



Wood for Alcohol Fuels

Status of technology and cost/benefit analysis of farm forestry for bioenergy

**A report for the RIRDC/Land & Water Australia/FWPRDC/MDBC
Joint Venture Agroforestry Program**

by Enecon Pty Ltd

in association with
Centre for International Economics
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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 which 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 feed, particular attention is being paid to renewable energies. Not only do renewable electricity and liquid transport fuels offer their own environmental benefits, they also offer the potential of large markets for sustainably-grown trees across many parts of Australia.

This publication presents an investigation of the opportunity for making ethanol and methanol from wood, to be utilised as renewable liquid transport fuels. It considers the technologies and costs involved, and then discusses the “balancing” of those costs against the many potential benefits that environmentally benign fuels and increased farm forestry should deliver.

This project was funded by three R&D Corporations — the Rural Industries Research and Development Corporation (RIRDC,) Land & Water Australia and the Forest and Wood Products Research and Development Corporation (FWPRDC), together with the Murray-Darling Basin Commission (MDBC). These agencies are funded principally by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 800 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.

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Simon Hearn

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A number of individuals have generously provided assistance to the report team. In particular, Dr Roslyn Prinsley of RIRDC, Mr John Bartle of CALM, and WA forestry consultant Mr Graeme Olsen have assisted in development of the study and its concepts, and in the review of report drafts.

DISCLAIMER

This report has been prepared to assist with the appraisal of biomass to alcohol fuels and energy technologies and their costs. While care has been taken in its preparation, the study work and report are preliminary only and should not be used alone for commercial decisions or technology selection. 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

Background

1. The Joint Venture Agroforestry Program has identified a need to develop farm forestry in many agricultural regions, in particular low to medium rainfall areas. Trees can help balance water flows in many landscapes and thus reduce the adverse impacts of salt that is otherwise brought to the surface by rising water tables. As such, large scale tree planting is seen as an important mechanism for reducing and managing dryland salinity.
2. If new commercial uses were to be found for wood products, the incidence of tree planting by farmers would be expected to be far greater and more sustainable than if the trees were planted purely for environmental or aesthetic reasons. In addition, commercial uses for trees grown via farm forestry would provide new sources of income for farmers, and potentially add to the economic stability of rural Australia.
3. Plantation forestry, based around pine and eucalypts such as blue gum, is already well established in coastal regions with good rainfall. However, the dryer inland regions of Australia with rainfall of 600 mm or below are not so well suited to commercial forestry with such species. If commercial forestry is to be developed in these regions it will benefit from new industries that are based on the use of tree species particularly suited to the regions; for example the mallee eucalypts that grow in much of dryland Australia.
4. Of many potential new industries, one that receives particular interest is the production of renewable biofuels from wood. These include the alcohols ethanol and methanol for use as liquid transport fuels. The potential market for these fuels in Australia is considerable, and a liquid fuels industry using biomass for feed may be a driver for tree planting on a massive scale.

Why alcohol fuels?

5. Ethanol is already in use in a number of countries, both as a liquid transport fuel in its own right and via blends of ethanol and petrol. It is generally perceived to offer a range of benefits over fossil fuels, including:
 - a) Lower greenhouse gas emissions
 - b) Lower levels of certain exhaust emissions
 - c) Provides octane enhancement to petrol/alcohol blends
 - d) Domestic production of ethanol allows reduced imports of fossil fuels
 - e) Can utilise sugar or starch by-products and be part of integrated processing industries.
 - f) Favours rural industry and employment.
6. Another potential benefit for alcohol fuels, and certainly a reason to better understand them now, is the knowledge that, at some time in the future, crude oil will rise in cost. Ethanol (and methanol) from renewable sources are currently more expensive than fuels derived from crude oil.
7. Against the significant benefits above, these alcohols must not be thought of as the only way to address fuel security and balance of trade issues (with non-renewable options in Australia including liquid fuels from shale oil, natural gas and coal). Also, as the oil industry notes, there are alternative mechanisms for reducing vehicle exhaust emissions that do not require the use of alcohol fuels. If alcohol fuels are to find a significant and secure place in Australia they must offer demonstrable benefits to the triple bottom line of environment, economics and community that make them a preferred choice for our future energy needs.

Alcohol fuels from wood

8. Ethanol may be used as a fuel in several ways:
 - a) low level blends with petrol - at levels of up to 10% ethanol may be blended with petrol (commonly called E10) and used in most modern car engines with no modifications.
 - b) high level blends with petrol - in Brazil a blend of approximately 22% ethanol (E22) in petrol is used in many vehicles, with only minor modifications to fuel handling systems reported. In the USA there is increasing use of E85, with many major vehicle manufacturers producing flexible fuel vehicles (FFV) that have engines and fuel systems designed to properly utilise this level of ethanol.
 - c) pure ethanol - in both USA and Brazil some vehicles use pure, hydrous ethanol (an azeotrope of 96% ethanol and 4% water). In each case vehicles require engines and fuel systems that are designed with the high levels of ethanol in mind.
 - d) blends with diesel - low level blends of ethanol and diesel fuel are technically feasible. Several different mechanisms are being investigated to avoid phase separation between the ethanol and the diesel, including specialised emulsifiers such as those developed by APACE Research in NSW and other groups in Europe, and mechanical emulsification.
9. Ethanol in Australia is currently produced via the fermentation of materials available as by-products of the sugar and starch processing industries. Such production will be limited by the availability of such low value feed materials. Any new plants that use dedicated sugar and starch feeds successfully will presumably need to allow for the opportunity cost of such feeds for human or animal consumption. In the absence of such projects, any use of renewable alcohol fuels in Australia beyond a few percent of the total liquid fuels market will need to involve wood as feed material.
10. Technologies for the manufacture of ethanol from wood focus on two areas:
 - a) Hydrolysis of the wood to recover the sugars that make up the cellulose and hemicellulose in the wood feed. Most current technologies use acid hydrolysis to soften the wood and then break the sugar polymers down into individual sugar molecules. There is also considerable work underway to develop enzymatic hydrolysis to the stage where it can be used instead of acid hydrolysis.
 - b) Fermentation of the sugar solution produced. The sugars released from biomass by hydrolysis are a mixture of six carbon and five carbon sugars. This makes the fermentation step more complex than for cane sugar or sugars from starch, which are solely six carbon sugars. A range of organisms are being used and improved around the world for this fermentation step, including modified yeasts, bacteria such as *E. coli* and *Zymomonas mobilis*, and thermophilic organisms.
11. There are no full scale biomass to ethanol plants currently operating anywhere in the world. However there is considerable expertise already in the relevant technologies. More than half a dozen groups in the USA, Canada and Europe have developed, built and operated multi-million dollar pilot plants to investigate different feed materials (wood, MSW, agricultural residues), hydrolysis routes (acid and enzyme) and fermentation pathways. Ongoing R&D work, particularly by NREL and its associates in the USA, is estimated to cost in the order of tens of millions of dollars over the next few years alone. NREL has identified a range of opportunities for improvements that, if achieved, would serve to reduce the cost of ethanol from wood by up to 50% over the next 15 years. NREL has set a production target of US 28 cents/litre as a research goal for ethanol from wood. Therefore, while there is scope for improvement in many different areas, any work proposed for Australia should be viewed in the light of existing expertise and ongoing programs by experienced overseas organisations.

12. Wood can also be converted to methanol, via a quite different processing route to that used for ethanol. The wood is initially gasified to make a synthesis gas, followed by catalytic conversion of the gas and recovery of methanol. Biomass gasification is well understood already via its role in heat and power generation, although there is still much to learn about managing the gasification to produce synthesis gas optimised for subsequent catalysis. Similarly the catalysis of natural gas to methanol is practised world-wide and provides useful experience for potential wood-based systems. However the various elements of a wood-to methanol plant using this technology have not been put together into an integrated system, even at the pilot scale, and there appear to be no plans for any group in the world to develop such an integrated pilot plant. There are no full scale wood to methanol plants operating at present.
13. The National Renewable Energy Laboratory (NREL) in the USA has estimated the cost of a 200 ML/y wood to ethanol plant, and the BAL Fuels Project consortium in Sweden has estimated the cost of a 390 ML/y wood to methanol plant. Data from the reports by both groups have been used to estimate the Australian costs for plants to produce ethanol or methanol from wood. Data from these and other reports have also been used to consider the possibilities of feed and process improvements over the next ten to fifteen years, and their impact on production costs.
14. Ethanol is estimated to cost 82 cents per litre in a 200 ML plant built today in Australia using world's best technology. If multiple improvements are achieved over the next 15 years this price may fall by 50% to as low as 41 cents per litre. This cost is based on biomass feed available at \$30 per tonne delivered to the plant.
15. Methanol is estimated to cost 62 cents per litre in a 390 ML plant built today in Australia using world's best technology. Some improvements to technology may be possible over the next fifteen years and a price of 50 cents per litre has been used in this report for a lowest price projection in fifteen years time. As with ethanol, green feed delivered at \$30 per tonne is assumed.

Ethanol – wood versus molasses

16. These cost conversions and price estimates are considered to be very preliminary, but they do allow initial comparisons between the cost of renewable liquid fuels and their fossil fuel counterparts now and in the future. They also allow comparison of the relative costs of ethanol from wood and ethanol from molasses. At present, ethanol from wood is generally more expensive than ethanol from molasses, particularly if the molasses is available at low cost. However forecast improvements could reduce the cost of ethanol from wood to the point that it is similar to or even lower than the cost of ethanol from molasses. Environmental benefits from tree planting to make ethanol are not obtainable when ethanol is made from molasses.
17. It is also important to recognise that ethanol from wood provides significantly better greenhouse gas reductions than ethanol derived from molasses. Whereas ethanol from molasses reduces CO₂ emissions by 20 –50% over low sulphur diesel, ethanol from wood wastes provides a reduction of some 90%.

Pricing relative to petrol

18. A number of major energy groups world-wide regularly predict trends in the future price of crude oil. These have been summarised by the US Department of Energy¹. The consensus of these organisations is that while consumption of crude oil will increase significantly over the period 2000 – 2020, there will be no significant increase to the cost of crude oil over this period. This does not necessarily suggest that the price of crude oil will not increase *beyond* the twenty year horizon. Other forecasters predict that oil supplies will start to decline after 2010, with possible effects on prices. For this study an ex-refinery petrol price of 35 cents per litre in 2015 is assumed, which is similar to current prices. Note that alcohol fuels need to be compared with

petrol at an ex-refinery price and not a pump price. The price of methanol from natural gas is expected to fluctuate within the range US\$100 to 200 per tonne over the next fifteen years, with no major impact from any decline of natural gas reserves. If a figure of US\$150 per tonne is used, methanol from natural gas should be available in 2015 at 24 c/l.

19. Relative to petrol, ethanol has an energy density of 0.7. This suggests that, while in 2015 petrol may have an ex-refinery price of approximately 35 c/l, the amount of petrol with energy equivalent to a litre of ethanol will cost 25 c/l. With ethanol predicted to cost, at best, approximately 42c/l in 2015, there is still a considerable gap in relative costs.
20. Methanol has an energy density (MJ/L) that is lower than both petrol and ethanol. In 2015 there is also a cost gap anticipated, with methanol from biomass estimated to cost 50 c/l against methanol from natural gas at 24 c/l.
21. Alcohol fuels also provide octane improvements when blended with petrol for use in internal combustion engines, however a monetary value attributable to this benefit was not determined during this study. Petrol and alcohol fuels are both possible feeds to reformers for fuel cells, with similar energy efficiencies.
22. In view of this large price gap between the cost of alcohol fuels from biomass and the ex-refinery cost of petrol, alcohol fuels cannot be expected to compete on a simple economic basis (ie. No accounting for environmental or other benefits) against petrol unless there is a large, and sustained, increase in the price of crude oil. Such a cost increase is not anticipated over the next twenty years unless, perhaps, there is significant social, economic or political upheaval across the Middle East and the other oil producing nations. In its absence, and thus without consideration of security of supply, the case for alcohol fuels in Australia should be made on other benefits from such products and their manufacture.

Benefits of a wood-based alcohol fuel industry

23. It is recognised that alcohol fuels from wood feeds can provide significant benefits in terms of greenhouse gas reduction, both over petrol and over many other renewable fuels. The planting of trees in selected areas is also anticipated to bring about salinity benefits and potentially other benefits to the environment and rural Australia. In this study greenhouse gas benefits and on farm salinity benefits have been assessed in terms of their ability to “close the gap” that is identified for biomass based fuels. A value of \$56 per tonne for CO₂ abatement has been used, based on work by ABARE. Values of 1.4 c/l for methanol and 3 c/l for ethanol were estimated for on farm salinity benefits, based on a case study for planting mallee eucalypts in alleys in the Western Australian wheat belt and the different ratios of biomass required per litre of ethanol or methanol produced.
24. While both these benefits reduced the cost gaps between biomass based fuels and their fossil fuel equivalents, they did not close the gaps completely. The remaining gap, based on relatively constant petrol pricing over the next 15 years, was estimated to be 13 c/l for ethanol and 15 c/l for methanol. Australia is expected to import more than 50% of its crude oil from overseas by 2015, and if the price of crude oil increases, these gaps will decrease. Conversely, if the value of the Australian dollar increases against the US dollar (A\$1.00 = US\$0.50 was used in this study) the cost of importing crude oil will decrease, which will work against the use of alcohol fuels.
25. There are other environmental benefits and social benefits both on-farm and off-farm for widespread tree planting which could support the use of alcohol fuels. These benefits will help to further close the price gap, but they were not assessed quantitatively in this report. They include:

- a) Protection of roads, towns and other infrastructure from damage by waterlogging and salinity
 - b) Biodiversity benefits, particularly by reducing or preventing the flow of saline water into rivers, wetland and other biodiverse areas
 - c) Protection of the rivers in the Murray Darling Basin from salinity and its impact on irrigation-based industry
 - d) Contribution to sustainable farming, and thus to healthy, sustainable rural communities
 - e) Broader socio-economic benefits such as regional development and jobs (which have been identified in US studies of bio-ethanol production).
26. It is possible that other products could be produced in conjunction with the manufacture of alcohol fuels. The work proceeding in Western Australia with integrated processing of mallee eucalypts for renewable electricity, activated carbon and eucalyptus oil is one example of multiple products supporting improved project economics. Co-products relevant to liquid fuel production include oils extracted from leaf material and new products from the lignin. If produced in sufficient quantities or at sufficient value, such co-products would improve the commercial viability of alcohol fuel production.

Alcohol fuels or renewable electricity?

27. Electricity from biomass was also examined, as a comparison with biomass based liquid fuels. Technology for electricity from biomass is well established and widely used around the world. Based on a 30 MWe power plant using similar wood feed to the liquid fuel plants, electricity from biomass is more expensive than electricity generated from fossil fuels. However, when CO₂ benefits and on farm salinity benefits are costed in the same way that they were in the liquid fuels analysis, biomass electricity becomes marginally cheaper than fossil fuel electricity. As such, on the estimates prepared in this study, electricity seems to be a more economically attractive product from biomass than ethanol or methanol over the next fifteen years, even when potential advancement in liquid fuel technologies are considered. Distributed electricity generation can have other benefits over centralised generation (such as optimisation of transmission infrastructure) however such issues typically occur on a case by case basis and were not considered in this study. Any other benefits attributable to large scale tree planting and co-products should apply to electricity generation just as they would to alcohol fuel production.

