ATSE

BIOFUELS FOR TRANSPORT: A ROADMAP FOR DEVELOPMENT IN AUSTRALIA

REPORT OF A STUDY BY THE AUSTRALIAN ACADEMY OF TECHNOLOGICAL SCIENCES AND ENGINEERING (ATSE) 2008

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The key finding of this report by the Australian Academy of Technological Sciences and Engineering (ATSE) is that biofuels, both bioethanol (a petroleum substitute) and biodiesel (a diesel fuel substitute) have useful roles to play as Australian transport fuels and can contribute to greenhouse gas mitigation and energy security. While so-described Generation 1 biofuels are limited by competition for scarce resources with food production, Generation 2 biofuels, using prolific but lower-value resources, hold significant promise although production costs remain high with ill-defined conversion pathways. Focused RD&D, essential for eventual technological success and commercial outcomes, relies upon the improved financing, coordination and management of leading Australian RD&D facilities and people, as well as the establishment of productive linkages with international RD&D efforts. It is recommended that a Biofuels Institute be established.

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Executive Summary

This ATSE study comprehensively summarises the current status of transport biofuels and related technologies in the Australian context, to provide input to formulation of government policy development and to assist in guiding future research priorities. Biofuels potentially play a major part in a range of policy areas:

- energy security, through the partial replacement of oil imports;
- energy costs in a world where future oil prices are uncertain;
- greenhouse gas abatement, particularly after a price for carbon reduction is established;
- land and water use where experience elsewhere has seen adverse impacts on food prices emerge where fuel production competes for scarce resources; and
- taxation and other fiscal measures where questions of excises, subsidies, incentives etc need to be addressed.

The key findings of the report are firstly that Australia has only modest, albeit realistic, prospects in the domain of Generation 1 biofuels – ethanol and biodiesel – where a young industry is established, based mainly on food byproducts, within an uncertain policy environment. Competition for scarce resources, including agricultural land well suited for food production and water, make it unlikely that a substantial Generation 1 industry could further develop in Australia without market distorting mandates or subsidies, despite the compelling need for liquid fuels security.

Secondly, and more encouragingly, the report finds that, in the Generation 2 biofuels domain, Australia may be well-situated for the establishment of a thriving industry, albeit at some considerable time in the future. Such an industry would be based on seemingly prolific and lower-value resources which Australia appears to have in some abundance. The significant potential, for example, for the economic conversion of lignocellulosics to ethanol and specialised algae strains to biodiesel, at scales which could contribute realistically to each of the five policy areas identified, warrant enhanced commitment to focused Australian RD&D in this sector. Australia's RD&D initiatives should, where possible and where appropriate to do so, be aligned with the significantly greater RD&D efforts of other nations.

To this end it is recommended that a national Biofuels Institute be established, generally along the innovative lines of the recently announced Global Carbon Capture and Storage Institute, the National Low Emissions Coal Initiative and the soon-to-be-created Australian Solar Institute. These models, building on the clustering and industry creating experiences of a number of Cooperative Research Centres, are expected to be able to go further than CRCs realistically can. With strong governance, guaranteed funding and appropriately focused international linkages, it is believed that the impressive cadre of Australian researchers in the bio-industries could come together far more effectively than through the fragmenting competitive grant-driven step-by-step processes that characterise much of Australia's RD&D. Team building, sought by many but still seriously inhibited by competition for scarce funding, could be dramatically enhanced, as could creative relationships between RD&D, industry and government.

Despite its fragmented and underfunded competitive RD&D effort in the biofuels area, Australia has many worthwhile initiatives. Bioenergy Australia, as the national industry body, provides an effective leadership role in drawing the industry domain together. The National Collaborative Research Infrastructure Strategy (NCRIS) Biofuels Project is a worthy program but further steps, for example the recommended Biofuels Institute, are needed to improve mutual cooperation between Australian researchers and to build and sustain collaborative international arrangements. Australia's engagement in the International Energy Agency's Bioenergy Task 39, *Commercialising First and Second Generation Biofuels from Biomass*, current until 2010, is strongly supported and should be continued, while membership of the Global Bio-Energy Partnership (GBEP) to further enhance meaningful international engagement is commended.

Findings and Recommendations

Based upon inputs from four project workshops, the project Steering Committee and the Reference Group, a wide spectrum of researchers, industry stakeholders and a number of Academy Fellows, several clear recommendations for action are made.

RECOMMENDATION 1

Biofuels are able to enhance Australia's liquid transport fuel security but this must not be at the expense of food production

Biofuels - both bioalcohol (ethanol) and biodiesel - can contribute to enhancing Australia's presently limited transport liquid fuels security while reducing GHG emissions. However Generation 1 biofuels are severely constrained by competition, mainly with food production for scarce resources, arable land and water in particular, giving rise to the "food versus fuel" debate. Any meaningful and substantial biofuels contribution to national security will need to come from Generation 2 resources and conversion technologies. Although Generation 2 technologies will not directly compete with food, the large-scale production of lignocellulosic feedstocks could, if not carefully managed, indirectly compete for land, water and labour resources.

RECOMMENDATION 2

Present Generation 2 biofuel technologies are not cost competitive and an expanded RD&D effort is required

Although Australia is unusually well endowed with Generation 2 biofuels resources (including abundant sunshine, brackish water (for algae), waste carbon dioxide and low-productivity land), the costs of current lignocellulosic processing and other processes, such as algae growth and processing, remain prohibitive. Transport distances from less productive land could also be high. Much focused RD&D and international RD&D collaboration is needed.

RECOMMENDATION 3

Biofuels research is fragmented and poorly coordinated and needs to be better funded

Australia's transport biofuels RD&D facilities and resources, and their associated RD&D objectives, could be better focused towards the achievement of Australia's poorly defined national objectives for the biofuels domain; objectives which must include transport liquid fuels security. More coordinated and better-funded national RD&D and international RD&D collaboration is needed if these objectives are to be achieved.

RECOMMENDATION 4

A national Biofuels Institute needs to be established to provide research coordination and funding

Australia's widespread transport biofuels RD&D efforts, generally worthy and highly competent in themselves, are collectively inadequate to underpin a vigorous, growing and complex industry. A national Biofuels Institute would be an appropriate support structure for administering RD&D funding (including, for example, the recently launched Second Generation Biofuels Research and Development Grant Program) while guiding subsequent and related programs towards national policy objectives. While broad work areas are identified, the Institute would develop and oversight an integrated program concentrating on feedstocks, in association with the RIRDC, through to production, where Australia has natural advantages and specific needs. A Cooperative Research

Centre, unless focused on a specific industry segment, would lack the critical mass or national focus that it is believed is warranted in the national interest as it could not realistically embrace all relevant Australian research groups.

RECOMMENDATION 5

Suitable models for a national Biofuels Institute, already being developed in other energy fields, should be drawn upon for consistency of approach

A broadly embracing national Biofuels Institute should be established generally along the innovative lines of the recently announced Global Carbon Capture and Storage Institute, or the soon-to-be-created Australian Solar Institute. The Biofuels Institute would integrate appropriate existing resources and expertise into a coherent and integrated program of research, development and demonstration that covers feedstocks, processing technologies and bioproducts. Given the very significant overseas funding levels that Australia cannot conceivably match, the Institute should, where appropriate, conduct much of its work in focused partnerships and/or joint ventures with appropriate international agencies. ATSE believes funding in the region of $15 million a year for five years would be necessary, but the interest in this field should be such that growing industry support would be expected.

RECOMMENDATION 6

Australia needs to build upon its significant existing strengths in biofuels research

Although on the world scale Australia's RD&D efforts are miniscule they are in many instances world-class. Centres of excellence have developed or are developing within CSIRO, Australia's leading research universities and, to a very small extent, within the private sector. The Australian biofuels industry, interest groups and other stakeholders are well represented by Bioenergy Australia, a relatively lean alliance of some 70 RD&D, government and industry organisations. Bioenergy Australia makes a significant impact in co-ordinating, informing and communicating industry activities, news and events with its members as well as organising well respected industry conferences. The Rural Industries Research and Development Corporation (RIRDC) provides strong national leadership in bioenergy and biofuels RD&D planning and coordination, a role that has recently (July 2008) been endorsed by state and federal ministers. The National Collaborative Research Infrastructure Strategy (NCRIS) Biofuels Project already brings together a number of Australia's leading researchers. Australia's long standing role in the International Energy Agency's Bioenergy Task 39 is an effective means of contributing to and receiving the latest news of interest. Australia's membership of these fora must continue. As well it is commended that Australia consider membership of the Global Bio-Energy Partnership (GBEP) to build further its meaningful international engagements.

RECOMMENDATION 7

Australia must enhance the knowledge base of its more promising biofuels resources

Australia is well-endowed with the resources to produce a wide range of potential Generation 2 feedstocks. However the current knowledge base is inadequate for informed decisions. ATSE recommends that significant additional evaluative research, including life-cycle analyses, is conducted for the full range of Generation 2 feedstock candidates and associated resources. Most importantly this work should include studies of the identification, analysis and protection of Australia's unique biodiversity relevant to the biofuels domain – an analysis that CSIRO, RIRDC or others would be well-placed to manage. Careful consideration is also needed, not only of plant resources themselves, but of the full range of related land and other resource use and non-use issues including market and non-market values (externalities), indigenous worth, biodiversity, carbon storage, opportunity and bequest values. Assessment of intended and unintended consequences and possible tradeoffs is critical.

RECOMMENDATION 8

Australia has limited biofuels production capacity which needs to be supported

Australia currently has the industrial capacity to produce only around 1.5 per cent of Australia's transport liquid fuels demand. Ethanol capacity is relatively well-utilised but is currently well below the declared national target of 350 ML/yr. Australia's biodiesel capacity is severely underutilised as rising resource prices (canola, tallow, palm oil, etc) and changes in the taxation regime have led to plant closures. With Generation 1 feedstocks and technologies, production capacity is unlikely to increase significantly. However with government, community and industry support (as recommended in a 2003 study) and foreshadowing successful RD&D outcomes, it is expected that Generation 2 biofuels can and will make a significant contribution to Australia's transport fuels security and GHG reduction. Accordingly it is recommended that the still evolving Australian industry remains adequately sustained and skilled, with investor interest maintained to ensure that investment capital and industry capabilities are available when needed. Subject to sufficiently attractive economics a stronger focus is needed on biodiesel relative to ethanol as world preferences, evident in Europe, suggest a progressive swing to this fuel in smaller vehicle engines.

RECOMMENDATION 9

Biofuels industry development must be directed not only to the production of economic transport biofuels but also to creation of profitable co-products

The world-wide petroleum industry produces a significant and profitable range of co-products from its many feedstocks, providing enhanced returns and increased product mix flexibility to respond to market opportunities. The biofuels industry must be encouraged to follow this model; developing its own range of profitable co-products in addition to fuels. To this end Australia's recent joining of the International Energy Agency (IEA) Bioenergy Task 42 *Biorefineries: Co-production of Fuels, Chemicals, Power and Materials from Biomass and Task 34 Biomass Pyrolysis* are to be commended.

RECOMMENDATION 10

Australia needs to remain mindful of human resources development to provide the range and quantum of skills needed for industry development, both in Australia and overseas

Australia is currently encountering a shortage of technologically trained people. While not yet acute in the biofuels industry, the longer-term professional skills required, both agricultural and technological, will call for specialist education and training. Given Australia's proven international educational capacity, especially in agriculture, it is recommended that a needs survey be undertaken to identify the opportunities in this field.

RECOMMENDATION 11

Australia should be positioned to respond effectively to the biofuels sector assistance needs of developing countries

Australia has a proud history of agricultural and energy sector development assistance in its region. It is recommended that the Crawford Fund model for the training of overseas indigenous rural communities be employed, where and when appropriate, to support the structured creation of biofuels industries in developing countries.

RECOMMENDATION 12

Australia can valuably draw from the European Community in developing a vision for strategic biofuels research

The European Biofuels Technology Platform (EBTB) vision delivered in its Strategic Research Agenda (2008) offers significant guidance of value to Australia as it sets its own directions. Using its considerably greater resources and biofuels industry experience, the EBTB has identified and clearly articulated the key RD&D steps ahead for the emerging European industry. Australia needs to learn and draw from this work and where possible engage cooperatively in it where appropriate and where it is in Australia's interests to do so. Such an approach is consistent with the emerging findings of the current ATSE project on *Accelerating Technological Responses to Climate Change*.

RECOMMENDATION 13

Australia can likewise valuably draw from the United States in developing a vision for strategic biofuels RD&D

The USA's Biomass Research and Development Technical Advisory Committee has developed a Roadmap for Bioenergy and Bio-based Products (2007). This too offers significant guidance of value to Australia. Using its considerably greater resources and experience, the Committee has identified the research and policy measures needed to convert the national biomass resources into economically and environmentally desirable fuels, power and products, while outlining the technology, infrastructure and policy recommendations to accelerate the contribution of biofuels to the President's 'Twenty in Ten' goal (to reduce petrol usage by 20 per cent in 10 years). The USA's consequent and current investment in associated biofuels RD&D is massive. Again Australia should learn and draw from this work and, where possible, engage cooperatively in it where appropriate and where it is in Australia's interests to do so.

RECOMMENDATION 14

Australia needs to develop clear-cut long term policies for biofuels

If the Australian government elects to support biofuels as one of the strategies adopted to enhance energy security and achieve its emission target the relevant policies will need to embrace:

- A sound balance between 'technology push' and 'market pull'. There is a role for both mandated and aspirational targets to stimulate the industry (as in NSW); Australian RD&D is likely to be more effective where it supports a thriving industry instead, possibly, of getting ahead of it.
- An evaluation of the demands for and impacts of biofuels production and distribution infrastructure and related logistics. While regarded as adequate at current levels, any substantial biofuels industry growth would give rise to additional infrastructure needs, for example should flexible fuel vehicles (FFVs) be introduced.
- A firm commitment to supporting Generation 2 biofuels, consistent with broader alternative transport fuel policies, without affecting food security.
- A major injection of RD&D funding to address the priorities identified in this report.
- More effective clustering and cooperation of Australia's fragmented biofuels RD&D efforts. A national Biofuels Institute is suggested as an appropriate means of creating the necessary leadership and focus; imperative if the prizes are to be won.
- A communications program and regulatory support to provide for the necessary changes in agricultural practices and business models.
- A tax/excise regime that ensures the defined targets can be met and that adequate investment capital is attracted and retained.
- A monitoring and oversighting regulatory regime, recognising that Australia's land and water resources are increasingly contested for food, fibre, energy, carbon sequestration and biodiversity. Biofuels choices will have substantial implications for the economy, the environment and society. A large-scale Australian biofuels industry will have to demonstrate robust credentials in GHG emissions, land and water impacts, financial viability and social acceptability.

Acknowledgements

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A brief background of the two Chief Investigators of the report is given below:

Mr Martin Thomas[1] AM FTSE

Concluding as a principal of Sinclair Knight Merz, Martin Thomas had an extensive career in energy consulting and then became founding MD of the Australian CRC for Renewable Energy, ACRE. Other roles included deputy chairman of Australian Inland Energy, directorships of Tyree Group and EnviroMission, chairmanships of Austenergy, NSW Electricity Council and the Sydney 2000 Olympic Energy Panel. He is chairman of Dulhunty Power Ltd and Alecto Energy Plc, adviser to ZBB Energy and was a member of the Uranium Mining, Processing and Nuclear Energy Task Force. He is a past president of the Institution of Engineers Australia, the Federation of Engineering Institutions of South East Asia and the Pacific and the Australian Institute of Energy, and a past vice-president of the Australian Academy of Technological Sciences and Engineering.

Dr John Wright FTSE

Dr John Wright is the Director of the CSIRO Flagship Program Energy Transformed, focusing RD&D on issues of national importance in key areas of the Australian economy, and was Chief of CSIRO Energy Technology from 1994 to 2002, in which role was also the coordinator of the Energy Sector, responsible for the strategic development of all CSIRO's energy portfolio and activities. He is a member of the Implementation and Liaison Committee of the International Partnership on the Hydrogen Economy, an Executive member of the IEA Hydrogen Implementing Agreement, a member of the Australian Energy Alliance, a Board Member of the Queensland Low Emissions Technology Centre, a Member of the Faculty of Engineering Advisory Committee and a Board Member of the Priority Research Centre for Energy, University of Newcastle.

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This project was overseen on behalf of the Academy by a Steering Committee comprising:

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The production of this publication was overseen by Mr Bill Mackey, Communications Director, ATSE.

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1 Introduction

1.1 ATSE TRANSPORT BIOFUELS PROJECT

Biofuels are on the sustainability agenda, supported by the climate change debate, volatile oil prices and growing concerns for Australian liquid fuels security. But does a biofuels industry make economic sense for Australia? And do biofuels really contribute to long-term climate change mitigation and environmental sustainability? If the answer to either of these questions is yes, then what supportive policies should be in place in Australia? What uniquely Australian research and development is needed or warranted? What research collaborations should Australia seek? Where should Australia focus its efforts?

The international scene presents compelling contrasts. In the United States rising corn prices, driven by subsidised ethanol demand, have placed pricing pressure on a range of cereal food staples, contributing both to a degree of inflation and some social unrest. In some developing countries the clearance of native forest for palm oil threatens the ecology and calls into question the reality of carbon benefits. In Australia the escalating cost of tallow and imported palm oil, along with removal of Government subsidies, have rendered investments in biodiesel capacity uneconomic.

On the other hand new pathways to biofuels, using previously unattractive low-value resources, are emerging from laboratories and research projects worldwide. These so-described Generation 2 biofuels, derived from otherwise low-value lignocellulose, algae and other plentiful sources of hydrogen and carbon, hold promise, especially where prime food production land is not compromised, the sun is plentiful, nutrients are available and where there is adequate water, albeit of low or even brackish quality. *Prima facie* these routes would appear to offer the greatest promise for Australia's conditions and needs, as well as superior environmental and sustainability outcomes. However much RD&D is needed to support a sustainable industry; conversion costs are still too high and environmental consequences need to be better evaluated.

Should mandated biofuels usage or carbon pricing through a robust emissions trading system become reality, then could the economics of biofuels change dramatically? These are clear policy options; meantime the uncertainties and business risks are such that investment in the domain is still insufficiently attractive to build a viable industry.

The Academy's transport biofuels study, in addressing its terms of reference, aims to:

- identify a coherent approach to the RD&D as well as policy pathways for biofuel industry development in Australia;
- improve linkages between researchers and users of research in the area of biofuels; and
- provide a better understanding of world research directions in areas of interest and hence a more focused approach to research in Australia.

Through wide-ranging consultation and literature searches, and recognising earlier work by the by the National Energy Research, Development and Demonstration Council (NERDDC)[3] in this domain, it is hoped this study will help clarify what is already known in terms of the potential for biofuels and alternative hydrocarbon fuels to become significant components of Australia's transport fuels mix. It seeks to define and prioritise that knowledge in order to map out critical research, development and adoption pathways for an emerging sustainable industry.

3 http://www.austehc.unimelb.edu.au/asaw/biogs/A001274b.htm

Biofuels offer some potential for reduced dependence on fossil fuels, reduced carbon dioxide emissions and improved liquid fuels supply security at a time of increasing oil scarcity, growing demand and rising prices. Strategic positioning of Australia in sustainable biofuels production could possibly even open niche export markets. Nevertheless it is well recognised that today's Generation 1 feedstocks and land and water resources share competing market demands and are thus particularly price sensitive, evidenced by the recent decline in biodiesel's commercial viability with sharply lifting feedstock prices.

Inevitably the study covers some well-understood background, essential for an adequate understanding of the complex and multi-faceted biofuels industry, its prospects, its potential and its downsides. Where possible such information is confined to appendix references. In focusing on strategic research directions the Academy has consulted widely within the Fellowship as well as throughout the broader biofuels industry, its research population and related industry bodies.

