. As an example of this, the case of Toolibin Lake is summarised below.

Toolibin Lake is a seasonal wetland east of Narrogin in Western Australia. It is a RAMSAR listed wetland of international importance, under the control of the Conservation Commission of WA and managed by the Department of Conservation and Land Management. Approximately 95% of the Toolibin catchment (47,000 ha) has been cleared of deep-rooted, perennial native vegetation in the past 100 years.

Secondary salinity – from increasingly saline surface water and rising hypersaline groundwater – poses a serious threat to the biodiversity values of the lake and catchment, and to the agricultural values of the catchment.

Toolibin Lake has a history of management intervention for the protection off natural values. The Toolibin Lake Recovery Team and the Toolibin Lake Technical Advisory Group have initiated a variety of actions to protect the Lake and the surrounding areas, including:

- Actions to reduce recharge in the catchment, including remnant vegetation protection and revegetation
- Changes in agronomic practice in the catchment
- Surface water management
- Groundwater pumping.

The program for salinity management at Toolibin Lake was recently recognised with the inaugural award of the Institution of Engineers Australia National Salinity Prize. The work takes advantage of a number of mechanisms to manage salinity, including tree planting. While no financial value has been placed on these wetlands to justify such expenses, it is estimated that salinity management activities have already cost several millions dollars or more.

16.3.9 Infrastructure Implications

Establishment of a bioenergy plant would require the movement of plant and equipment, materials, fuel, personnel, and usually a high voltage electrical connection. This may require the upgrading of local roads, reinforcing bridges, improvements to drainage and other civil works, vehicle depots, and other power plant related developments. This augmentation of local infrastructure would generally benefit the local community.

A bioenergy power plant, with dispatchable energy, strategically located within or at the extremities of the power grid, may obviate the need to upgrade the power transmission network to supply the local region. The bioenergy plant could inject power close to the point of usage, possibly removing the need to upgrade transmission infrastructure. The connection of such distributed generation could also assist with controlling the voltage levels at the extremities of the power grid and improve quality of supply.

16.3.10 Waste Management and Minimisation

The use of bioenergy, particularly near urban areas, can reduce the need for landfill. Various jurisdictions in Australia are seeking to dramatically reduce landfill. Bioenergy using thermal or biological conversion technologies offer an alternative in this regard. The Waste Management Association of Australia, supported by Bioenergy Australia and others, is currently engaged in an RECP Industry Development grant-funded project to establish a Code of Practice and Sustainability Guidelines for using municipal solid waste biomass as an energy feedstock. Australia, through Bioenergy Australia is also a participant in IEA Bioenergy Task 36 ‘Energy from Integrated Solid

Waste Management Systems' which is researching and further developing the link between waste management and bioenergy.

Various thermal energy conversion technologies substantially reduce the volume of residual waste by up to 90%, vastly reducing the need for landfill. Currently, significant quantities of wood waste are landfilled, or burned without energy recovery for disposal. Energy recovery can be integrated into waste management practices.

In WA a 10MW chicken litter bioenergy plant is under investigation. This plant would combust chicken litter, which consists of chicken manure and wood residue bedding material. This enables odour and pathogens to be eliminated, thus controlling stable fly, with the ash being a valuable fertiliser.

Bioenergy plants have been established in Spain to process olive wastes to energy. Similarly wine marc, cotton ginning trash, rice wastes, corn stover, wheat straw, bagasse and a variety of other agricultural wastes may be used as a resource for bioenergy.

16.3.11 Discussion

The co-values outlined above cover many different facets of bioenergy projects. Generally however they fall into one of two categories:

- Benefits that are directly attributable to the bioenergy project
- More general benefits, for example the other environmental and social benefits that could come from new tree planting.

It must be remembered that, at present, bioenergy projects in Australia will only be developed if they are commercially comparable and competitive with other forms of energy. This is regardless of their triple bottom line performance. Principally, bioenergy for electricity must compete with other forms of renewable electricity under the Mandatory Renewable Energy Target. Similarly, liquid fuels such as ethanol from biomass must be competitive in whatever tax system or requirements for mandatory use are established by the Government. A bioenergy project will ultimately go ahead or not based on the cost of the electricity, heat or liquid fuel being produced. And within this framework for bioenergy in Australia, only co-values that have assessable monetary value attributed to them will be of assistance in allowing bioenergy projects to proceed.

Thus for waste minimisation it should be possible to reflect avoided waste disposal costs in the cost of biomass feed. In this way the biomass might be costed at a rate sufficiently low as to enable a bioenergy project to be commercially competitive and proceed. Added benefits, such as avoiding methane generation during waste breakdown, are not able to be captured in the current decision making process.

If bioenergy plants can assist in woody weed removal it might seem reasonable to expect that the cost of the weeds to the bioenergy plant will include some valuation of the benefit from their removal, be it in reduced costs for management or removal by other means, or in the value of land that is returned to productive agriculture.

16.4 Co-Products

The concept behind "co-products" is simple: if additional products may be developed in conjunction with a project making bioenergy, there is a chance that the project economics will be more favourable than if bioenergy alone is produced. Projects with co-products are already in operation, and in Australia and the rest of the world there is considerable activity to find new products and new ways of realising multiple products from bioenergy projects.

In Australia, RIRDC, CSIRO and others are examining this concept from the perspective of new tree crops and also new uses for wood:

- In Western Australia the ‘Search’ project is being conducted by a consortium including the WA Department of Conservation and Land Management (CALM) to identify indigenous tree species for the multiple values of salinity control and biobased products.
- PIRSA and the Co-operative Research Centre (CRC) for Plant-Based Management of Dryland Salinity are further developing this area in their ‘Florasearch’ project [1], with similar objectives.
- CSIRO Forestry and Forest Products is conducting the ‘Best Bets’ project to identify prospective tree species for bio-based value-added products.
- CSIRO is also investigating new bio-based products from lignin, with the aim of value-adding to this component of wood and thereby enhancing the economics of bioenergy projects which use the cellulose and hemicellulose fractions of the wood (principally ethanol production).