Recommendations

Technology In any new Australian work looking at ethanol from wood, the large amount of technology available from overseas, and the large amount of research expected overseas this decade, should both be given careful consideration. In this way, local research can be focussed to give the best result for Australia without simply reproducing the work that will be available from other groups. Particular areas of interest could include the examination of Australian biomass feeds (eg. eucalypts) as opposed to the straws and corn stover that are the focus of much of the overseas work. Examination of the processes and costs of taking these local feeds through to fermentable sugars will also be relevant to other new industries (for example renewable plastics such as PLA) and to production of co-products.

The assessment of methanol from wood in this study has been hampered by a relative lack of data on its manufacture and its use in petrol blends. In the absence of integrated work overseas, even at the pilot scale, the development process for this technology in Australia could be more costly than that for ethanol. Prior to any major research undertakings for methanol production, it is important that issues of blending and use are considered in more detail. It would also be possible to conduct a more

accurate feasibility and costing study based on information from providers of each of the relevant processing units to make up a wood to methanol plant.

Benefits to the triple bottom line If a more comprehensive cost benefit analysis is desired, work will need to be undertaken to examine the range of off-farm salinity benefits as well as other benefits, across a variety of regions. Ideally, particular regions would be identified that offer maximum benefits from large scale tree planting. This would be a far more significant undertaking than the work done for this report.

Co-products Other products produced synergistically with alcohol fuels offer another method of reducing the price gap between these fuels and petrol. Specific research pertaining to alcohol fuels and co-products from Australia plantation trees is in its infancy, and yet it offers great potential for sustainable new rural industry. Current work with multiple products from Australian tree species must continue if this avenue for helping to close the alcohol fuel price gap is to be better understood. Work with value-added products from lignin may assist a new alcohol fuels industry and may also provide technologies of benefit to the existing lignin producers in the pulp and paper industry. In the absence of lignin co-products, the economics of parallel production of renewable electricity from lignin should also be better understood.

Government policy A large price gap exists between the cost of alcohol fuels from biomass and the ex-refinery cost of petrol. Unless there is a large, and sustained, increase in the price of crude oil, alcohol fuels cannot be expected to compete “head to head” against petrol on a simple economic basis (ie. No accounting for environmental or other benefits). However, it is possible that alcohol fuel plants may be justified in certain regions from a “triple bottom line” perspective that offers multiple benefits to the community. In this case, it is essential that there are Government policies in place to provide financial incentives for alcohol fuel manufacturers that reflect these community benefits. As with similar situations in other alcohol-producing countries such as the USA and Brazil, the policies will need to be sufficiently stable as to underpin major capital investments.

Given the decline of domestic crude reserves and increased imports of overseas crude over coming years, it is expected that the Government will regularly consider the implications to Australia of increased crude oil *prices* and of increased *risk* to crude oil supply. The strategic implications of an alcohol fuels industry should be included in any such considerations. It must be remembered that a large biomass alcohol fuels industry will involve billions of dollars of investment in plantations and processing plants and significant lead times for establishment of even short rotation plantations. Such an industry will ideally be established from a comprehensive base of technical, financial and environmental data.

1. INTRODUCTION

1.1 *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 the Land and Water R&D Corporation and the Forest and Wood Products R&D Corporation.

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”².

“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 mm).....Unless trees are profitable for farmers in these areas they will never be planted on a sufficient scale to achieve desired environmental benefits”³.

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 damaged already 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.

For some time it has been technically feasible to produce liquid transport fuels from woody biomass. The alcohols ethanol and methanol can each be produced. Ethanol is produced via fermentation of sugars released from the cellulose and hemicellulose in the wood. Methanol may be produced via gasification of the wood and then catalytic conversion of the gas stream to methanol. Each alcohol can then be used as a fuel in its own right (in purpose built engines) or via controlled blending with petrol or diesel as appropriate. While technically feasible, neither alcohol is currently produced from wood in commercial quantities in Australia or overseas.

Because of the size of the Australian liquid transport fuels market, new liquid fuels from biomass are seen by many as an opportunity to commercialise tree planting on a scale not possible through other new plantation industries. For example, woody biomass to ethanol based on current technology would require the supply of more than 10 million tonnes of green wood each year to provide 10% of Australia's liquid transport fuel requirements.

1.2 Structure of this Report

This report is structured as follows:

- a) Background information is provided to describe the potential for renewable liquid fuels and assist with understanding the technical sections.
- b) Technical sections are then provided to introduce current and projected technologies for production of ethanol and methanol from biomass feedstocks.
- c) Following the technical sections is a summary of work to provide indicative costs for biomass-derived liquid fuels and, for comparison, renewable electricity from biomass.
- d) Based on these cost projections a cost/benefit analysis has been carried out to compare biomass-derived renewable energies with their fossil-fuel based counterparts.
- e) Finally, an overview of the policies and schemes of the Federal Government that relate to this topic is presented.

Items (a), (b) and (c) were written principally by Colin Stucley of Enecon Pty Ltd, Melbourne.

Item (d) was written principally by Martin van Bueren and David Vincent of the Centre for International Economics, Canberra.

Item (e) was written by Stephen Schuck of Stephen Schuck & Associates Pty Ltd, Sydney.

Editing was principally by Colin Stucley, with review by Stephen Schuck. Agricultural comment was also provided by Graeme Olsen and John Bartle who are closely involved with mallee eucalypts and other dryland tree crops in Western Australia.

1.3 Feedstocks

Before considering the conversion of wood to ethanol in any detail it is important to understand the general characteristics of wood itself.

Wood is either a hardwood (such as eucalypts) or a softwood (such as pine). The composition of wood varies between hardwoods and softwoods as follows ⁴:

Table 1-1 Major Components of Wood

Component	Hardwoods % present	Softwoods % present
Cellulose	45 +/- 2	42 +/-2
Hemicellulose	30 +/- 5	27 +/-2
Lignin	20 +/- 4	28 +/-3
Extractives	5 +/-3	3 +/-2

Within the hemicellulose present in wood, the proportions of pentose (C5) and hexose (C6) sugars can vary. Softwood hemicellulose has a higher proportion of C6 sugars (especially glucose and mannose) than hardwood hemicellulose, which is dominated by the C5 sugar xylose.

Agricultural residues vary in composition from wood, but contain essentially the same components and are considered to be closer to hardwoods in that they have a low lignin content ⁵.

1.4 Useful Energy Data

As with a basic understanding of the composition of wood, it is useful to understand the differences between ethanol, methanol and petrol. Of particular relevance are the differences in specific energy and octane number. Both ethanol and methanol contain less energy than petrol per unit mass, but in contrast offer higher octane numbers than petrol.

Table 1-2 Useful Energy Data for Liquid Fuels

Property	Methanol	Ethanol	Petrol
Formula	CH ₃ OH	C ₂ H ₅ OH	C ₄ -C ₁₂
Molecular weight	32.04	46.07	
Density (kg/m ³ at 25°C)	790	790	720-780
Higher Heating Value (MJ/kg)	19.92	26.78	41.8-44.0
Higher Heating Value (MJ/L)	15.74	21.15	
Lower Heating Value (MJ/kg)	15.74	21.16	31.4-33.0
Lower Heating Value (MJ/L)	12.43	16.71	
Research Octane No. (RON)	106	106	91-93
Blending RON	135	114-141	118
Reid vapour pressure - blending (kPa)	214+	82.7-186	55.1-103.4

Adapted from Johansson *et al* ⁶.

2. MARKETS FOR TRANSPORT FUELS

2.1 Demand for Petroleum Products in Australia

The table⁷ following shows the demand for petroleum products Australia-wide from 1987 to 1998 inclusive.

Table 2-1 Demand for Petroleum Products in Australia

	Demand in megalitres											
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Petrol												
Leaded	14,318	13,830	13,098	11,930	10,860	10,234	9,485	8,323	7,452	6,782	5,915	5,129
Unleaded Premium		75	95	98	102	133	149	183	260	338	421	519
Unleaded	1,897	2,869	4,046	5,120	5,919	6,703	7,639	9,158	10,038	10,847	11,565	12,385
Total	16,215	16,774	17,239	17,148	16,879	17,070	17,273	17,665	17,750	17,967	17,901	18,033
Automotive Diesel Fuel												
Inland	8,641	9,212	9,830	9,876	9,659	9,895	10,409	10,789	11,165	11,869	12,239	12,408
Bunkers	223	153	164	146	125	159	129	233	289	264	339	212
Total	8,864	9,365	9,994	10,022	9,784	100,054	10,538	11,022	11,453	12,133	12,578	12,620
Liquefied Petroleum Gas	2,183	2,308	2,836	3,489	3,066	3,372	3,636	3,869	4,116	3,715	3,712	3,708

Unleaded petrol sales are expected to increase nationally from approximately 13,500 ML⁸ in 1999 to an estimated 19,000 ML in 2008. Conversely, leaded petrol sales are expected to phased out by 2008 from approximately 4,500 ML sold in 1999.

In general, petrol demand is expected to increase 5% between 1999 and 2008, and auto diesel 20% for the same period.

2.2 Use of Ethanol in Vehicles

Ethanol may be used as a fuel in several ways:

- low level blends with petrol - at levels of up to 10% ethanol may be blended with petrol (commonly called E10) and used in most modern car engines with no modifications.
- high level blends with petrol - in Brazil a blend of approximately 22% ethanol (E22) in petrol is used in many vehicles, with only minor modifications to fuel handling systems reported. In the USA there is increasing use of E85 with vehicles that have engines and fuel systems designed to properly utilise this level of ethanol.
- pure ethanol - in both USA and Brazil some vehicles use pure, hydrous ethanol (an azeotrope of 96% ethanol and 4% water). In each case vehicles require engines and fuel systems that are designed with the high levels of ethanol in mind.
- blends with diesel - low level blends of ethanol and diesel fuel are technically feasible. Several different mechanisms are being investigated to avoid phase separation between the ethanol and the diesel, including specialised emulsifiers such as those developed by APACE Research in NSW and other groups in Europe, and mechanical emulsification.

The use of pure ethanol, or high level blends such as E85, will open up significantly greater markets for ethanol than are possible with low level blends such as E10. They will also require greater investment in storage and distribution facilities, together with vehicles with engines that operate effectively on such fuels. The Brazilian ethanol industry progressively introduced vehicles with engines designed to run on pure ethanol rather than petrol, but then had problems when local ethanol supply could not meet demand. This potential problem has now been addressed by Flexible Fuel Vehicles (FFV), which are vehicles with engines and fuel systems capable of running on high ethanol blends, petrol, or any mix of the two. FFVs are already in limited use in the USA, largely in the recreational vehicle and utility markets. Ford and Daimler Chrysler offer FFVs already⁹. Chrysler literature¹⁰ and personal communications¹¹ indicate that FFVs are available at no additional cost over

conventional petrol driven vehicles, however this study was not able to determine whether any subsidies are involved to make this pricing possible.

As an alternative to internal combustion engines there is also considerable research into the potential for fuel cells to use liquid fuels for electricity generation and operation of electric vehicles.

The market for ethanol (or methanol) fuel could therefore be considered to be capable of expanding progressively as increasing ethanol supplies become available and the vehicle fleet changes to accept a variety of fuels. For example:

- Initial use based on blends of approximately 10% in petrol, possible immediately with Australia's existing fleet of internal combustion vehicles.
- Progressive introduction of FFVs or dedicated ethanol vehicles, for example in public transport or government fleet vehicles, linked to fuel outlets that provide high ethanol blends or pure ethanol
- Use of ethanol in diesel blends as emulsification methods are implemented commercially
- Use of alcohol fuels in fuel cell vehicles as these become commercially available and progressively replace the existing vehicle fleet. Note that the increased efficiency of fuel cells is expected to reduce the fuel required per kilometre of travel. The extent to which this impacts on the total liquid fuel market will depend on the actual efficiencies of such vehicles using liquid fuels and the rate and extent of market penetration of the fuel cell technology.

2.3 Sources of Renewable Ethanol and Methanol

2.3.1 Ethanol from Sugarcane and Starch

The sugar industry in Queensland and NSW reported sugar production averaging 5.0 million tonnes per year for the five years from 1994 - 1998¹². Over this period the industry averaged 7.4 tonne cane per tonne sugar, with an average harvest of 37 million tonnes of cane.

C molasses is the residual material following recovery of economically-available sugar for crystal sugar production. This molasses still contains significant amounts of sugar and may be fermented to produce ethanol. Yield of this molasses from sugar production is typically 2.8% on cane¹³.

Table 2-2 Sugar Industry Potential Ethanol Yield

Feedstock	Million tonnes per year	Conversion rate (l/t)	Ethanol (thousand megalitres)
Cane	37	92	3.4
Sugar	5.0	620	3.1
C molasses	1.0	270	0.3

Note that the economics of using molasses and sugar are quite different. The opportunity cost of molasses is determined against its value for opportunities such as animal feed supplements. However the opportunity cost for sugar is currently determined by its value for human consumption. It may be expected that manufacture of ethanol from sugar diverted from existing markets will be at a considerably higher cost than ethanol made from the molasses by-product. There are currently investigations proposed by the John Holland group for an 80 Ml ethanol plant at Nambour in Queensland that would use sugar cane as feed, with a feasibility study possibly commencing in the second half of 2002.

Ethanol currently produced from starch in Australia also utilises industry by-products, for example at the starch to ethanol plant at Nowra in NSW. Total production at present costs may therefore be limited by the amount of low cost starch available. There are plans for new starch to ethanol plants in

Australia at Dalby in Queensland and Gunnedah in NSW. These plants are reported to be considering sorghum as feed material and produce ethanol and also cattle feed. The status of these projects is not known.

2.3.2 Alcohols from wood

Alcohol production from sugar and starch by-products will be limited by the availability of such materials. Any new plants that use dedicated sugar and starch feeds successfully will presumably need to allow for the opportunity cost of such feeds for human or animal consumption. In the absence of such projects, any use of renewable alcohol fuels in Australia beyond a few percent of the total liquid fuels market would need to involve wood as feed material. For an indication of the possible requirements for wood supply consider the following scenario in 15-20 years:

- Total liquid fuel usage in 15-20 years at 35,000 MJ/y
- Average efficiency of alcohol manufacture at 300 litre produced per green tonne of wood feed (which is more optimistic than the most optimistic NREL predictions for ethanol)
- Do not consider relative energy densities or efficiency differences between internal combustion and fuel cell vehicles.

Table 2-3 Possible biomass requirements for future alcohol fuel use

Market % as alcohols	Quantity of alcohols (megalitres/year)	Wood feed required (green tonnes /year)	Annual value of wood feed (at A\$30/green tonne)
10	3,500	12 million	360 million
30	10,500	35 million	1 billion
60	21,000	70 million	2 billion

2.3.3 Alcohol fuels from Annual Crop Residues

The technologies available or under development for manufacture of ethanol and methanol from biomass may be used with residues from annual crops as well as with wood. Such agricultural residues contain significant amounts of cellulose and hemicellulose, and much of the work overseas on ethanol fermentation uses such residues (straw, corn stover) as feed material. The residues may also be gasified to a gas capable of reforming and synthesis to methanol.

Relative processing costs and yield data for alcohols from wood and crop residue feeds are still not well known, making it difficult to suggest that one may be a more “suitable” feed than the other. Relative feed supply costs are also little known. There is great potential for development of low cost harvesting systems for both short rotation wood crops such as mallee and annual crop residues. The latter’s cost and availability will be influenced by issues such as soil conservation, which may vary considerably from region to region.

Data on the availability of agricultural residues is being developed as part of the Biomass Atlas that is being developed for RIRDC and AGO. A report on agricultural residues for electricity generation in NSW has also been published recently by SEDA¹⁴.