It is hoped that its findings will contribute to robust, coordinated and productive RD&D programs and directions for Australia as well as supportive and stable long-term transport biofuel policies.

1.2 REPORT OVERVIEW

1.2.1 Report structure

The following section sets out the overall structure of the ATSE report *Biofuels for Transport: A Roadmap for Development in Australia*. The flow of chapters has been chosen to proceed logically through to derivation of the recommendations presented. Each chapter is prefaced by a series of key points highlighted for easy reference.

Following Section 1.2 of Chapter 1 are two further sections; the first (Section 1.3) briefly reviewing the Australian biofuels industry context, while the second (Section 1.4) reviews the biofuels industry context of the major economies of biofuels relevance to Australia.

1.2.2 Chapter 2 – Australian bioalcohol fuels

Chapter 2 examines in more detail the overall picture for ethanol in Australia. It covers an assessment of resource demands, Australian production capacity and targets and the potential for both Generation 1 and Generation 2 feedstocks and conversion processes. It gives a brief review of Australian RD&D, leaving the main discussion on this aspect to the later Chapter 5 for more exhaustive treatment leading to recommendations.

1.2.3 Chapter 3 – Australian biodiesel fuels

Chapter 3 examines in a similar manner the overall picture for biodiesel in Australia. As for bioethanol it covers an assessment of resource demands, Australian production capacity and targets and the potential for both Generation 1 and Generation 2 feedstocks and conversion processes. It gives a brief review of Australian RD&D, again leaving the main discussion on this to the later Chapter 5 for more exhaustive treatment leading to recommendations.

1.2.4 Chapter 4 – Biofuels feedstocks: a research and development roadmap

Chapter 4 builds on Chapters 2 and 3 and explores the key research and development directions (elements of the Australian roadmap) in the complex area of agricultural and other potential biofuels resources, drawing on the considerable body of work already undertaken by the Rural Industries Research and Development Corporation (RIRDC) with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The chapter concludes with a recommended RD&D Roadmap for Generation 1 and Generation 2 resources.

1.2.5 Chapter 5 – Bioconversion technologies: a research and development roadmap

Chapter 5 explores the current and known proposed biofuel RD&D conversion programs, both in Australia and overseas. Where it is realistic to do so, the potential for enhanced research team clustering in Australia is highlighted. Such strategically driven clustering is needed to overcome both the tyrannies of distance and the evident fragmentation of research teams competing for limited grant funding.

The Chapter concludes with a Roadmap setting out a coordinated framework for Australian transport biofuels research and development.

1.2.6 Chapter 6 – Assessing the impacts of biofuels

The external impacts of biofuels and their cultivation are many. Encouraged by their potential contribution to fuel security and a presumed 'greenhouse-positive' image, it is important to define, or at least point the way to defining, the whole of life impacts of biofuels from their biological origins through to their consumption as fuel and the disposal of their wastes.

Chapter 6 discusses in broad outline the critical importance of life-cycle analysis (LCA) issues and identification of the metrics associated with transport biofuels. These include energy consumption, GHG and other emissions, land use, water consumption, eutrophication, biodiversity, air quality and social impacts such as job creation and health. While attempting to provide a guide to the relevant metrics and calculators for each of the above factors, the chapter also provides comment on other less quantifiable externalities associated with transport biofuels.

The chapter concludes with commentary on the criticality of the analysis and protection of Australia's unique biodiversity, including in the biofuels domain; an analysis that CSIRO or RIRDC might be well placed to undertake.

1.2.7 Chapter 7 – Policy issues

Chapter 7 concludes the report, summarising a range of policy observations and recommendations. A consistent long-term policy environment, including policies associated with mandated targets, industry subsidies and tax regimes, as well as a clear understanding of the likely economic impact of the proposed Carbon Pollution Reduction Scheme (CPRS), is essential if Australia is to develop and maintain long-term stable businesses which can attract reliable private investment and create rewarding employment.

Without a consistent policy environment, which gives proper weight to the value of transport fuels security and environmental sustainability, the Australian transport biofuels industry may continue to absorb and perhaps waste investors' money, management effort and scarce research and development resources. At worst it may create IP which, lacking domestic investor support, will be taken up overseas with little benefit to Australia. This is a not-uncommon outcome in Australian IP creation; effort is warranted to avoid it.

1.3 THE AUSTRALIAN TRANSPORT BIOFUELS CONTEXT

1.3.1 The transport industry context

Before providing details of the Australian biofuels industry it is appropriate to give some relevant statistical background on its main customer, the Australian transport industry.
An overview of Australian motor vehicles and fuel usage is given below (ABS 2008a):

- in 2007 an estimated 14.8 million vehicles were registered in Australia;
- these consumed 30.1 GL of fuel in the 12 months ending October 2007;
- of this, 62.8 per cent (18.9 GL) was petrol and 31.2 per cent (9.4 GL) diesel;
- in this period passenger vehicles used 15.9 GL of petrol; some 87.9 per cent of all passenger vehicle use; and
- 6.2 GL of diesel was used by articulated and rigid trucks; some 66.2 per cent of all diesel used. Light commercial vehicles used 1.7 GL, a further 18 per cent.

Features of the Australian petroleum industry, in terms of import and refining, are given below (ACCC 2007):

- Australia imported 72 per cent of its crude oil needs in 2006-07 to supply domestic petroleum refineries; and
- Australia imported 2.9 GL and exported 0.8 GL of petrol, thus being a net importer of some 2.1 GL, around 10 per cent of its needs.

Geoscience Australia (2005) reported that the identified and undiscovered accumulations of crude oil and condensates in Australia would peak in 2007 and then decline.

Aspects of Australia's 2006 GHG inventory are given below (DCC 2008a & DCC 2008b):

- Australia's 2006 net GHG emissions across all sectors totalled 576 Mt carbon dioxide equivalent (Mt CO_2-e) under Australia's Kyoto accounting provision obligations; and
- the transport sector accounted for 79.1 Mt CO_2-e of these emissions, of which motor vehicles accounted for 71.1 Mt CO_2-e, some 12.3 per cent of all GHG emissions.

While Australia has substantial crude oil production, around 62 per cent was exported in 2005-06 (AIP 2006). However to meet the Australian demand mix crude oils are also imported; hence Australia is a net crude oil importer, amounting to some $6.4 billion in 2005-06 (ABS 2008b). The overall cost of imported crude ($12.4 billion) represents some 56 per cent of the total cost of energy products imported into Australia ($21.5 billion) or 31 per cent of the total export value of Australia's energy products ($39.4 billion). Accordingly, sustainably produced biofuels, available at a similar cost to fossil oils, would benefit Australia in terms of energy security, balance of payments and the national economy.

1.3.2 The biofuels industry context

Biofuels production in Australia at the time of reporting has established but underutilised capacity, especially for biodiesel arising from recent plant closures due to the high costs of raw materials (canola, tallow, palm oil, etc). In 2007 ethanol and biodiesel plant capacities were 148 ML/yr and 323 ML/yr respectively, representing about 1.5 per cent of Australia's 2007 automotive transport fuel demand of 30.1 GL. However in that year only around 25 per cent of this capacity was utilised commercially (O'Connell *et al*. 2007). Although blamed initially on poor government support, lack of consistent policies, buyer resistance at the filling station, oil company conservatism, lack of adequate infrastructure and other factors, it has since become clear the shortfall may also be contributed to by process control and product consistency problems.

The industry is still small and fragmented, having but a modest lobbying voice while production plants are generally small, hampering profitability. Rapidly rising feedstock prices have shown how unpredictable process variable costs can be. Australia's extended drought has contributed to higher grain prices although prices on world markets are at unprecedented highs, in part due to reduced stocks and growing competition for Generation 1 resources, principally cereal grains for ethanol and tallow and palm oil for biodiesel.

The study assumes an ongoing and probably growing demand for transport liquid fuels for the foreseeable future, with biofuels playing a small but important role in meeting this. CSIRO's Future Fuels Forum identified mining, agriculture, tourism and aviation as particularly vulnerable to the difficulties of switching to non-liquid fuels.

Although emerging developments in the fields of electric battery storage; advanced electrical wheel drives; hydrogen and natural gas (methane) fuel cells and intelligent guidance systems hold out medium-term expectations of profound changes in personal and eventually freight and possibly air transport, it is unrealistic to imagine that liquid fuels for combustion engines will be superseded for many decades, and then only in some sectors. As petroleum fuels become more expensive, with international demand growing and supplies stabilising and possibly diminishing, the demand for biofuels is likely to continue to increase. In parallel, and in competition, the production of liquid fuels from coal (CTL) and natural gas (GTL) can be expected to play increasing roles in Australia's energy security and independence.

Currently, around twice as much petrol as diesel is used for the Australian transport task, whereas world-wide the proportions are near equal. Australians, like North Americans, have only taken slowly to diesel cars although virtually all long-haul trucks, farm and mining machinery are diesel-driven as are more than half all recent European cars sold. This suggests that a stronger focus on biodiesel may be warranted for Australia.

Reference is made in the literature and throughout this report to the terms Generation 1, 2 and 3. Table 1-1 sets out the meanings of those terms as used in this report.

Table 1-1 Descriptors for Australian biofuels research, development and demonstration

Generation	Resources	Research, development and demonstration status
1	Sugarcane and cereal crops	Mature worldwide
2	Bioethanol – lignocellulosic wastes; Biodiesel – algaes, FT synthetic diesel, methanol and DME	Early stage worldwide with numerous competitive approaches. Pathways are enzymatic and non-enzymatic
3	Biorefineries	Systemic integration and commercialisation

1.4 THE INTERNATIONAL BIOFUELS INDUSTRY CONTEXT

1.4.1 The international context

Throughout the international transport fuels industry there is widely accepted awareness that oil discovery is slowing while demand for liquid fuels continues to grow. Recent indications are that volatile prices have had an impact, moderating demand growth world-wide, although it remains to be seen if more recent price falls will remove the impetus for this trend. Nevertheless world oil was being pumped at 86 Mbbl/day in 2007 (International Energy Agency 2008), while orders for 2008, subject to unpredictable international trading conditions, may exceed this.

When world oil prices increase by a few per cent, biofuels interest blossoms. When prices subside, research wanes. The recent, albeit transient, oil price increases triggered unprecedented concerns over 'peak oil', fuel security and climate change impacts. Although such increases create a seemingly more encouraging economic climate for the biofuels industry there are clear signs that cost increases in Generation 1 resources, especially cereal grains, could negate that advantage. Expected biofuel production will nevertheless be subject to strict biodiversity management and environmental sustainability criteria; these carry their own costs.

Rising fuel prices inevitably initiate interest in alternative means of personal mobility and goods transport. Greater public transport use, cycling, nuclear electricity generation serving electric battery vehicles and eventually hydrogen fuel cells are often canvassed options. While all may have a role in Australia's transport future, analysis shows that none, either alone or in combination, is likely to replace liquid fuel for transport. Light city electric vehicles re-charged from the grid, as well as providing grid support at times of supply-system peak, are unlikely to displace more than a small portion, say 25 per cent at most, of Australia's transport fuel over the next 15 years. The so called 'hydrogen economy' is yet more distant, although the concept has been demonstrated. Thus, provided the economics remain sufficiently attractive, transport demand will readily absorb Australia's sustainable biofuels production (Jaramillo *et al*. 2007). Nevertheless the economic potential for gas to liquids (GTL), coal to liquids (CTL) and even oil from shale will certainly come to the fore in competitive transport liquid fuels markets of the decades ahead provided 'well to wheel' conversion pathways become economic.

The following sections provide brief pictures of the relevant activities of biofuel producer nations.

1.4.2 Brazil

Brazil has long been cited as the world leader in biofuel use, often quoted as producing 70 per cent of its total liquid fuels. In reality, while petrol replacement may lie in that range, ethanol is only around 14 per cent of Brazil's total transport fuel. The International Energy Agency (IEA) estimates by 2030 this could reach 28 per cent.

1.4.3 Europe

Europe has a 2020 target of 10 per cent biofuels. The IEA estimates that Europe could reach 12 per cent by 2030, mostly from biodiesel. For the rest of the world IEA believes 8 per cent to be the best achievable by 2030. Australia may be within range but could be limited by land and water availability and the challenge of soil carbon removal, yet to be assessed. Higher Australian targets are only possible if suitable Generation 2 crops can be identified able to cope with dry low productivity with suitable technologies for profitable fuel extraction.

The European Union's primary policy tool behind the bioethanol industry is the Directive on promotion of biofuels for transport. Its priorities are to improve energy supply security and reduce transport sector environmental impacts. It sets reference values for increasing biofuels from 2 per cent in 2005 to 5.75 per cent of total fuel supply in 2010, based on energy content. The European Commission target is 10 per cent by 2020, but relatively slow industry growth means renewable fuels are anticipated to occupy only 4.8 per cent of the market by 2010, well below that target (Neeft *et al*. 2007).

European concerns, as with the USA, have been raised on the environmental impact of biofuels and the diversion of feedstock from food to fuels. In May 2008 the European Parliament called for more research into developing biofuels to combat climate change, a strategy criticised in the light of looming world food shortages. The Parliament "advocates additional research into the impact of the policy of promoting biofuels and their effects on the increase of deforestation, the expansion of cultivated land and world food supplies". As elsewhere, Generation 1 biofuels have been criticised understandably for using crop land needed for food and for deforestation (Clift & Mulugetta 2007).

4 The European Biofuels Technology Platform represents a broadly based group of stakeholders associated with the biofuels industry.

To reduce transport fossil fuel dependence and meet sustainability goals, the European Commission has developed a foresight report – a biofuels vision to 2030 and beyond. This addresses relevant issues and facilitates increased biofuels deployment (Biofuels Research Advisory Council, March 2006). In response to this vision the European Biofuels Technology Platform[4] (EBTP) has published a Strategic Research Agenda (EBTP January 2008). This aims to provide solutions and highlight the research, technology development and demonstration needed to achieve the vision for biofuels in Europe. An accompanying Strategy Deployment document discusses non-technical issues to be considered in developing the road transport market to its full potential.

The EBTP report notes that European biofuel production is significantly limited. To meet ambitious EC targets biofuels must achieve better environmental sustainability than displaced fossil fuels. New biomass-conversion pathways must be able to achieve high volumes. Against this background the EBTP report identifies the following research, development and demonstration priorities, reproduced here in view of their relevance to the emergent Australian biofuels industry:

- Feedstocks:
  - develop availability-cost curves for all biomass sources (energy crops, forestry and agriculture residues, wastes) and geographical locations;
  - develop new high-yield and low-input agricultural and forest systems with crop and tree breeding optimised for multiple objectives, some of which may be environmental; and
  - develop efficient biomass logistics (harvesting/collection/storage) for the full range of conversion concepts and production scales.
- Conversion processes:
  - improve current conversion processes to their full potential (biodiesel, bioethanol from starch-sugar) for higher GHG reduction, increased flexibility for different raw material and lower cost;
  - develop thermochemical and biochemical conversion processes with feedstock flexibility for different lignocellulosic biomass;
  - develop integrated biorefinery concepts making full use of a variety of biomass feedstocks to obtain diverse high-value bioproducts; and
  - demonstrate both at pilot and industrial scale reliability and performance of new technologies.
- Fuel-engine optimisation:
  - establish logistical compatibility of biofuels and blends with existing systems and existing and new powertrains; develop vehicle modifications for neat biofuels and high blends for specific market needs;
  - generate engine-fleet test data and set sound biofuel quality standards; and
  - develop in-depth understandings of biofuel quality and engine performance relationships for future fuel and powertrain combinations to deliver superior combined performance.
- Overall system sustainability:
  - further develop indicators and coherent methodology to assess and monitor the three sustainability dimensions – economic, environmental and social; and
  - generate data and carry out sustainability assessments of promising existing and potential production chains (land, feedstock, process and fuel use).

To develop a viable European biofuels market the report identifies a number of non-technological deployment measures to be addressed:

- coherent, long-term harmonised political and open market frameworks to secure investor confidence in innovative capital-intensive technologies;
- joint public/private financing of RD&D and demonstration of new production routes and end-uses. Additional funding for high risk large-scale demonstrations;

- biofuel quality standards based on sound science without unnecessary deployment barriers;
- simple coherent global certification system to assure environmental sustainability of production chains; and
- social awareness to be increased and acceptance gained through open communication of both the benefits and potential drawbacks of biofuels.

1.4.4 United Kingdom

The Royal Society report (2008) notes that, if biofuels are to substitute for conventional fuels and meet sustainability criteria, substantial efficiency improvements are needed throughout the whole feedstock-to-wheels supply chain. Major public and private research and development is needed with the key objectives to:

- increase yields per hectare while reducing negative environmental impacts;
- develop new feedstocks that can be grown in more hostile environments, be more readily processed and be able to generate a variety of products;
- improve processing methods, in particular for lignocellulose feedstocks;
- develop new physicochemical systems for biofuel synthesis;
- develop and demonstrate integrated biorefineries;
- integrate supply chains for maximum efficiencies;
- integrate biofuel development with engine development; and
- establish internationally agreed sustainability assessment methods.

The report recognises that while the UK cannot afford to invest in every potential opportunity, UK science can make a significant contribution in research, development and demonstration of biofuel crops, feedstocks, processing techniques and end products – particularly those relevant to the UK, parts of the EU and developing countries; understanding and quantification of soil N_2O emissions for biofuel production; calculating more accurate land use figures and estimating biofuel supply potential. Incentives to take the outcomes from research and development through to demonstration and deployment are essential. Much research and development is fragmented and lacking coordination, including supply chain research groups working on related areas which are not yet focused on biofuels. There is a real need to improve coherence in public and private sector funding mechanisms and to improve linkages to and between sometimes isolated research groups and the research community.

The Royal Society report observes the limited potential of biofuels to replace fossil fuels, noting they must not be regarded as a 'silver bullet' to limit transport emissions. Transport sustainability and mobility need an integrated approaches combining biofuels with vehicle and engine design development; hybrid and fuel cell vehicles and supporting infrastructure; public transport; better urban and rural planning to address the increasing demand for transport; and more specific policies to reduce demand and encourage behavioural change.

1.4.5 United States

The United States biofuels industry is growing dramatically with a 15 per cent increase in the area of corn planted in 2007 compared to 2006 and a large share for corn-based ethanol. In 2007 at least 127 corn-based ethanol refineries were operational with many more scheduled to come on line over the next few years, while major RD&D efforts are underway to develop commercial scale technologies for cellulosic biofuels. While nearly half US petrol is blended with at least some ethanol, less than five per cent of domestic demand is currently met by ethanol.

This growth in biofuels feedstock production and refineries construction has been stimulated in large part by federal policies, most importantly via subsidies. Support for industry expansion has been driven by the US need for greater energy independence and improved long term energy security, as well as the desire to stimulate rural economies and support farm interests. Biofuels are also seen as a way to reduce GHG emissions and so address global climate change issues (Koshel & McAllister 2008).

In his 2007 State of the Union Address, President Bush committed to expanding US biofuel production and use by seven times current levels – to 130 BL/yr in 10 years. This would reduce by 15 per cent petrol otherwise consumed in 2017. This proposal is part of the 'Twenty in Ten' plan, a US goal to reduce petrol usage by 20 per cent in 10 years (National Research Council 2008).

To meet these ambitious goals the US Department of Environment (DOE) has developed ambitious RD&D programs that focus on increasing the range of feedstocks available for fuels and reducing the costs of converting feedstocks to fuels. Recognising that cellulosic feedstocks will likely be the primary source of ethanol in the future, DOE has committed about US$1 billion to cellulosic ethanol production and RD&D which it expects to be matched by private sector funding. DOE expects to support the construction of 16 cellulosic ethanol plants with at least six at commercial scale (Koshel *et al.* 2008).