Bioenergy can involve not only the production of heat and power, but also the displacement of petrochemical products. World wide there is significant interest in biobased products, which may be based on dedicated feedstock crops or produced in conjunction with biomass-derived energy. Often heat and power are needed for the production of biobased products. This provides opportunities for integrating the biobased product and bioenergy production processes. An example is the Visy pulp and paper mill at Tumut, NSW where bark, paper sludge and black liquor from the pulping process provide fuel for 20 MW electricity generation using on-site power plants. Paper is the main product from the mill, and is produced using energy from the power plants.

As noted, biobased products may be stand-alone or co-products of bioenergy. As many of these biobased products have been positioned as ‘green products’, displacing petrochemicals or energy intensive products in their manufacture, they generally fall under the umbrella of bioenergy.

C.A.R.M.E.N. (Centrales Agrar-Rohstoff-Marketing- und Entwicklungs – Netzwerk), a German organisation, has been at the forefront of developing biobased raw materials for industry in Europe.[2] Product lines are from: wood/cellulose; hemp/flax; vegetable oils; and starch/sugar. Cellulose uses range from paper and insulating material to chemically-modified forms such as cellulose esters, cellulose ethers and regenerated cellulose for use in the chemical industry. Cellulose esters are used in the production of glasses, tool grips, hair ornaments, laminated book covers, and cigarette filters. BIOCETA®, a new material based on cellulose acetate, is used in the field of blister packaging for collapsible boxes with a viewing window and in molded articles, such as containers for dry powder. Cellulose ethers are used in construction materials, in adhesive agents, as thickeners, water binders, and film-forming components as well as a stabilising agent for foodstuffs. Other interesting biobased products being promoted and developed by C.A.R.M.E.N. include car door panels made from flax fleece, lubrication oils, cosmetics, pharmaceuticals, paints and leather care products from vegetable oils, linseed oil used for the production of linoleum (a floor covering), biodegradable packaging materials from starch, and polyhydroxy butyric acid (PHB), a substance which can be synthesised by several bacteria species and which can be polymerised. PHB is used in various biobased biodegradable packaging materials.

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[1] http://www.rirdc.gov.au/reports/AFT/02-121sum.html

[2] www.carmen-ev.de

A landmark 1992 publication, *The Carbohydrate Economy – Making Chemicals and Industrial Materials from Plant Matter* [1] examined in detail the opportunities for biobased products. This publication provides an excellent analysis of opportunities for a range of biobased products in various industrial market sectors, focusing on: surface coatings, pigments and dyes, soap and detergents, adhesives and glues, plastics and resins (plasticisers, co-polymers with bio-components, bioplastics), intermediate and specialty chemicals, biosources (vegetable oils, tree oils, lignin), and chemicals from plant matter (surfactants, fatty acids, acetic acid, activated carbon and phenolics, methyl aryl ethers, polyol, glycerol, and furfural). In a sister publication, *Replacing Petrochemical with Biochemicals – A Pollution Prevention Strategy for the Great Lakes Region*, Morris and Ahmed further promote opportunities for displacing some 43 petrochemicals with biobased chemicals.

The US Department of Energy [2] presents an overview of its Plant/Crop-Based Renewable Resources 2020 Vision 'to provide continued economic growth, healthy standards of living, and strong national security through the development of crops, trees and agricultural wastes for industrial production'. This Vision sets the goal for 2020 to achieve 10% of basic chemical building blocks from plant derived renewables and to build the supporting links with industry, growers, academia, and government. In support of this Vision is a 'Roadmap' document which identifies a range of biobased products to target. The US Department of Energy has supported various projects such as 'Production of Glycols from Corn Fiber Using Fractionation', 'Succinic Acid from Lignocellulosic Hydrosates' and 'Plastics from Agricultural Feedstocks'. This direction within the US Department of Energy has been in support of a Presidential Executive Order requiring the US to triple its level of biobased and bioenergy production by 2010.

Five US Government Laboratories, including the National Renewable Energy Laboratory, prepared a 232 page report under the Alternative Feedstocks Program entitled 'Thermal/Chemical and Bioprocessing Components' [3] assessing in detail chemicals from renewable biomass resources. Near term RD&D opportunities which are largely still current, identified in the report include:

- Succinic acid (used to manufacture polymers and resins for lacquers, dyes and perfumes)
- Clean fractionation of biomass (into cellulose, hemicellulose and lignin)
- Acetyled wood (resists biological degradation)
- Starch plastics (for packaging)
- Fast pyrolysis of wood (for phenolics used in molding and adhesives)
- Benzene, toluene and xylene from wood
- Acrylic acid (from starch waste).

Mid term RD&D opportunities are identified as:

- Butanol (for butyl butyrate, considered as a 'green' solvent)
- Xylose, sylitol, furfural, furan resins, levulinic acid, gluconic acid, sorbitol, mannitol and succinic acid from inexpensive cellulose.
- Anthraquinone from lignin for pulping processes.
- Butadiene and pentane/pentenes via fast pyrolysis.
- Acetic acid from syngas from biomass.
- Peracetic acid for non-chlorine bleaching.

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[1] *The Carbohydrate Economy – Making Chemicals and Industrial Materials from Plant Matter* by David Morris and Irshad Ahmed, Institute for Local Self-Reliance (USA), 1992.

[2] Agriculture- Industry of the Future, US Department of Energy, document 454-567/80095, 1999.

[3] Alternative Feedstocks Program- Technical and Economic Assessment, Thermal/Chemical and Bioprocessing Components, prepared for US Department of Energy, Office of Industrial Technologies, by Argonne National Laboratory, Idaho National Engineering Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest Laboratory, editors: Joseph J. Bozell and Ron Landucci, July 1993.

Longer term RD&D opportunities include:

- Levoglucosan from fast pyrolysis for high value and specialty polymers.
- Vinylphenol, used in coatings and micolithography, via pyrolysis.
- Hydroxyacetaldehyde, a byproduct of the fast pyrolysis of wood.
- Polyhydroxybutyrate/valerate from biomass derived syngas for biodegradable polymers.

As noted in the Pyrolysis section of this report, an evolving concept is that of a biomass refinery, where a range of products related to bio-oils can be derived together with activated carbon and saleable ash.