2.4 Greenhouse gases from alcohol fuels

A consortium consisting of the CSIRO, University of Melbourne, Centre for Design at RMIT, Parsons Australia and the Southern Cross Institute of Health Research has recently finalised a comparison of transport fuels. The study examined existing lifecycle analyses and data in order to compare different

fuels' greenhouse gas emissions and emissions affecting air quality. The results have been published as **Comparison of Transport Fuels** (Report to the Australian Greenhouse Office on the Stage 2 Study of Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles), which is available via the AGO website¹⁵.

Table 6.14 in part 2 of the study report provides estimates of greenhouse gas emissions (measured as kg CO₂ per MJ of fuel) for low sulfur diesel and also for ethanol produced from a range of feed materials. These data are summarised in the table below.

Table 2-4 Greenhouse gas emissions from fuel ethanol

Fuel	Greenhouse gas emission (kg CO₂ per MJ fuel)	Relative greenhouse gas emissions
Low Sulfur diesel	0.0858	100
Ethanol (azeotropic)		
▪ From molasses (exp. System boundary)	0.0398	46
▪ From molasses (economic allocation)	0.0689	80
▪ From wheat (starch waste)	0.0349	41
▪ From wheat	0.0633	74
▪ From wheat (fired with wheat straw)	0.0314	37
▪ From wood waste	0.0076	9

This data shows major differences in greenhouse gas emissions for ethanol from different feed stocks. In particular, ethanol from wood offers significantly better greenhouse gas reduction than ethanol made from either sugar or starch crops.

These differences come in large part from the requirements for energy during:

- the provision of feed to the ethanol processing facility
- conversion of feed to ethanol, and ethanol concentration and recovery.

In some cases the majority of such energy can be derived from renewable sources, whilst in others there is a requirement of fossil fuel energy.

2.5 Combustion Characteristics

The combustion characteristics for ethanol in a vehicle are independent of the feed material used to make the ethanol, however the pre-combustion emissions (for example small particulate material) for ethanol manufacture will vary considerably depending on the source of feed. Further data are provided in the AGO report 'Energy from Fossil Fuels'.

The cost of renewable ethanol, methanol or electricity must be considered relative to the alternatives produced from fossil fuels. These costs are considered below.

2.5.1 Cost of Petrol

It is important to understand how the price for petrol at the service station pump is made up of industry and government cost components:

- The industry cost components include the price paid for petroleum at the refinery, plus transport, handling and service station costs.
- The government components can include both federal and state excise, plus other taxes and fees.

The opportunity for ethanol or methanol to develop a sustainable market as a transport fuel will be defined by its ability to compete with oil-based products, either against the refinery price for petroleum or, if ethanol is more expensive than ex-refinery petrol, with some form of support to reduce the impact of government charges.

The table following shows the cost breakdown of unleaded petrol for each Australian capital city¹⁶. These figures are for May 1998.

Table 2-5 Cost Breakdown of Australia's Unleaded Petrol - May 1998

Source of Revenue	Sydney (¢/L)	Melbourne (¢/L)	Brisbane (¢/L)	Adelaide (¢/L)	Perth (¢/L)	Hobart (¢/L)	Canberra (¢/L)	Darwin (¢/L)
GOVERNMENT REVENUE								
Product excise	34.7	34.7	34.7	34.7	34.7	34.7	34.7	34.7
State/Territory franchise fee	8.1	7.7	0.0	8.1	8.1	6.2	8.1	7.0
replacement, less								
State/Territory rebate								
Royalties and resource rent	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
tax								
TOTAL	45.9	45.5	37.8	45.9	45.9	44.0	45.9	44.8
NON-GOVERNMENT								
REVENUE								
Oil Producer	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
Oil Refiner	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Oil Marketer	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Freight differential	0.0	0.0	0.0	0.0	0.0	0.1	1.6	0.0
Service Station	4.0	4.0	4.0	4.0	5.0	8.0	4.0	6.0
TOTAL	28.8	28.8	28.8	28.8	29.8	32.9	30.4	30.8
INDICATIVE PUMP PRICE	74.7	74.3	66.6	74.7	75.7	76.9	76.3	75.6

From the 1st July 2000, States and Territories no longer receive excise payments from the Commonwealth Government, but instead receive the 10% GST applied to the retail price of a litre of petrol.

There is considerable variation in the pump price of petrol in Australia. Capital city prices have reached \$1.00 per litre over the past year and are now somewhat lower. The two major components of the pump price are the ex-refinery cost and the cost of government excise, which is presently 38.143 cents per litre for petrol and diesel. These combine to account for approximately 83 cents per litre of petrol.

2.5.2 Forecasts of World Oil Prices

Much of the interest in renewable fuels is based on the knowledge that fossil fuels are, by their very nature, finite resources. This suggests that their use in ever increasing amounts must contribute to increasing scarcity of supply. As the lowest cost sources of crude oil are exhausted, higher cost alternatives will presumably need to be exploited. New technology may allow more efficient exploitation of such resources and the overall price of crude oil in the future will reflect a combination of such factors.

A number of major energy groups world-wide regularly predict trends in the future price of crude oil. These have been summarised by the US Department of Energy¹⁷. The consensus of these organisations is that while consumption of oil will increase significantly over the period 2000 – 2020, there will be no significant increase to the cost of crude oil over this period. This does not necessarily suggest that the price of crude oil will not increase beyond the twenty year horizon.

2.5.3 Crude Oil Availability in Australia

Moving from world price predictions to availability in Australia, Dr Malcolm Wegener of the University of Queensland¹⁸ has indicated that Australian crude oil production will fall from 720 million to 341 million barrels per year within 5 years¹⁹. Dr Wegener suggests that this may cause local, competing energy prices to rise.

The Australian Institute of Petroleum (AIP)²⁰ notes that Australia's eight domestic oil refineries currently source approximately 40% of their crude oil from Australian oil fields, with the balance

coming from overseas. Over 2000-2001 the largest single supplier of overseas crude was Vietnam, which provided 12% of Australia's requirements. The Middle East region collectively provided 18%, of which 8% came from Saudi Arabia. The AIP notes that:

- Overseas crude oils are usually heavier than the light crude available from Australian oil fields, and Australian refineries need to use a proportion of these heavier feedstocks to produce products such as lubricating oils and bitumens.
- Overseas crude oils can be purchased at lower prices than Australian crude oil.

As crude oil production in Australia decreases, the shortfall will need to be made up from overseas sources. The data from the US DOE and the AIP suggest that now, and over the next twenty years, this is unlikely to have a major cost impact on the price of petrol in Australia. However it does increase Australia's exposure to any unanticipated cost increases that occur across the world crude oil markets, for example due to war, other political instability, or adverse changes to the current collective bargaining position of the major oil producing countries.

2.5.4 Efficiencies and Emissions

Comparing alcohol fuels against petrol on energy value alone may not provide a full picture of the relative values of these fuels. The different combustion characteristics and oxygen contents of alcohols means that they offer different fuel efficiencies and emissions to petrol.

Flexible fuel vehicles (FFVs) already available in the USA have fuel management technology that enables them to run on a variety of petrol and ethanol blends. Efficiency data from the US EPA indicates that, when running on pure ethanol, these vehicles can only be driven approximately 70% of the distance that they could achieve on a similar volume of pure petrol.

Dedicated alcohol fuel engines seem to allow better use of the different combustion characteristics of alcohol fuels. The US EPA²¹ notes that "due to its favourable chemical and combustion properties, methanol is about 27% more efficient in a dedicated internal combustion engine vehicle than gasoline". Johansson⁸⁵ references several reports that quote efficiency improvements of 10-30% over current, petrol-fuelled vehicles. If dedicated alcohol-fuelled internal combustion vehicles were used then such issues would need to be taken into account. However, whereas FFVs can operate largely within the existing fuel delivery and retail infrastructure, dedicated alcohol fuel engines would require substantial new infrastructure and security of fuel supply if they were to be used.

The addition of ethanol or methanol to petrol to produce blended fuels can achieve reductions in certain tail-pipe emissions, that are of benefit in the achievement of air quality standards, particularly in urban areas. It may be possible to attribute value to the use of alcohol in blends if those blends achieve air quality targets that would otherwise require modifications to petrol formulations. The extent to which this will assist the economics of alcohol fuels is unclear. For example, the US EPA²¹ notes that the cost of producing reformulated gasoline in the USA to meet air quality standards adds 5 cents to the cost of each gallon of fuel (approximately 2.5 Australian cents per litre). In contrast, it has also been noted²² that blending ethanol with petrol can impose restrictions and costs on existing refinery operations, particularly if it is necessary to reduce volatile components in the petrol (primarily butane) to accommodate the relatively greater volatility of the ethanol.

A number of Australian studies have examined emissions in the blending and use of alcohol /petrol mixtures^{22,23,24,25,26}. Information is also available from overseas, for example the US EPA and the Argonne National Laboratory in the USA. It is important to recognise that the reduction of vehicle emissions is a dynamic goal, and that it is being addressed by several, sometimes competing groups. The alcohol fuel, oil and engine industries all point to improvements to emissions that can be achieved through reformulations, refinery upgrades, engine modifications and so on. It becomes a complex challenge for regulators and industry groups to determine the most cost effective path to satisfactory emissions.

3. ETHANOL PRODUCTION

3.1 Introduction

Ethanol may be produced by fermentation, using yeasts or other micro-organisms to convert sugars into ethanol with CO₂ 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. 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.

3.2 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 through meetings

with the relevant groups during a study tour to North America in May 2001 by Colin Stucley of Enecon and subsequent communications.

3.2.1 AGROL & Institute for Agrobiotechnology

3.2.1.1 Organisation

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.

3.2.1.2 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 straw²⁷. 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.

3.2.1.3 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.

3.2.2 Apace Research

3.2.2.1 Organisation

APACE Research is based in NSW and conducts research into renewable fuels, looking at ethanol from biomass and also developing emulsifying agents to stabilise ethanol/diesel fuel blends.

3.2.2.2 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 Dr Peter Rogers has been working with *Z. mobilis* for some two decades).
- Following fermentation, ethanol is extracted via a two stage process involving potassium carbonate salts. One of the aims of using salts for phase separation and ethanol extraction is to reduce the energy requirements for ethanol recovery by avoiding the conventional distillation step. This potassium salt technology has been developed by APACE.

3.2.2.3 Status

APACE reports²⁸ 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 support of \$2 million on offer from the Federal government since 1994. State Forests of NSW is also charged with supporting the pilot plant. A study in 2000 by Manildra Energy²⁹ has indicated that the total cost of a pilot plant to produce 160,000 litres per year is approximately A\$16 million. Neither APACE nor UNSW have estimated the cost of a full scale plant using the technologies described.

3.2.3 Arkenol

3.2.3.1 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 cogeneration facilities. Initially, ethanol production was seen by ARK Energy as a mechanism to help develop new cogeneration 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).

3.2.3.2 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.

3.2.3.3 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.

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.

3.2.4 BC International

3.2.4.1 Organisation

BC International (BCI) is a private company based in Dedham, Massachusetts. 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.

3.2.4.2 Technology

BCI achieves feed hydrolysis in two stages using dilute 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.

3.2.4.3 Status

Most of BCI's industrial work takes place at a site in Jennings, Louisiana. 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 a small existing fermentation facility (used for yeast production) to make a 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.

3.2.5 Iogen

3.2.5.1 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.

3.2.5.2 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.

3.2.5.3 Status

Iogen has built and operated two pilot scale facilities. It has recently completed a demonstration scale 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 Canada, the USA and the UK. In May 2002, the Royal Dutch Shell Group paid US\$46 million for a 20% share of Iogen and first right to Iogen's biomass to ethanol technology. Iogen hopes to commence work on a full scale plant in 2004.

3.2.6 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
- micro-organism selection and development.

The University has recently built a pilot scale ethanol process unit ³⁰. The University appears to have no affiliations with industry for ongoing development of in-house technology.

3.2.7 Masada

3.2.7.1 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).

3.2.7.2 Technology

Masada's ethanol technology has been labelled the CES OxyNol™ 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.

3.2.7.3 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. Final permitting was completed in July 2000. Ground breaking to start plant construction is anticipated to occur late in 2002.

The Middletown plant is based on receiving 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.

3.2.8 NREL

3.2.8.1 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 consultants³¹.

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.

3.2.8.2 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 °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 overliming.
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 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.

3.2.8.3 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 tonne 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)³¹. 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.

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 funding. The corn (starch) to ethanol industry provides most of the 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 US\$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 current levels of activity to use as a baseline. (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.

3.2.9 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.

3.2.10 TVA

3.2.10.1 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. The 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.

3.2.10.2 Technology

TVA has investigated a range of biomass to ethanol process pathways, including work with both dilute and concentrated acid hydrolysis.

3.2.10.3 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 reports that its current focus is working with dilute acid hydrolysis³².

TVA has worked with US hardwood feeds, both as single species and mixed species feeds.

TVA has modelled ethanol processes using the alternatives of concentrated and dilute acid and enzymatic hydrolysis.

3.2.11 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
- more than 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 A\$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, and are capable of 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 the table below.

Table 3-1 Summary of Major Technology Providers

	Arkenol	BCI	logen	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 <i>Z.mobilis</i>	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. Hope to start small full scale in Asia with JGC this year	Closing finance to complete full scale plant at Jennings, LA, based mainly on 2 nd hand equipment.	Small full scale plant already in operation in Ottawa	Closing finance for first plant, Middletown NY	No plans	No plans

3.3 Other Technologies

3.3.1 Nitric Acid Hydrolysis - HFTA/University of California

3.3.1.1 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.

3.3.1.2 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.

3.3.1.3 Status

HFTA report³³ that 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.

3.3.2 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, CO₂ and H₂, 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.

3.3.2.1 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.

3.3.2.2 Oklahoma State University

The 23rd Symposium on Biotechnology for Fuels and Chemicals at Breckenridge Colorado³⁴ 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.

3.4 Costs of Production

3.4.1 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 3). The prices included approximately 10% for dunder handling equipment.

These prices compare well with cost data from the Energy Research and Development Corporation (ERDC) report *Biomass in the Energy Cycle* 1994³⁵, 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.

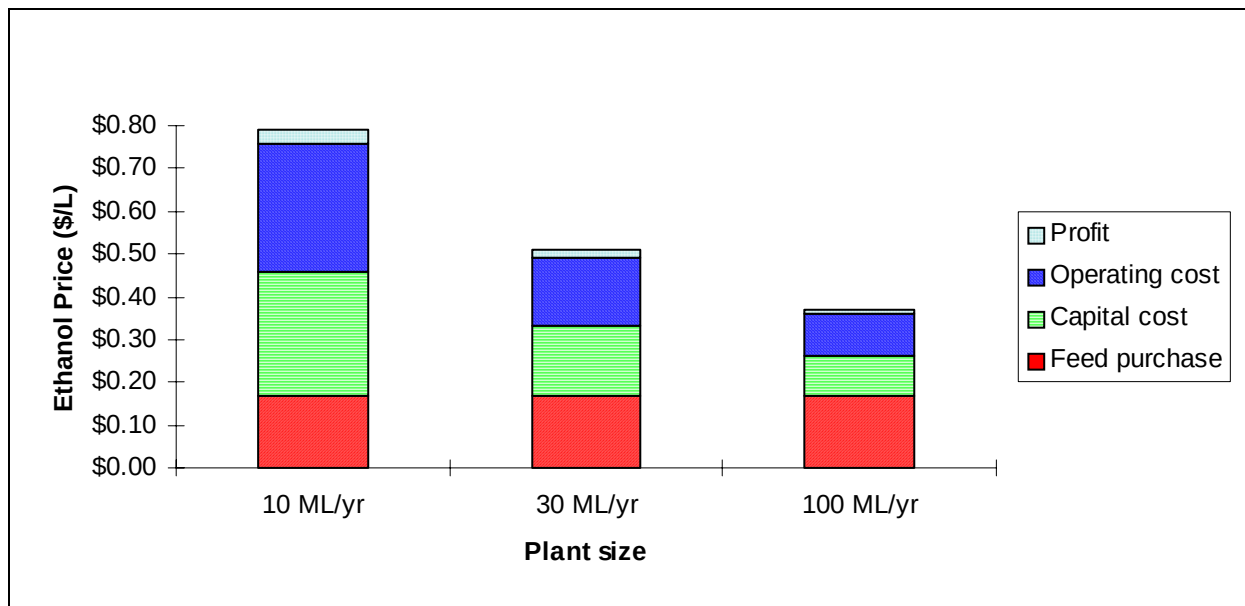
Plant capital costs were estimated for three plant sizes: 10 ML/year, 30 ML/yr; and 100 ML/yr are shown below.