USA biomass RD&D is guided by the Biomass Research and Development Technical Advisory Committee, established by the *Biomass R&D Act* of 2000. The Committee has developed a Roadmap for Bioenergy and Biobased Products (Biomass Research and Development Technical Advisory Committee 2007) which identifies the research and policy measures needed to convert national biomass resources into economically and environmentally desirable biobased fuels, power and products. It outlines the technology, infrastructure and policy recommendations to accelerate biofuel's contribution to the 'Twenty in Ten' goal.

As well as RD&D recommendations, the Roadmap update advocates that a mix of policies and incentives supportive to bio-based fuels, power and products be pursued in combination with education of both decision makers and the public on their benefits; workforce education also will be required.

2 Australian Bioalcohol Fuels

- Though Generation 1 feedstocks, primarily cereals (wheat starch) and sugar (molasses C) already compete internationally with food products at the margins, the majority of Australian biofuel producers use C-molasses, wheat starch or tallow which, being largely process co-products, do not directly compete with food.
- Any major Generation 1 industry expansion will however need animal and human food feedstocks. As well as exacerbating pricing pressures such expansion could, depending on its scale, require importation of grain in drought years with a consequent biosecurity risk.
- Any diversion of feedstocks from human and animal foods must also include comparative assessments of nutritional and social merits. These can differ considerably between feedstocks, for example sugar and wheat or corn.
- Other non-competing 'waste' resources may not have markets but do have functions. Agricultural residues, for example, help prevent soil surface erosion and retain soil carbon, thus improving soil health and microbial biodiversity.
- Purpose grown energy feedstocks like cassava may be cultivated on land of limited alternative economic value. However many are still untested in Australia and could prove to have unintended consequences. Careful planning with firm data is vital.
- Generation 1 domestic feedstocks are likely to remain at the margin of Australia's transport future, meeting no more than two to five per cent of transport fuel demand, but they provide a valuable stepping stone in any broader transition to biofuels.
- Some Generation 2 conversion technologies can usefully co-exist or form transitional strategies with Generation 1. Enzymatic conversion has compatible infrastructure with lignocellulosic materials and, although requiring additional pre-treatment, can share distillation and distribution facilities.
- Generation 2 feedstocks (lignocellulose materials) avoid direct competition with food using otherwise waste resources or resources which may be cultivated on land of otherwise limited alternative economic value. However, if not managed carefully, development of such resources could lead to indirect competition for land, water and labour.
- A significantly heightened and more effective coordinated RD&D effort on Generation 2 feedstocks is warranted for Australia (Chapter 5).
- Generation 2 lignocellulosic feedstock potential for Australia must be evaluated by a robust assessment of sustainable resource capacity.
- Ethanol can add to Australia's energy security, but is unlikely to become a viable industry which is attractive to investors in the absence of an assured policy framework, perhaps including mandated production levels.
- Other potential alternative liquid fuel competitors, notably GTL, CTL and shale oil, may compete with ethanol in the petroleum market space, albeit with markedly differing GHG profiles, in the medium to long term future.
- Other transport technologies, notably electric vehicles, will also compete in the overall transport energy space.
- Australia has a shortage of engineers experienced in the biotechnologies. Training of bioengineers is an essential precursor to a viable biofuels industry.

2.1 INTRODUCTION

Transport biofuels can be liquids (ethanol and biodiesel) or gaseous (biogas or hydrogen). In contrast to fossil fuels (coal and petroleum) biofuels, regardless of source, production route or chemical composition, are derived from biological feedstocks as the only true renewable transport liquid fuel. Fossil-sourced fuels, apart from conventional petrol and diesel, are increasingly likely, as prices rise and fuel security becomes increasingly imperative, to be derived from conversion of natural gas or coal seam methane to liquids (GTL) and coal to liquids (CTL). The process technologies, as well as oil from shale, are well understood but are outside the scope of this report, mentioned only because they will compete in the same market as biofuels.

Grain commodity prices have been at unprecedented highs through 2007-08. Many factors have contributed including population growth, increased dietary protein demand, global drought, increases in energy input prices (e.g. fertilisers, pesticides and diesel) and a number of crop yield plateaus. Biofuels have placed extra pressures on already stressed systems, for example diversion of food crops to non-food uses such as biofuels. In 2007 globally this totalled 8.4 per cent of coarse grains, 0.6 per cent of wheat, 17.3 per cent of sugar, 3.8 per cent of sugar beet and 8.7 per cent of vegetable oils (OECD, 2008).

Economic theory however shows that after a short period of price increase due to increased demand, supply increases and, in the longer term, prices stabilise slightly above the cost of production. This supply response is constrained when other key resources are constrained as for example is the case for arable land and water in Australia. Nevertheless there is some evidence of a substantial supply response in (e.g. corn) in the USA. Thus national implications can differ depending, for example, on whether increased supply displaces other important crops or requires clearing of new land. The economic dynamics are feedstock and region specific.

Commercial petroleum replacement biofuels include not only ethanol but also biogas and methanol. (Biodiesel is discussed in Chapter 3). Table 2-1 compares the properties of ethanol with petroleum.

Table 2-1 Comparison of properties of ethanol and petroleum

Property	Ethanol	Petroleum
Boiling point	78°C	range
Research octane number (RON)	110–130	92–96
Solubility in water	miscible	no
Miscibility with petroleum	yes	n/a
Miscibility with biodiesel	No, forms an emulsion	yes
Specific gravity	0.79	0.72–0.78
Energy density	21.3 MJ/L	32.0 MJ/L
Exhaust emissions	low	high
Storage	special	tanks
Distribution	tanker	pipeline and tanker
Compatibility with current internal combustion engines	E10 compatible	compatible
Air–fuel ratio	9.0	14.6
Auto-ignition temperature*	365°C	280°C
Flash point	9°C–11°C	< – 40°C

• The lowest temperature at which a material will ignite without an external source of ignition.

2.2 CURRENT AND FUTURE FEEDSTOCKS

Currently almost all Australian Generation 1 biofuels derive originally from cropland feedstocks (and their wastes) using around 26 Mha, some six per cent of Australia's agricultural land base of 445 Mha[5] . Livestock grazing uses some 85 per cent of this base (ABS 2007).

Australia's current ethanol feedstocks, referred to as Generation 1, are produced primarily from molasses C (from sugar refining) at CSR Sarina and from starch wastes (from wheat) at Manildra. Other non-food feedstocks are suggested, some yet to be trialled, as presented to the 2007 Crawford Fund Conference (Crawford Fund 2007). Generation 1 conversion technologies can also certainly be improved, for example by using sugarcane bagasse to produce energy as well as molasses.

Generation 2 biofuels will derive from a wider range of lignocellulosic resources, exploiting advanced biotechnology to transform much or all of the economically available resource into commercial products. These would typically be waste streams from purpose-grown agricultural and forest enterprises and may well show favourable GHG outcomes.

Australia has a rich history of extensive work in RD&D, techno-economic analyses, land availability and actual trials on a wide variety of crops. These include cassava, assessed in the 1980s as a crop of potential high and economic productivity in terms of tonnes of starch per hectare-year and well suited to land marginal for food production. Sweet sorghum has also been considered as complementary to sugar, allowing processing in sugar mills in their present 'off season', so using otherwise idle capital assets. Furthermore, serious proposals have been developed for Jerusalem artichokes.

In 2002 the Rural Industries Research and Development Corporation (RIRDC) published the Bioenergy Atlas of Australia (www.brs.gov.au/mapserv/biomass) as a planning tool for Australia's emerging bioenergy industry. This Atlas is discussed further in Section 4.1. Furthermore, in a report to the RIRDC (O'Connell *et al*. 2007), a table was prepared classifying Australian crops by Generation 1 and 2 potential. This is reproduced as Table 2-2 (page 14).

2.2.1 Generation 1 feedstocks

Generation 1 feedstocks are detailed in Boxes 1 and 3 in Table 2-2. While in Box 3 it is noted that expansion of food-based feedstocks is possible, this is not advocated by the Academy since there are too many issues surrounding the competition of diverting food-based feedstocks for use producing fuel. Oil-bearing trees have also mooted for Australian conditions although much is to be learned about their growing range, productivity in differing environments and agronomy and harvesting. For example *Pongamia pinnata* is a promising candidate because it is a legume and therefore does not require a nitrogen fertiliser. The oil produced is of high quality and can be converted with current biodiesel technologies. *Jatropha curcas* has shown promising yield characteristics in other countries such as India but is untested in Australia's variable rainfall environments. Its relative *Jatropha gossypifolia* is a declared noxious weed in some parts of Australia which currently prevents *Jatropha* importation and further development. GM technologies may be able to improve its characteristics and RD&D is active in this direction.

2.2.2 Generation 2 feedstocks

Feedstocks suited to Generation 2 conversion are listed in Box 2 in Table 2-2. There are a number of issues surrounding sustainability of the effect of removal of crop and forest residues on ecosystem carbon and biodiversity need to be considered, as well as the availability of processing technologies.

5 Australia's total land area is 7,692,024 square kilometres (769 million hectares).

Table 2-2 Scheme for assessing feedstocks for biofuels and bioenergy based on Generation 1 and 2 processing technologies

	1st generation biofuels	2nd generation biofuels (or 1st and 2nd generation electricity)
Current production base	Box 1 Ethanol and biodiesel Ethanol • sugar, C-molasses • wheat • barley • oats • sorghum • maize • sweet sorghum • sugar beet Biodiesel • used cooking oil • tallow • canola • mustard	Box 2 Lignocellulosics for ethanol, butanol, methanol, biogas or electricity, as well as Box 1 crops in biorefining to produce multiple co-products Crop residues • sugar bagasse and cane trash • cereal stubble Grasses • annual and perennial grasses Farm forestry crops • oil mallee • short rotation coppicing trees Forestry • wood harvested for sawlogs and pulpwood • firewood • residue currently left in native forests • residue currently left in plantations • increased forest thinnings Waste streams • waste from wood processing facilities • urban wood waste • black liquor (byproduct of pulping) • residues from food processing • municipal solid waste
Future production base	Box 3 Ethanol and biodiesel • expanded production of Box 1 crops • GM crops • tree crops with high production potential, largely untested in Australia e.g. *Jatropha, Pongamia, Moringa, Hura crepitans* • algae	Box 4 Biorefineries for range of high-value biobased products, with energy co-products Forestry or farm forestry • expansion of current hardwood or softwood plantation forestry • expansion of oil mallee industry • 'FloraSearch' type farm forestry – high value, new wood products with energy as co-product Grasses • expansion or new grasses e.g. switchgrass Algae GM crops, grasses, trees Other unidentified 'biorefinery' initiatives

Source: Australian Government; Rural Industries Research and Development Corporation *Biofuels in Australia – Issues and Prospects*, May 2007

2.2.3 Generation 3 technologies

Generation 3 technologies – biorefineries for a range of high-value biobased products, with biofuel and energy as co-products – are listed in Box 4 above. Native woody species are being investigated for a range of new products, including novel wood products, bio-based products as well as energy. Grasses, such as switchgrass, are being investigated in the USA and Canada and may be worthy of further investigation for Australia subject to evaluation of any biodiversity risk. Genetically modified crops, trees and algae are also a potential future resource but have many technical and consumer acceptance hurdles (O'Connell *et al*. 2007).

As noted in this RIRDC report, the quality and reliability of the information for each of the different boxes in Table 2-2 differs greatly. Existing assessments of the feedstock resource (in terms of land, production rates, environmental impacts and economic effects of removing material that is currently retained on site, and proximity to processing and markets, effects of markets and prices on availability) are reasonably reliable but have not been comprehensively collated for Box 1, less available and more uncertain for Box 2, and very scant with high levels of uncertainty for Boxes 3 and 4. The above noted RIRDC report contains a comprehensive list of references to work done on many crops listed in Table 2-2.

It is well beyond the scope of this report to explore in any detail the different array of feedstock options available for Australia. Furthermore, feedstocks cannot be evaluated in isolation; they must be evaluated using well-established criteria such as available technology, economic and environmental factors, and by careful consideration of available harvesting, transport and processing technologies. This is a major task and it is recommended that this becomes a priority task of the proposed Biofuels Institute (see Chapter 5).

2.3 BIOALCOHOL RESOURCE DEMANDS

The issue of mandating a quantum of bioalcohol production has attracted significant comment in the Press and elsewhere. Policies which impact markets so directly are a critical matter for producers and investors. Accordingly it is appropriate to put the demand for bioalcohol resources into a broader context by considering a notional scenario for Australian bioalcohol production. This is based on the authoritative findings of CSIRO's 2007 report to the Rural Industries Research and Development Corporation (RIRDC). The report, *inter alia*, provides an analysis of ethanol as well as biodiesel production from domestic feedstocks.

The scenario selected for the purposes of this section of the report assumes ethanol to form three per cent of Australia's transport petroleum market. This is considerably above present production levels, requiring ethanol production of around 600 ML/yr if compared to 2006-07 petroleum use of around 19.5 GL (O'Connell *et al*. 2007 Table 1-1). This notional 'Three per cent Scenario' is examined solely to indicate the range of implied resource demands (e.g. biomass, land, industry capacity, uptake by users, distribution impacts and the needs for advanced technologies and associated research and development). It is hoped this simple analysis will assist in policy development if such a scenario (or any other multiple) is believed appropriate. It certainly does not purport to form any prediction, forecast or recommendation for Australia's transport biofuels industry of the future.

The paragraphs following discuss briefly each key resource demand to meet the notional 'Three per cent scenario'.

Biofuel production

Australia's current bioethanol production capacity from cereal starch waste and cane molasses is 148 ML/yr and 323 ML/yr for biodiesel although in 2007 output was only around 75 ML/yr for ethanol and 50 ML/yr for biodiesel (O'Connell *et al*. 2007).

Land

In a world likely to experience increasing demands for food, replacement of food with fuel crops for personal mobility will be neither acceptable nor economic. This underscores the attraction of non-food Generation 2 resources such as trees, shrubs, grasses, weeds and anything other than food grains that can be converted into synthetic fuel hydrocarbons or cellulosic ethanol and be produced on low productivity cropping land with little or no fertiliser, pesticides or other energy inputs. This is probably a strategic advantage for Australia. Some low productivity land may be accessed within existing cropping zones without competing with food production, with the added advantage that much of the necessary farming infrastructure is already in place.

As Australia responds to the impacts of climate change there will need to be ongoing reassessments of land availability and competition for its use. Soil quality, water availability, salinity and sustainability will need to be more rigorously evaluated and understood as outlined in RIRDC's report (Howard & Olszack 2004). Windows of opportunity may open and close as rainfall moves and temperatures change outside ranges suitable for candidate crops. Candidate inventories are vast and will probably increase as biotechnology enhances the characteristics governing candidature. Biological and climate sciences will be challenged to identify, model and forecast the changes. Governments will be challenged to formulate long term policies that permit optimum exploitation of land and resources without economic, social or environmental distortion.

Uptake by users

Internal combustion engine modifications would not be needed. Current generation Australian cars run satisfactorily on ethanol/petrol blends up to 10 per cent (E10) (Federal Chamber of Automotive Industries 2007). Flexible fuel vehicles (FFVs) are common in Brazil, running from E85 to pure gasoline.

Distribution

Bulk storage capacity, blending and distribution of ethanol-petrol blends would need to be expanded significantly.

2.4 BIOALCOHOL PRODUCTION TARGETS

The RIRDC report (O'Connell 2007) makes a number of further observations on the uptake of bioalcohol fuels. Further valuable reference data is also given in the later RIRDC report (Warden & Haritos 2008). These reports assist in gaining an authoritative understanding of the national context of ethanol production potential and prospects from Australian resources. Accordingly relevant data is reproduced below (O'Connell 2007).

2.4.1 Generation 1 technologies

With Generation 1 conversion technologies:

- conversion of all domestic sugar and grain to ethanol would equate to only 50 per cent replacement of Australia's 2004-05 petrol consumption;
- conversion of all domestic used cooking oil (UCO), tallow and oilseed crops to biodiesel would equate to only 10 per cent of Australia's 2004-05 diesel consumption (see Chapter 3);
- conversion of all export fractions of Australian sugar and grain would equate to only 33 per cent of Australia's 2004-05 petrol consumption; and
- conversion of the export components of UCO, tallow and oilseeds (including canola, cottonseed and others) would equate to only six per cent replacement of Australia's 2004-05 diesel consumption (refer to Chapter 3).

In short, a massive uptake of ethanol and biodiesel, using all available Generation 1 resources, would still fall well short of meeting Australia's burgeoning petroleum and diesel fuel demand. Moreover, ATSE is not advocating an expansion of food-feedstocks to fuel-feedstocks. Clearly Generation 1 technologies and resources can therefore only be but a relatively small portion of any national ethanol vision although they form a valuable and essential stepping stone to Generation 2 technologies.

2.4.2 A national E10 scenario

A national E10 target would require about 1.9 GL/yr of ethanol; significantly beyond present industry capacity. Since C-molasses and waste starch capacity is also limited the target, if limited to Generation 1 feedstocks and processes, would have to be met from cereals, achievable in average years but seriously exacerbating 'food versus fuel' issues. In drought years the 1.9 GL target would require wheat import, for which biosecurity risks could create legal obstacles. ASTE does not support the diversion of food-feedstocks to fuel feedstocks and thus an E10 target would certainly call for Generation 2 feedstocks.

2.4.3 Generation 2 feedstocks

Generation 2 lignocellulosic resources have the potential to make a significant contribution to Australia's transport future, going well beyond Generation 1 limits. However, feedstock data is still unreliable for current production and, even more so, for any future production. The RIRDC reports noted above give the following examples which demonstrate the potential contribution of lignocellulosic feedstocks[6]:

- ethanol produced from some 60 per cent of current crop residues, about 30 Mt/yr in average years, would yield around 30 per cent petrol replacement;
- conversion of the entire current sawlog and pulpwood harvest to ethanol could yield six to18 per cent petrol replacement, while conversion of just that portion exported as woodchip (some 40 per cent of total production) could produce from three to 7 per cent petrol replacement;
- full utilisation of waste from wood processing facilities and firewood could provide from five to 22 per cent petrol replacement;
- the recent rapid expansion of short-rotation hardwood plantation is expected to increase total wood harvested by approximately 14 Mt/yr, 90 per cent of which is expected to be converted to woodchips. Used for ethanol it could yield from six to 20 per cent petrol replacement;
- large scale plantings of dryland woody crops such as oil mallee on poor agricultural land show considerable potential for environmental, economic and social benefits. The scale of any expansion will depend on product markets, competing land uses and land availability. Broad estimates of potential plantings range from one to 20 Mha over the next 25 years, yielding from two to100 Mt/yr. Conversion to ethanol of the entire resource could produce from one to 30 GL/yr. Depending on feedstock source this could yield from three to 100 per cent of current petrol usage.

The CSIRO Energy Transformed Flagship has a major research activity to improve the assessments of current and future feedstock production potential and the implications of industry expansion based on these.

2.4.4 Summary

ATSE concurs with the observations made in the RIRDC reports; essentially that ethanol from Generation 1 domestic feedstocks will remain at the margin of Australia's transport future, meeting no more than two to five per cent of transport fuel demand. High input agricultural systems, geared to producing food and animal feed, make biofuel feedstock more expensive – especially with upward pricing pressures from the international impacts of rapidly increasing biofuel production as well as prolonged drought and climate change impacts. Generation 1 biofuels may well form a useful first step along a transition pathway to Generation 2 biofuels, provided the supply chain economics and energy security drivers become sufficiently compelling.

Biofuels could move beyond these limits to become a significant portion of Australia's transport future if Generation 2 technology industries develop.

