An Australian Government Initiative

Joint Venture Agroforestry Program

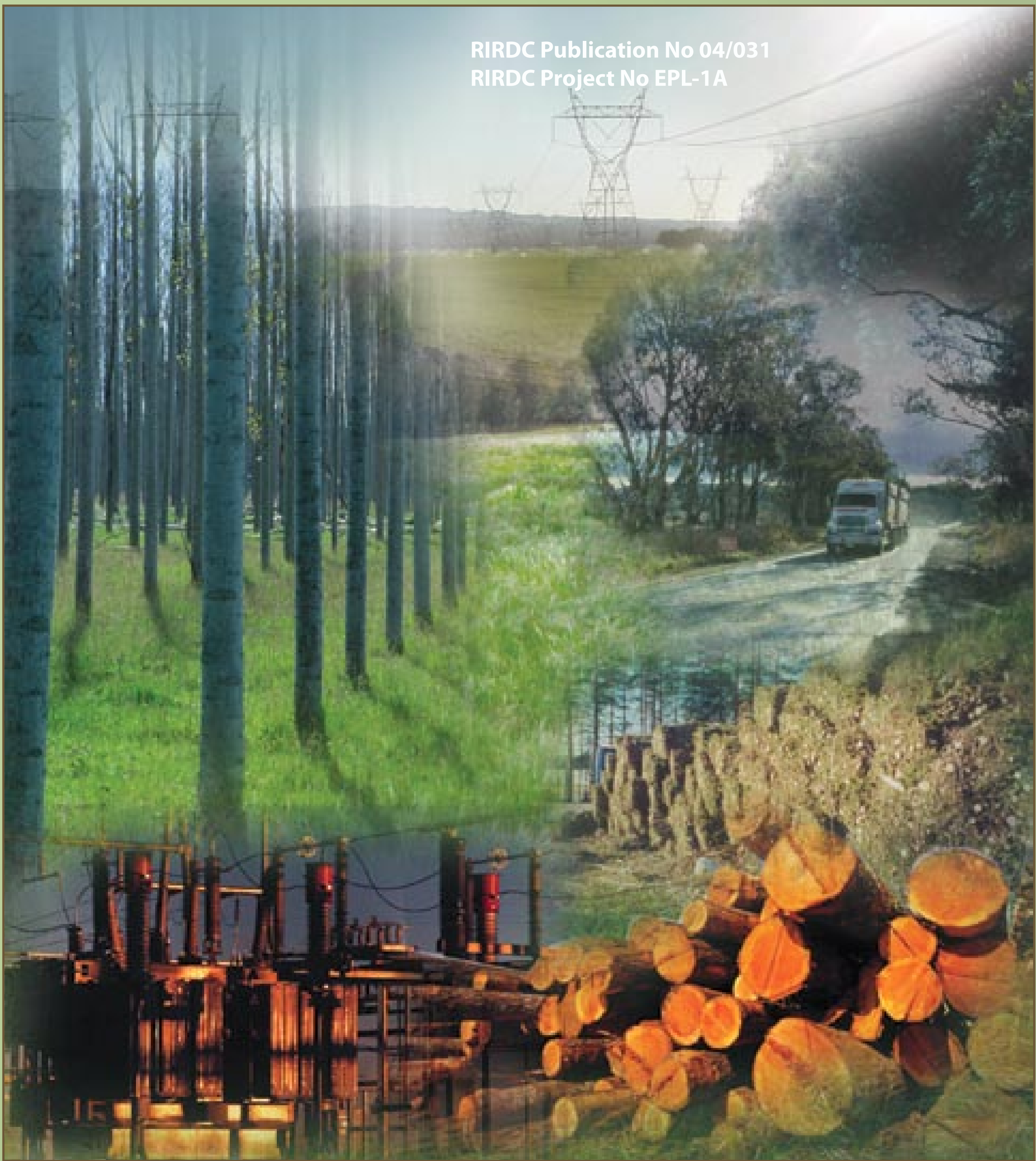
Rural Industries Research & Development Corporation
Forest & Wood Products Research & Development Corporation
Land & Water Australia
Murray-Darling Basin Commission

Biomass energy production in Australia

Status, costs and opportunities for major technologies

A report for the 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



An Australian Government Initiative

Biomass energy production in Australia

Status, costs and opportunities for major technologies

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

February 2004
RIRDC Publication No 04/031
RIRDC Project No EPL-1A

ISBN 0 642 58741 8
ISSN 1440-6845

'Biomass energy production in Australia: Status, costs and opportunities for major technologies'
Publication No. 04/031
Project No EPL-1A

Researcher Contact Details
C.R. Stucley* and B.E. Marino
Enecon Pty Ltd
Level 2, 35 Whitehorse Rd
Deepdene, Vic. 3103 Australia

Phone:	03 9817 6255
Fax:	03 9817 6455
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

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.