Table 3-2 Ethanol Plant Costs - Molasses Feed

10 ML / yr	30 ML / yr	100 ML / yr	Notes:
(prices in A\$ million)			
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

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 the figure below:

Figure 3-1 Ethanol Price Break-down (A\$/litre) - 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.

3.4.2 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 NREL³¹ 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 very preliminary 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 (refer 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.

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).

3.5 Future Developments

3.5.1 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 attention³¹, which are described below:

3.5.1.1 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 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 over several years, with the aim of reducing the cost of using cellulase enzymes ten-fold.

3.5.1.2 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 lower ethanol tolerance.

3.5.1.3 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.

3.5.2 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, DOE³¹ has estimated that if all process improvements are realised in the time frame envisaged, the following yield and cost benefits should occur:

Table 3-3 Summary of Projected Improvements in Ethanol Processing

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

Note that these estimates are for a large scale plant in the USA, not Australia, with feed provided at US\$25 per dry ton.

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.

3.6 Co-production of Electricity

When biomass is hydrolysed to break down cellulose and hemicellulose into component sugars there is residual matter that includes unhydrolysed 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. This is included in the NREL model that is used above. The electricity that is generated may 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 unhydrolysed material as fuel for electricity generation

Several groups have studied systems for the co-production of ethanol and electricity. For example, researchers at IFA-Tulln²⁷ 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.

¹ This equates to approximately 140 litres per green tonne of feed.

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, NREL³¹ 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.

3.7 Discussion

3.7.1 Process Selection

3.7.1.1 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 of hemicellulose and cellulose hydrolysis is required. 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 enzyme 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.

3.7.1.2 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.

3.7.2 Lignin

Lignin is a complex crystalline material that acts as a “glue” 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 cannot 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 products³⁴ 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 production of fuel oxygenates. Personnel at the University of Utah³⁶ are investigating the possibility of “cracking” lignin and processing it into chemicals that can be used as octane boosters in liquid fuels. If the lignin could be successfully modified to produce value-added products in this way it could assist the overall economics of ethanol production. Interestingly, the greenhouse gas benefits of the lignin may well be the same whether it is used as boiler fuel or as an octane enhancer in liquid fuels.

3.7.3 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 may be preferable. Note that this may still be possible with multiple sub-species, with further work needed for specific feeds to look at the benefits of biodiversity for pest tolerance against variations in feed processing.
- Pretreatment of the feed is required 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) appear 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.

4. METHANOL PRODUCTION

4.1 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 year³⁷. 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 MTBE³⁸. 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 petrol³⁹.

4.1.1 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°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. Approximately 16kg of methanol could be recovered per 1000 kg of air-dried wood that was carbonised⁴⁰.

4.1.2 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 process⁴¹. Now almost all of the methanol used world-wide comes from the processing of natural gas. In general, methanol production from natural gas feed consists of three steps⁶:

- 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.

4.2 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 a relatively early stage of development using biomass feed, with no units operating commercially yet.
- 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 Uil⁴¹, which has been summarised below.

4.2.1 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 contents below specific levels.

4.2.2 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 ⁴¹ summarise the gas streams from these technologies as follows:

Table 4-1 Composition of dry synthesis gas produced by different biomass gasifiers

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	-

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* ⁴² and Faaij *et al* ⁴³, suggesting there is some variability in the composition of the gas output from each gasifier.

4.2.3 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.

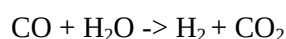
4.2.4 Synthesis Gas Conditioning

For optimal production of methanol, three parameters are of particular importance:

- a) The ratio of CO₂ 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) = H₂/(2CO + 3CO₂) will be approximately 1.
- c) The concentration of inert materials (eg. N₂, CH₄) should be minimised.

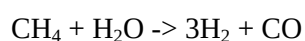
The CO₂/CO ratio and the stoichiometry number can be adjusted by the water-gas-shift reaction and then CO₂ removal. Inert materials such as CH₄ may be reduced by additional steam reforming.

The water-gas-shift reaction is a catalytic process operating at 200-475 °C to convert CO and steam to H₂ and CO₂, via the reaction:



For the production of methanol from biomass only partial conversion is required. Excess CO₂ may then be removed by one of several commercially available processes.

If the raw gas from the gasifier contains significant quantities of CH₄, steam reforming may also be used, as follows:



4.2.5 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 °C and pressures of 50 - 100 bar.

4.2.6 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.

4.3 Engineering and Costing Studies

With no integrated research or demonstration facilities to investigate methanol from biomass, 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 Ecotrafic R&D AB and Nykomb Synergetics AB investigated biomass-derived methanol in some detail and issued its final report in 1997⁴⁴. 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.

4.4 Methanol from Dual Feeds

The opportunity for methanol production from a combined natural gas and biomass feed is described generally as follows by Borgwardt²¹:

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 CO₂ is lost. By adding natural gas, the gas leaving the reformer has the proper H₂/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 H₂ is produced beyond that required for methanol synthesis and can only be used as reformer fuel.

4.4.1 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 process⁴⁵:

- 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.

4.5 Co-production of Electricity

In the Altener BAL Fuels Project⁴⁴ 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 Ecotrafic and Nykomb Synergetics has investigated the development of a “Biomass based Methanol energy combine - Trollhatten region” or BioMeeT project⁴⁶. This study considers synergies between the co-production of electricity and methanol. 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.

5. COMPARATIVE 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.

Table 5-1 Ethanol Project Cost Parameters

Parameter:	Large plant	Small plant
Ethanol output of plant (megalitre/year)	200²	100
Conversion (litre ethanol per tonne green feed) ³	140	140
Green feed required (tonne/year) ⁴	1,430,000	715,000
Conceptual estimate of capital cost (A\$ million)	470⁵	310⁶
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 ⁷	12,000,000	6,000,000
▪ Labour and on costs	3,632,000 ⁸	2,900,000 ⁹
▪ Maintenance at 1% of capital expenditure ¹⁰	4,700,000	3,100,000
▪ Insurance and taxes at 1.5% of capital expenditure ¹¹	7,050,000	4,650,000
Total of operating costs (\$)	70,282,000	38,100,000
Product selling price (\$/L)¹²	0.82	0.99

² Plant size in 1999 study by NREL

³ Conversion based on NREL figure of 68 US gal/dry US ton of feed

⁴ Assuming feed at 50% moisture, wet basis

⁵ 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.

⁶ Figure for 200 ML plant, varied by exponent of 0.6

⁷ Based on direct conversion of NREL costs - for chemicals, utilities etc

⁸ NREL labour requirements and proportion of on costs, using assumed salaries in Australia

⁹ Assume 80% of labour for larger plant, as most functions will still be needed in smaller plant

¹⁰ Similar to NREL at 1% of total capital as opposed to 2% of equipment.

¹¹ Same as NREL

¹² This selling price takes into account capital and operating costs as per the financial model described

Table 5-2 Methanol Project Cost Parameters

Parameter	Large plant	Small plant
Methanol output of plant (megalitre/year)	390¹³	200
Conversion (litre methanol per tonne green feed) ¹⁴	290	290
Green feed required (tonne/year) ¹⁵	1,340,000	690,000
Estimated cost in Sweden in 1997 (US\$)	417	-
Conceptual estimate of capital cost (A\$ million)	830¹⁶	560¹⁷
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 ¹⁸	3,500,000	2,800,000 ¹⁹
▪ Catalyst ²⁰	2,000,000	1,000,000
▪ Insurances, taxes ²¹	8,300,000	5,600,000
▪ Maintenance at 3% of capital expenditure ²²	24,900,000	16,800,000
Total of operating costs (\$)	78,900,000	46,900,000
Product selling price (\$/L)	0.62	0.79

¹³ Plant size in 1997 BAL study in Sweden

¹⁴ Conversion based on BAL figure of 390 ML methanol from 1.33 million tonne green feed

¹⁵ Assuming feed at 50% moisture, wet basis

¹⁶ Swedish price by 2, comprising currency change and small allowance for inflation. Refer attachment for further discussion.

¹⁷ Figure for 390 ML plant, varied by exponent of 0.6

¹⁸ BAL labour requirements at 63 staff but average Australian rate, plus 40% on costs.

¹⁹ 80% of larger plant

²⁰ BAL price - Catalyst at A\$2 M/year

²¹ BAL estimate is 1% of total investment

²² BAL and NREL maintenance estimates vary by 300%.

Table 5-3 Electricity Project Cost Parameters

Parameter		
Output of plant (MWe)	30	
Conversion	Conventional ²³	
Green feed required (tonne/year) ²⁴	333,000	
Capital cost (A\$ million)	52	
Operating costs:		
▪ Unit cost of green feed	30	
▪ Total cost of green feed	10,000,000	
▪ Labour and on costs	1,010,000	
▪ Maintenance at 3% of capital expenditure	1,551,000	
Total of operating costs (\$)	12,561,000	
Product selling price (\$/MWh)	\$94.86	

²³ Eg. Alstom package for wood-fired boiler and steam turbine

²⁴ This is based on 28% overall efficiency from wood partially dried (to 30% moisture). Efficiency figures – and plant capital costs - can vary with boiler and turbine configuration and feed moisture content and pretreatment

The product selling prices indicated above were each developed via project financial analysis according to the following parameters:

Table 5-4 Project Financial Assumptions

Item	Value used
Project life	15 years from first investment ²⁵
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% ²⁶
Interest on borrowings	10%, all loans repaid by end of 5 th year.
Financing	40% debt financing
Required project IRR	15%

²⁵ Longer project times may be applicable, depending on the risk assessment by investors. Longer timers would improve project economics.

²⁶ 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.

6. COST/BENEFIT ANALYSIS

6.1 Introduction

The following sections summarise work by personnel from the Centre for International Economics (CIE) in Canberra. CIE has calculated and analysed some of the external benefits of a large new industry utilising eucalypt mallee for biomass to produce ethanol, methanol or electricity. These benefits are compared with the associated costs, and the case for providing government support for renewable energies in Australia is considered. The focus of the analysis is on projects some fifteen years into the future.

The CIE work recognises that:

- the costs of converting biomass to these liquid fuels might fall significantly over the medium term - which will increase the economic attractiveness of biomass based fuels.
- a carbon tax or regulatory cap on greenhouse emissions may be introduced - which will favour the production of renewable, low emission energies relative to non-renewable energies.
- the costs of producing electricity and transport fuels from non-renewable sources are also expected to decline over the period under review - which may reduce the economic attractiveness of renewable energy pathways such as eucalyptus biomass. ABARE⁴⁷ forecasts substantial efficiency gains in the generation, distribution and use of energy. It is estimated that efficiency improvements will average 0.5 to 1 per cent per annum over the next 20 years. Note that greater gains may be possible with biomass plants, particularly as technology improvements may be more achievable with new plant (as for bioenergy) than for existing infrastructure as with fossil fuel power stations.

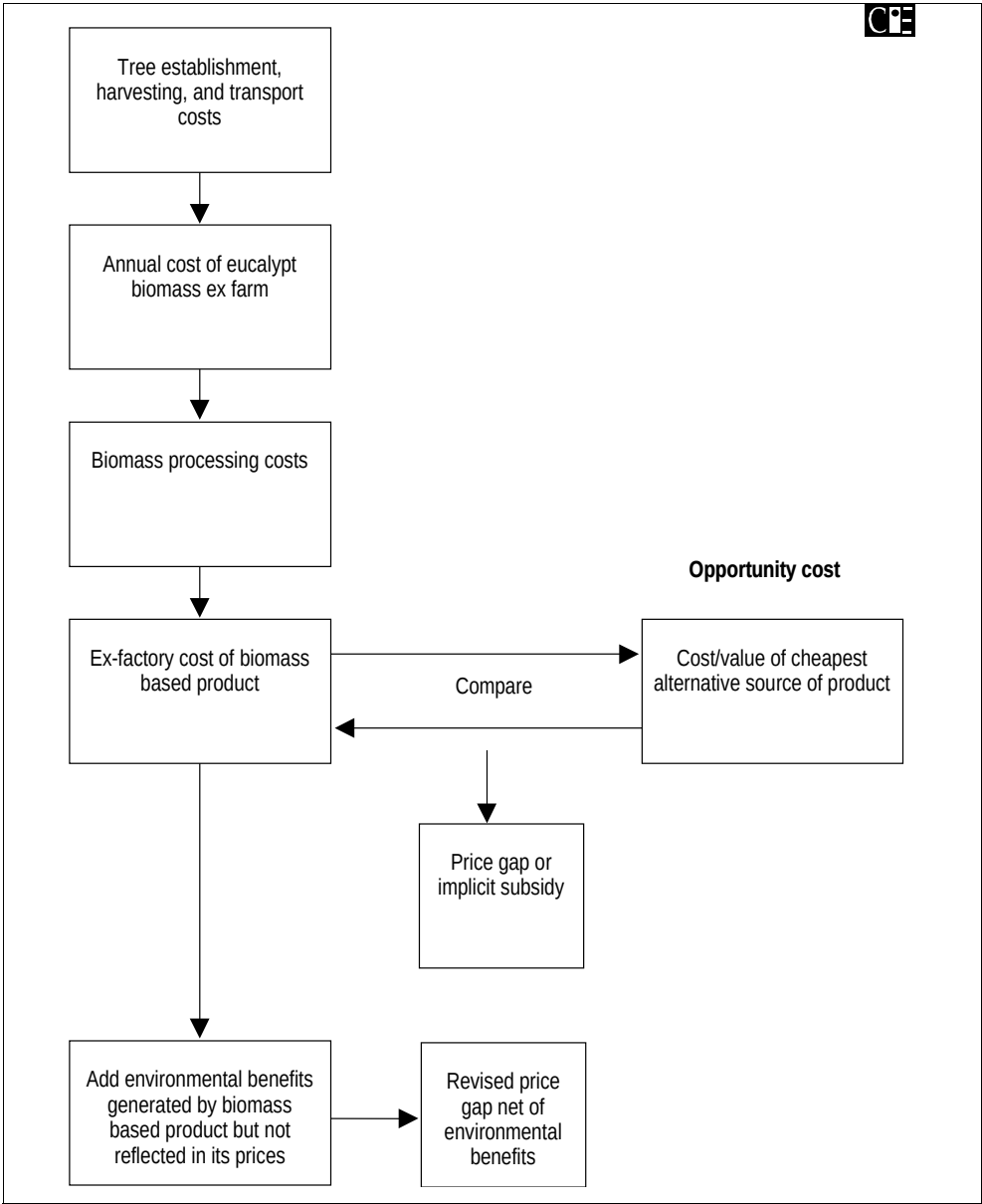
6.2 Approach

The approach taken by CIE involves three successive steps as follows:

- a) The first step is to develop a scenario based on current technology and then develop a second scenario set 15 years hence, when biomass processing technology is expected to be more advanced. Other Australian studies⁴⁸ have considered more distant time horizons, however this study considered a horizon of approximately 15 years so that data predicting fuel costs at that distance could be utilised. It was also felt that a time scale of fifteen years was appropriate to assist with policy directions now. The scale of operations is set by:
 - the volume of biomass available for harvest - and the area of tree cropping needed to support it
 - the economic size of the conversion plant - which will depend in part on the:
 - volume of feedstock available within a 'commercial' distance of the plant
 - the size of the market for the product located within a 'commercial' distance of the plant (this is an important issue in the case of electricity)
 - the economies of scale achieved by large processing plants.
- b) The second step involves establishing the cost of producing each biomass product (ethanol, methanol and electricity) and comparing these costs to the price of equivalent energy products generated using 'conventional' non-renewable sources (Figure 6-1). The difference is termed the 'price gap' or implicit subsidy required to support biomass fuels. Thus, ethanol is compared to petrol (ethanol is substitutable for petrol as a transport fuel), biomass methanol is compared to methanol produced from natural gas, and the cost of producing biomass electricity is compared to conventional coal-fired power generation.
- c) Having established the price gap between the biomass products and their conventionally produced counterparts, the third step is to estimate environmental benefits associated with tree cropping and

determine the extent to which these benefits close the gap. In this study the benefits from reductions to carbon dioxide and on-farm salinity were quantified.