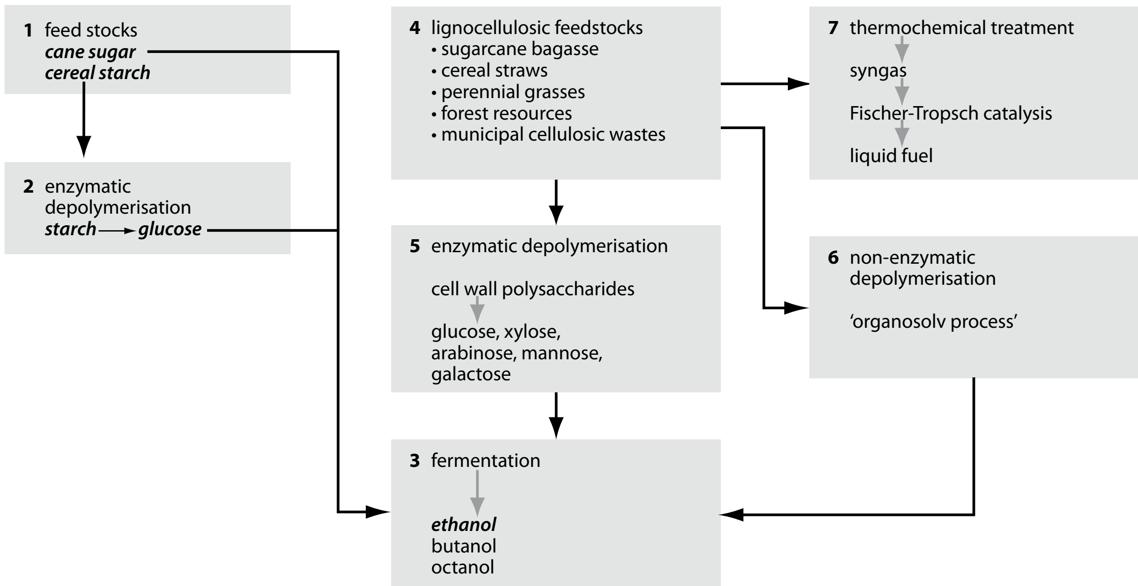
For biofuels to become a significant component in Australia's future transport fuel mix, Generation 2 lignocellulosic feedstocks must be underpinned by a robust assessment of resources – both in the current and future production base. Resource availability will be constrained by the feedstock costs and the sustainability of producing, handling, refining and disposal of biomass wastes.

2.5 BIOMASS RESOURCES FOR BIOALCOHOL PRODUCTION

The following sections outline the production pathways for Generation 1 – sugar and starch feedstocks, and Generation 2 – lignocellulosic feedstocks. Figure 2-1 outlines current and developing bioalcohol technology pathways for each.

6 It must be noted that these estimates are entirely "theoretical values" and do not take into account technical, economic and sustainability constraints. For example, the high costs of collection of raw materials (such as crop residues) from widely dispersed sources throughout the country could make the process uneconomical and hence the projections may be overly optimistic.

Figure 2-1 Bioalcohol production pathways



2.5.1 Generation 1 – Sugar and starch feedstocks

Globally the bioethanol industry relies on two feedstock groups, cane or beet sugar and cereal starches (Figure 2-1 Module 1). These are depolymerised in enzymatic processes to their constituent monosaccharides (Figure 2-1 Module 2), then fermented by strains of the yeast *Saccharomyces cerevisiae* to ethanol for recovery by distillation (Figure 2-1 Module 3). These Generation 1 processes are extensively employed, particularly in the USA where the feedstock is generally maize starch and in Brazil where it is cane sugar. Cane sugar and cereal starches are the primary Australian feedstocks, widely available with collection and distribution routes well established. Enzymatic digestion of starch to glucose is a well-developed technology used extensively for the food industry's high-fructose syrups. Fermentation to ethanol and its recovery are also well-established.

Most arguments, although not all, favour cane sugar rather than cereal starch as the preferred Generation 1 ethanol feedstock because:

- starch needs additional handling (it is not water soluble) and processing (saccharification);
- the climate change mitigation potential (the fossil energy balance[7]) for ethanol from cane sugar is about eight whereas from wheat is only about two (Worldwatch Institute 2007). This indicates that life-cycle GHG emissions from cane sugar ethanol are about one quarter those of wheat starch;
- ethanol production costs (see Figure 2-3) from cane sugar are said to be considerably lower than from cereal grain (Doornbosch and Steenblik 2007);
- annual feedstock variability is likely to be far less for cane sugar than cereal grain. Sugar is grown in high rainfall areas along the north-eastern coast, or under irrigation, whereas wheat growing regions are more drought-prone. Climate change could exacerbate this factor;
- the food security implications of cane sugar are likely to be less since it is used primarily as a sweetener rather than energy source or food staple; and
- Australia's cane growing regions are remote from major population centres; thus transportation costs may be a disincentive.

7 The fossil energy balance is the ratio of energy contained in the final biofuel to the "fossil" energy used to produce it (Worldwatch Institute 2007).

2.5.2 Generation 2 – Lignocellulosic feedstocks

Bioethanol markets and competition with food for starch and cane sugar have triggered significant efforts in the USA and Brazil to develop non-food feedstocks, the so-called lignocellulosic or woody biomass, essentially comprising the cell walls of cereal or grass straws and stems, sugarcane bagasse, perennial grasses, woody plants, municipal cellulosic wastes and the like (Figure 2-1 Module 4). These are rich in carbohydrate; the cellulose and non-cellulosic polysaccharides comprising between 55 and 62 per cent of biomass dry weight, depending on source, and are rich in hexose and pentose sugars for fermentation to bioalcohols.

Lignocellulosic options however still need much critical research and development and, for Australia, further LCA for the economic potential of each of its abundant resource opportunities. The brief comments following highlight possible impacts and concerns associated with alcohol production from each Australian candidate lignocellulosic feedstock. They however highlight the lack of adequately evaluated hard data.

Sugarcane bagasse

Sugarcane bagasse (the fibrous residue from commercial sugar production) is a prime Generation 2 feedstock candidate. Australia produces more than 10 Mt/yr bagasse, approximately 250 kg/t of cane presented to its sugar mills, which is burnt to generate process steam and electricity, increasingly with a substantial surplus for export to electricity distributors. As bagasse is already transported to the mills it attracts negligible additional harvesting costs. Depending upon relative profitabilities, sugarcane varieties can be engineered to maximise sugar or cellulose.

Bagasse cell wall polysaccharide content is 38.6 per cent cellulose, 23.0 per cent non-cellulosic polysaccharides and 23.1 per cent lignin. Today's biorefineries could be retrofitted for lignocellulosic technologies, for example enzymatic or organosolv processes (Figure 2-1 Modules 2, 5 and 6). Unprocessed cane, without juice expression, could be used as feedstock so converting both sugar and polysaccharides to bioalcohol. Syngenta–QUT has recently announced a project to explore bioethanol production from Australian bagasse.

The Burdekin and Ord River regions offer modest prospects for expansion of irrigated sugarcane. The potential additional Greater Burdekin irrigation area, including Bowen, is about 35,000ha. This assumes that half the presently unallocated water from Burdekin Falls Dam and half the approximately 540,000 ML of prospective additional storage in the region (Queensland Department of Natural Resources, Mines and Water 2006) might be used for sugarcane; also that 10 ML/yr water per hectare might be applied (Qureshi *et al*. 2001). The Ord River Irrigation Area is about 16,000 ha (Economics Consulting Services 2007). Such developments would probably be opposed by environmental groups and certainly be impacted strongly by market forces and related policies. A recent analysis of Ord River cane sugar and ethanol potential by Economics Consulting Services is exuberantly supported by Matthews (2007).

Cereal straws

Cereal straw, largely internodes and leaves, is a potential feedstock containing 32.6 per cent cellulose, 22.6 per cent non-cellulose polysaccharides and 16.9 per cent lignin. A first approximation of availability from Australia's winter grain crop of about 33 Mt/yr (ABARE 2007), assuming a harvest index[8] of 0.35 (R A. Fischer, personal communication) with 50 per cent sustainably harvestable. The remainder must be retained in the soil. Thus some 30 Mt/yr could be available, yielding around 11 GL/yr ethanol based on a theoretical yield of 0.365 ML/t. However the high cost of baling and transportation is a disincentive, while environmental and agronomic penalties of straw removal have yet to be evaluated.

8 The harvest index (HI) is the proportion of total crop biomass contained in the harvested component (usually the grain). In practice, for cereals, HI is expressed as the proportion of grain in the above-ground biomass.

As long as Australia continues to grow cereals, straw will be available. With climate change impacts previous production peaks are unlikely to be repeated, although even at the lowest yields significant quantities are available, including from areas not harvested for grain. It is unlikely that Australian cereal growing will expand unless drought and salt tolerant varieties become available. Cereal straw, like bagasse, is seasonal so lacks supply consistency for continuous production. Biorefineries would have to accept multiple feedstocks, including say perennial grasses implying increased capital and processing costs.

Perennial woody plants

Currently less than 40 million of the 450 million hectares of the Australian continent (less than 10 per cent) are used for food and fibre crops. Within the southern and north-eastern cropping lands considerable areas are allocated to agroforestry and conservation plantings of woody perennials for salinity abatement and biodiversity purposes. Indications are that such plantings are likely to increase for just these reasons.

Perennial grasses

Perennial grasses are a potential Generation 2 feedstock, particularly those varieties suited to semi-arid conditions (noting that southern Australia may become drier), poor soils and mechanical harvesting. Australian native grasses are already well adapted to its climates, soils and biota. Introduced varieties may also be suitable, for example Gamba grass (*Andropogon gayanus*) released in the Northern Territory for beef cattle forage. Gamba has high biomass yields and could be attractive, especially as it and other grass root systems are significant carbon sinks ('t Mannetje 2007).

Perennial grasses from unused low productivity land are explored in the report *Biomass as Feed Stock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Perlack *et al*. 2005) and the later *DOE Road Map: From Biomass to Biofuels* (US Department of Energy 2006). A number of grasses have been selected for intensive evaluation e.g. elephant grass *Miscanthus*. The Australian potential for perennial grasses as biofuels feedstock is however still essentially unknown but is currently being evaluated by the Sustainable Biomass Production project in CSIRO in collaboration with RIRDC. Until this work is complete the potential for perennial grasses in Australia needs to be treated with considerable caution.

Forest resources

Forest resources are abundant. Primary sources include residues from harvest operations (tops and small branches), forest management, land clearing and fire control operations. Secondary sources include saw-log and pulp-wood sawdust and offcuts. Tertiary sources include municipal and urban residues from construction and demolition sites, tree trimmings and packaging wastes, all of low value but requiring disposal. Collection and handling may call for new technologies although transport costs will inevitably remain high. Furthermore there will be competition for the more accessible forest resources from export wood chips and paper pulp. Incentives for waste recycling may need to be enhanced through policy intervention.

Additional resources could be planted. Poplar (*Populus alba*) is a USA candidate species but Australian natives may be favoured being well adapted to the climate, soils and biota. Biodiesel (discussed in Chapter 3) is already produced on a very small scale from mallee tree oil but its lignocellulosic residues could possibly become a valuable bioalcohol feedstock.

Municipal and commercial cellulosic wastes

The total amount of wastepaper recovered for recycling in Victoria was around 820,000 tonnes in 2006-07 (Sustainability Victoria 2008). With adequately attractive economics this feedstock could deliver a gross ethanol yield of about 450 ML/yr. Mixed paper has a theoretical yield of 485 L/t. Collection pathways are established and the feedstock has high cellulose and low lignin. Substances inhibitory to enzymes, such as printers' ink, would make it more suitable for non-enzymatic processes such as organosolv (Figure 2-1 Module 6).

2.6 BIOCONVERSION PATHWAYS

Two technology pathways show promise – enzymatic and non-enzymatic.

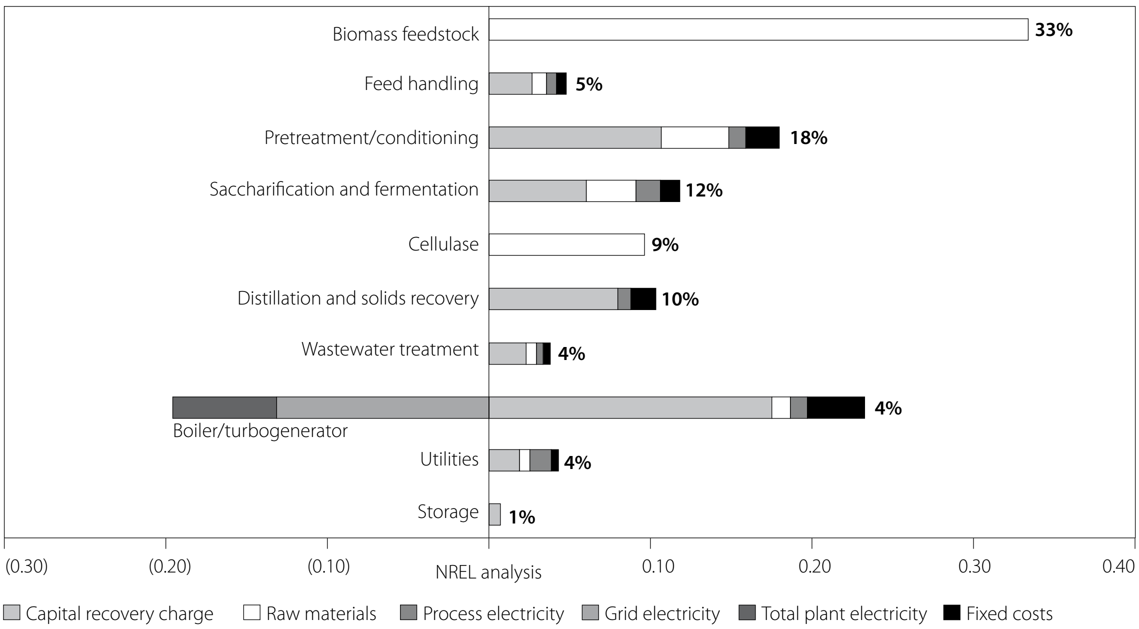
2.6.1 Enzymatic pathways

A generic process being developed, notably in the USA, uses mixtures of enzymes to depolymerise the cellulose and non-cellulosic polysaccharides to their component hexose and pentose building units (Figure 2-1 Module 5). However biological barriers to mobilisation of cell-wall polysaccharides arise from their intimate association with one another and, in many biomass cell wall types, with a non-carbohydrate phenolic polymer, lignin. Unlike starch and cane sugar, ethanol feedstocks which are readily accessible to depolymerising enzymes, lignocellulosic material must be treated to liberate the polysaccharides from their tightly structured cell walls which severely inhibit enzyme access to their substrates. Pre-depolymerisation can employ acid or alkali treatment or steam explosion (Mosier *et al.* 2005). The free sugars liberated by the enzymes are fermented by micro-organisms to produce ethanol or other alcohols such as butanol (Figure 2-1 Module 3).

Figure 2-2 shows the relative cost factors for the lignocellulosic enzymatic process steps for bioethanol (NREL Analysis 2006, as cited by Somerville 2007[9]). It must be emphasised that the estimates given in Figure 2-2 are variable; the larger cost components are highly variable and uncertain.

Currently the enzymatic process suffers from high depolymerising enzyme costs and is relatively slow.

Figure 2-2 Relative cost factors of cellulosic ethanol production



Source: NREL Analysis

Research, especially in the USA, is directed to broadening the spectrum and lowering enzyme costs. Yeasts for starch-ethanol and sucrose-ethanol processes will ferment the hexoses, glucose and fructose, but not pentoses. Thus new species or strains of micro-organisms with wider co-fermentation capabilities

9 Somerville, C, 2007 *Development of Cellulosic Biofuels*, Powerpoint Presentation; see http://www.usda.gov/oce/forum/2007_Speeches/PDF%20PPT/CSomerville.pdf

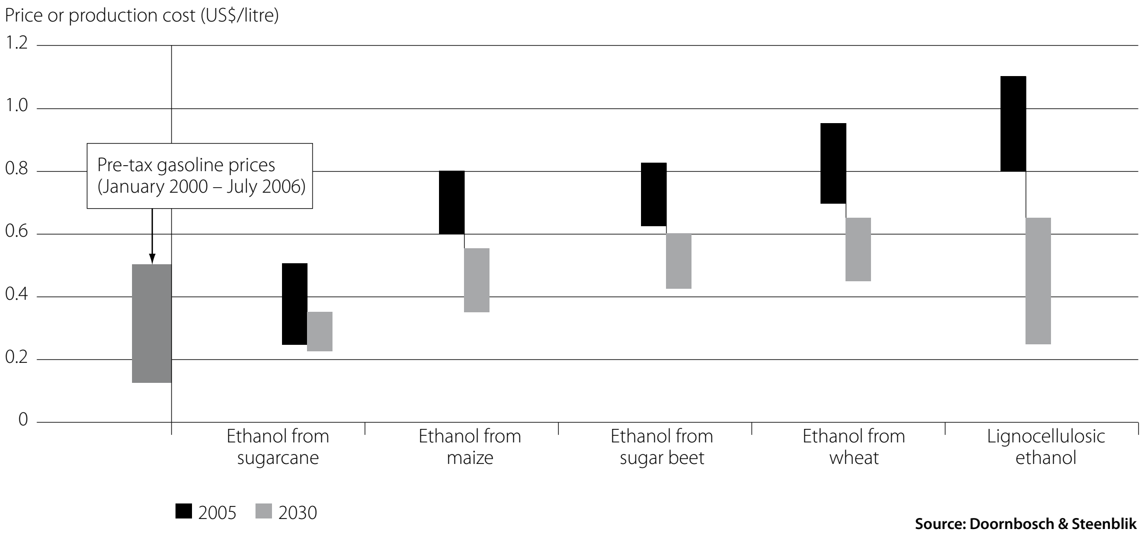
are being identified while existing micro-organism capacity is being extended by metabolic engineering. Attention is also being directed towards lignocellulosic feedstocks with higher polysaccharide and lower lignin contents (US Department of Energy 2006). Distillation residues from enzymatic pathways can find use as animal feed, an issue that must be taken up in the full LCA of all pathway options.

Over the last century biofuels have almost always been more expensive than petroleum fuels. Government incentive programmes have generally been necessary to allow biofuels to play a role in the marketplace (Worldwatch Institute 2007). Despite being generally more expensive than gasoline, biofuels have often appeared cheaper at the pump. This is, in part, because they contain less energy per unit of volume than petroleum fuels; but it is primarily because of government tax credits. Feedstock costs account for the majority of the cost of biofuels, while processing costs and a small proportion for transport represent most of the balance. For ethanol, feedstock comprises 50 to 70 per cent of the production cost, while for biodiesel, which requires less extensive processing, feedstock can be 70 to 80 per cent of the production cost (Worldwatch Institute 2007). Accordingly, the cost variations attributable to feedstock have a major influence on the variation of biofuels costs. Conventionally produced biofuels, especially ethanol, have become significantly cheaper as the industries in Brazil and the US have developed. In Brazil, the price of ethanol in 2005 was one third of what it was in 1980 (Worldwatch Institute 2007).

Current and projected bioethanol costs from various feedstocks are compared in Figure 2-3[10] with recent (pre-tax) petroleum process equivalents (Doornbosch & Steenblik 2007). Cost trends shown in Figure 2-3 illustrate a possible long-term economic prospect for lignocellulosic pathways. Demonstration enzymatic biorefineries using lignocellulosic feedstocks operate in the USA, Spain and Sweden. Costs vary from US$0.8 to US$1.0/L ethanol.

Figure 2-3 highlights that the cost of production of bioethanol is critically dependent on the type of raw material, and that Generation 2 biofuels are only likely to have comparable production costs (to sugar

Figure 2-3 Current and future ethanol production costs



Source: Doornbosch & Steenblik

10 The pre-tax gasoline prices given in Figure 2-3 are based on monthly average import prices for crude oil into the IEA region, where crude oil import prices varied between $20 and $70 per barrel during the period. The cost estimates in the Figure exclude from consideration subsidies to crops or to the biofuel itself. The information presented in this Figure has been adapted from data provided by the International Energy Agency (reference details are provided by Doornbosch and Steenbilk).

and corn for example) some years into the future. The pre-tax price of petroleum (petroleum) indicates the need for government support for Generation 2 biofuels over the medium term if they are to be competitive. This support is clearly happening very significantly in the USA, Canada and Europe with governments often providing a substantial part of the capital cost of demonstration plants.