The following are also co-products associated with bioenergy production:

16.4.1 Renewable Energy Certificates

The Mandatory Renewable Energy Target (MRET) has been established by the Australian Federal Parliament, and requires wholesale purchasers and other large users of electricity to source an additional 9,500 GWh/a from new renewable energy sources by 2010 and maintain that level until 2020. This mandated market operates via the creation, trading and surrender of 1 MWh Renewable Energy Certificates (RECs) from accredited renewable energy sources. Bioenergy generally attracts RECs, subject to the fuel conditions set out in the Renewable Energy (Electricity) Regulations 2001 and accreditation by the Office of the Renewable Energy Regulator. Liable parties under this legislation are subject to a $40/MWh penalty (non tax deductible) for failing to surrender the required RECs.

Accordingly, the creation of Renewable Energy Certificates provides a co-product for renewable electricity production and sale.

16.4.2 Greenpower

Australia has a national Greenpower scheme through which most electricity retailers offer their customers the option of purchasing renewable electricity with predetermined environmental credentials, at a price premium. Greenpower products exclude the use of native forest materials, whether or not those materials are produced according to principles of sustainability. Greenpower runs in parallel with MRET. RECs that meet Greenpower guidelines (see www.greenpower.com.au) can be surrendered to supply Greenpower (to avoid achieving double credits). Greenpower accordingly provides a co-product for bioenergy.

16.4.3 Other Environmental Instruments

Trading of other environmental instruments, such as salinity credits and carbon credits has commenced in Australia. A salinity trading scheme currently operates in the Hunter Valley, NSW and State Forests NSW has engaged in prototype trades of carbon with power companies such as Delta Electricity, Pacific Power and Tokyo Electric Power Company (TEPCO). In NSW, legislation has created carbon as a separate right from the trees. While a useful beginning, these are isolated or state-based examples of trading and there are not yet any large scale or national trading schemes in place. In the near term, salinity trading may become widespread, offering a tradable instrument with a monetary co-value that may be directly applicable to financial viability for bioenergy projects. Recognising its importance in commercialisation of new tree planting, RIRDC has initiated analysis of environmental trading[1].

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[1] Dr Martin van Bueren - Emerging Markets for Environmental Services: implications and opportunities for resource management in Australia. Summary online at: http://www.rirdc.gov.au/comp02/aft1.html#CIE12A

16.4.4 Saleable Ash

Biomass generally has a low ash (non-combustible material) content. In stem wood this may be as low as 0.4% of the mass of the biomass. Biomass ash does not contain any significant quantity of toxic metals common in coal ash, and may be used as a soil amendment. Biomass ash is high in nutrients, and is preferably returned to the land to sustain nutrient levels. There are generally two types of ash; fly ash from the gas stream, and bottom ash from the furnace grate or bed. The fly ash from the 36 MW Grayling Power Plant in Michigan, USA is certified and sold in that state as a soil improver. Bottom ash is often used as road base. Coal ash is widely used in cement in Australia, and investigations are proceeding to use ash from co-firing in large power stations for the same purpose.

16.4.5 Biofertilisers

As noted in the pyrolysis section (Section 12.2.8), bio-oil can be reacted with ammonia to form slow release fertilisers. IEA Bioenergy Task 22 – *Techno-Economic Assessments for Bioenergy Applications* has produced a 23 page report[1] *Slow release fertilizer production plant from bio-oil; technical-economic assessment*, on the production of slow release fertilizer based on the patented technology developed by Resource Transforms International Ltd, of Waterloo, Canada. The assessment report was based on scaling up the technology to a production plant producing approximately 20,000 tonnes/a of solid fertiliser from whole bio-oil, containing 10% nitrogen.

UK firm Fibrowatt, who operate three large-scale chicken litter bioenergy plants in the UK, currently sell a premium fertiliser derived from the ash of chicken litter.

In Australia, Biomass Energy Services and Technology Pty Ltd of NSW has also been involved in researching and developing Biofertilisers for a commercial customer.

16.4.6 Ethanol

Ethanol may be produced through the fermentation of sugars from sugar, starch and celllulosic feeds. The fermentation of C molasses and wheat starch wastes is well established in Australia. In the USA corn is the main feedstock, while Brazil is the world’s dominant producer of ethanol from sugar. As discussed elsewhere in this report, it is technically feasible to use biomass feedstocks for ethanol production. This requires ‘preprocessing’ of the biomass by acid or enzymatic hydrolysis to liberate sugars for fermentation. Ethanol production from woody biomass is still under commercial development, and is likely to be co-produced with energy to run the process. This is possible because the lignin present in the biomass feed is not convertible to sugars for fermentation and is thus available as boiler fuel.

Alternatively, it is also possible that higher value products may be developed using fractions of the wood as feed. For example, the C5 sugars recovered via hemicellulose hydrolysis may provide better economic returns via production of acids or plastics than via fermentation to ethanol. The lignin may be a feedstock for other products as well. CSIRO is currently examining the use of modern biotechnology for the production of new products from lignin.

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[1] Slow Release Fertilizer Production Plant from Bio-oil; Technical-Economic Assessment, by David Beckman and Desmond Radlein, in Proceedings of Task 22 meeting, VTT, Finland, 1998-1999 final report.

16.4.7 Pyrolysis Oil Products

It is technically possible to produce a variety of chemicals from pyrolysis bio-oil. These range from fine chemicals and speciality chemicals such as levoglucosan [1] to commodities such as resins [2] and fertilisers. Food flavourings are already commercially produced from wood pyrolysis. Such chemicals are of interest due to their much higher added-value compared to fuels and energy products, and they lead to the possibility of the bio-refinery concept in which the optimum combinations of fuels and chemicals are produced.

Meier, Oasmaa and Peacocke [3] present a list of some 65 chemical compounds quantified in bio-oils. Radlein [4] presents information on various chemical products from bio-oil including resins and adhesives, flavour chemicals (eg vanillin), plant growth inhibitors, plant pathogen control agents, pharmaceutical precursors, sulphur-free cosmetic ingredients, fertilisers, road de-icers, emission control agents for power plants, pesticides and surfactants. The figure below [5] (Figure 16-3) illustrates a range of chemical products from a conceptual bio-refinery based on pyrolysis oil as the intermediate product.