Figure 6-1 Estimating the gap between value and cost of biomass products



7. ESTIMATING THE NET BENEFITS OF FUELS FROM BIOMASS

To utilise the approach described in the preceding section a case study has been developed which focuses on the low to medium rainfall zone of Western Australia (250 to 400 mm). This area already has major problems with dryland salinity and has been identified as having good potential for supporting a large-scale eucalypt mallee industry. A distinct advantage of mallee cropping is that the trees coppice after harvesting, which obviates the need for replanting after harvest. An annual availability of around 1.5 million green tonnes of biomass is assumed, to support one of:

- an ethanol plant of 200 million litres (ML) per year
- a methanol plant of 390 ML per year
- several power plants generating electricity.

Over the last few years there has been a great deal of local interest in establishing an oil mallee industry in this region as a means of diversifying farm income and addressing dryland salinity. It is forecast that salinity will affect 30 per cent of agricultural land in the Western Australian wheatbelt within the next 50 years if current farming practices based on annual pastures and crops continue⁴⁹. Mallee trees are capable of reducing groundwater recharge and are therefore a potential management tool for controlling salinity. To date approximately 7,000 hectares of oil mallee have been planted, and this area is set to increase with the planned development of a full-scale integrated tree processing plant that will be built in the region⁵⁰. This demonstration plant will use mallee eucalypt biomass to produce eucalyptus oils, activated carbon and renewable electricity.

7.1 Biomass production

The cost of producing ethanol, methanol, or electricity from biomass will depend in part on the scale of operations. The larger the scale the lower the unit costs. The scale of operations that can be supported will in turn depend on the availability of biomass and hence the extent of mallee eucalypt plantings within a deliverable range of the processing plant. How much planting is undertaken by farmers will depend on the incentives they face - the returns from planting (sale of biomass plus the value to them of any positive environmental effects) relative to the opportunity cost (what farmers could earn from the land from the next best alternative use).

This analysis draws on information contained in a feasibility study led by Enecon Pty Ltd that was commissioned by the Rural Industries Research & Development Corporation in the lead up to the development of Western Australian processing plant to produce activated carbon, energy and eucalyptus oil from mallee trees⁵⁰. That study provides detailed estimates for biomass yields and the cost of growing, harvesting, and transporting biomass to a processing plant. For this alcohol fuels study, with projections of feedstock cost in some fifteen years, a figure of \$30 per green tonne delivered to the processing plant has been used. This figure assumes that high capacity, large volume continuous harvesting systems are established as outlined in the RIRDC report.

In order to supply 1.5 million tonnes of feedstock each year, it is estimated that approximately 714,000 hectares of agricultural land would need to be converted to mallee belts with 50 metres of alley land between the belts. Alternatively, 120,000 hectares of block plantings would be required. In practice, most mallee tree cropping projects in Western Australia have adopted an alley planting design which allows agricultural cropping and grazing to be practised in the alleys⁵⁰.

It is technically feasible that tree cropping on this scale could be implemented as the low to medium rainfall zone occupies 10 million hectares of cleared agricultural land, of which at least one million

Table 7-1 Required tree cropping adoption rates to supply 1.5 M tonnes biomass

<i>Radius from processing plant</i>	<i>Area of zone</i>	<i>Required proportion of area to be tree cropped</i>
Kilometres	Hectares	per cent
50	785 400	90
60	1,131,000	63
70	1,540,000	46

Source: CIE calculations

hectares (10 per cent) is regarded as suitable for growing mallee trees (Shea et al. 1998). Provided that 46 per cent of land within a 70 kilometre radius of the processing plant is converted to tree cropping, it is possible that all biomass requirements could be sourced from within this zone (Table 7-1). This area of agroforestry represents a very large increase on current plantings. The logistics of achieving tree cropping on such a large scale within 15 years have not been investigated.

7.2 Ethanol from biomass

7.2.1 Production costs

As described in section 5, an ex-factory selling price for ethanol of \$0.82 per litre would be required for a plant with this cost structure to generate the required rate of return for this investment (which is taken to be a 15 per cent internal rate of return over 15 years).

Our focus is not on production costs now but in 15 years time. In the interim, the unit cost of ethanol production and hence the required selling price ex factory to ensure profitability of the plant, could fall significantly. In parallel, the minimum quantity of biomass required to support a 200 ML plant would fall as conversion efficiencies improve. Based on US data, the most optimistic scenario on R&D outcomes could lead to up to a 50 per cent reduction in total processing costs over the next 15 years. If this is achieved, the required selling price for ethanol could fall to around 42 cents per litre ex factory based on feed delivered to the factory at \$30 per green tonne.

Note the influence of feed costs on this projected ethanol price. The sensitivity of ethanol price to changes in feedstock price may be assessed by remembering that, if a wide range of process improvements are achieved by 2015, some 230 litres of ethanol will be produced from each green tonne of wood (see Table 3-3).

On this basis, a cost increase of \$10 per green tonne would translate into an ethanol cost increase of $(10 \text{ by } 100)/230 = 4.3$ cents per litre.

7.2.2 The cost of fuel from alternative sources

We have taken the relevant cost comparison to be with petrol as a transport fuel because it is envisaged that the primary use of ethanol from biomass will be a petrol additive, thus serving as a partial substitute for petrol.

The price of petrol 15 years hence will depend on the world price of crude oil in US dollars and the A\$/US\$ exchange rate. World crude oil prices are extremely volatile. Over the past decade they have ranged from US\$29 per barrel in 1990 to around US\$12 per barrel in 1998. World recoverable reserves of crude oil are estimated by some to be around 30 years of supply at current rates of consumption⁵¹, but such estimates are controversial. Other estimates suggest that 80 per cent of the world's available oil and 95 per cent of its gas remain in the ground⁵². With new techniques the economically viable proportion of a reserve that can be brought to the surface (currently around 30–35

per cent) could be increased to 50–60 per cent within a decade and it is considered quite possible that new reserves will be found⁵³.

Taking into account the likely introduction of new technologies to dramatically improve energy use efficiency, on balance the prospect over the next 15 years at least, is for declining rather than increasing crude oil prices. Many institutions provide long term forecasts of crude oil prices. Consensus forecasts collated by the Energy Information Administration in the US suggest prices between US\$21 and US\$22 per barrel between 2010 and 2015. We take US\$22 as the figure for comparison here.

On the basis of previous forecasting experience long term projections in the exchange rate of the Australian dollar with the US dollar have little credibility. Previous forecasts have invariably proved to be wide of the mark. Most forecasters are projecting a recovery of the Australian dollar from its present level to between US\$0.60 to US\$0.65 per Australian dollar. An optimistic forecast from the vantage point of a domestic ethanol from biomass industry would be for no recovery — an exchange rate in 2015 at the present level. When cost analysis was undertaken for this report the exchange rate was A\$1.00 = US\$0.50 and this rate has been used throughout the report.

There is no simple relationship between the crude oil price and the price of refined petrol. The gap depends on the size of the refinery, supply and demand conditions at the time for the various products of refined crude oil and the product mix targeted by the refinery. Refinery margins are not static. Current margins of Australian refineries are considered inadequate to attract new refinery capital into the industry. But new refinery equipment will be needed to meet the planned introduction in 2006 of the proposed new Euro standards for sulphur content. This could add up to 2 cents per litre to petrol costs⁵⁴.

This study assumes an ex-refinery petrol price of 36 cents per litre (before tax), which is based on no recovery in the exchange rate and allows for the cost of transporting oil to the refinery and standard refining costs (including a small increase post-2006 to meet the higher fuel standards).

7.2.3 Ethanol and Methanol Distribution and Utilisation Costs

Fuel distribution costs could be higher for ethanol than petrol because ethanol has a strong affinity for water, which can result in phase separation of blended alcohol/petrol fuels, causing engine damage or poor vehicle performance. The Australian petroleum production and supply system is currently a relatively ‘wet’ system, and it is expected that the use of this system to distribute ethanol would result in contamination by water throughout the entire process⁵⁵. Therefore, if ethanol as a blended fuel were to be used widely in Australia, it would be necessary to change to a more ‘dry’ system at some considerable cost. Furthermore, given that ethanol and methanol have lower energy contents than petrol, additional infrastructure and transport costs would be incurred to distribute the fuel. It is expected that these costs could increase the total unit cost of alcohol fuels by 10 per cent. Whilst this report does not explicitly take account of post factory costs, it should be noted that alcohol fuels may involve higher distribution costs than conventional fossil fuels.

The change-over costs to motorists are expected to be negligible because conventional motor vehicles can generally run on ethanol-petrol blends with minimal or no engine modifications.

7.2.4 The gap between ethanol and petrol

For the purposes of comparing ethanol with petrol it is necessary to account for ethanol’s lower energy density relative to petrol - a factor of 0.7. Therefore, the optimum ethanol price of 42 cents per litre projected for 15 years hence becomes 61 cents per litre for comparative purposes with petrol at 36 cents per litre. The gap, which needs to be made up to make ethanol from biomass equivalent to petrol as a transport fuel, is therefore around 25 cents per litre. At this point in the analysis ethanol is clearly uncompetitive compared with petrol. A number of potential environmental benefits will be considered below to examine their impact on this gap in costs.

7.2.5 Environmental benefits

A number of environmental benefits are associated with the production of ethanol, and these need to be taken into account if a valid comparison is to be made between the price of ethanol and the price of alternative fuels. The potential benefits examined here are:

- greenhouse benefits from the sequestration of CO₂ by tree crops
- lower air pollution from the use of ethanol as a road transport fuel
- reductions in on-farm damage caused by dryland salinity.

Not included in the CIE examination were issues such as:

- salinity benefits off-farm
- quality of river water
- biodiversity.

Economic returns are estimated for each of these environmental benefits so that their impact on the biomass ethanol – petrol price gap may be assessed.

7.2.5.1 Greenhouse benefits

The carbon sequestered by mallee trees could be eligible for accreditation under the Kyoto Protocol. The establishment of mallee plantations on agricultural land satisfies the requirements of Article 3.3 of the Protocol, which states that carbon sinks must result from direct human-induced land use change undertaken after 1990. Under the Protocol's accounting rules, carbon credits (or Removal Units) are provided for increases in carbon stocks over the 2008–2012 commitment period.

Following the recent round of climate change negotiations in Marrakech, it is now likely that the Protocol will be ratified by the European Union, Japan and Russia. The ratification by these countries would be sufficient to bring the Protocol into force, perhaps as early as 2003⁵⁶. While Australia and the United States are not yet party to ratification, it is probable that domestic trading schemes for carbon credits and emission entitlements will become established in these countries as international trading arrangements and accounting systems evolve.

If an international trading scheme is implemented and the Kyoto targets are upheld, ABARE⁴⁷ forecast that the price of carbon permits (and credits) could be in the order of US\$102 per tonne of carbon. This is equivalent to A\$56 per tonne of CO₂.

The carbon credits generated by tree cropping would be sufficient to offset CO₂ emissions from ethanol combustion, thus rendering ethanol from such biomass a zero-emissions fuel. The roots of mallee trees are capable of sequestering 0.5 tonnes of carbon per hectare of plantation each year during the first four years of growth, and then one tonne per hectare in subsequent years⁵⁷. In addition, it is possible to maintain an average of 3 tonnes of carbon per hectare in the tree foliage in a plantation that is harvested in rotation. Together, the above and below ground biomass is sufficient to offset downstream CO₂ emissions from fuel combustion.

Therefore, while the downstream emissions from petrol and ethanol are approximately the same on an energy equivalent basis (Table 7-2), ethanol has the advantage of having virtually zero emissions over its 'life cycle'. Thus for every litre of ethanol substituted for petrol, approximately 1.6 kilograms of CO₂ is prevented from entering the atmosphere. This is calculated on the basis that petrol combustion emits 2.3 kilograms of CO₂ per litre and a litre of ethanol is equivalent to 0.7 litres of petrol on an energy equivalent basis (table 3.4).

Assuming a carbon price of A\$56 per tonne of CO₂, the economic value of the greenhouse benefit is 9 cents per litre of ethanol.

Table 7-2 CO₂ emissions from the combustion of different fuels

	<i>CO₂ emissions</i>	<i>Energy content</i>	<i>CO₂ emissions on energy equivalent basis</i>
	kg/L	MJ/L	kg/MJ
Ethanol ^a	1.5	23.0	0.065
Diesel	2.7	38.6	0.070
Petrol	2.3	32.4	0.071

^a Assumes anhydrous form.

Source: CSIRO (2000).

7.2.5.2 Other air pollutants

Much research has now been undertaken on the potential benefits of using ethanol as a blend with petrol to reduce air pollutants from motor vehicles such as carbon monoxide, nitrous oxides, sulphur dioxide, and volatile organic compounds. In fact ethanol's potential for reducing carbon monoxide emissions is one rationale given for the government support it receives in the US.

Several Australian studies have been undertaken on the effects of ethanol blends on toxic emissions and smog precursors and the relevance of this in the Australian context. These studies have examined ethanol's contribution to reducing each of the air pollutants mentioned above. Whilst it has been found that ethanol combustion does result in lower levels of these pollutants, cost effective technology now exists to control petrol emissions. For example, carbon monoxide and nitrous oxides can be efficiently reduced by fitting a catalytic converter to the vehicle, and sulphur dioxide can be managed by modifying the properties of petrol at the oil refinery. No comparative data for the relative costs of such methods and alcohol fuel blends was identified during this study. The literature suggests that blending ethanol with petrol may actually produce a small net increase in emissions of volatile organic compounds, although the use of ethanol in fuels at the concentrations mooted is unlikely to have any harmful effects on humans and the environment.

Thus, on balance, it is concluded that blending ethanol with petrol does not offer a significant environmental benefit in terms of reducing toxic air pollutants.