In Australia, the RIRDC report (O'Connell *et al.* 2007) provides some indicative production costs for biofuels based on capital costs, operating costs and feedstock costs; any co-product revenues are considered as a negative cost. Some observations from these results follow:

- ethanol from waste starch and C-molasses, and biodiesel from waste oil can be produced at a cost less than 45c/L. This would roughly be competitive with oil at US$40/barrel, with a corresponding cost of production of some 45c/L (representing the pre-tax price of petrol); and
- ethanol from sugar and biodiesel from tallow and canola can be produced for less than 80c/L. This would roughly be competitive with oil at US$80/barrel with a corresponding cost of production of some 90c/L (representing the pre-tax price of petrol).

These costs estimates must be considered as being highly variable, principally due to variations in the cost of feedstock. For example, the cost of grains will increase as a result of competition for food and the livestock industry. Likewise biofuel feedstocks will face competition from alternative uses of the input feedstock.

The Royal Society (2008) has noted that cost estimates for biofuels have high uncertainties and that in general, the cost of biofuels are more expensive than the pre-tax price of petroleum products based on 2006 data. Nevertheless, the scale of the uncertainties does not obscure three general points:

- higher oil prices are beginning to make current biofuels commercially more attractive;
- the possibilities for cost reductions through economies of scale and innovation are appreciable for all biofuels; and
- the post-tax prices of petrol and diesel fuels in Europe are universally higher than the pre-tax costs of biofuels, often appreciably higher.

However, the Royal Society does not mention in the above list, the increasing costs of feedstocks for biofuels. Increasing costs of feedstocks have resulted in the recent closure of a number of biodiesel plants in Australia.

2.6.2 Non-enzymatic pathways

Non-enzyme polysaccharide depolymerising processes have been developed (Figure 2-1 Module 6). The proprietary 'organosolv' process (Oliverio and Hilst 2004), in which recalcitrant biomass is treated at high pressure and temperature with a dilute acidified aqueous ethanol solution, releases free sugars from sugarcane bagasse cell wall polysaccharides in a single step. The retained lignin co-product is a significant industrial chemical. Brazil's Dedini SA, owned by Spain's Albengoa Bioenergy, has implemented the process at its São Luiz Mill in São Paulo State. It claims a reduction in sugarcane bioethanol costs of US$0.27/L to make it competitive with oil at US$42/bbl (Biopact 2007). High process pressures and temperatures can be energy intensive although bagasse, as in sugar mills, can be the energy source.

Other non-enzymatic Generation 2 processes involve thermochemical gasification of biomass with transformation of syngas to liquid. Syngas sources include wood, straw and other biomass, with conversion to liquid fuel in the well understood Fischer-Tropsch catalytic process, although the high capital costs and wide product distribution with various raw materials need to be recognised. (Figure 2-1 Module 7).

2.7 AUSTRALIAN BIOALCOHOL ECONOMICS

Detailed economic analysis of biofuels lies outside the study scope. It needs to take into account the complex price interplay of petrol, grain and sucrose feedstocks, production and distribution, biorefinery construction and operation and, critically, government policies in Australia and overseas. Some of these factors suffer unpredictable change, for example the collapse of Australia's fledgling biodiesel industry, following modifications to previous tax arrangements, the rising cost of tallow feedstock due to developing country demand and the prospect of emissions trading. In a recent economic analysis of grain accumulation for Australian ethanol production (Anderton and Kingwell 2007), the authors note that in south-western Australia that all locations and all plant sizes are characterised by marked volatility in the cost of grain accumulation. The profitability of ethanol production based on wheat in this region of Australia is particularly exposed to any prolonged period of high grain prices relative to petroleum prices, given current biofuel-policy settings in Australia.

In a paper by Grains Australia (2007) it is noted that while the development of a biofuels industry represents a significant opportunity for the Australian grains industry, it would seem that Generation 1 biofuels are in general terms, less sustainable than is desired. There are also big resource questions about the impact of large scale harvesting of grains and biomass on Australia's ecosystems. The report suggest that the most attractive future for Australia lies in Generation 2 technologies and that it is critical for the Australian grains industry to focus on this longer-term opportunity.

2.8 FUTURE BIOALCOHOL TECHNOLOGIES

If production cost advantages of butanol over ethanol, its superior internal combustion engine performance and its easier handling are realised, then the fermentation step (Figure 2-1 Module 3) would have to reflect the different micro-organisms needed and the most likely alcohol recovery routes. Appropriate technology could be retrofitted in biorefineries using current ethanol fermentation (Ezeji *et al*. 2007). Two demonstration biorefineries producing butanol, one from lignocellulosic feedstock and one from cane, beet sugar or maize starch, are being commissioned in the UK.

2.9 RESEARCH AND DEVELOPMENT

Australia clearly needs to prepare for Generation 2 lignocellulosic technologies (Figure 2-1 Modules 4 and 5), requiring a thorough resource assessment and life-cycle analysis of its many candidate feedstocks. RD&D pathways are discussed in Chapter 4 (Feedstocks) and Chapter 5 (Bioconversion processes). Comparative vehicle performance assessments under Australian conditions of ethanol, butanol and octanol and over-the-horizon bioalcohol in various proportions with petroleum, including exhaust emissions, are also needed to provide baseline industry development data.

2.10 HUMAN RESOURCES

The conduct of theoretical and applied research, the establishment of demonstration projects and the design, construction and operation of bioalcohol refineries depends on skilled professionals. The demand for and the supply of biochemical and chemical engineers and other engineering and physical science professionals need to be evaluated in an environment where professional technological and engineering resources are increasingly scarce (Carrick Institute 2008).

3 Australian Biodiesel Fuels

- Expansion of Australia's biodiesel industry will increase competition with soap and detergent manufacturers unless other sources (e.g. algal) are found).
- Generation 1 feedstocks (tallow, oilseeds, palm oil and UCO) have risen sharply in price due to worldwide resource competition. They will remain at the margin of Australia's transport future, meeting only a small percentage of transport fuel demand.
- Generation 2 alternative feedstocks (microalgaes, oil mallee, some agricultural residues, certain tree crops and syngas) all offer considerable promise for synthetic biodiesel. Australia is unusually well-endowed with the necessary resources for these feedstocks (including abundant sunshine, brackish water, waste carbon dioxide and low productivity) although the costs of the necessary enzymes remain prohibitive.
- Biodiesel energy yield is 0.8 L/L when compared to conventional mineral oil. With the appropriate feedstocks Australia's entire diesel demand could be met from 11 kha of land.
- A significantly heightened and more effectively coordinated RD&D effort on Generation 2 feedstocks is warranted for Australia (Chapter 5).
- Biodiesel can add significantly to Australia's energy security, but is unlikely to become a viable industry which is attractive to investors in the absence of an assured policy framework including mandated production levels.
- Australia has a shortage of engineers and technologists experienced in the biotechnologies. Training of bioengineers is an essential precursor to a viable biofuels industry.

3.1 INTRODUCTION

Biodiesel describes non-petroleum based oils comprising long-chain alkyl (methyl or ethyl) esters, typically made by transesterification of vegetable oils or animal fats. Biodiesel can be used alone or blended with conventional petro-diesel in unmodified diesel-engine vehicles. It is defined in legislation as the product of esterification of vegetable oils and animal fats. 'Renewable' or 'green' diesel can be produced by hydrogenation of these products. Existing mineral oil refineries could implement hydrogenation more readily as hydrogen is already a byproduct, although such scale economies could make it harder for traditional biodiesel producers to compete without subsidy.

Australia, unlike some other countries, does not offer significant biodiesel subsidies; merely tax excise relief only available only to large producers able to afford testing costs of about $1000 for each major production batch. With the added challenge of competition against established oil refineries, plus increasing feedstock prices, some Australian companies (most recently Australian Renewable Fuels producing tallow biodiesel) have been forced to reduce or cease commercial production.

Biologically biodiesel is not dissimilar to vegetable cooking oils and indeed cooking oil can power some diesel engines. However modern diesel engines are designed for maximum power with strict controls on emissions. Thus biodiesel, replacing diesel from crude oil, must conform to equivalent standards of consistency and composition.

Any oil-bearing seed or plant or tree has biodiesel potential. As with bioalcohol, the vast range of potential biodiesel feedstocks fall into the range of currently used and proven resources, broadly described as Generation 1, while the yet to be commercially proven resources are described as Generation 2. Again, as with bioalcohol, Generation 1 resources give rise to 'food versus fuel' issues while Generation 2 resources do not to the same extent. The biodiesel resource policy environment is complex; national rather than state based policies are needed.

Generation 1 resources include used cooking oil (UCO), tallow, canola and mustard; all readily available, in commercial use but having competing uses and diminishing economic attraction. Generation 2 biomaterials for liquid fuel production, essentially microalgaes and woody wastes, are still in the early research and development phase but are aimed to avoid such resource competition. In time it is confidently anticipated that Generation 2 feedstocks will offer higher yields through new propagation and conversion technologies. Considerable RD&D remains to be undertaken, both in Australia and internationally, before Generation 2 'green' diesel takes its place in the portfolio of diesel fuel options.

The sections below outline the commercial status, the technologies involved, the production pathways and the broad economic factors for the range of Generation 1 (Section 3.2) and Generation 2 (Section 3.3) biodiesel feedstock resources of interest to Australia.

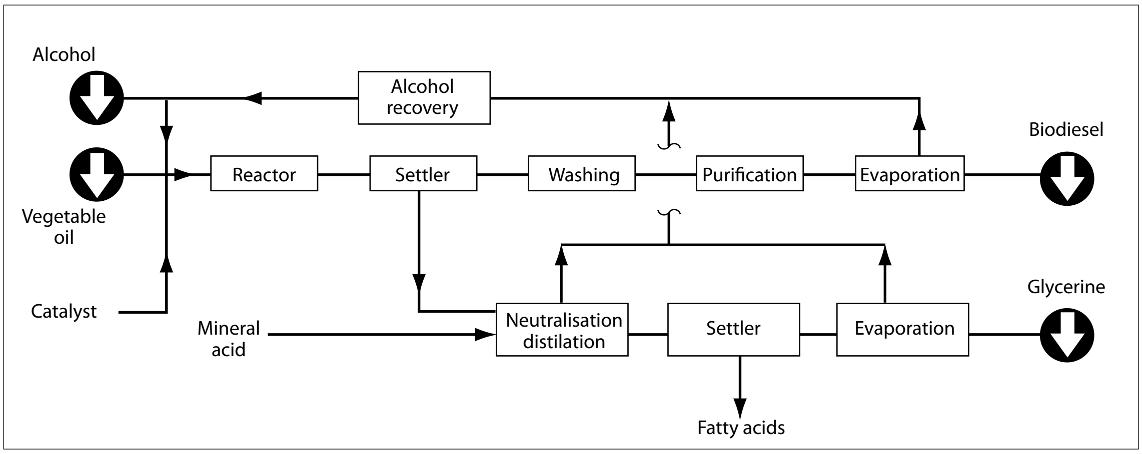
3.2 GENERATION 1 BIODIESEL RESOURCES

3.2.1 Used cooking oil (UCO)

Used cooking oil (UCO) is a waste product formerly generally disposed of as landfill. Refined and used as biodiesel, for which it is well suited, landfill needs and ground pollution are reduced. As a waste product UCO upstream costs, including GHG emissions, are already absorbed by the primary use as cooking oil. Its downstream use as biodiesel gives rise to very low life-cycle GHG emissions. However biodiesel production from UCO is limited by the quantum cooking oil used. Large users such as fast-food outlets already contract to supply all of their UCO for biodiesel. However industry estimates suggest that little extra collection effort from other catering industry sources could generate an additional 0.6 per cent of Australia's biodiesel needs.

At high temperatures UCO can be used directly in a diesel engine after processing to remove cooking residues. A pre-heating device is normally used to increase volatility when starting the engine. In colder climates, tallow can partially solidify and block the fuel system of a motor vehicle, so it is generally treated in a transesterification process which results in a product very similar to diesel oil.

Figure 3-1 Transesterification process flowchart for biodiesel



Source: National Biodiesel Board, biodiesel production

The alcohol additive in the transesterification process can be methanol or ethanol (or even other alcohols). Methanol is generally used for three reasons:

- reactions proceed at lower temperatures;

- methanol is generally cheaper than ethanol. Typical prices[11] (based on estimated production costs and thus ignoring excise or fuel taxes) are 62c/L for methanol compared to 82c/L for ethanol and 37c/L for petrol. Other alcohols (such as butanol) are more expensive; and
- European standards only allow for methanol as the reacting alcohol, also specifying an iodine number which acts to limit feedstock to canola (also known as rapeseed) oil[12]. Because most of the world's biodiesel production emanates from Europe the installation of European plants in other countries will tend to perpetuate the use of methanol as the preferred alcohol.

The transesterification catalyst is generally caustic soda (sodium hydroxide, NaOH) although potassium hydroxide (KOH) can be used.

GHG emissions from the processes shown in Figure 3-1 depend on fossil fuel use in alcohol production. Methanol emissions are higher as its production uses fossil fuel feedstocks like natural gas or coal. By contrast ethanol from renewable resources (e.g. biomass) shows lower GHG emissions. Methanol can be produced from biomass gasification but this is not done in Australia.

A process gaining petroleum refinery popularity is hydrogenation. Hydrogen is added to UCO, or more commonly tallow, to produce a diesel-like fuel often called 'renewable diesel' or 'green diesel'[13], first produced in Australia by BP. Most biodiesel definitions, including the Australian Government's biodiesel fuel quality standard[14], only refer to oils or fats that have undergone esterification. Despite this the Australian government in 2006 extended tax excise relief to producers of 'renewable diesel'[15], allowing BP to collect up to $25 million per year[16,17]. According to some reports[18,19], hydrogenated tallow is superior to both biodiesel and standard diesel, although it is only produced in small amounts and used as a one to five per cent blend in standard Australian diesel from at BP's Brisbane refinery.

As a waste product UCO requires its producers (fast foods, fish and chip shops, etc) to pay for disposal. Thus UCO feedstock is relatively cheap; estimated by Beer, Grant & Campbell 2007 at about $170/t or 20c/L while tallow has traditionally cost $450/t or 50c/L. With chemicals costs and byproduct revenues (e.g. glycerol) included, UCO biodiesel can be produced for about 35c/L and tallow biodiesel for 66c/L, compared to ultra low sulphur (ULS) diesel at around $1.50/L at the outlet[20].

3.2.2 Tallow

Tallow is rendered fat from animal parts, mainly cattle and sheep. The highest grade is suitable for human consumption but, since discovery of bovine spongiform encephalopathy (BSE or mad-cow disease) it has been used more for animal feed and soap where demand is buoyant. Lower grades are used in the chemical industry. Biodiesel can be made from any type but lower grades need more pre-processing and chemical treatment and have higher processing costs[21,22,23]. As high-grade tallow has historically been only marginally more highly priced it has been preferred for biodiesel.

11 http://www.afg.asn.au/resources/pdfs/Grower/Grower26,1/Grower26,1-p27-38.pdf
12 http://www.deh.gov.au/atmosphere/fuelquality/publications/submissions/pubs/epa-vic.pdf
13 http://www.energy.wsu.edu/documents/renewables/RenewableDieselWhitePaper.pdf
14 http://www.environment.gov.au/atmosphere/fuelquality/standards/biodiesel/index.html
15 http://www.pm.gov.au/media/Release/2006/media_Release1850.cfm
16 http://www.aph.gov.au/library/pubs/bd/2005-06/06bd144.htm
17 http://www.aph.gov.au/Library/pubs/RN/2006-07/07rn09.htm
18 http://www.eere.energy.gov/afdc/fuels/emerging_green.html
19 http://www.bp.com/sectiongenericarticle.do?categoryId=9019280&contentId=7037544
20 http://www.aip.com.au/pricing/retail/diesel/index.htm
21 http://www.meatupdate.csiro.au/whats-new/whats-new2007-2.pdf
22 http://cat.inist.fr/?aModele=afficheN&cpsidt=13534385
23 http://www.rsc.org/ej/CC/2007/b704189f.pdf

Tallow was once a waste product but, with increasing use in animal feeds and chemicals, this is no longer the case with the high-grade tallow price tripling to around \$800/t[24] in late 2007. As a byproduct tallow has no impact on land or other biomass resources. Its availability depends on the size of the livestock industry but, if tallow now exported were used for biodiesel then Australia could meet a further two per cent of its diesel fuel requirements.

Approximately the same amount of renewable diesel as biodiesel can be created from a given amount of animal fat or vegetable oil feedstock. As with biodiesel, the hydrogen used to create renewable diesel can come from either fossil fuels (as it currently does for commercial production) or renewable sources (e.g. solar electrolysis of water), so the GHG emissions can vary significantly.

As well, due to its influx into the market as a biodiesel byproduct, glycerol has fallen dramatically from about \$850/t to \$330/t[25]. This would yield 108c/L biodiesel; still competitive with fossil diesel but with a much reduced margin, to be reduced even further with biofuels excise from 2011[26]. Tallow has traded to nearly \$1000/t[27], yielding biodiesel at around 133c/L before retail outlet transport, unable to compete with early 2008 conventional diesel fuel prices.

3.2.3 Oilseeds

Oilseeds, including canola and mustard, are common biodiesel feedstocks. Canola, known in Europe as rapeseed, colours much of agricultural Australia in spring with its brilliant yellow flowers. Like other Generation 1 biodiesel feedstocks it is primarily grown for the cooking oil market. Canola biodiesel has much better cold-weather properties than UCO or tallow biodiesel and so is often created in very small quantities to blend with UCO or tallow biodiesel in the southern states of Australia to allow its widespread use in winter, rather than being sold as a high percentage blend by itself[28].

If canola were to be more extensively used as a fuel feedstock the resulting 'food versus fuel' competition would certainly further raise the prices of both. Indeed any increased Australian oilseed production is likely to find more attractive markets overseas, making domestic Generation 1 biodiesel at more than token levels unlikely without government mandate or financial assistance. The attraction of mustard is that it is less water dependent.

Three processes are employed for extracting oil from oilseeds:

- expeller/pressing[29] – in this simple technique oilseeds are squeezed under high pressure. Olive presses powered by donkeys pulling a heavy stone wheel around a central pillar can still be seen in primitive communities;
- hexane solvent oil extraction – oil dissolves in hexane (cyclohexane) which is filtered to extract the oil. This can be combined with expeller/pressing to extract more oil. As cyclohexane is toxic the process is generally not used for consumption; and
- supercritical fluid extraction[30,31] – when a gas (generally carbon dioxide) is compressed to 100 times atmospheric pressure or more and heated to 30°C to 50°C it gains the chemical properties of a solvent (such as cyclohexane) whilst retaining its ability to diffuse into vegetable matter such as oilseeds. As such it acts as a very efficient solvent, able to extract almost 100 per cent of oil from oilseeds. Filtration is simple as decreasing pressure allows the carbon dioxide to regasify, leaving behind the oil. The technique is not used widely as it is relatively expensive and requires complex equipment.

24 http://tinyurl.com/25cpwd
25 F.O. *Licht's World Biodiesel Price Report*, Volume 1, Number 40, 11 October, 2007.
26 http://tinyurl.com/2xnkcw
27 http://tinyurl.com/yrenbd
28 Personal communication with (South) Australian Farmers Fuel, http://www.farmersfuel.com.au/
29 http://www.feedscrews.com/shownews/305
30 http://www.supercriticalfluids.com/faqs.htm
31 http://www.phasex4scf.com/supercritical_markets/supercritical_fluids_nutraceuticals.htm

Each of these processes leaves residues high in protein and other nutrients which, sold for animal feed, reduce the net biodiesel cost. As noted by Beer, Grant & Campbell (2007) the average cost of canola oilseed was $353/t in late 2007 yielding biodiesel at 95c/L, much less than for UCO and tallow. This cost is further offset by the animal feed byproduct, yielding a net cost of about 76c/L; little more than tallow biodiesel on average and less since its price has risen. However oilseed prices, especially canola, have risen to around $600/t by late 2007[32], with prices of at least $550/t or more expected for the foreseeable future. At $550/t, with no increase in meal revenue[33], canola biodiesel would cost around 135c/L without delivery charges.