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone:	02 6272 4819
Fax:	02 6272 5877
Email:	rirdc@rirdc.gov.au.
Website:	http://www.rirdc.gov.au

Published in February 2004
Printed on environmentally friendly paper by Canprint

Foreword

There is growing 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 project was jointly funded by the Joint Venture Agroforestry Program (JVAP) and the Australian Greenhouse Office. JVAP is in turn 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). These agencies are principally funded by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 1000 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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

Simon Hearn
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

Funding of this study by the Joint Venture Agroforestry Program and the Australian Greenhouse Office is gratefully acknowledged.

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

Contents

List of Figures

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.

[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

[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 [CH2O]). Oxygen is produced and emitted.

$$CO_2 + 2H_2O \xrightarrow[\text{Heat}]{\text{Light}} ([CH_2O] + H_2O) + O_2$$

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.

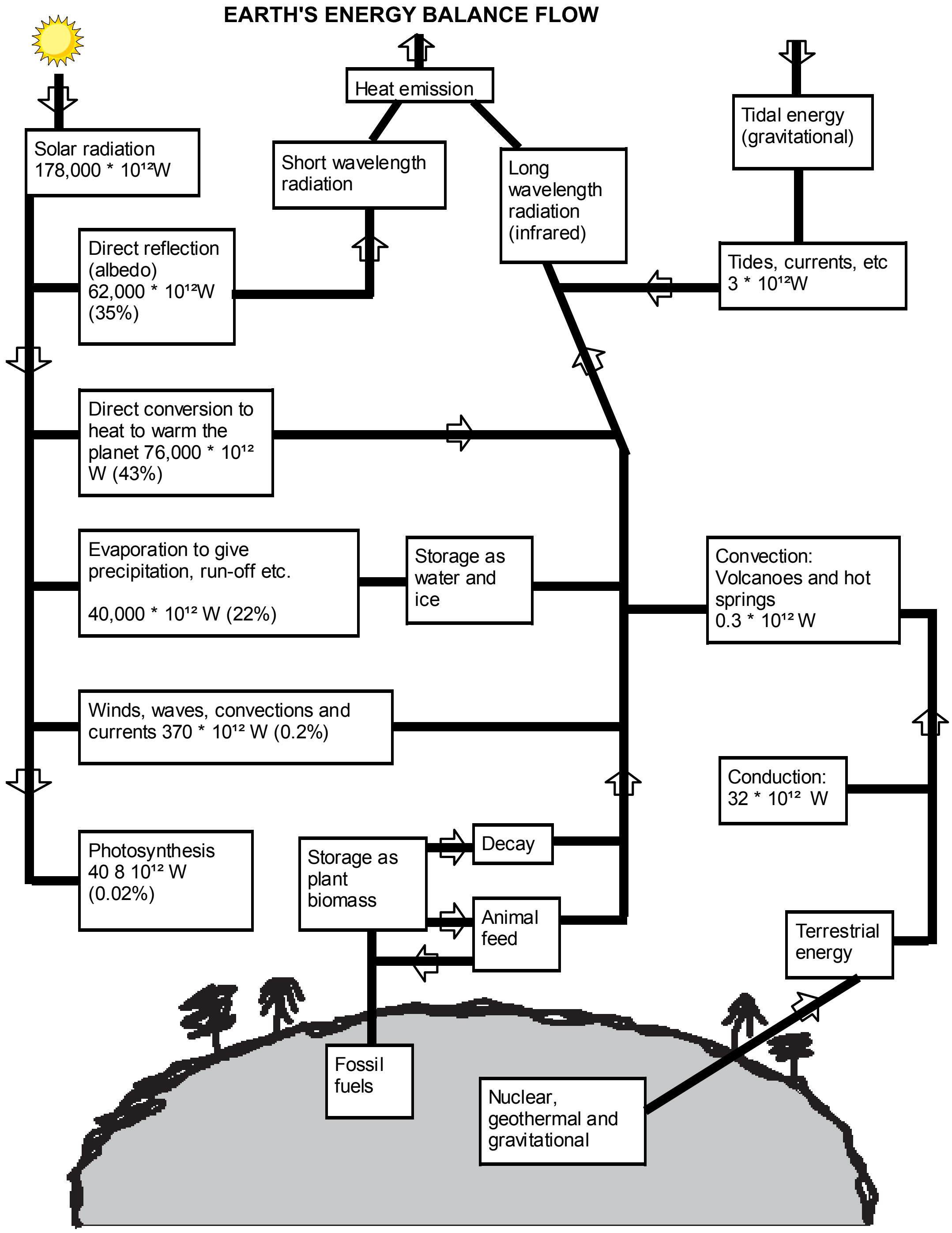


Figure 1-1: The Earth's energy flows are in balance
(Most of the Earth's energy supply comes from the sun but due to continuous heat losses to space, the Earth's energy flows are in balance.)