7.2.5.3 Dryland salinity benefits

Tree cropping with mallee has the capacity to control salinity by reducing the amount of recharge entering the ground water aquifer. The potential benefits from controlling salinity stem from:

- yield benefits to agricultural production in the alleys
- increased agricultural production on land 'downstream' to the tree cropping enterprise
- off-farm benefits including:
 - improved water quality for household consumption and industrial uses
 - improved water quality in rivers and irrigation systems
 - reduced damage to roads, railways, and buildings
 - protection of natural areas (for example, wetlands and associated biodiversity)
 - reduced flood risk
 - reduced soil erosion.

It is a difficult task to estimate the value of these benefits. However, it is possible to use a threshold value approach and determine how big the salinity benefits would need to be to offset the price gap between ethanol and petrol. After accounting for the greenhouse benefits associated with ethanol, a price gap of 16 cents per litre remains. Based on a plant producing 200 megalitres of ethanol per annum, this equates to a gap of \$32 million per annum. In other words, the tree cropping project –

which involves 714,000 hectares of land – would need to produce a salinity benefit of \$32 million each year in present value terms to break even with the option of using petrol.

Is it feasible that tree cropping could prevent this amount of salinity damage? To put this figure in perspective we calculate the ‘on-site’ agricultural profit losses that could be expected in the absence of tree cropping. It is assumed that, on average, agricultural land in the low to medium rainfall zone of Western Australia could suffer a \$20 per hectare loss in gross margin within the next 20 years due to the effects of salinity. If these losses rise in a linear fashion over the next 20 years, the net present value loss would be \$111 per hectare, equivalent to an annualised loss of \$8.90 per hectare (5 per cent discount rate). Under tree cropping, these losses could at best be averted on agricultural land in the alleys. Of the 714,000 hectares devoted to tree cropping, 83 per cent is alley land. Therefore, the value of salinity benefits on this agricultural land is calculated to be \$5.3 million per annum ($=0.83 \times 714,000 \times \8.90) or 3 cents per litre.

This leaves \$27 million of annual benefits to be made up by off-farm salinity benefits or downstream agricultural benefits. It is beyond the scope of this study to undertake a detailed examination of these potential off-site impacts. Pannell⁵⁸⁵⁹ notes that in some areas the impact of trees on reducing saline discharges into waterways could be a century or more into the future, and it is important to recognise that in many situations trees may not be the simple answer to a salinity problem. However in other locations the benefits could be much quicker. With good hydrological and silvicultural planning, the optimum sites for tree planting could be determined to maximise total benefits. Also, the existence of poor sites for salinity mitigation via tree planting should not be used to detract from the opportunities that may exist to use sites where benefits are more easily achieved. Some work is already underway that seeks to classify catchments to better determine the opportunities for trees and other methods of water and salinity management⁶⁰. It may also be the case that while Western Australia has salinity issues that require useful, immediate solutions via pumping and drainage (sometimes referred to erroneously as “engineering” solutions), some salinity-prone regions of the Murray Darling Basin may benefit over the longer term through careful tree planting to manage conditions that would otherwise lead to salinity problems. While pumping and drainage help to *manage* rising water tables and salinity, tree planting can help to *prevent* such problems from occurring.

7.2.6 Closing the gap

The price gap between ethanol and petrol is estimated to be 25 cents per litre before any environmental benefits are considered. The greenhouse benefits of ethanol close this gap to 16 cents. Air pollution benefits are considered to be negligible in view of other methods for achieving similar benefits over the next 15 years, although the comparative cost of these other environmental options is not known and has not been factored into the cost benefit analysis. On-site salinity benefits in the form of prevented agricultural profit losses are estimated to contribute 3 cents per litre. Analysis on these parameters only leaves a price gap of 13 cents per litre (or \$27 million/year for the 200 ML project) which needs to be made up by off-site salinity benefits and any other benefits that have not been assessed in this study.

7.3 Methanol from biomass

Methanol has a variety of existing and potential uses. It is the base for a diverse range of industrial products such as:

- formaldehyde and its derivatives (35 per cent of current world demand)
- methyl tertiary butyl ether (MTBE) which is used to enhance octane ratings in petrol (27 per cent)
- acetic acid, which is used in PET plastics, polyester fibres, water based paints and adhesives (9 per cent)
- a variety of other solvents and fuels.

It has potential for use in fuel cells for a range of micro applications and as direct methanol fuel cells for road transport in the next ten years.

Methanol-derived MTBE is a major additive to petrol world-wide to increase the fuel's octane number and thus improve its combustion characteristics. However recently MTBE has caused public concern because it can contaminate ground water. In California MTBE has been declared an environmental risk and it is to be eliminated from Californian gasoline by the end of 2002⁶¹. Ethanol is favoured as an alternative octane enhancer in Californian fuel. A number of other US States have also banned MTBE in gasoline.

7.3.1 Production costs

The current cost of producing methanol from biomass and the required selling price to cover production costs is developed in Section 5. The estimates are based on a plant producing 390 ML of methanol per year and requiring 1.3 million tonnes of green biomass annually. To cover operating costs and achieve a 15 per cent internal rate of return on the investment over the next 15 years would require an ex factory selling price for methanol of 62 cents per litre.

Because of the relative maturity of component technologies, the scope for reducing unit production costs for methanol over the next 15 years is considered to be less than for ethanol. The maximum unit cost reduction is considered for this report to be around 20 per cent. Should this occur, the required selling price for methanol from eucalyptus biomass would fall to around 50 cents per litre.

7.3.2 Price of methanol from alternative sources

Methanol is conventionally produced from the processing of natural gas. The price of methanol produced using this standard process serves as a benchmark against which to compare the economics of producing methanol from eucalypt biomass. A comparison against petrol could be undertaken as per the ethanol comparison above. However for this study it was considered inappropriate to use the price of petrol as a basis for comparison because of toxicity concerns associated with the use of methanol as a petrol additive. Instead, an anticipated future use of methanol is as a fuel for fuel cells. Manufacturers of fuel cells will obtain their methanol requirements from the cheapest source. Thus, the question becomes: How cheap does biomass methanol need to be before it becomes competitive with conventionally produced methanol?

Current world methanol production capacity is around 35 million tonnes per year from over 90 methanol plants, primarily using natural gas as feed. Long term demand growth is anticipated to be strong at around 3 per cent per year. Since 1995 there has been an excess supply problem caused in part by pressures on environmental grounds to eliminate MTBE from US gasoline. As a result prices have been depressed falling from an industry high of over US\$500 per tonne in 1994 to as low as US\$75 in 1999.

The long term price of methanol will be determined by the price of natural gas. Production is shifting to low cost, world scale facilities located next to large natural gas reserves. Methanex Corporation, for example, which is the global leader in methanol production and marketing, is planning to locate a large scale production facility (3 million tonnes per year) in north-west Australia to access either Timor Sea or north-west shelf natural gas. An output of three million tonnes per year is about ten times larger than the scale of the biomass-to-methanol considered in this study.

There are numerous potential natural gas developments. What is lacking is long term markets for the gas to cover the massive capital investments needed to extract and use it. In this situation the long term price of methanol will be determined by gas supply conditions rather than methanol demand conditions.

Prices are expected to fluctuate substantially within a wide range of US\$100 to US\$200 per tonne around a declining long term trend. Current prices of around US\$225 per tonne greatly exceed cash costs of production of around US\$80 per tonne at a gas price of US\$1 per GJ. The gas price of new developments may well fall by up to 20 per cent to ensure development of new large scale gas reserves. The continued relocation of extremely large scale production facilities to new fields of low cost natural gas should keep downward pressure on methanol prices. An optimistic scenario, from the

vantage point of a domestic methanol-from-biomass industry, would be a methanol price of around US\$150 per tonne and with a continued low value for the Australian dollar, translating to a domestic price of A\$300 per tonne.

Methanol has a specific gravity of 0.7915 grams per millilitre. One tonne of methanol is therefore equivalent to 1263 litres. This means that the opportunity cost of methanol from biomass is likely to be no higher than 24 cents per litre by 2015.

7.3.3 The gap

This analysis finds that in 2015 it is to be expected that the cost of producing methanol from biomass will significantly be greater than the cost of producing methanol using conventional fossil fuel inputs. The relative prices for each product will be:

- biomass methanol at a projected best price of 50 cents per litre
- conventionally produced methanol at 24 cents per litre

which amounts to a price gap of 26 cents per litre.

7.3.4 Environmental benefits

As for ethanol, there are a number of environmental benefits associated with methanol from biomass which could reduce the price gap between biomass methanol and methanol produced from natural gas. The main potential benefits examined here are:

- greenhouse benefits from CO₂ sequestration
- reductions in dryland salinity.

7.3.4.1 Greenhouse benefits

Upstream emissions of greenhouse gases from the conversion of biomass to methanol could be slightly lower relative to conventional methanol production from natural gas, although this will depend on the source of power used to process the biomass. A survey of the literature suggests that, on balance, the difference in greenhouse emissions between the two processes is likely to be negligible. However, biomass methanol provides a carbon sequestration benefit from the growing of biomass. Natural gas recovery that involves the flaring of carbon dioxide at the wells may also have a more negative effect on the greenhouse gas balance than assumed here.

In this study, carbon sequestration benefits are calculated on the basis of 120,000 hectares mallee (ie 714,000 hectares of tree cropping in alley design) which sequesters 1.5 tonnes of carbon per hectare each year - one tonne in the roots and the remainder in above ground biomass. The change in stocks of above-ground carbon reflects the fact that one third of the trees are harvested each year to supply 1.5 million tonnes of biomass as feed for the methanol plant. At a CO₂ price of A\$56 per tonne the annual value of carbon sequestration is \$37 million, which is equivalent to 9.5 cents per litre of methanol.

7.3.4.2 Dryland salinity benefits

As for ethanol, the on-site salinity benefits of tree cropping are estimated to be \$5.3 million in present value terms, or 1.4 cents per litre. It is difficult to determine the off-site salinity benefits but we can identify what size they would need to be to make biomass-methanol break even with conventionally produced methanol. Before considering any environmental benefits, the price gap between these two products is 26 cents per litre. If we consider the greenhouse benefits of 9.5 cents plus the on-site benefits of salinity reduction (1.4 cents), the outstanding gap is 15 cents per litre. Thus off-site salinity benefits would need to be at least this amount (equating to an annual figure of \$58.5 million for the project), if they were required to completely bridge the expected gap.

7.4 *Electricity from biomass*

7.4.1 Production costs

Estimates of the current cost of producing electricity from eucalyptus biomass are set out in section 5. The unit cost of production is estimated to be \$95 per megawatt hour (MWh). This figure is based on a combustion plant producing 30 MW of electricity (240,000 MWh per year). This is less than one third of the estimated annual harvest of 1.5 million tonnes, which has been used in the calculations for the ethanol and methanol plants. A slightly lower unit cost plant could be built on a larger scale. However, in much of the area where biomass would be available, it is felt that the existing electricity grid cannot take more than 30 MW of electricity from local generations without a major upgrade. Major grid work (and capital expenditure) could be expected to accept input from a plant with a generating capacity in excess of 30 MW. We have not considered any of the benefits that may be possible from biomass stations actually supporting a weak grid in areas remoter from centralised power stations.

Combustion and turbine technology for the expected 30 MW plant is generally mature. There are opportunities for cost improvements over the next fifteen years, for example from Biomass Integrated Gasification Combined Cycle (BIGCC), however such technologies have not been considered here.

7.4.2 The cost of electricity from alternative sources

Electricity generation costs from fossil fuels are currently around \$10 per gigajoule (\$35.70 per MWh) (Table 7-3). These costs could fall in the next 15 years by up to 0.5 per cent per year due to efficiency gains in power generation. For this study it has been assumed that these costs will have fallen to around \$33 per MWh by 2015.

Table 7-3 Unit costs of electricity generation from non renewable sources

Feedstock	Costs (\$ per gigajoule) in 1998/9
Black coal	
Existing	9.08
New	8.74
Brown coal	
Existing	9.70
Natural gas	
Existing	10.22
New	9.09
Oil	
Existing	38.54
New	34.52

Source: ABARE Australian Energy Projections to 2019–20, Research Report 01.11 (2001).

7.4.3 The gap

The price gap between biomass energy and conventionally-generated electricity likely in 2015 is therefore estimated to be \$60.50 per MWh, which assumes that conventional power costs will have dropped to \$33 per MWh and biomass energy costs are at \$95 per MWh (technology costs as per today, feed at \$30 per green tonne).

7.4.4 Environmental benefits

As for ethanol and methanol, there are a number of environmental impacts associated with producing electricity from biomass. These benefits/costs need to be considered if a valid comparison is to be made between ‘green’ electricity and power produced using a conventional coal-fired generator. The potential benefits include:

- greenhouse benefits from CO₂ sequestration
- reductions in dryland salinity.

7.4.4.1 Greenhouse benefits

Before considering sequestration, the generation of electricity from biomass produces higher CO₂ than conventional coal fired power stations. The latter emits approximately one tonne of CO₂ per MWh of electricity output, while biomass plants typically emit 1.7 tonnes of CO₂ per MWh⁶².

However, biomass produced from tree cropping is generally regarded as sequestering sufficient quantities of carbon to completely offset these emissions. Under the Kyoto Protocol and, for instance, NSW legislation, zero net CO₂ emissions are assigned to the generation of electricity from biomass crops grown for energy use on land which has not supported native forest since 1990⁶³.

Therefore, assuming a CO₂ price of \$56 per tonne as before the greenhouse benefit from biomass electricity in terms of emissions prevented from entering the atmosphere is \$56 per MWh.

7.4.4.2 Dryland salinity benefits

Approximately 32,000 hectares of mallee trees would be required to provide the 333,000 tonnes of biomass needed to support a 30MW power station. This translates to 193,000 hectares of productive farmland with partial land use for tree cropping. Of this total area, 83 per cent is considered alley land which could benefit from the salinity protection offered by trees. As before, if we assume that the annual on-site damage cost of salinity in the absence of trees is \$8.90 per hectare (in present value terms), then the tree cropping project could prevent \$1.4 million of damage. This equates to a benefit of \$5.90 per MWh for on-farm benefits alone. Other on farm benefits such as the use of trees for wind breaks have not been costed. Any off farm benefits would also be additional.

7.4.5 Closing the gap

Before considering environmental benefits, the gap between biomass electricity and conventionally generated power is \$60.50 per MWh. But when greenhouse benefits and on-farm salinity benefits are incorporated, biomass electricity is estimated to break even with fossil fuel electricity. At a CO₂ price of A\$56 per tonne, the greenhouse benefits of biomass electricity are \$56 per MWh and on-farm salinity benefits are at least \$5.90 per MWh, which puts biomass slightly in front of conventional electricity.

7.5 Discussion

7.5.1 Summary of findings

This study demonstrates that at present or in some fifteen years, neither of the biofuels (ethanol and methanol) are directly cost-competitive with equivalent products sourced from fossil fuels. The addition of several environmental benefits as studied does narrow the gap between biomass fuels and conventional fuels. However, consideration of likely greenhouse benefits and on-farm salinity benefits alone is not sufficient to completely offset the price gap (Table 7-4). For biomass electricity, the picture is better. It is estimated that at the ABARE forecast price of \$56 per tonne CO₂, the carbon sequestration benefits - plus on-farm salinity benefits- are sufficient to make this form of renewable electricity cost-competitive with conventional electricity.