Other oilseeds that can produce reasonable oil yields in low-rainfall areas include several varieties of mustard bred specifically for fuel use. These are under development[34] and, if successful, could be grown on land unsuited to cropping. Australian Renewable Fuels Limited (ARF) was funding research in SARDI on oilseed crops for biodiesel production although this is under threat due to curtailment of ARF activities.

3.2.4 Palm oil

Palm oil is a widely used biodiesel feedstock having a yield some five times that of canola per unit area. Malaysian palm oil yields 6 kL/ha compared with 1.2 kL/ha for European Union canola (Worldwatch Institute 2007). Oil palms are not grown commercially in Australia but the oil is imported inexpensively from major producers in Indonesia and Malaysia. Natural Fuels Australia Ltd has a biodiesel refinery in Darwin based on imported palm oil although this has recently closed due to production issues and adverse economics, essentially rising palm oil prices.

When produced sustainably palm oil biodiesel is second only to UCO in reduced GHG emissions and costs (Beer, Grant & Campbell 2007). However virtually all Malaysian and Indonesian land available for cropping is already taken. Any increase in palm oil production in these countries, short of depriving existing food and chemical markets, leads to tropical rainforest logging to open new land. Full life-cycle analysis shows that palm oil biodiesel derived from such land leads to far higher GHG levels per unit of production than conventional diesel.

Natural Fuels Australia Limited, when operational, sourced palm oil from Roundtable on Sustainable Palm Oil (RSPO)[35] members who are required to use existing cropland such as rubber trees rather than newly cleared land. Ignoring the consequences of reducing these and other crops it does not guarantee that plantations will not be based on dried peat swamps. Indonesian government data (Hooijer *et al*. 2006, Silvius 2007) indicate that fully 27 per cent of oil palm plantations are so located and that Malaysia may have a similar distribution. CO_2 generated by drying peat swamps is so high that palm oil biodiesel from such plantations over a full life-cycle emits between eight and 21 times the GHG generated by conventional diesel (Beer, Grant & Campbell 2007). This is clearly not sustainable, nor does it take into account sociological impacts of rapidly increasing palm oil production as noted by Beer, Grant & Campbell (2007).

Australian palm oil production would be similarly problematic. High yields require a tropical climate, narrowing suitable lands to north-east Queensland, north-west Western Australia and part of the Northern Territory. These already have extensive tropical rainforests and other biomass so land clearing would increase GHG levels.

32 http://www.cargill.com.au/images/Cargill per cent20Daily per cent20Oilseed per cent20Prices.pdf
33 http://agebb.missouri.edu/dairy/byprod/bplist.asp
34 http://www.pir.sa.gov.au/grains/grain_value_chains/biofuels
35 http://tinyurl.com/2psqlj

OECD[36] and other institution reports generally agree that biofuels from food-crops have very limited potential to reduce GHG emissions without compromising food prices, the environment and developing country living standards. Thus non-food crops must be considered.

3.2.5 Jatropha

Jatropha (specifically *Jatropha curcas*) is used for biodiesel production overseas but not yet in Australia. It has however an attractive characteristic of special interest to Australia; it can grow in infertile soils while improving soil quality via nitrogen fixation, the addition of nutrients from fallen leaves including carbon[37] and reduction of erosion. Oil yield substantial (about 50 to 60 per cent higher than canola per unit area[38]). The plant is productive after only one year as well as yielding a seed cake byproduct useable as a high-grade nitrogen-rich organic fertiliser[39,40].

Such a plant would seem ideal given Australia's large tracts of low productivity, but jatropha exhibits three serious drawbacks[41]:

- there is currently no known way of harvesting jatropha nut without manual labour, making it suitable for developing countries such as Africa and India but not for Australia;
- all jatropha species are declared weeds in some Australian States and Territories. From past lessons with intrusive species it is unlikely that a potentially highly invasive weed would be permitted without many years of testing; and
- it is suggested that, unlike food crop oils, jatropha oil is relatively unstable and breaks down quickly, as does its biodiesel product. Without transport and storage modifications (e.g. storage in nitrogen rather than air) it may only be useable soon after production. This would make it unsuitable for south eastern Australia where demand is greatest, and unsuitable for local refining. However some European countries import jatropha oil[42]. Thus the problem may be surmountable although requiring further research for Australia.

There is said to be some evidence of a carcinogenic protein in the plant. This assertion needs further study, possibly through the Centre for Plant Conservation Genetics at Southern Cross University.

3.2.6 Trees

Apart from jatropha and similar 'weeds' such as water hyacinth, the main non-food feedstocks suitable for synthetic biodiesel are trees. Australian research into oil mallee for both energy and food appears promising. As with jatropha, oil mallee can rehabilitate poor soils (especially those of high salinity), reduce erosion and provide livestock and animal shelter. Oil mallee and related species provide eucalyptus oil for medical and chemical markets but plantations could be expanded to include synthetic biodiesel.

CSIRO has used data from Foran & Crane (2002) and Foran & Mardon (1999) to model various CO_2 emission reduction scenarios using biomass to generate electricity and fuel. One scenario postulates 90 per cent of current fuel and electricity from biomass by 2050 using 31 Mha dedicated short-rotation perennial tree plantations including oil mallee. Another scenario requires some 20 Mha of plantations which, combined with urban, industrial and agricultural wastes, could produce around 40 per cent of Australia's needs. Similarly 10 Mha could support production of 20 per cent of needs. It is thought possible (Diesendorf 2007) to plant that much oil mallee in Western Australia alone, using belts along contours in wheat farms in order to intercept down-slope water surpluses, without competing with

36 http://www.foeeurope.org/publications/2007/OECD_Biofuels_Cure_Worse_Than_Disease_Sept07.pdf
37 http://www.jatropha.de/rf-conf1.htm
38 http://tinyurl.com/783fp
39 http://www.reuk.co.uk/Jatropha-for-Biodiesel-Figures.htm
40 http://www.jatropha.de/harare98.htm
41 http://envirofuel.com.au/2007/07/07/bp-backs-jatropha-as-a-biodiesel-feedstock/
42 http://www.reuk.co.uk/D1-Oils-PLC-Biodiesel.htm

existing wheat or other food crops. Experience in Australia confirms that oil mallee may be harvested by coppicing for over 100 years without negative effects on soils, requiring little or no fertiliser.

Although the figure of 10 Mha is substantially more than the approximately 1.8 Mha of plantation forest currently in Australia[43], it is believed there is more than enough low productivity available in all Australia to meet the total plantation need without competing with existing crops for land or water.

3.3 GENERATION 2 BIODIESEL RESOURCES

Climate change may offer enhanced opportunities for Generation 2 synthetic biodiesel feedstocks. Projections show significant drying and warming in southern Australia and rainfall increases in northern and particularly north western Australia. Currently little of northern Australia is used for cropping outside established areas such as the Ord River Irrigation region. Analysis of its biofuels potential will only proceed when a national biofuels strategy is in place identifying Generation 2 feedstock species and their agronomic climate and soil needs. Candidates include oil bearing shrubs and trees that grow well in similar environments overseas such as *Jatropha curcas* and *Pongamia pinnata* even though the former is classified in some states as a noxious weed. These plants are attractive as their demands for water and fertiliser are low. However plants which are harvested by manual labour in other countries offer the design challenge of a mechanical harvester suitable for Australia. Systematic studies will identify more; already a number of funded and unfunded programs seek to identify new species for specific applications in specific agronomic environments. For example the CRC for Future Farm Industries through its Florasearch Program seeks to identify perennial plants suitable for a range of South Australian biomass applications. Each species needs a detailed agronomic evaluation of water and nutrient requirements, productivity, drought tolerance and potential weediness.

The mineral oil industry produces many high-value products apart from transport fuels. It is said that the industry profits more from these 'high-end' products than from transport fuel. For biofuels to replace mineral oil to any significant extent the emerging industry will need to produce similar 'high-end' products for the pharmaceutical industries.

The following sections outline the principle Generation 2 biodiesel feedstock candidates of interest to Australia.

3.3.1 Microalgae

Although still in prototype stage, algae are a highly promising Generation 2 biodiesel feedstock with recent and fast growing research efforts suggesting that algae may have singular advantages. While needing large water volumes algae can be produced without any soil whatsoever. It has been suggested that algae strains that can reproduce at high rates in salt water may also be found (seaweed is an algae, after all), meaning that fresh water would no longer be a constraint. Despite some scepticism[44], much progress has been made in algae culture using gases high in CO_2 and NO_x rather than air as used in breweries, ethanol refineries and fossil fuel power stations. This adds to the appeal of algae; it potentially offers a GHG sequestration sink to other industries. Algal strains producing high levels of hydrogen, itself a fuel, have also been discovered[45]. In short algae use resources for which there is little competition and with which Australia is well endowed. 'Food versus fuel' ceases to be an issue.

Additionally algae need carbon dioxide to thrive. This presents the attraction of locating a microalgae farm next to an electricity generating plant whose carbon dioxide emissions offer an important microalgal

43 http://www.affashop.gov.au/PdfFiles/inventory_update_final_04.pdf
44 http://www.nanostring.net/Algae/CaseStudy.pdf but also see http://www.nanostring.net/Algae/CaseStudyFollowup.pdf
45 http://www.green-trust.org/2000/algaehydrogen.htm

growth ingredient, potentially increasing overall financial viability. Sustainability becomes increasingly important with the widening range of biomass being converted.

Algae lipid content varies from one to 50 per cent of dry weight, although for some species can be as high as 60 to 80 per cent dry weight. The technology for mass culture, harvesting and extracting oil is being trialled in several countries, including in Australia by the South Australian Research and Development Institute (SARDI), the Victor Smorgon Group, Murdoch University and others.

Algae is ideally grown in closed environments such as plastic pipes, known as photobioreactors, rather than in open pools subject to vagaries of weather and contamination. Moreover air which is high in CO_2, such as that from the exhausts of breweries, ethanol refineries and fossil fuel fired power stations, is beneficial. CO_2 concentration can be much higher than the normal 300 to 400ppm, as can nitrogen oxides (NO_x). Worldwatch Institute 2007 reported that GreenFuel Corp had reduced CO_2 from gas-fired generation plant by 30 to 40 per cent and NO_x by 80 per cent.

Prototype bioreactor tests suggest 140 kL/ha/yr of oil could be produced before the vertical dimension is taken into account. Unlike land crops, which only grow in one plane, algae bioreactors can stack vertically[46]. Thus one ML/ha/yr of oil is feasible, over 150 times that of the prodigious oil palm. Furthermore, due to algae encapsulation, virtually any land can be used that has a water supply. A combination of low productivity, saline water and CO_2 rich exhaust gas could provide ideal conditions.

Algae expeller-pressing techniques can recover 70 to 75 per cent[47] of oil content and, when combined with hexane solvent, a further 20 to 25 per cent can be extracted. Alternatively supercritical (CO_2) fluid extraction can result in near 100 per cent extraction although the plant is considerably more expensive and complex. Algae oil extraction techniques, many still in the research stage, include:

- enzymatic extraction – as with ethanol and other cellulosic alcohols, an enzyme breaks down cell walls to ease oil fractionation. Issues are high enzyme cost and the need for different enzymes for each algae strain;
- osmotic shock[48] – the surrounding pressure on the algae is suddenly reduced to an effective vacuum; the cell walls rupture and the oil is easier to extract. A comparable process introduces a high salt concentration (hyposalinity), which results in a rapid change in water movement of across cell membranes; and
- ultrasound[49,50] – ultrasonic waves result in cavitation (microscopic bubbles) which upon collapsing near cell walls of the algae cause them to rupture as in osmotic shock. This is generally used in combination with a solvent.

Australia can become an international leader in microalgal biodiesel innovation and enterprise development. Its competitive advantages include high solar radiation, a warm climate, substantial acreages of non-arable land, excess saline water and excellent intellectual capabilities in algal biology, aquaculture and engineering and a track record in growing algae commercially for other applications. Microalgae can use waste nutrients, water and carbon dioxide, reducing production costs and, in some cases, the cost of alternative waste disposal or treatment. The potential biofuels business is large as transport fuels are a big component of the economy. Producing 10 per cent of Australia's diesel from microalgae could generate business turnover of around $1.9 billion per annum, mainly in regional areas.

46 http://www.gminsidenews.com/forums/showthread.php?t=55356
47 http://www.oilgae.com/algae/oil/extract/extract.html
48 http://en.wikipedia.org/wiki/Osmotic_shock
49 http://www.gov.pe.ca/ftc/index.php3?number=1006554&lang=E
50 http://ospt.tnw.utwente.nl/pdf/posterbook/posters/WU-Boom-Bosma.pdf

Substitution of fossil fuels with renewable fuels reduces GHG inventories as carbon dioxide is absorbed rather than released. Currently crop-based biodiesel reduces carbon dioxide equivalent by up to 60 per cent compared to mineral diesel (IEA). However GHG emissions from biofuels processing and on-farm fuel, fertiliser and pesticide use and land-clearing remain significant. With microalgal productivity said to be up to 30 times that of terrestrial crops, and with significantly reduced energy and agricultural inputs, GHG reductions are expected to be much more significant. SARDI's desk-top studies, using the then Australian Greenhouse Office (AGO) calculator and published productivity rates, show carbon dioxide savings of 72 per cent or 2.45 kg carbon dioxide per litre of microalgal biodiesel combusted. Microalgae can also yield co-products such as nutraceutical oils, enzymes and industrial products; thus biorefineries that make both bioenergy and bioproducts is the long-term goal for economic and environmental sustainability of the biofuel industry.

3.3.2 Oil mallee

Some crops have the potential to mitigate soil salinity. As earlier noted, oil mallee is one such crop that has been proposed as a candidate by the Oil Mallee Association. Genetic modification of plants to make them more productive as biofuel feedstocks is a technical challenge as well as one of public acceptance.

When suitable plant species such as oil mallee are identified, along with suitable tracts of land, economic systems are needed to harvest, separate and process the products. Promising beginnings have been made with the oil mallee harvester in the WA wheat belt. An innovative pelletising technology for handling and processing products has also been developed. The Oil Mallee Association and associated research projects are developing solutions targeting dryland salinity abatement using perennial deep rooted woody crops like oil mallee to lower saline water tables. Substantial productivity improvement has been achieved through plant selection; more are foreshadowed through systematic plant breeding.

It must be emphasised however that oil mallee's potential lies in its biomass production and drought tolerance rather than oil content. The oil is found in the leaves rather than the seeds making it difficult for the plant to harbour large quantities of oil. Product oil can become a valuable byproduct of potential Generation 2 synthetic biofuel feedstock.

3.3.3 Agricultural residues

Agricultural and forestry residues are more likely to be used for generating heat and electricity rather than as a biofuel resource. However practically all the techniques suited to tree crops (see below) are effective for agricultural residues. The main problems with using residues for fuel production are:

- transport costs – residues are lightweight and diffuse. Collection is time-consuming and expensive;
- contamination – residues can lie in varying weather conditions with soil contamination from fungi, agricultural chemicals, animal manure and the soil itself. Conversion technologies are impacted and transport costs increased;
- need – pulp and paper mills and sugar refineries need residues for heat and electricity; more so than for biofuel feedstock; and
- efficiency – fuel, especially liquid, is a higher energy grade than biomass having much higher energy density. Thermodynamic principles dictate that liquid fuel production from lower grade resources uses a higher proportion of that resource's available energy. Thus, if refineries can use energy from residues for heat or electricity generation, it is more efficient and generally more cost-effective to do so.

3.3.4 Tree crops

Tree crops can be converted into electricity, char or liquid fuel via several technologies. Some new technologies use enzymes called cellulases[51], produced from plants or fungi that directly break down the plant structure into alcohols such as methanol, ethanol, butanol and the like, often producing small amounts of oil as well, especially crops such as oil mallee where it occurs naturally. However different plant species require different and costly enzymes, making production uneconomic. Worldwide research is focusing on better cheaper enzymes.

Pyrolysis has been used for centuries. Wood and other carbon products, including sewage, are heated in the absence of oxygen to 475°C to 500°C. Applying 'slow pyrolysis' about one third of the feedstock weight is released as water (or steam), one third converts to char[52] and one third to a fuel gas which can be further processed to a liquid fuel using, for example, the Fischer-Tropsch process, or burned to generate electricity.

Lehmann, Gaunt & Rondon (2006) report that minor process modifications can alter product compositions and can convert between 40 and 50 per cent of feedstock carbon conversion to char. Although char can itself then be burned for heating, as outlined by Marris (2006), Amazonian Indians for thousands of years have known that char burial leads to substantial crop improvement. Recent testing[53,54] by the NSW Department of Primary Industries shows that as well as improving yields up to 200 per cent, char also reduces agricultural nitrous oxide emissions[55], possibly more so than achieved by replacing mineral oils with biofuels. This benefit adds to more obvious GHG reduction by carbon sequestration, e.g. burying carbon. Amazonian soil tests show that carbon remains in the soil for centuries, making it more effective than tree sequestration and competitive with geosequestration on a long time scale.

Over 1100°C gasification occurs. In combination with the Fischer-Tropsch process it is thus possible to produce diesel fuel from coal (Worldwatch Institute 2007). Currently this combination at large scale is uneconomic for biomass. Gas cleaning of tars and fine particles is problematic. Stucley *et al.* (2004) illustrates differing sized gasification plants costs. He notes that if sited close to gas use, and with carbon tax and dry land salinity reduction payments introduced, the process may be economic depending on the size of the subsidies. Small biomass plants, suitable for large towns, are also economic without subsidy whereas scale economies require coal-fired power stations to be far larger. At still higher temperatures (5500°C or more) plasma is formed[56] and virtually the entire resource transformed into fuel gas. An advantage is that any bacteria or viral contamination (e.g. sewage or hospital waste) is rendered inactive. Small scale prototypes have proven cost-competitive with conventional fuels operating at this temperature[57].

'Fast' or 'flash' pyrolysis has been under active development for the past 25 years. In this process up to 75 per cent of the biomass may be transformed into a liquid, having approximately 60 per cent the energy content of petroleum diesel on a volume-for-volume basis. This bio-oil can be used in various applications, such as for food flavouring but needs to be upgraded for use as a transport biofuel because of its high phenol content. It has been trialled for stationary energy applications and is being researched internationally as a transportation fuel. The Canadian company Dynamotive has built commercial plants up to 200 tonnes per day of biomass and has successfully run a 2.5 MW combustion turbine on this fuel.

Acid hydrolysis of biomass is promoted by the Worldwatch Institute 2007. Developed in Germany a century ago, sulphuric acid is added to plant matter to break it down quickly into sugars for conversion to ethanol. Problems still being researched include arresting the process before it breaks down the sugars using dilute acid under pressure, and the high cost of both the acid and its recycling when using concentrated acid at lower pressures. Almost as many companies are investigating these problems as are researching enzymatic breakdown of plant matter.

51 http://tinyurl.com/25cv43
52 http://www.bestenergies.com/companies/bestpyrolysis.html
53 http://www.abc.net.au/catalyst/stories/s2012892.htm
54 http://www.dpi.nsw.gov.au/aboutus/news/agriculture-today/june-2007/soils-offer-new-hope
55 http://www.energybulletin.net/29250.html
56 http://www.magnegas.com/technology.html
57 http://www.magnegas.com/technology_detail.html

3.3.5 Syngas

Biomass (trees, weeds, shrubs, or almost any other carbon source including sewage) can be converted efficiently into fuel gas (syngas) comprising hydrogen, methane (natural gas) and carbon monoxide using elevated temperature (>700°C) chemical processes. This distinguishes it from biological processes such as anaerobic digestion which produces biogas. Syngas can be used in standard internal combustion engines with only minor modifications and much more efficiently than direct combustion of the original fuel. Although syngas can be further converted into a liquid fuel using the Fischer-Tropsch process[58], it is more energy efficient to compress it for vehicle use, as with LPG and CNG. Technology already exists for operating large trucks on a combination of gas and liquid fuels[59] or even entirely on LPG[60]. Gas fuels have less adverse effect on air quality because they burn more cleanly than liquid fuels with lower toxic emissions (Beer *et al*. 2001) and less impact on human health.