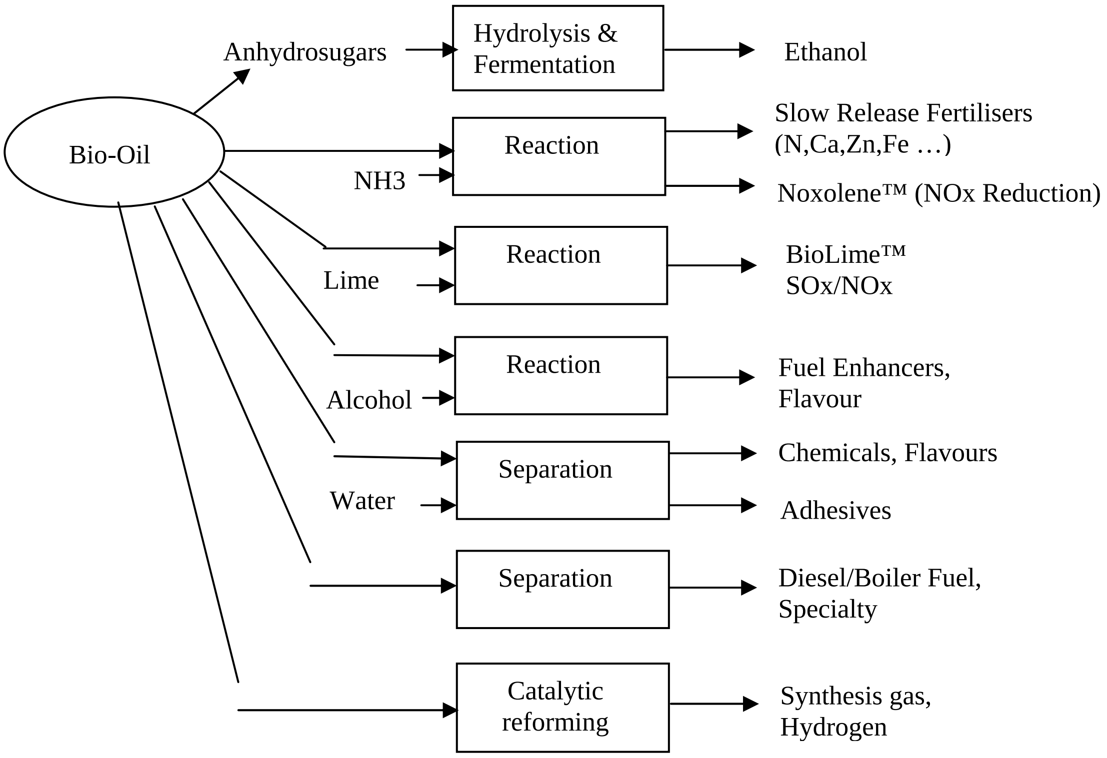

Figure 16-3: Concept and Products from a Bio-Refinery

It must be remembered that in every case where production of a chemical is technically feasible, production must also be commercially feasible and have identified markets before any large scale production occurs.

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[1] PyNE newsletters 4 and 5 at www.pyne.co.uk

[2] PyNE newsletters 6 and 7

[3] Properties of Fast Pyrolysis Liquids: Status of Test Methods, page 85 of Fast Pyrolysis of Biomass: A handbook

[4] Fast Pyrolysis of Biomass: A handbook, page 164

[5] Fast Pyrolysis of Biomass: A handbook, page 184

16.4.8 Charcoal, Activated Carbon and Eucalyptus Oil

Purpose-designed bioenergy technologies enable the co-production of electricity and char. The char in the form of charcoal has potential applications as a reductant (for example in silicon smelting and other metal manufacture) or as a fuel, and it may also be 'activated' by the application of steam or acid to produce various grades of activated carbon. Applications of activated carbon include the absorption of contaminants and odours in air filtration and impurities in water. Activated carbon is also used for processing gold and in the manufacture of 'supercapacitors'.

An example of this approach is already being developed in Western Australia at present, with the first full scale Integrated Tree Processing plant. This plant is being built by Western Power Corporation with assistance from Enecon Pty Ltd and will convert whole mallee eucalypts into activated carbon, electricity and eucalyptus oil. The plant offers multiple products from one site and the electricity can be produced at a cost that is lower than if it was the only product.

If significant world-wide markets can be developed for eucalyptus oil as a solvent or other large scale uses, then its manufacture alongside an energy plant may help the economics of that plant. If one contemplates the use of 1 million green tonnes of wood for energy recovery, the parallel production of eucalyptus oil may be in excess of 10,000 tonnes per year. This is greater than the total use of eucalyptus oil world-wide at present in its traditional markets, but is a small amount when compared with the world-wide market of approximately 1 million tonnes per year that existed for the banned solvent trichloroethane in the early 1990s. The first full scale Integrated Wood Processing plant being built at Narrogin, WA is being constructed during 2003.

16.4.9 Exports

Many areas of the world have inadequate electricity supplies. Bioenergy can be implemented in most parts of the world, using local biomass as the feedstock. The Renewable Energy Action Agenda (www.industry.gov.au/agendas) has as one of its key initiatives the implementation of a renewable energy export strategy. Coupled to this, the Kyoto Protocol allows for Joint Implementation projects with non-'Annex 1' countries and also projects in other countries under the Clean Development Mechanism.

Development of bioenergy projects within Australia would improve Australia's capability to develop export markets, including through technologies being developed with government support, such as supported through the Australian Greenhouse Office's Renewable Energy Commercialisation Program and Renewable Energy Showcase. Significant export potential also exists for the related areas of short cycle crops based on Australian species, harvest and transport systems and equipment, and Australian companies capable of developing and implementing bioenergy projects.

16.4.10 Support Services

The development and implementation of bioenergy technologies and projects require various professional support services. These include environmental, legal, intellectual property, project management, community consultation, and expertise in negotiating, connecting and managing bioenergy plants in the electric power grid. These services are anticipated to be further developed with the expansion of the bioenergy industry.

16.4.11 Plant Breeding and Biotechnology

It is likely that new varieties of biomass will be developed to achieve greater tolerance to saline conditions and to increase yields of biomass per hectare per annum as well as to optimise feedstocks capable of conversion to liquid fuels and co-products. It is possible that GM technology will be investigated to implant certain biomass species with desired characteristics. This will spawn new methods and technologies. It is likely that any use of genetically modified materials will need broad community understanding and acceptance.

16.4.12 Others

A co-product of biodiesel production is glycerin. Biodiesel may be produced from a range a vegetable oils, tallow and waste cooking oil. Typically, for every tonne of biodiesel produced, approximately 100 kg of glycerin is produced. Glycerin is used as an industrial feedstock.