Table 7-4 **Summary of findings**

Biomass product	Project scale	<i>Price gap relative to alternative product</i>	
		Before selected environmental benefits	After selected environmental benefits
Ethanol	200 ML	25 cents per litre	13 cents per litre
Methanol	390 ML	26 cents per litre	15 cents per litre
Electricity	240,000 MWh	\$60.50 per MWh	-\$1.50 per MWh

Source: CIE estimates

8. EVALUATING ARGUMENTS USED TO JUSTIFY SUPPORT FOR BIOMASS FUELS

8.1 Balancing costs with benefits

It should be clear from the previous sections of this study that producing ethanol, methanol and electricity from eucalyptus biomass involves significantly higher costs than processes that use non renewable energy sources to produce these products. Further, this situation is not expected to change over the next 15 years. When selected environmental benefits (principally greenhouse gas mitigation and on-farm dryland salinity benefits) are considered, the gap estimated for electricity closes, while the gap for ethanol and methanol does not.

However, a number of other benefits may help to offset the cost disadvantages shown above. These include other environmental benefits, social benefits, and improvements in various indicators of economic performance. How valuable these benefits will be to the wider community 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.

8.2 Contribution to balance of payments

The use of domestically grown biomass to produce energy may save on imported fuel imports. The direct or first round impact, assuming all other things equal, will be a (very small) improvement in the balance of trade component of the balance of payments. But the final outcome for the balance of trade may be quite different to the first round effect.

The balance of trade outcome is simply the balancing item in an accounting identity relating aggregate-national income (GDP) to aggregate-national expenditure (consumption expenditure, investment expenditure, government expenditure). If aggregate income exceeds aggregate expenditure then the balance of trade is in surplus and vice versa. The balance of trade outcome will be determined by the interplay of all those policies which influence the economy's aggregate income and expenditure not by whether a particular import is avoided by domestic production. In any case, whether the balance of trade is in surplus or deficit, or improves or worsens as a result of a particular change in the economy is of no particular relevance as an indicator of economic performance.

8.3 Contribution to employment

Relative to energy from coal, green power from eucalyptus biomass is labour intensive. On-going jobs will be created to plant trees and manage and harvest plantations. Furthermore, new jobs will be provided in transportation and processing the biomass. Most of these jobs will be in regional areas where alternative employment prospects may be poor.

Our calculations suggest that to sustain a tree cropping enterprise capable of producing 1.5 million tonnes of green feed per year will involve 250 extra direct jobs in planting, harvesting, and transportation. In addition, up to 50 full time positions could be created by the establishment of a biomass processing plant.

The value of these jobs to the economy will depend on the employment prospects of the persons that fill them, and the value that society places on sustaining rural towns. If these persons are recruited from the ranks of the unemployed their employment in aggregate and the economy's overall performance will be improved. But to the extent that some are transferred from employment elsewhere in the economy the net gains to employment and national income will be reduced.

Although not specifically a liquid biofuels study, a recent German study⁶⁴ assessed the value of bioenergy for addressing high 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 compensate 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 oil, and power 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.

In addition, Task 29 of IEA Bioenergy ‘Socio-Economic Aspects of Bioenergy Systems’ has explored the BIOSEM model based on Keynesian Multiplier Theory to capture both the employment and income impacts from the installation of a bioenergy project⁶⁵. A study based on a 3 MW bioenergy plant in the UK showed a 2.13 times gain to the local economy over direct and indirect expenditure from the power plant.

Broader socio-economic benefits such as regional development and jobs have also been identified in US studies of bioenergy. For instance, in a paper by Larry Johnson, of US ethanol fuels company Delta-T Corporation, given at the Pacific Ethanol conference, 4-6 June 2002, regarding economic benefit for the Minnesota renewable energy model, it was reported that “the Minnesota Legislative Auditor’s report was released in 1997 and reported that ‘an annual payment of \$27 million of state investment resulted in an estimated \$341 to \$549 million in annual state-wide economic benefits. This is a range of \$12.6 to \$20 return for each dollar invested, in addition to a one-time benefit of \$174 to \$261 from plant construction”.

8.4 Contributions to greenhouse gas abatement

We noted earlier that energy from eucalyptus biomass produces lower greenhouse gas emissions (net of carbon sequestration) relative to energy from non-renewable sources. How valuable those reductions will be in an economic cost/benefit analysis depends on the amount of abatement in aggregate that is enforced by government policies and the domestic and international policy mechanisms put in place to achieve that abatement. This in turn will be reflected in the price of carbon reductions, either through a carbon tax or a permit price.

At a price of A\$56 per tonne of CO₂, which has been assumed throughout this analysis, carbon sequestration from tree cropping is not sufficient on its own to offset the additional production costs associated with methanol and ethanol. For ethanol, a CO₂ price of A\$140 per tonne (or \$513 per tonne of carbon) would be required to cover the additional production costs. In the case of methanol, the break-even CO₂ price is estimated to be A\$550. These calculations are net of the on-site salinity benefits that could be obtained from tree cropping.

It is unlikely that carbon prices will attain these levels. Consequently, a policy of using biomass fuels as a means of achieving greenhouse benefits will involve an implicit subsidy, being the gap between the price of biomass-derived products and the price of cheaper, alternative fuels.

For biomass electricity, the picture is better. It is estimated that at the ABARE forecast price of \$56 per tonne CO₂, the carbon sequestration benefits - plus on-site salinity benefits - are sufficient to make this form of renewable electricity cost-competitive with conventional electricity.

8.5 Contribution to salinity abatement

It was estimated above that tree cropping could conservatively produce annual on-farm salinity benefits of \$8.90 per hectare of agricultural land protected in the alley — amounting to \$5.3 million across the whole project for either ethanol or methanol production and \$1.4 million for the smaller land area for a typical biomass electricity project. In addition, there is scope for off-site benefits to be realised from tree cropping at the scale envisaged by these projects.

In the case of ethanol and methanol, the size of these off-site benefits would need to be substantial to cover the higher production costs associated with these products. The fourth column of Table 8-1 summarises the size of salinity benefits required to “break-even” if only salinity is considered to close the gap. The estimates are net of greenhouse benefits using a CO₂ price of \$56 per tonne. In the case of renewable electricity, the break-even salinity benefits are relatively small because the greenhouse benefits alone are almost sufficient to make the project break-even.

Table 8-1 Estimated on-site salinity benefits from biomass production

<i>Biomass product</i>	<i>Project scale</i>	<i>Estimated salinity benefit</i>		<i>Break-even salinity benefit for whole project</i>
			Whole project	
	Hectares	per unit output	(\$mill per year)	(\$mill per year)
Ethanol	714,000	3 cents/ litre	\$5.3	\$32.0
Methanol	714,000	1.4 cents/ litre	\$5.3	\$63.8
Renewable electricity	193,000	\$5.90 per MWh	\$1.4	\$1.4

Source: CIE estimates

It is recognised that the off farm benefits from salinity mitigation vary significantly from region to region, with the quantum and timing of benefits depending upon many different factors. As more work is undertaken to understand and assess the nature of off farm 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 ⁶⁶ 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.

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.

Table 8-2 Annual costs due to water tables/salinity (\$m) in Western Australia

	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	

8.6 Biodiversity

A major problem that can be caused by dryland salinity is the effect of saline water flow on remaining biodiverse areas. In Western Australia many of the remaining biodiverse 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 more⁶⁷.

8.7 Co - Products

One possible method of reducing the cost of renewable fuels or electricity from biomass is the co-production of other products alongside energy production. 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.

If mallee eucalypts can provide oil as a co-product then other native trees may also offer the ability to co-produce useful and marketable materials. There are several research projects underway at present that are seeking such tree species, including the Search project in Western Australia, and Florasearch and the Best Bets program administered by the Joint Venture Agroforestry Program (JVAP).

Another possibility for co-products from ethanol manufacture lies with the lignin that is left after the cellulose and hemicellulose are hydrolysed to sugars. If value-added products can be produced from the lignin they could help the economics of ethanol production. However, while this raises the prospect of closing the current cost gap between ethanol and petrol, several points must be remembered:

- The lignin already has a value, and a use in ethanol plants, as boiler fuel to provide process heat and power. In doing so it also helps maintain the greenhouse gas balance for the process (as the alternative to burning lignin may be the use of fossil fuel for heat and power on site), which helps make ethanol from wood more greenhouse friendly than ethanol from sugar or starch. It is possible that efficient use of the lignin for power generation could result in excess electricity from the plant being exported to the grid and sold at a premium as renewable electricity.
- The pulp and paper industry already produces lignin in large quantities (approximately fifty million tonnes world-wide per year), and an industry already exists to make a range of products from the lignin. The availability of large quantities of lignin and an established processing industry suggests that developing new products and markets may not be an easy task.
- It is possible that new products can be developed using lignin as feed. If they are, to have a significant impact on an ethanol project they must have large markets that are comparable with the large amount of lignin that would be produced. A high value product with a small market may be feasible and exciting in its own right, but may not impact significantly on the economics of an ethanol project that is using up to 1 million tonnes of green wood each year and generating a lignin stream approaching 100,000 tonnes per year.

9. FEDERAL GOVERNMENT POLICY FRAMEWORK

There are a number of Federal Government programs and initiatives relevant to alcohol fuel development and renewable electricity. The most relevant are described below.

9.1 Mandatory Renewable Energy Target

The Federal Government has enacted a Mandatory Renewable Energy Target (MRET) through the Renewable Energy (Electricity) Act and its Regulation, which requires large wholesale purchasers of electricity to source an additional 9,500 GWh/a of new renewable electricity by 2010. This target is being gradually phased in from April 2001 and also requires the level of 9,500 GWh/a be maintained from 2010 until 2020. Compliance by liable parties is overseen by the Office of the Renewable Energy Regulator. A penalty for non-compliance is set in the Renewable Energy (Electricity) Charge Act at \$40/MWh. The MRET operates by the creation, trading and surrender of Renewable Energy Certificates, each of 1MWh. Liable parties need to acquire the predetermined number of certificates annually. The Regulations place requirements on the source of biomass. In 2003 the MRET will be reviewed to assess its operation and uptake from the various renewable energy sources. Details of MRET may be obtained through the ORER web site at www.orer.gov.au.

9.2 Renewable Energy Action Agenda

The Federal Government initiated the Renewable Energy Action Agenda in 1999. This entails renewable energy industry participants working with government, primarily through the Department of Industry Tourism and Resources and the Australian Greenhouse Office, to move the renewable energy industry to sustainable and international competitiveness with a target of annual sales of \$4 billion by 2010. The industry participants have identified five overarching strategies to achieve this goal. These strategies relate to:

- Market Development
- Building Community Commitment
- Building Industry Capability
- Setting the Policy Framework
- Encouraging a Culture of Innovation.

The Renewable Energy Action Agenda⁶⁸ launched by the then Minister for Industry, Science and Resources in June 2000, identifies nine priority initiatives to implement the strategies. Of particular relevance to this study is Initiative 2 “Promote the Development of the Renewable Transport Fuel Industry”. The objective of this Action Agenda Initiative is to identify key opportunities for the sustainable development and use of renewable transport fuels. To this end Government and Industry have established a Working Group, led by the Australian Greenhouse Office and with government membership including the Department of Industry Tourism and Resources, Agriculture Fisheries Forestry Australia, the Department of Transport and Regional Services and Environment Australia to ‘ensure that major opportunities for renewable energy transport fuels are addressed’. The ‘Project Champion’ for Initiative 2 is Mr. Bob Gordon of the Australian Biofuels Association, with the project leadership from the Australian Greenhouse Office. Issues that this group was formed to analyse include:

- a) Consideration of the technical, environmental and economic issues associated with the exploitation of renewable transport fuels
- b) Consideration of the merit of additional Government support mechanisms for the use and/or local production of renewable transport fuels such as:
 - strategies to increase the affordability of biofuels
 - firm commitment on excise policy to reduce commercial risk
 - the introduction of a target for biofuels similar to the initiative for renewable energy

- strategies to address market access and institutional impediments to the uptake of renewable transport fuels
- recognition of the 'clean fuel' status of biofuels and development of appropriate standards
- Australia participation in the 'Liquid Biofuels' task of the International Energy Agency's Bioenergy program
- Assessment and mapping of resources to identify suitable biomass feedstocks
- Strategies to encourage the agricultural/forestry industries to utilise crops with multiple uses
- Strategies to promote greater community awareness and acceptance of renewable transport fuels.

The Working Group convened for the first time in September 2000. The work of this group is mainly being achieved through the development of a two phase report:

- a) Phase 1 to examine the technical, environmental and economic issues relating to renewable fuels; and
- b) Phase 2 will consider the merit of additional Government support for the use and production of these fuels.

Progress to date has been the preparation of the Phase 1 report. It has been intended that Phase 2 will proceed once the results of a CSIRO full fuel cycle analysis of different renewable transport fuels, conducted for the AGO, was complete. This study builds on an earlier CSIRO life cycle analysis of diesel and alternative fuels study and is accessible through the AGO website⁶⁹.

Subsequent to work commencing on this initiative under the Renewable Energy Action Agenda, the Coalition announced prior to the November 2001 General Election the 'Biofuels for Cleaner Transport' initiative which contains many of the elements being developed under the Action Agenda. Accordingly, work under Initiative 2 of the Action Agenda has slowed and may well be absorbed into the 'Biofuels for Cleaner Transport' (see below) initiative.

The CEO group having carriage for overseeing implementation of the Renewable Energy Action Agenda has reported progress on implementation of the Action Agenda to the Minister. A meeting of those involved in the Renewable Energy Action Agenda is now scheduled for early July 2002 to take stock of the Action Agenda and its continuation.

9.3 Sustainable Transport

The Commonwealth Government's 'A New Tax System' legislation of June 1999 included a number of commitments for alternative and renewable transportation fuels under the 'Measures for a Better Environment' element of the 'Tax Package Agreement'. Most notable were the Alternative Fuels Conversion Program and the Diesel and Alternative Fuels Grant Scheme. As a support activity, the Australian Greenhouse Office commissioned the CSIRO to conduct a comprehensive assessment to gauge life cycle emissions of various alternative and renewable fuels⁶⁹, including ethanol (as noted above).

The Diesel and Alternative Fuels Grant Scheme (DAFGS) commenced operation in July 2000. It encourages the wider use of alternative transport fuels such as ethanol. The scheme is directed at maintaining the existing price relativities between diesel and a range of alternative fuels by allowing transport operators that are eligible for the diesel fuel grant to also be eligible for the alternative fuel grants. The grant applies to ethanol and is currently indexed at 20.809 cents per litre. The Australian Taxation Office administers this scheme. The grant is available to businesses and other enterprises for the on-road use of diesel and alternative fuels in vehicles that have a gross mass of 4.5 tonnes or more and are registered for use on public roads. Eligibility for primary producers requires vehicles up to 20 tonnes to transport goods or passengers. Above 20 tonnes, any trip on public roads is eligible. Other non-primary enterprises using 4.5 to 20 tonne vehicles are not eligible for trips inside defined metropolitan areas.

Other alternative fuels may be certified as eligible under the Scheme by the Chief Executive of the Australian Greenhouse Office. This is required for alcohol fuel blends such as diesohol, which are currently being considered for their eligibility under DAFGS. Methanol is not listed as a qualifying fuel under DAFGS.

From July 2003 DAFGS is scheduled to be replaced by a new Energy Grants (Credits) Scheme. The proposed Energy Grants (Credits) Scheme will provide active encouragement for using cleaner fuels by providing additional incentives, while at the same time preserving the entitlements under the existing Diesel and Alternative Fuels Grants Scheme. It is recognised that ethanol producers would want such a scheme to be guaranteed for a sufficiently long period to allow investors to commit to a plant with a long payback period (10-15 years).