3.4 BIODIESEL RESOURCE DEMANDS

The Australian Bureau of Statistics (ABS)[61] reports that Australian fuel demand in 2006 was 30 GL, about one-third of which was diesel, say 10 GL. Petrol is still the fuel of choice for cars although diesel dominates in the larger engines of long-distance road transport, farm equipment, construction equipment, ships and mining plant. Diesels are preferred for steady power output over extended periods of continuous operation, being around 20 to 25 per cent more efficient than petrol. As fuel prices increase and consumption becomes more relevant, many car buyers have converted to diesel. A decade ago few diesel cars were on the Australian market; by 2007 the figure had become 17 per cent and rising. With current technology, available feedstocks (O'Connell *et al*. 2007) and no major technology or infrastructure changes it is possible to produce around 2.6 per cent of Australia's biodiesel needs using Generation 1 feedstocks.

Biodiesel energy content is currently 80 per cent that of conventional mineral oil. Australia's entire diesel demand could thus be met from a mere 11 kha of land, with around 40 kha providing the entirety of liquid fuel needs. This is extremely small compared, for equivalent production, to the several Mha of trees including regular harvesting. Establishment costs for algae production infrastructure are naturally high and, until saltwater varieties with good oil production rates are found, water too will be an issue. However these challenges may well be far less than those of competing technologies, including conventional fuels as 'peak oil' issues impact supply markets.

This report shows however that replacing a proportion of petro-diesel with biodiesel may be more difficult than replacing the same proportion of petrol. In the event of any serious crude oil shortage it is presumed that government would act to secure available fuel for food distribution, farming and mining. As well Australian refineries may now place increasing emphasis on refining diesel, recognising that Australian oil reserves are diminishing and reliance on imported oil is increasing.

3.5 BIODIESEL CONVERSION TECHNOLOGIES

The two principal conversion technologies for biodiesel are transesterification and hydrogenation. Conventional refineries use hydrogen to upgrade mineral oil product to diesel fuel. However hydrogenation capability will not be present in a traditional biodiesel production facility; hence these will employ transesterification. Moreover hydrogenation of biodiesel is also desirable.

58 http://www.fischer-tropsch.org/
59 See http://www.gfsi.com.au/ and http://www.greencarcongress.com/2007/03/dual_fuel_syste.html
60 http://www.fleeteffect.com/Technologies/Overview/Technologies_Overview.htm
61 http://tinyurl.com/2smdm2
62 http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

Australia, unlike many other countries, does not offer significant subsidies to biodiesel producers; merely a tax excise relief, and this is only available for large producers able to afford the cost of testing their product (testing is required for each major batch and each test costs about $1000). Added to the cost of competing against established oil refineries, and increasing feedstock prices, this has forced some companies (most lately Australian Renewable Fuels, who produced tallow biodiesel) to cease commercial production.

Enzymes

The barriers to biomass breakdown (mainly into bioalcohols but to a lesser extent synthetic biodiesel) are enzyme costs and the need of each plant species for its own specific enzyme. It is claimed that enzymes will be cheaply available 'in about five years' but similar statements have been made for the past 20 years (Ethanol Production Technology Panel 2007).

Pyrolysis

Pyrolysis (and to a lesser extent plasma pyrolysis) may be nearer economical, especially with carbon costs applied, due to reduced GHG and NO_x LCA emissions, increased crop yields and direct soil sequestration of carbon.

The advantages of char have been rediscovered recently but have had little impact in Australia. With climate change and oil security concerns it is possible that Australia could seize the benefits with pyrolysis in combination with char becoming more widespread. This would be assisted by policies that encourage short-term coppicing of plantings such as oil mallee, especially in the WA wheat belt where they can help reclaim land from salinity and reduce erosion.

3.6 FUTURE BIODIESEL TECHNOLOGIES

The technological aspects of production of energy, char and biomass from tree crops by pyrolysis are well understood although newer enzymatic breakdown and acid hydrolysis production techniques are still some years away. Algal biodiesel needs considerable further research for scaling to commercial levels. The quest for enzyme strains that can produce high levels of oil from algae grown in salt water could still take many years.

Industry is unlikely to make long-term investments which assure Australia's transport fuel needs without a national plan and focused incentives. Technological breakthroughs alone cannot assure continuity of supply, although high crude prices may accelerate the drive to bring new technologies on stream. Measures to accelerate such developments may include incentives to make low carbon (or carbon reducing) processes attractive; encourage more fuel-efficient vehicles; encourage low emission electricity generation; and provide logistical arrangements to make best use of biofuels potential.

3.7 RESEARCH AND DEVELOPMENT

Australia needs to continue to focus on the thorough evaluation of candidate biodiesel feedstocks and conversion processes. The work on feedstocks is discussed in more detail in Chapter 4 (Biofuel Feedstocks: a Research and Development Roadmap). It is also well covered in the work of CSIRO for the RIRDC and therefore not repeated here. Australia has expert but limited RD&D capacity. Thus effort must be prioritised and focused to provide the most effective outcomes given the unique natures of the Australian landscape, its climate and its biodiversity.

For biodiesel it would appear that work on algae strains and associated enzymes, albeit appearing costly at present, may yield the most beneficial long term results. Although worldwide RD&D efforts are prodigious, the promise of biofuels from algae, again given Australia's low cost advantages of available land, reliable sunshine, saline or brackish water and CO_2-rich exhaust gases – countered by Australia's vulnerability to mineral oil supplies and pricing - suggest that such research may be a strategic imperative for Australia.

3.8 HUMAN RESOURCES

As with bioethanol, the conduct of theoretical and applied research, the establishment of demonstration projects and the design, construction and operation of biodiesel refineries depends on skilled professionals. Training needs and resources for biochemical and chemical engineers need to be evaluated.

4 Biofuel Feedstocks: a Research and Development Roadmap

- Undertake research on suitable woody perennial plants for biofuel feedstocks to be grown on marginal agricultural land in temperate, subtropical and tropical areas of Australia.
- Enhance RD&D into bioethanol from cellulosic non-food feedstocks.
- Enhance RD&D into biodiesel from algal feedstocks.
- Enhance RD&D to increase crop yields, including GM research.
- Investigate means to streamline access to non-food wood products and wastes.
- Investigate potential feedstock streams from agro-forestry in agricultural areas.
- Investigate potential feedstock streams from forestry waste.
- Study means to introduce and manage a mandated minimum biofuels quantity to underpin Australian production.
- Develop further the Australian Biofuels RD&D Roadmap. RIRDC's work serves as an authoritative base to date.
- Create policies that support start up and scale up of a cellulosic biofuels industry.

4.1 INTRODUCTION

This chapter focuses on current and likely feedstock production leading to development of a Biofuel Feedstocks RD&D Roadmap. Potential feedstock sources are catalogued in Table 2-2 and in Chapters 2 and 3.

The inherent variability of Australian regional climates must be recognised in production planning. This can dramatically influence seasonable production and planned feedstock availability. However this variability becomes another argument for the establishment of a biofuels industry based on lignocellulosic feedstocks deriving from non-perishable woody perennial plants that do not have to be harvested annually. Such harvest flexibility may well have advantages in maintaining constant feedstock flow through the processing plant.

Several reports have been published on the viability of an Australian biofuels industry and some states have inquired into potential industry development opportunities. CSIRO and RIRDC (O'Connell *et al*. 2007) have assessed the quantum of feedstocks and hence biofuels available from current Generation 1 technologies. They report on the GHG consequences of each option and conclude that Australia can produce only a small proportion of its transport fuels from Generation 1 biomass conversion. However significant emission reductions are possible with UCO feedstock as emissions are not re-counted when refined to a transport fuel. Emission savings from other feedstocks are modest to non-existent.

Articles and conference presentations claim, sometimes with more enthusiasm than logic, that Australia could benefit from a stronger 'bio-economy'. New refining technologies may indeed create opportunities for agricultural and forest range including both transport fuels and other high-value products, customarily derived from mineral oils. Rising oil prices and growing scarcity are expected to enhance economic conditions attractive to biorefinery investment.

A useful prototype on-line resource is the Bioenergy Atlas of Australia (Bugg *et al*. 2002). This web accessible tool[63] was designed to aid industry planning, conjoining the best available data on resources, industry and infrastructure using online GIS technology. The project was undertaken collaboratively by the University of Adelaide, the Bureau of Rural Sciences, the Australian Greenhouse Office and the Joint Venture Agroforestry Program.

The Atlas has two main components: a Geographic Information System (GIS) providing online mapping and query capabilities and a Decision Support System (DSS) to perform pre-determined analyses. The DSS can identify the locations and extent of bioenergy resources that meet specified criteria, for example processing residues within 50 kilometres of roads and population centres. As well as the GIS and DSS, more detailed information is given for the south-eastern catchments of the Lachlan and Goulburn-Broken rivers. Further user-consultative development will include Australia wide industry data.

A new and improved Bioenergy Atlas has been developed (Bugg 2007). This incorporates more up-to-date data and has other enhancements. The creation of maps online is simpler with improved quality and enables an on-line reader to make a map for selected themes and regions. Maps can be customised and queries performed using the Geographic Information System (GIS) to incorporate a choice of data.

New data compiled for inclusion in the Atlas includes the extent and type of forest, existing plantations, and the potential distribution of plantations of selected tree species. Data on the location of renewable energy plants and biomass database sample sites was added, along with updated data for wood processing facilities.

4.2 FUTURE DIRECTIONS: LESSONS FROM THE US ROADMAP

The US, with its huge investment in biofuels, provides a comprehensive model for Australia, especially in biofuels RD&D. The recent US Report, *Roadmap for Bioenergy and Biobased Products in the United States* (2007), is summarised below. This document sets out to:

- define a set of achievable quantitative goals; and
- develop an RD&D strategy to achieve those goals.

Specifically its objectives are to 'identify measures needed to advance biomass technologies and enable economically viable, sustainable and socially desirable biobased industries to be established'. The US Roadmap is put forward as a reference document for industry, academia and policy makers to plan, fund and implement the steps necessary to achieve these goals.

Some comment on the latest US Roadmap is required. The earlier US Roadmap reflected the market-share goals of the 2002 Expert Committee Report, namely:

- biofuels: four per cent by 2010 (exceeded by 2006 for bioethanol and biodiesel);
- biopower: four per cent by 2010 (unlikely to be met); and
- bioproducts: estimated to have increased from five per cent in 2002 to eight per cent in 2005 (but difficulties in obtaining hard data).

Achieving the biofuels four per cent target by 2006 led to the US President's interim 'Twenty in Ten' declaration that year, with the objective of "offsetting 20 per cent of US petroleum consumption by 2017 with alternative and renewable fuels and vehicle efficiency".

The US Report makes a series of technical and policy recommendations to achieve the 'Twenty in Ten' goal, as well as identifying its major barriers. The technical barriers at which specific RD&D programs

63 http://adl.brs.gov.au/mapserv/biomass/index.phtml

should be focused are related to feedstocks, processing and conversion, and infrastructure (transportation, storage, distribution). Non-technical barriers relate to end-use markets, region-specific barriers in the US, as well as lack of consistent government policies, availability of finance, regulatory barriers and issues of public education/awareness. Parallels with Australia are evident and useful lessons can be drawn.

4.3 ROADMAP FOR AUSTRALIAN BIOFUELS

Australia's biofuels roadmap is a complex mix of enormous potential and great uncertainties. In such circumstances it is relatively easy to claim that one crop or another, or one technology or another, will be the answer, at least in part, to Australia's future transport fuel needs. The missing part of the roadmap is the hard scientific knowledge and analysis of the resource alternatives, projected onto the canvas of Australia's most likely climate map for decades ahead.

Excellent work has already been carried out in Australia but much more is required to evaluate the impacts of projected climate changes. Many more crops need to be studied before reliable assertions on viability, sustainability and the most appropriate use of land and water resources can be made.

An exception is the sugar industry. Brazil has shown its ethanol industry to be sustainable and efficient. However rainfall changes are not predicted to affect Australia's sugar producing regions and sugar may not be regarded by some as part of the 'food versus fuel' controversy. CSIRO projections show rainfall reduction is possible in on the coast with increased cyclone risks.

Reliable feedstock production at sustainable high levels (for process economies of scale) and at an economic cost attractive to both farmers and biofuel producers are essential components of a future successful industry. As set out in Table 4-1, Australia should build on its world-class strengths in plant breeding and agricultural research with a specific focus on feedstocks for Generation 2 processes. In the short term this should involve maximising the potential value of existing raw materials, while in the medium to longer term the focus should shift to the development of new 'energy' crops and novel sources of biomass (including algae). Some of this new feedstock technology may well be unique to Australia and its geographic conditions, and its successful development could well provide significant potential for future international RD&D collaboration and licensing.

Table 4-1 provides a simple thematic roadmap showing how Australian RD&D, on the lines set out above and combined with good policy, could lead to the achievement of sustainable biofuels goal for Australia.

Table 4-1 RD&D Roadmap – key issues for feedstocks

Near term (0 to 3 years)	Medium term (3 to 5 years)	Long term (5 to 10 years)
1. Focus on efficient recovery of cellulosic residues from existing sugar and starch crops. 2. Identify region-specific sources of these crops and residues with potential for medium and large-scale bioethanol production. 3. Identify and evaluate potential new biomass crops for cellulosic ethanol. 4. Initiate RD&D on new GM 'energy crops' (high biomass yield, modified C5:C6 and lignin composition, drought tolerance, insect resistance, 'in planta' enzyme expression). 5. Screen for algae with high lipids or hydrocarbons suitable for biodiesel and aviation fuels.	1. Continue field trials for large-scale production of new biomass crops. 2. Develop improved varieties of new biomass crops through traditional plant breeding. 3. Continue RD&D and initiate small-scale field trials on new GM 'energy crops'. 4. Develop algal biomass production at pilot scale under various environmental conditions.	1. Establish new GM energy crops following field trials in a range of different climatic and geographic conditions. 2. Further develop GM crops in view of processing requirements. 3. Develop full-scale algal biomass production for biofuels and incorporate improved strains in response to processing requirements.

4.4 RECOMMENDATIONS

Based on previous roadmaps, the key RD&D recommendations and the barriers to be overcome, if Australia is to achieve a sustainable biofuels goal, are summarised below.

4.4.1 Feedstock production and yields

Government should provide RD&D funding to increase yields of existing crops that are or could be used for biofuels. This is likely to involve genetic research to develop enhanced conversion properties and identification of new crops, as well as genomic research to modify plant genes in different species to enhance specific traits such as resistance to pests, growth at high and low temperatures, and drought resistance. Modification of lignin characteristics, as well as alterations in hemicellulose:cellulose lignin ratios in plants could also enhance process efficiencies. Other issues concerning feedstocks are GMO acceptance for new GM feedstocks, the need for new harvesting strategies, processing technologies, resource management and sustainable feedstock production as well as achieving economic viability in particular regions.

A study is recommended on the most effective way to introduce a mandate on the minimum total quantity of biofuel to be produced and sold but without causing unnecessary transportation of fuels merely to achieve the mandated level. The study should investigate the relative effects of locating biofuel processing plants close to feedstock source or close to mixing location so that mandates or incentives can avoid unproductive side-effects.

Research is also needed to explore measures to streamline access to wood waste on both private and public lands, providing appropriate environmental safeguards are retained. Increasing access to wood products and wastes are essential to long-term biofuels development. Again RIRDC has been and is funding R&D into feedstocks, while the SCU has a formidable team working in this general area, including on native species for bioenergy and biofuels.

4.4.2 Feedstock processing and conversion

RD&D for the processing and conversion of biofuels from cellulosic feedstock should be accelerated to reduce costs and environmental impacts and to increase the range of potential feedstocks. Specific barriers in the pre-processing and conversion of such feedstocks include:

- relatively high enzyme costs and slow rates of enzyme hydrolysis. Further research is needed via microbial screening and protein engineering to enhance enzyme characteristics although some major improvements have already been made;
- the need for efficient micro-organisms (natural or genetically engineered for fermentation) capable of high yields of ethanol from the products of cellulose breakdown;
- the scalability of new technologies needs to be proven given the importance of achieving high capacities with economies of scale. However smaller modular size processes may be applicable in certain cases to minimise feedstock transportation and fuel distribution costs; and
- flexible conversion technologies are needed for large scale processing of range of raw materials (cellulosic and non-cellulosic) and also to interface with existing grain and sugar based production facilities.

Thermochemical research must also be accelerated to produce petroleum, diesel and higher value chemicals (e.g. propylene, ethylene, and other short-chain compounds). In particular hydrogen production is now largely derived from mineral oil since the price of electrolysis is prohibitive and hydrogen will need to be formed biosources such as biodiesel or residues.

Government needs to create policies that will support the start-up and scale-up of the cellulosic biofuels industry, including the establishment of significant areas of energy and byproduct crops (non-food), including harvester development.

Additional scientific, engineering staff and process operators need to be trained to create an effective work force to meet the needs of this potentially rapidly growing Australian industry.

5 Bioconversion Technologies: a Research and Development Roadmap

- Bioethanol from waste lignocellulose and biodiesel from algae appear to be the candidate products most worthy of Australian RD&D support. Dedicated energy crops including coppicable woody plants are also worthy of consideration although with a longer path to market.
- Australia, although a small player in world biofuels RD&D, has unique advantages (e.g. huge tracts of level poor-quality land, magnificent sunlight, abundant saline water, readily available carbon dioxide, geographic location and minimal indigenous competition) that warrant strategic development of products for which these advantages are critical.
- There is a significant case for stimulatory government support for investment in specialist harvesting technology for coppicable woody plants. There is the opportunity to innovate (e.g. improve feedstock quality by reducing soil content through harvester design) although it is reasonable to assume this would be funded by the private sector.
- The technical and economic feasibility of harvest and transport needs to be assessed carefully for new feedstocks. Such studies will generally require cross-discipline and cross-organisation collaboration and life-cycle analysis.
- Collaborative research networks, currently fragmented and competing for limited grant funds, need to be enhanced if bold and rewarding objectives are to be met.
- The work of the Rural Industries Research and Development Corporation (RIRDC) through its Bioenergy, Bioproducts and Energy Program is of critical importance in stimulating the production of expert reports and coordinating biofuels RD&D within the overall spectrum of Australia's rural industries. However funding is very limited.
- The National Collaborative Research Infrastructure Strategy (NCRIS) managed by Ausbiotech is a worthy existing program that warrants ongoing support and enhanced industry involvement.
- The Department of Resources Energy and Tourism's recently announced Second Generation Biofuels Research and Development Grant Program (Gen 2) is strongly commended.
- Australia already has considerable strength and diversity in niche areas of current Australian biofuels RD&D; those showing economic promise warrant sustained Government and industry support.
- A Cooperative Research Centre (CRC), while attractive for specific purposes, would not be the mechanism to draw together or fund the diverse range of Australian RD&D initiatives or engage all relevant Australian researchers.
- Where it is neither viable nor economic for Australia to take a leading RD&D role, but nevertheless has economic interests and can contribute, collaborative engagement with international centres of biofuels RD&D excellence is strongly encouraged.
- To this end it is recommended that Australia become a member of the Global Bio-Energy Partnership (GBEP), a G8 initiative.
- Furthermore Australia's ongoing participation in international RD&D collaborative agreements such as IEA Bioenergy Task 39 (biofuels), Task 34 (pyrolysis) and Task 42 (biorefineries) is also strongly supported.