17. Attachments

Attachment 1:	**Glossary and Abbreviations**
Attachment 2:	**Bioenergy Related Units**
Attachment 3:	**Standardisation of Capital Costs**

17.1 Attachment 1 - Glossary and Abbreviations

<	Less than
>	Greater than
Anhydrous	No water present - for example, anhydrous ethanol is ethanol that has been taken through a final distillation stage or similar process to remove the small amounts of water still present following initial distillation.
Arisings	In-forest residues from logging operations
Ash	Inert material in biomass that does undergo energy conversion.
Azeotrope	When the ethanol in an ethanol water mixture is concentrated by distillation the highest concentration of ethanol that can be achieved initially is approximately 96%. At this point the vapour and liquid equilibrium concentrations of ethanol and water are the same, so there is no “driving force” to allow further concentration of the ethanol. To break this azeotrope a further distillation stage is often used, with a third chemical (such as cyclohexane) introduced.
C*	Abbreviation for a sugar with * carbon atoms. Thus a hexose such as glucose is C6, and a pentose such as xylose is C5.
CFB	Circulating Fluidised Bed (gasifier or combustor)
Comminution	The reduction of biomass by mechanical means to obtain a more uniform and valued bulk material.
Coppice	(Verb or noun) As a verb, coppice refers to the ability of a tree species (including many eucalypts) to resprout and regrow from a stump after harvest. As a noun, it usually refers to a stand of trees with coppicing ability.
Corn Stover	The cellulosic residue remaining in the field after the corn cobs are harvested.
Distillation	Distillation is the process of using energy to concentrate one component of a liquid so that it may be progressively separated from other components. In this study it applies to mixtures of ethanol in water, which will leave the fermentation vessel at concentrations of less than 10% ethanol and need to be concentrated to pure ethanol for use as a fuel.
Distillery	Generally taken to mean a plant to produce ethanol from a variety of sugar sources, and includes any feed preparation and the fermentation stage.
Dunder	Common name for the principal residue stream generated from ethanol fermentation and distillation and containing residues from the biomass feed and fermentation products.
e (subscript)	Electrical
E**	Common abbreviation for a blend of ** percent of ethanol in petrol .
Electrolysis	Dissociation of water into hydrogen and oxygen gases using electricity.
Exothermic	A chemical process that give out heat. An example is combustion.
Gallon	Volumetric measure. This report uses US gallons, which are equivalent to 3.785 litres.
GJ	Giga-Joule. A thousand million Joules, the unit of energy. A Joule is a Watt multiplied by a second.

GVW	Gross vehicle weight
HGV	Heavy goods vehicle
HHV	Higher heating value
IEA	International Energy Agency. An Implementing Agreement of IEA is IEA Bioenergy.
LHV	Lower heating value
m.c.	Moisture content. On a wet basis, moisture content is the percentage water in the total biomass, including the mass of moisture. Moisture content may also be expressed on a dry basis. See section 15.2 for detailed explanation.
Miscible	Ability to mix. E.g. ethanol and water are miscible in all proportions.
MSW	Municipal Solid Waste
NOx	Oxides of nitrogen, a pollutant produced during combustion processes. Partially formed from atmospheric oxygen, and partially from the nitrogen in the fuel.
o.d.t.	Oven dry tonne (of biomass)
Oxygenate	A chemical that includes oxygen (such as ethanol) and is added to petrol to increase the overall oxygen level in the fuel.
ppm	Parts per million
RDF	Refuse derive fuel
Saccharide	Sugar, with a polysaccharide being a polymer (or chain) of many sugar molecules.
SCC	Short cycle crop. Also referred to as short rotation coppice (SRC), short rotation forestry (SRF) and plantation energy crops (PEC).
Ton	Measure of mass. In US the short ton is used (2,000 lbs). Approx 909 kg.
Viscosity	Property of a liquid which determines its ability to flow. Honey is for instance more viscous than water. A measure of (kinematic) viscosity is the cS or centiStoke.
Volatile matter	Biomass, when heated to about 400°C to 500°C, gives up a large fraction of its weight in the form of combustible gases. The percentage of volatile matter on a dry basis in biomass typically ranges from 63 percent for rice hulls to over 80 percent for wood. One consequence of high levels of volatiles is that energy may be lost from fuel storage piles, via the loss of volatile organic compounds.

17.2 Attachment 2 - Bioenergy Related Units

Units relating to biomass fuels

Biomass fuels vary with plant species (tree genus, crop species), nature of the resource material (straw, wood, bark, leaves, sludge, municipal wastes, algae, manure etc.), and moisture content (from 95% moisture content wet basis) for dairy farm wastes to 10% m.c.(w.b.) for wheat straw. The basic energy value is measured as Joules of energy in 1 kilogram of fuel, (J/kg). For convenience, biomass energy values are normally quoted as MJ/kg or GJ/t.

Since biomass contains varying amounts of water it is also important to specify the **moisture content** when quoting the weight of fuel. For easy comparisons between fuels, this is usually presented as the weight of biomass material as if it was at 0% moisture content (m.c.), when it is termed **tonnes dry matter (tdm)** or **oven dry tonnes (odt).**

Volume. The usual metric unit used for biomass is **cubic metres (m^3).** When individual pieces of biomass are collected together there is always a considerable voidage (volume of air in the spaces between the separate pieces of wood) which is associated with the total observed volume. This makes the simple unit of volume of limited practical use.

Density is normally defined for any object as its weight / volume. Biomass density is sensitive to moisture content, and since biomass varies widely in moisture content as well as material composition, it is more difficult to define. The fundamental measure for biomass is its **basic density**. Taking wood as an example, this is the weight of oven dry wood contained in a unit volume of green wood.

The type and form that the biomass material takes means that there can be a considerable difference in the mass of material contained in any given volume. Bulk density (which allows for the density of the material as well as the voidage when the material is being stored or handled) varies with species, piece shape, piece size, and moisture content. It is a useful measure as it affects the amount of biomass fuel that can be carried by a truck or that can be stored on a given area of land alongside a combustion plant. For biomass there is a relationship between bulk density and the moisture content of the material.