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:

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

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

[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.

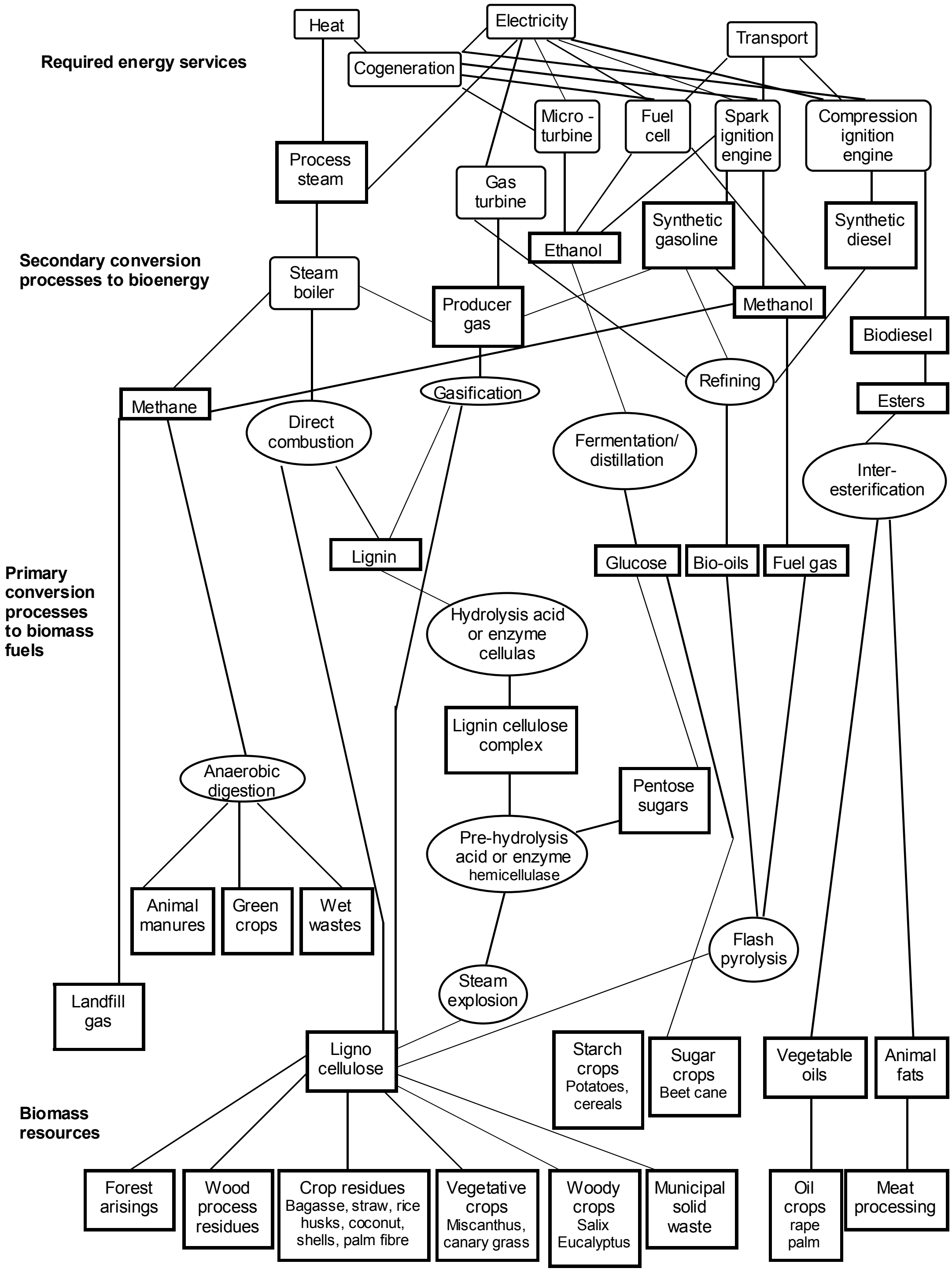


Figure 1-3: Some routes for converting a number of different biomass materials into useful energy products

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.