9.3 Biofuels for Cleaner Transport

As noted above, in the lead-up to the November 2001 Federal Election, the Coalition announced the 'Biofuels for Cleaner Transport' initiative. This announcement undertook to maintain fuel excise exemption for ethanol and set an objective that fuel ethanol and biodiesel produced in Australia from renewable resources will contribute at least 350 million litres to the total fuel supply by 2010. To implement the 350 million litre objective, the Coalition undertook that when returned to government they would provide, through a grant process from 2002/03, a capital subsidy for new or expanded domestic production infrastructure of 16 c/litre of biofuel, until total new domestic production capacity reaches 310 million litres or by the end-2006/07, whichever would be sooner. To access the subsidy, each plant would need to produce a minimum of 5 million litres of biofuel per year. A maximum grant of \$10 million would apply per plant.

Subsequently on 10 May 2002, the Government announced a two year, \$5 million study, as part of the initiative, to address market barriers to the increased use of biofuels in transport. The study is to develop a broad strategy to increase the production of biofuels to 350 million litres per year by 2010 and will include vehicle testing and a technical assessment of E20 ethanol blends in standard vehicles to address concerns by some vehicle manufacturers and other stakeholders that higher blends may pose operational or mechanical problems. The announcement also indicated the study will examine options for addressing market access difficulties including an assessment of the respective merits of nationally mandated minimum biofuel standards for transport fuel, and voluntary arrangements. The study is to assist in determining the detail of measures needed to implement the Coalition's election commitment.

9.4 Taskforce Examining Higher Levels of Ethanol in Petroleum

A Government/Industry Taskforce, led from within Environment Australia and including industry members the Australian Biofuels Association, Park Petroleum, Manildra, the FCAI, Australian Institute of Petroleum (AIP), and government members of DOTRS, DISR, ABARE, the AGO, Treasury, the ATO, AFFA, the ACCC, and the Prime Minister's Department examined ethanol blends with petrol higher than E10.

Environment Australia issued a discussion paper "Setting the Ethanol Limit in Petrol" in early 2002⁷⁰ which covered issues relating to the impact of higher ethanol blends on fuel parameters, vehicle operability and performance, and the storage and distribution network. The report recommended blends be limited to 10%, with Park Petroleum/Australian Biofuels Association providing a dissenting report on the basis of E20 blends having been used for several years in NSW.

This difference of views is expected to be resolved through the vehicle testing program noted above.

9.5 Ethanol from Lignocellulosics Pilot Plant

The Prime Minister announced an ethanol from lignocellulosics pilot plant would be built in his “*Safeguarding the Future*” announcement made in November 1997. The Federal and the NSW governments each committed \$2 million towards this project, with the industry partner (Manildra) to provide an in-kind contribution of \$1.4 million. Stage 1 of this project, a detailed design and costing study has now been completed and the cost of the pilot plant has been estimated at some \$16 million. Additional capital will be required for the project to proceed, casting some doubt over whether this project will proceed as originally planned.

9.6 Federal Government Funded Ethanol Study

The Minister for Agriculture, Fisheries and Forestry, Hon Warren Truss MP announced on 25 September 2000 that the Federal Government would be conducting a study, co-ordinated by ABARE, into the commercial viability of increasing the production of ethanol fuel by the Australian sugar industry. The client for the internal government study was AFFA. The announcement indicated that the study would examine new technology developments, ways of using and disposing of major waste products, the market demand and other feedstock options.

9.7 Excise Treatment of Ethanol

The Federal Government is currently providing exemption from all excise payments for ethanol and most other alternative and renewable transportation fuels. This exemption of ethanol commenced on 1 April 1994 when the Excise Regulations No. 176(2)(j) commenced under the Excise Regulations 1925. This came about as a result of the Customs and Excise Legislation Amendment Act 1993 No. 113, which provided for the insertion of s.77(g) into the Excise Act 1901. This provision relates to blended petroleum products. The current excise treatment does not provide any firm time horizon or specify limits on levels of production.

There has been concern expressed that a continuation of excise exemption might encourage alcohol fuels to be sold in Australia by other ethanol-producing countries. An alternative means of supporting the development of a domestic ethanol industry could involve a system of greenhouse or renewable energy credits. This was to have been considered by the Renewable Energy Action Agenda Initiative 2, described above, and is now likely to be considered in the ‘Biofuels for Cleaner Transport’ study related in Section 10.3 above.

9.8 Greenhouse Gas Abatement Program (GGAP)

The Greenhouse Gas Abatement Program is a \$400 million program over four years to support initiatives for large scale and sustained greenhouse gas abatement, such as could be delivered from widespread use of renewable transport fuels. The focus of this program is on additional actions to those which would be commercially viable or currently funded under other State or Commonwealth programs. GGAP themes are:

- Technology Deployment
- Regional Greenhouse Partnerships
- Built Environment and Infrastructure
- Greenhouse Abatement Facilitation.

The program operates through a competitive bidding process. The applications are required to indicate greenhouse gas savings in excess of 250,000 tonnes carbon dioxide equivalent per annum. Round 1 of GGAP approved two ethanol related projects; one from the Douglas Shire in Queensland and the other from BP Australia.

9.9 National Fuel Quality Standards

The Federal Government has been moving towards adopting international vehicle and fuel technology standards to achieve reductions in emissions of all significant air pollutants. As part of this review, the Government through Environment Australia has been investigating changes to fuel which will have a direct benefit for air quality. This is linked to the phasing out of leaded petrol. Studies have been undertaken to assess the effects of changing fuel specifications for petrol and diesel ⁷¹. An aspect of this review is the future requirement for increased octane fuel for new, lower emission vehicles. Octane enhancers, ranging from chemical additives, ethers and alcohols have formed part of the study. The level of oxygen allowable in fuel (ethanol as a fuel component is an oxygenate) is still under discussion and is integral to the assessment of E20 blends (see above). Environment Australia is also aware that the Euro standards imply lower ethanol in petrol blends than the E10 and E20 blends currently being used in parts of NSW and Victoria.

National fuel quality standards are set through the *Fuel Quality Standards Act 2000*. Objectives of this Act are to: reduce levels of pollutants and emissions from the use of fuel that may cause environmental and health problems; facilitate the adoption of better engine technology and emission control technology; and allow more effective operation of engines. The first standards to be made under the Act are environmental standards for petrol and diesel and were implemented from 1 January 2002.

9.10 Financial Assistance Programs

The Commonwealth provides a number of assistance programs that may be of relevance to an emerging alcohol fuels industry. These include:

9.10.1 Commercialising Emerging Technologies (COMET)

Administered by AusIndustry⁷², this fund assists new start-up firms in their innovation and commercialisation strategies. Funding up to \$100,000 for the development and implementation of a tailored assistance plan, focusing on the commercialisation objective is available. This supports areas such as; strategic and business planning, market research, intellectual property strategy and establishing a working prototype plant.

9.10.2 Pooled Development Funds Program

This fund is administered by AusIndustry. Pooled Development Funds invest in Australian Small and Medium Enterprises with the requirement for the SMEs to have fewer than 200 employees or turnover less than \$50 million per year.

9.10.3 Renewable Energy Commercialisation Program (RECP)

RECP ⁷³ has been a \$56 million program over five years, providing up to \$1 million as a grant per project. Although the Commercialisation program has now concluded, there is an expectation that it may be renewed. Grants have been for projects leading to the commercialisation of innovative renewable energy equipment, technologies, systems or processes. There have been two funding rounds per year. A component program within RECP is the Renewable Energy Industry Development Program, which funds feasibility and resource assessment studies where an entire industry sector benefits. This sub-program has not as yet concluded.

9.10.4 Renewable Energy Equity Fund (REEF)

REEF provides venture capital for small innovative renewable energy companies for activities leading to commercialisation of renewable energy technologies or services. Investee companies need to be at the seed, start up or early expansion stage of development. Details can be obtained from CVC REEF, the REEF licence holder at www.cvcreef.com.au.

9.10.5 R&D Start Programs

For a project with an R&D component, there are a number of different R&D Start Programs. R&D Start-Core provides assistance of up to 50% of eligible costs for small to medium Australian companies for R&D, employment of graduates and loans for early commercialisation. R&D Start-Plus provides grants of up to 20 percent for R&D projects for companies with annual turnover of more than \$50 million, and R&D Start-Premium provides a repayable component to top up an R&D Start-Core or –Plus grant. Following a recent large draw-down on funds, R&D Start has been suspended, probably until the 2001/03 financial year.

9.10.6 R&D Taxation Concessions

This program, administered by AusIndustry, allows taxation deductions for eligible R&D Expenditure at 125 percent.

9.11 State Initiatives

It should be noted that in addition to the above Federal Government support programs and policies, various State governments are promoting ethanol production and usage. For example, the Queensland Government has announced all government fleet vehicles will in future be fuelled on E10, and an Inter-Departmental Committee has been set up to promote the ethanol industry.

10. DISCUSSION AND RECOMMENDATIONS

10.1 Discussion

When the production of alcohol fuels from biomass is considered as a means of commercialising tree planting for environmental benefits, the benefits of:

- greenhouse gas mitigation (with CO₂ valued at \$56/tonne)
- on farm salinity mitigation (such as might be achieved with mallee eucalypts in WA)

do not appear to be enough to justify a new industry over the next fifteen years.

There are other environmental and social benefits possible, which have not been valued as part of this study. There may also be possibilities for the co-production of energy and other products. Each of these situations may help close the cost/benefit gap. None of these issues have been costed in this study

The final cost/benefit ratio that may be achieved for an alcohol fuel project will probably vary from site to site, with some sites offering greater opportunities than others because of the ability to maximise environmental benefits, social benefits, co-production of other products or a mixture thereof. Further work is required to seek out those sites that offer the greatest returns and thus help to identify the first locations for any commercial alcohol fuel projects that may occur.

The gap analysis carried out in this study was based on optimistic reductions for ethanol and methanol costs over the next fifteen years, via a range of improvements to feed quality and cost, and processing improvements. Continuous monitoring is required of the technologies for biomass conversion and their unit costs of conversion, particularly in view of the substantial commitment anticipated in this area by researchers in the USA.

This study has assumed that the cost of petrol in fifteen years will be very similar to the cost today. Continuous monitoring is also required of this variable, as sustained increases in the price of petrol caused, for example, by conflict in the overseas oil-producing regions, would reduce the gap between petrol and alcohol fuels.

Monitoring is required of the analytical work on global costs and benefits of reducing greenhouse gas emissions. Estimates of carbon taxes or the value of tradable permits are key components in the comparative analysis between energy from biomass and energy from non-renewable resources.

ATTACHMENT 1: GLOSSARY

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
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
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
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**	common abbreviation for a blend of ** percent of ethanol in petrol
Gallon	Volumetric measure. This report uses US gallons, which are equivalent to 3.785 litres.
MSW	Municipal Solid Waste
Oxygenate	A chemical that includes oxygen (such as ethanol) and is added to petrol to increase the overall oxygen level in the fuel
Saccharide	Sugar, with a polysaccharide being a polymer (or chain) of many sugar molecules

ATTACHMENT 2: 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*⁷⁴, 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.

Inflation Index

The process industry monitors the impact of inflation on the cost of plant construction, and regular reports of this impact are available^{74,75}. 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:

Cost of plant in Australia (US\$)

Cost of equivalent plant in USA (US\$)

We extend this to define a conversion factor that includes currency conversion:

Cost of plant in Australia (A\$)

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, Humphreys⁷⁶ 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 USA⁷⁷. These indicate that hourly rates, in A\$/h, for Australian trades personnel are generally 80-100% of the equivalent rates, in US\$, in the USA. Based on an 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 2000⁷⁸. 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 Brennan⁷⁹ 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.

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 will 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 $\pm 20\%$, the accuracy of Australian estimates may fall to $\pm 30\%$.

ATTACHMENT 3: FUEL CELLS AND FISCHER TROPSCH SYNTHESIS

Fuel Cells

Fuel cells are power generating systems that combine hydrogen and oxygen in a controlled environment to generate electricity and heat, with water as a by-product.

The concept of fuel cells has been known for more than 150 years. However, the efficiency with which electricity may be generated, combined with low emissions, has led to a considerable expansion of interest and research into fuel cell technology over the past decade⁸⁰. Interest covers applications for stationary power and also for provision of power to vehicles.

Recently, Daimler Chrysler became the first automotive company to actually offer fuel cell vehicles for sale, with plans to build up to 30 Citaro city transit buses by the end of 2002, using hydrogen powered fuel cells to drive electric motors⁸¹. Many other vehicle manufacturers have fuel cell programs underway.

There are six different types of fuel cells under development worldwide. Of these, the Proton Exchange Membrane Fuel Cell (PEMFC) is generally favoured for vehicle use⁸². It may be operated using hydrogen as fuel, and one of the perceived barriers for widespread use of fuel cells is the storage and handling of hydrogen. Hydrogen may be stored as a compressed gas or as a metal hydride, however its energy density (energy per unit weight) is very low compared with fuels such as petrol. This leads to fuel storage on vehicles that is generally unacceptably heavy, or limits the vehicles to short distances before the need to refuel. The use of hydrogen also requires new infrastructure for fuel distribution and refuelling of vehicles.

Hydrogen is a component of all liquid hydrocarbons, including petrol, methanol, ethanol and other synthesised fuels that offer greater energy densities and compatibility with existing fuel infrastructure. Processors are being developed that can “reform” these liquid fuels into hydrogen and carbon dioxide. Thus fuel cell vehicles of the future may well carry three distinct elements in their power systems: on-board reformers for hydrogen production, fuel cells to generate electricity, and then electric motors to provide motive power to the vehicle. The Argonne National Laboratory (ANL) in the USA has investigated three reforming technologies to assess their performance with a range of liquid fuels⁸³. ANL defined efficiency as the lower heating value (LHV) of hydrogen produced divided by the LHV of the fuel used. Maximum theoretical efficiencies and other parameters for several fuels were calculated to be as follow⁸⁴:

H₂ and CO₂ yields from several liquid fuels

Fuel	% efficiency	max. H ₂ yield (kg/kg)	min. CO ₂ yield (kg/kg)	Implied ratio of CO ₂ to H ₂
Methanol	96.3	0.159	1.38	8.68
Ethanol	93.6	0.204	1.87	9.17
Gasoline	90.8	0.321	3.09	9.63
FT Gasoline	91.2	0.336	3.08	9.17

It may be seen from the above table that, in terms of theoretical performance, there is little difference between several alternative liquid fuels. Perhaps there will be greater differences in what may be achieved practically because of physical characteristics of the different fuels, with the relatively simple chemical structure of methanol possibly an advantage for on-board reformers. As few as five years ago methanol was seen as a preferable fuel to ethanol for reforming and use in fuel cells⁸⁵. Recent

advances in reforming technologies may have changed this position⁸⁶, and the work underway by groups such as Argonne suggests that reformer technology and fuel use will continue to change and improve in the future.

Fischer Tropsch Synthesis

The Fischer Tropsch process was developed last century to provide a method for production of liquid transport fuels from coal feedstock. The fuels produced were typically more expensive than transport fuels from crude oil and the process was not utilised to any great extent. Work by CE-CERT is now incorporating Fischer Tropsch technology into a Modified Hynol Fischer Tropsch Co-production Process (MHFTCP), which combines biomass feed and hydrogen to produce a synthesis gas which may be used to create clean burning fuel, process heat and electric power. Bench scale demonstrations of this technology have indicated total carbon conversion efficiency of more than 85%. CE-CERT note that synthetic high molecular weight paraffins such as cetane ($C_{16}H_{34}$) for use as an ultra-clean diesel substitute fuel have more market acceptance than methanol in the USA. The emerging dual-fuel combustion engines that may be created via simple modification to conventional engines has reportedly made the market for fuel grade hydrogen and synthetic crude more attractive than the market for methanol⁸⁷.

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