Densification. Biomass in small particle forms such as sawdust or shredded municipal green waste can be “densified” to increase the density and enable easier handling and storage. Such **briquettes** or **pellets** can vary from 600kg/m^3 to 1500kg/m^3 actual density depending on the equipment used for densifying the material and the biomass (Figure 17-1). Moisture content usually needs to be between 7 – 14% as if wetter it will not compact easily, as any water present does not compress.

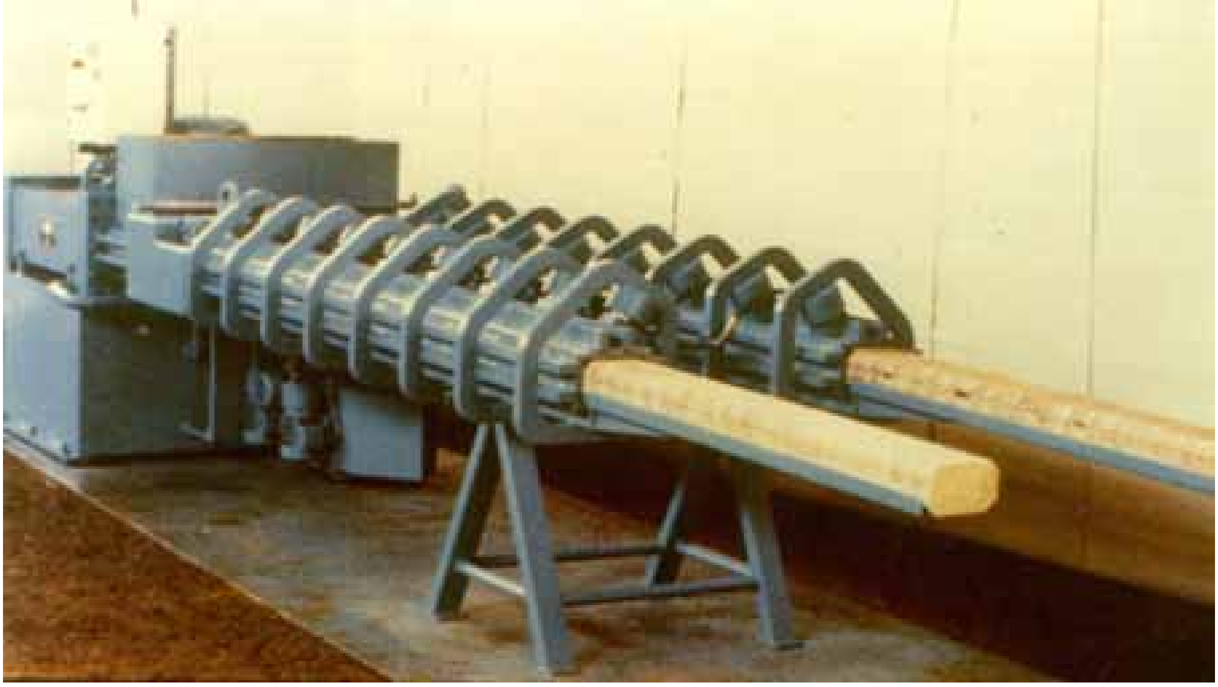

Figure 17-1: Large compacted briquettes of around 1kg each, produced from shredded whole trees
(Grown in a Eucalyptus plantation and dried to less than 20% moisture content.)

Moisture content The moisture content / dry matter ratio of biomass material varies widely and this has a significant effect on many of the conversion processes. For example the percentage of **solids** present in the digestate affects the biogas yields obtained from an anaerobic digestion process. For dry biomass fuels such as straw or wood, any water present has a considerable effect upon the proportion of the total heat content of the wood that it is possible to recover as a result of combustion systems.

$$\text{Moisture content on a wet basis} = \frac{\text{weight of moisture present} * 100}{\text{total weight of biomass}}$$

$$\text{Moisture content on a dry basis} = \frac{\text{weight of moisture} *100}{\text{total oven dry weight of biomass}}$$

Since energy is derived from biomass fuels by burning, the energy content is the **heat energy** released on combustion in air. It is also termed the **calorific value.** This measure has an upper **gross** value and lower **net** value, the difference being the energy necessary to evaporate the water that is present in the fuel and that formed when the hydrogen in the fuel combines with oxygen during combustion.

Units relating to Bioenergy

For heat and transport fuel applications, **MJ**, **GJ** and **TJ** units are most commonly used. When the biomass is converted into electricity, **kWh**, **MWh** and **GWh** are generally preferred. The **capacity** of a conversion plant is in terms of the maximum output expressed as **kW** or **MW**. When this is in the form of heat the subscript $_{th}$ for “thermal” is added; when as electricity it is as $_{e}$. Thus a heat plant might have an installed capacity (or nameplate output) of $25MW_{th}$ and a power generating plant of $8MW_{e}$.

Co-generation is when a plant produces both useful heat and electrical power. It is then also termed a **combined heat and power** plant.

Plant conversion **efficiencies** are generally quoted as overall thermal efficiencies =

$$\frac{\text{useful energy output of the conversion plant}}{\text{energy contained in the biomass fuel}}$$

The physical, chemical and combustion characteristics of biomass fuels can be determined by laboratory test procedures. This information does not need to be carried out for each delivered truck load, but is often useful to determine the value of a resource as feedstock for a power plant. When a power plant is being planned a critical element is to ensure that there is sufficient biomass fuel available in the vicinity for the life of the plant (at least 20 years normally). This means not only assessing the volumes but also the fuel characteristics. Then fuel supply contracts can be negotiated.

The ash content of biomass is generally low at 0.4% to 2.0% by weight (though cereal straw is an exception and can be over 10% due to its relatively high silica content). Higher ash contents of woody biomass can result when poor harvesting and handling methods cause soil contamination of the fuelwood. (Soil consists mainly of non-combustible mineral material that ends up as ash). Ash is a key element of some burners and the lower value can be a problem, not during combustion as such, but for certain designs of moving grate burners, the ash covers the moving surface and protects it from the heat. If the ash content is low, the protection is less and the grate will need to be made of more expensive heat resistant materials.

Variations in heat value are greater with varying moisture content than with biomass type. However, this situation warrants closer examination. Take a pile of green wood chips at 60% m.c. and weighing 1 tonne: 600kg is water and 400kg is dry biomass. The nett energy content is around 8MJ/kg giving a total of 8GJ. If the pile is left to dry to 50% moisture content it loses some weight as the water evaporates off and results in a pile that looks the same, is of similar dimensions and size but now with 400kg dry biomass and only 400kg water. At 50% m.c. it has a heating value of around 10.4 MJ/kg giving 8.3GJ of total energy available for use. Now after some weeks it has dried to 20% m.c. and may have shrunk slightly in volume. It now has 400kg dry matter (though in reality this would have reduced slightly due to respiration losses and some decomposition) and 100kg water so weighs 500kg total. At 17 MJ/kg it has in total 8.5GJ of available energy. So the key point to note is that although the moisture content has dropped the available energy has not increased relatively since the pile has simultaneously become lighter as it dries out.

17.3 Attachment 3 - Standardisation of Capital Costs

When developing cost estimates for process plants (such as alcohol fuel plants) in Australia at current costs, one source of reference material is studies of similar plants overseas. These data can be useful but must be interpreted with due regard for variations in:

- plant size
- the impact of inflation
- the relative costs at the overseas location and the proposed Australian location.

In his book Process Industry Economics[1], David Brennan of Monash University provides a generalised relationship that shows the impact of these factors:

$$I_p/I_r = (Q_p/Q_r)^b\,(F_p/F_r)\,L$$

where:

I = fixed capital investment
Q = production capacity of plant
F = inflation index
L = location factor
b = an exponent
p denotes the proposed plant
r denotes the reference plant

Production Capacity

Consider a plant of a known size. Will a plant of identical technology and purpose, but double the capacity, cost twice as much? It will not, but the actual relationship between the two plant costs is largely a function of the different ways in which the increased capacity is achieved. In some cases, larger units of equipment are needed to provide greater capacity; for example larger heat exchangers, pumps, pressure vessels and so on. Doubling the size of a piece of equipment rarely doubles the cost and this economy of scale is reflected in the overall cost for the larger plant.

Alternatively the equipment may not be capable of a doubling in size, and many or all of the items required may need to be duplicated. In this case many costs do double, but general project costs, such as infrastructure and services, engineering and management costs, will not.

These two alternatives are reflected in exponents that are derived from data gained in many instances of process plant construction at different capacities. From this empirical data, Brennan notes that:

- for plants that are increased in capacity by adding streams (ie. duplication rather than expansion), the exponent b is typically 0.8 to 0.9
- for plants that increase capacity while remaining single stream b is lower, typically between 0.5 and 0.6.

Renewable energy plants are generally single stream overall, even if there are some multiple equipment items such as ethanol fermentation vessels. Single stream methanol plants based on natural gas are built at sizes well above those considered here for biomass to methanol. An exponent of 0.6 has therefore been used in this study for capacity changes. Note that these exponents do not hold across the entire range of plant capacities.

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[1] David Brennan - *Process Industry Economics.* Published by the Institution of Chemical Engineers, Rugby UK, 1998. ISBN 0 85295 391 7

Inflation Index

The process industry monitors the impact of inflation on the cost of plant construction, and regular reports of this impact are available[1]. Thus if the cost of a plant in 2001 is to be estimated from the known cost of a similar plant built in, say 1994, the ratio of the inflation indices for the two years provides a guide of the change in cost.

The Chemical Engineering Plant Index for the USA over recent years is:

Year:	1987	1988	1989	1990	1991	1992	1993
Index:	323.8	342.5	355.4	357.6	361.3	358.2	359.3

Year:	1994	1995	1996	1997	1998	1999	2000
Index:	368.1	381.1	381.7	386.5	389.5	390.6	394.1

Location Factor

To convert the price of a plant in the USA or Europe to a plant in Australia involves an analysis of the extent of imported and local equipment in that plant together with an understanding of how prices and productivities for fabrication and construction in Australia compare with those overseas.

Location factors for Australia may be generally considered as:

$$\frac{\text{Cost of plant in Australia (US\$)}}{\text{Cost of equivalent plant in USA (US\$)}}$$

We extend this to define a conversion factor that includes currency conversion:

$$\frac{\text{Cost of plant in Australia (A\$)}}{\text{Cost of equivalent plant in USA (US\$)}}$$

The capital cost of a process plant includes allowances for equipment and labour (in factories and on site), as well as legislative requirements and so on. Each of these will influence how the cost of a plant in one country may be redeveloped for another country:

The total cost of constructing a processing plant includes cost components for equipment, bulk materials (pipe, cables, concrete etc), construction (labour, management and profit) and engineering/project management costs. These components will vary from project to project, however as a general indication, Humphreys [2] quotes the following split of costs:

• labour (construction etc)	33%
• equipment and bulk materials	53%
• indirect costs and office labour	14%

Of these amounts a proportion of the equipment will not be manufactured in Australia and will be brought from overseas.

Labour - The International Cost Engineering Council publishes trade labour rates for Australia and the USA [3]. These indicate that hourly rates, in A$/h, for Australian trades personnel are generally

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[1] See also, for example, the magazines "Chemical Engineering" by McGraw Hill USA, or "Chemical Engineer" by the Institute of Chemical Engineers, Rugby UK.

[2] Humphreys KK - *Sources of international cost data* - Keynote address at NORDNET 1997 Conference. Refer http://www.webpages.charter.net/icoste/intldata.htm

[3] http://www.webpages.charter.net/icoste/laborsteel.htm

80-100% of the equivalent rates, in US$, in the USA. Based on a current exchange rate of approximately US$1 = A$2, this suggests Australian trades labour is 40-50% the cost of US labour.

In contrast, the US Department of Labor publishes data that indicates Australian manufacturing labour rates were 71% of US rates in 2000 [1]. At the same time Swedish rates were 101% and UK rates 80% of those in the USA.

Taking a point mid way between these two examples, we have assumed that the average cost of all labour in Australia will be 60% of that in the USA or Sweden at current exchange rates. Note that no allowance is made here for relative productivities between countries.

Materials - Breuer and Brennan [2] considered 1991 data for common process equipment, such as carbon steel pipe, basic pressure vessels and electric pumps, and concluded that at the time there was little cost difference overall between these items in Australia, the UK, or the USA. In 1991 the exchange rate between Australia and the USA was US$1 = A$1.3. It is conceivable that the current exchange rate of US$1 = A$2, would mean that manufacture in Australia is cheaper than in the USA.

For other items that are not made locally and may make up 20% of the equipment and materials, the full overseas cost plus shipping, handling and any agents' fees must be assumed.

We have assumed that the overall cost of equipment and bulk materials in Australia and the USA/Sweden will be the same.

Office costs - In the absence of any data it has been assumed that the costs in different locations will be similar

Overall - From the information above it could be suggested that the cost of building a plant in Australia will be up to 10% below the equivalent overseas cost, based largely on reduced labour costs, but without taking relative productivities into account.

To gain a different perspective on this issue, informal discussions have been held with the chief estimators for two major Australian engineering groups. Both suggested that the Australian cost of a process plant would be slightly above the US or European cost. In addition, confidential information has been made available to Enecon for a specific example of a large chemical processing plant. Cost estimates were developed for this same plant to be built in the USA and Australia in 1994. These estimates indicated that the Australian plant would cost approximately 12% more than the equivalent US plant. Note, however, that the relative exchange rate has dropped since 1994, making it possible that this cost difference has also changed.

As well as the location factors for converting plant costs to Australian sites, there are location factors within Australia that reflect the remoteness of a site, labour availability and so on. Labour costs are considered to have the major impact on cost increases at remote locations, with a 30% premium over capital city rates likely to affect the project cost by some 10% overall. Another impact of building at remote locations is the lack of infrastructure that might be available for city locations, such as power, water, and operational staff and labour. General plant infrastructure, such as product storage and handling may vary significantly between a remote Australian site and an overseas site closer to markets and other infrastructure.

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[1] US Dept of Labor - *International comparisons of hourly compensation costs for production workers in manufacturing, 2000* - USDL 01-311

[2] Breuer PL, Brennan DJ - *Capital cost estimation of process equipment* - Institution of Engineers Australia, 1994. ISBN 85825 617 7

Prices also vary within the USA and Europe, being influenced by all of the same issues described above.

These different perspectives highlight the uncertainties associated with converting overseas plant costs to costs for the same or similar plants in Australia. It could be argued that the Australian cost would be lower, or higher, than the overseas cost. We have adopted the approach that the cost conversion will be based on exchange rate, but with the understanding that the accuracy of the Australian cost developed will be correspondingly less than the accuracy of the overseas estimate. Given that many overseas estimates quoted in studies and reports are no better than +/-20%, the accuracy of Australian estimates may fall to +/- 30%.

Biomass energy production in Australia

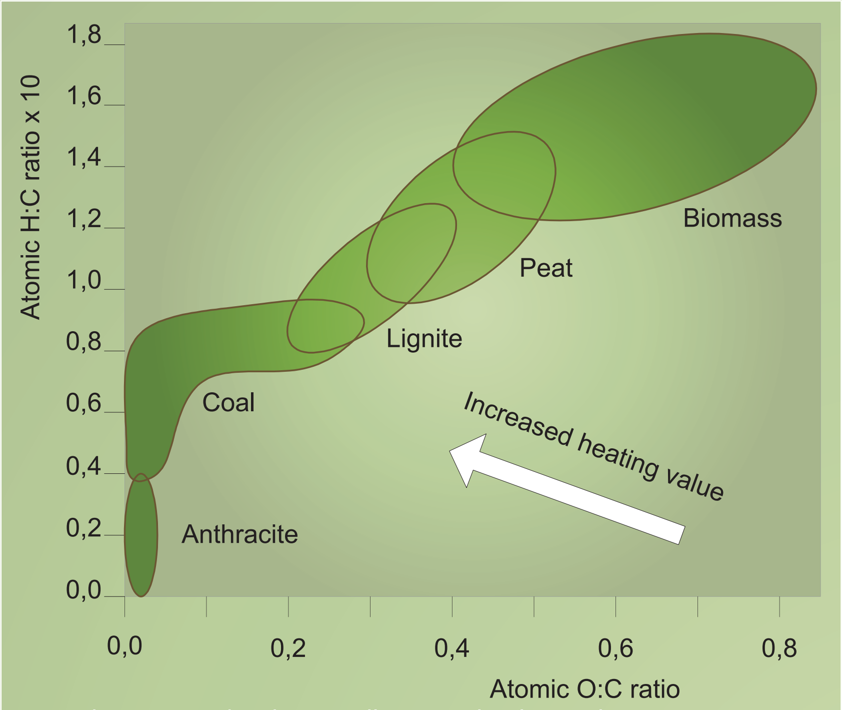
Status, costs and opportunities for major technologies

by C.R. Stucley et al
RIRDC Publication No 04/031

This publication appraises technologies and costs for projects involving energy from biomass. It acknowledges that there is growing appreciation across much of rural Australia for the benefits that may be realised from increasing tree cover on farms, while still maintaining existing farming activities such as cropping and livestock production. These benefits can be significant and may include:

- environmental improvements, such as salinity, water quality and soil protection
- protection of biodiversity and remnant vegetation
- commercial opportunities for farmers to use farm forestry as an additional income stream.

In the search for large, new industries that could utilise wood as feedstock, particular attention is being paid to renewable energies. Not only does renewable electricity offer its own environmental benefits, it also offers the potential of large markets for sustainably-grown trees across many parts of Australia.



The Van Krevelen diagram illustrates the chemical composition of biomass compared to other solid fuels.

Joint Venture Agroforestry Program
Rural Industries Research & Development Corporation
Forest & Wood Products Research & Development Corporation
Land & Water Australia
Murray-Darling Basin Commission

Joint Venture Agrogorestry Program

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In November 2008 *Bioenergy Australia* provided funds to reprint this publication. *Bioenergy Australia* aims to foster and facilitate the development of biomass for energy, liquid fuels and other bio-based products. *Bioenergy Australia* was established in 1997 and is an alliance of government bodies and industry organisations working side by side to foster bioenergy in Australia. It operates as a forum and focus for all aspects of biomass and bionergy production and use, as well as associated technical, commercial, economic, social, environmental, policy and market issues. *Bioenergy Australia* is managed by RIRDC on behalf of its members.

Level 2, 15 National Circuit
Barton ACT 2600

PO Box 4776 Kingston ACT 2604

Tel: 02 6271 4100
Fax: 02 6271 4199

Email: rirdc@rirdc.gov.au
Web: www.rirdc.gov.au

www.rirdc.gov.au