- To draw together and better coordinate and fund the several worthy programs currently supporting Australian biofuels RD&D, a national Biofuels Institute is recommended. This would help create critical mass in the most promising areas of Australian RD&D and achieve better integration and collaborative endeavour of Australia's many RD&D support initiatives. Most importantly it would help to align Australian RD&D with national policy objectives and contribute authoritatively to related policy settings.

5.1 INTRODUCTION

With limited resources and modest long-term policy directions (to which this report is aimed to contribute) it is unlikely that Australian researchers will be able to compete, other than in specific niche technologies, with nations whose policies promote positive investment in production and research and well-funded government subsidised RD&D activities underpin sustained future investment. Nevertheless a strategy for Australian investment in biofuels conversion RD&D, based on Australia's evident natural advantages (e.g. considerable tracts of poor quality land, abundant saline water, magnificent sunlight, limited indigenous liquid hydrocarbons and a good geographic location), can undoubtedly be formulated with a view to cementing such strategies within a long-term stable policy framework. This aspect is further developed in Chapter 7 of this report.

The purpose of this chapter, in respect of bioconversion technologies in the words of the Terms of Reference (see Appendix A) is *"to identify a coherent approach to the RD&D pathways … for biofuel industry development in Australia"*. Such an approach could be expected, it is hoped, to position Australia's biofuels researchers and emerging businesses as significant participants in Australia's energy future, a future in which biofuels can make a significant contribution to the transport fuel mix. Such a strategy must however fit within a framework of overarching principles and complement (rather than reproduce) the strategies of other nations with possibly quite different drivers.

Demonstration capability is also an essential element of this strategy. It is the precursor to attracting investment, the lifeblood without which no emerging industry can flourish. Until recently Australia had a significant lack of any unified national demonstration capability. With the advent of the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS) there is now, through the Biofuels Sub-Program with A$14 million over five years (2007–11), the promise of demonstrably more coherent and productive outcomes.

The scope of bioconversion technologies covers harvesting through to biofuel products, the value chain from field to fuel. The chapter introduces and briefly outlines the overarching principles of each processing step, namely harvesting, transport, process technologies and refining and identifies the relevant linked research activities.

Life-cycle analyses are discussed in Chapter 6. It outlines the RD&D activities of other nations where relevant to current Australian RD&D. The summary of Australian bioconversion RD&D is not an exhaustive or critical review but provides an overview which demonstrates Australian capabilities and current directions. The chapter concludes with a proposed overview of a RD&D Roadmap, linked to projected timeframes, to form the basis of a coherent forward RD&D strategy for Australia. It is recommended, once government agreement has been gained on the overall biofuels RD&D strategy, that a series of focused stakeholder workshops be convened to help develop the Roadmap in detail and determine the precise milestones to be used for performance accountability.
Prima facie Australian RD&D programs must create and support know-how and intellectual property (IP) focused on the Australian biofuels industry. Such programs should firstly target challenges either unique to Australia or in which Australia can develop a clear competitive or first mover advantage.

Strategic but formalised international collaboration can then access information on major technology and policy developments, allowing Australian researchers to position for second mover advantage; to identify and improve on best available technology and identify IP niche areas. The capture of niche IP, especially with potential for worldwide scalability, should be a driver of Australian RD&D investment strategy. An IP portfolio of novel processes and bioproducts would provide opportunities for Australian enterprises to become significant technology providers in the biofuels production and refining. CSIRO, with its highly sophisticated treatment of and protection skills for Australian derived IP, should be invited to contribute to the formation and management of such efforts.

Before moving to a more detailed discussion of transport biofuels RD&D in Australia it is first important to identify the overarching agencies to which RD&D responsibilities in the domain have been entrusted. These include:

- the Rural Industries Research and Development Corporation (RIRDC);
- the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Energy Transformed Flagship; and
- Bioenergy Australia.

The Rural Industries Research and Development Corporation (RIRDC)

RIRDC biofuels activities include three main components:

- leading the national RD&D plan for bioenergy and biofuels for the Government's Primary Industries Standing Committee;
- supervising the RIRDC Bioenergy, Bioproducts and Energy RD&D program; and
- managing the finances and administration of Bioenergy Australia.

National planning and coordination of RD&D and associated extension research, development and engineering (RD&E) is critical to the competitiveness of Australia's primary industries. Recently the Primary Industries Ministerial Council and Council of Research and Development Corporations (RDCs) provided RIRDC with the unprecedented opportunity to develop and implement new RD&D plans under the National RD&E Framework for Primary Industries. The Framework, which will improve national RD&E effectiveness through cooperation, information sharing and funding, has been endorsed by State and Federal Ministers and stakeholders. Planning will engage RDCs as lead agencies, supported by state agencies.

RIRDC's Bioenergy, Bioproducts and Energy RD&D program facilitates development, adaptation and sustainable implementation of bioenergy and bioproduct systems in rural Australia to address carbon sequestration, GHG emissions and fuel security.

RIRDC is Bioenergy Australia's lead organisation, managing its finances and administration.

CSIRO Energy Transformed Flagship

CSIRO, within its Energy Transformed Flagship, conducts an evolving range of RD&D projects outlined later in this chapter.

Bioenergy Australia

Bioenergy Australia, a government-industry alliance comprising some 70 members, actively fosters the development and use of biomass for energy, transport fuels, chemicals and other value-added products by promoting biomass as a sustainable energy source. Bioenergy Australia collaborates, coordinates and informs, acting as the focus and forum in Australia for bioenergy and biomass development. Its annual conferences attract significant interest within the overall bioenergy domain.

5.2 OVERARCHING PRINCIPLES

Social, economic and environmental sustainability is fundamental to any consideration of bioconversion technologies. It is the overarching development principle for biomass-to-energy agro-industrial enterprises. While internationally acceptable sustainability criteria are still evolving, the Clean Development Mechanism of UN Framework Convention on Climate Change and the World Bank Prototype Carbon Fund use their understanding of this principle as the primary filter for investments in all renewable energy industry developments. Such developments are considered sustainable if:

- the production chain GHG balance is favourable;
- biomass production is not at the expense of existing carbon sinks, both vegetation and soil;
- biomass production does not endanger food supply and existing business activities such as local supply of energy, medicines or building materials;
- biomass production has no negative impact on biodiversity (protected or vulnerable biodiversity is unaffected or strengthened);
- soil and soil quality are retained or improved;
- ground water and surface water are not depleted and water quality is maintained or improved;
- air quality is maintained or improved; and
- production and processing of biomass contributes to prosperity and social wellbeing for employees and local populations.

Among the sustainability criteria, the greenhouse balance of biofuel production chains and competition between food and energy crops for arable land has received most attention in public forums. These factors will strongly influence Australian Government policy and private sector investment.

A broad consensus view among climatologists and climate scientists is that on the balance of probabilities anthropogenic GHG emissions (principally carbon dioxide) are impacting on climate. It is believed that this impact will threaten some ecosystems and economies over the decades ahead unless steps are taken now to limit their seemingly near-exponential growth. It is also widely held that there is no single solution for reducing these emissions. Pacala and Socolow (2004) provide an analysis of the application of current technologies towards such limitation; they describe 15 complementary actions (denoted 'stabilisation wedges'), all of which need to be deployed to meet the world's growing energy needs while reducing GHG emissions. Pacala and Socolow (2004) describe a biofuels stabilisation wedge as equivalent to production of around 34 Mbbl/day of fossil-carbon free ethanol by 2054, some 50 times the 2004 global ethanol production. Such a target, based on Generation 1 technologies, would require 250 Mha committed to starch and sugar crops; about one-sixth of the world's cropland and a commitment which would undoubtedly compromise food production. Although the analysis is restricted to conventional starch and sugar conversions to ethanol, it indicates the enormity of the challenge if biofuels are to contribute significantly to alleviating the impacts of climate change.

The 'fuel versus food' issue is raised universally. The OECD Roundtable on Sustainable Development in the 2007 report, titled *Biofuels: Is the cure worse than the disease*, addressed two questions:

- Do the technical means exist to produce biofuels in ways that enable the world to meet demand for transportation energy in more secure and less harmful ways on a meaningful scale without compromising the ability to feed a growing population?
- Do current national and international policies promoting the production of biofuels represent the most cost-effective means of using biomass and the best way forward for the transport sector?

The authors estimate that Generation 1 and 2 biofuels would capture only 13 per cent of the world's transportation fuel market, about half that of other conservative estimates, noting that the logistical challenge of transporting biomass imposes a cost floor. While the conclusions were not overly supportive of biofuels, the report acknowledged that biofuels from tropical regions have a considerable cost advantage over those from temperate regions, and that nations with established sugarcane industries have a considerable supply advantages.

Rabobank, a worldwide agribusiness financial service, predicts that within the next five years food and energy markets will become increasingly related. The Generation 1 'fuel versus food' feedstock issue will prompt regulatory changes that could lead to a certifiable chain of feedstocks custody between sustainable production and processing, so altering market conditions by increasing feedstock prices and reducing supply. Rabobank also predicts that Generation 1 feedstocks will increasingly require more arable land, but that these increases will be small in comparison to those committed to meat production. Up to 2012 Generation 2 biofuels will be available only on a very small scale but, driven by changing market conditions and supported by new RD&D, will then expand rapidly (Hansen 2008). The 'food versus fuel' issue will undoubtedly limit the growth of Generation 1 biofuels.

The foregoing discussion on sustainability and related international developments, such as the UN Climate Change Conferences, supports the inevitable conclusion that Generation 1 biofuels have limited growth prospects. Moreover, it appears inevitable there will in the next decade be some form of universal carbon trading scheme. RD&D advice needs therefore to recognise these issues and help to underpin policies that support sustainable biofuels development, rather than all biofuels. The scientific community also must focus meaningfully on sustainability. Projects, such as those undertaken by CSIRO Sustainable Ecosystems that critically use sustainability criteria to assess proposed and existing biofuels enterprises, are worthy of continuing support.

5.3 HARVESTING AND TRANSPORT LOGISTICS

Feedstocks contribute significantly to biofuels production costs, often up to one-third including agricultural practices, harvesting and transport. This section deals only with harvesting and transport; biofuel feedstocks having been covered in Chapters 2, 3 and 4.

Biomass harvesting economics are clearly impacted by the design and selection of harvesting machines; at higher harvesting rates fewer larger units are needed. Agricultural residue harvesting, such as wheat stubble and sugarcane field trash, as well as forestry residues, employ well-developed technologies. Likewise harvesting dedicated energy crops such as giant reed (*Arundo donax*), sorghum, hemp or kanaf requires little innovation. However this is not the case with woody biomass coppicing. The thermal processing of mallee for eucalyptus oil, char and electricity has been demonstrated by VERVE Energy in Western Australia; mallee culture in the wheat belt has delivered significant soil salinity management benefits to the industry (Harper *et al.* 2007). However the lack of suitable harvesting systems has stalled development of this emerging opportunity.

Australia has a proud history of harvester innovation. Sugarcane chopper harvesters were first developed by the Australian sugarcane industry to move from manual harvesting. Continuing improvement by Australian manufacturers such as Austoft Industries led to harvesters capable of over 100t/h before manufacture passed to Brazil, closer to growing markets. No such obvious driver exists for mallee or other coppice energy crops; thus the costs and risks of mechanical harvester development are a barrier to enterprise development. There is thus significant potential value in harvesting technology RD&D support for coppicable woody plants.

Transport logistics has significant uniquely Australian elements including the spatial arrangement of biomass production (long narrow strips of arable land relatively close to the ocean) and long haulages between production, processing and markets. Optimal transport systems warrant industry-focused RD&D.

Australia has significant capabilities in transport logistics. For example Central Queensland University (CQU) has produced several confidential reports for the Australian sugar industry as well as public domain material (Pinkney 1990) on biomass rail transportation. CSIRO too has contributed work on biomass road transport (Higgins *et al*. 2006).

CSIRO and the Sugar Research Institute (SRI) collaboration has led to analysis of sugar industry whole of crop harvesting economics (Thorburn *et al*. 2006), in which income from electricity and Renewable Energy Certificates (RECs) was weighed against co-generation, the agronomic benefit of trash retained in the field and the costs of whole crop harvesting and transport with separation at the mill. Inputs to the analysis came from scientists, economists and engineers; a good example of cross-discipline, cross-organisation work from a well networked RD&D community.

5.4 BIOFUELS PROCESS TECHNOLOGY

While Generation 1 biofuels are believed to have limited long-term growth prospects due to resources competition, short-term growth is still likely with opportunities for innovation. However worldwide attention is now more strongly focused on Generation 2 processes and products, a field in which Australian RD&D is growing but still fragmented. In both bioethanol and biodiesel it is important also to distinguish between the two major technological process directions – thermochemical and biological.

For ease of comprehending the many active RD&D programs, worldwide but especially Australian, the further sub-sections of this chapter are set out as follows:

- bioethanol processes (5.5)
    - Generation 1 bioethanol processes (5.5.1)
    - Generation 2 bioethanol processes (5.5.2);
- biodiesel processes (5.6)
    - Generation 2 biodiesel processes (5.6.1)
    - Generation 2 biodiesel processes – microalgae (5.6.2);
- biorefining – value added products (5.7);
- linked research activities (5.8); and
- RD&D Roadmap (5.9).

It is first useful to illustrate, in Figure 5-1, the primary technological elements and interrelationships of the overall domain.

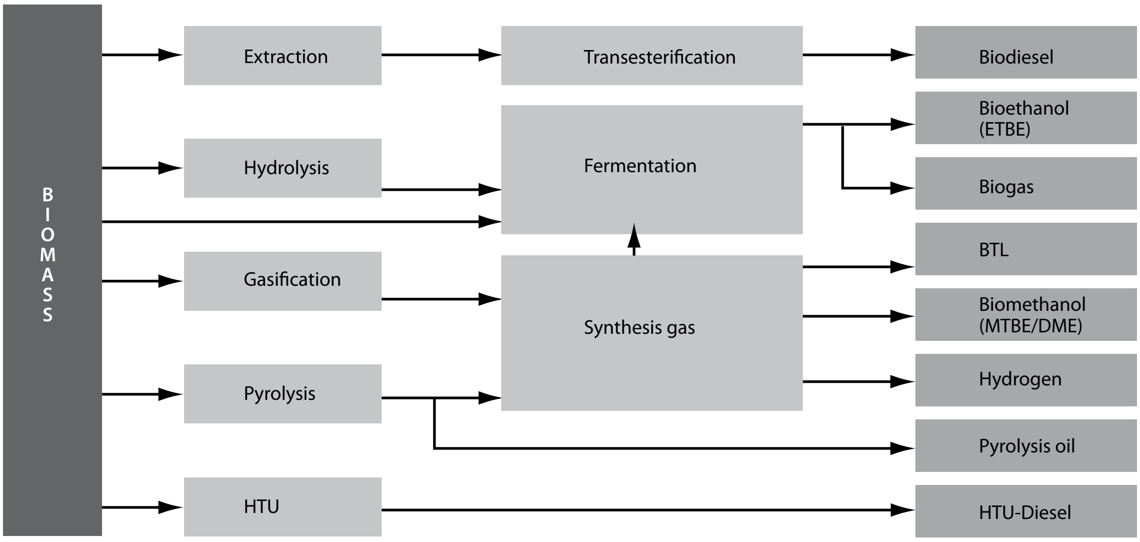
5.5 BIOETHANOL PROCESSES

5.5.1 Generation 1 bioethanol processes

The most attractive value-adding RD&D prospect for Generation 1 biofuels is towards improving yields and processing characteristics of feedstocks, as covered in Chapter 4. While new Australian Generation1 biofuels are still in their infancy, the processes and manufacturing facilities internationally are relatively mature. In mature process industries research is largely funded by industry and focused on improving capital utilisation, increasing throughputs, improving process efficiency, lowering input costs (especially energy inputs) and developing co-products. While focused Generation 1 research would undoubtedly yield benefits it is unlikely to be funded to any extent by the still fledgling Australian industry.

Instead the Australian Generation 1 biofuels industries will initially adopt best foreign technology with process research remaining offshore with technology providers. With this strategy Generation 1 1 biofuels contribution to fuel mix can grow until constrained, if not by feedstock supply (as is the case with biodiesel) then by appropriate sustainability policies. As the industry grows, so too will market

Figure 5-1 Schematic for Generation 1 and 2 feedstocks, technologies and biofuel products



competition – and the need to innovate for competitive advantage. As Generation 2 biofuels become technically and economically feasible biofuels suppliers, the adopters of Generation 1 technology may integrate or transition to Generation 2 technologies and fuels. Research may be needed to accelerate and effect this change. In the medium term there will be a need for Generation 2 biofuels process research to improve capital utilisation, lower input costs and develop co-products. This research is likely to be funded by industry.

5.5.2 Generation 2 bioethanol processes

Generation 2 bioethanol research is characterised worldwide by fast moving RD&D and strong commitment across private and public sector groups. Current work in the USA, Canada, Europe and Australia is briefly outlined below.

USA

At the forefront of US biofuels RD&D is the Department of Energy (US DOE) Biomass Program which aims to advance biofuels through management of an extensive RD&D portfolio that engages industry, university and government research providers.

The portfolio covers biomass supply, biomass fractionation to cellulosic and lignin components, and fermentation, thermochemical conversion of biomass to synthesis gas, further value-adding to the products of all process platforms and integration of platforms into biorefineries. The US DOE Biomass program aims to establish a Generation 2 biofuels industry and enhance national energy security.

In February 2007 the US DOE announced it will invest up to US$385 million for six biofuel projects over four years. These projects are outlined in Table 5-1. The technologies have been demonstrated at the pilot scale and are supported by economic feasibility data. Combined with industry cost sharing, more than US$1.2 billion will be invested in these six projects. Subsequently an additional US$200 milllion of competitive funding has been added for pilot demonstration of technologies that have some proof of concept, US$23 million for research on more efficient ethanolic fermentation micro-organisms and US$405 million for three new bioenergy strategic R&D centres (US DOE press releases 2007).

Table 5-1 US DOE-funded demonstration projects

Project participants	DOE funding	Technology
Abengoa Bioenergy (Abengoa Bioenergy R&D, Abengoa Engineering, Antares Corp & Taylor Engineering)	US$76 million	Steam explosion, saccharification & fermentation; gasification
Alico Inc (Bioengineering Resources, Inc, Washington Group International, GeoSyntec Consultants & BG Katz Companies/ JAKS)	US$33 million	Gasification & syngas fermentation
BlueFire Ethanol Inc (Waste Management, Inc, JGC Corporation, MECS Corporation, NAES & PetroDiamond)	US$40 million	Concentrated acid hydrolysis & fermentation (Arkenol)
Broin & Associates Inc (E. I. du Pont de Nemours and Company, Novozymes North America, Inc & National Renewable Energy Laboratory)	US$80 million	AFEX, saccharification & fermentation; integration into existing dry mill
Iogen Biorefinery Partners (Iogen Energy Corporation, Iogen Corporation, Goldman Sachs, and Royal Dutch Shell Oil Company)	US$80 million	Steam explosion, saccharification & fermentation
Range Fuels Inc (Merrick and Company, Praj Industries Ltd, Western Research Institute, Georgia Forestry Commission and Yeomans Wood and Timber)	US$76 million	Gasification & conversion of syngas to ethanol and methanol

Canada

Sustainable Development Technology Canada has announced C$500 million funding recently for demonstration-scale facilities for next-generation biofuels with 40 per cent funding of eligible project costs.

Europe

In Europe similar initiatives involving EU consortia of public and private sector RD&D providers are being funded through the European Union Framework Program. For example Nedalco announced that from the end of 2008 a Generation 2 bioethanol plant will be operational producing 200 ML/yr bioethanol (2.5 per cent of the European market). The process will use a patented yeast capable of converting the major sugars in wheat bran to ethanol and has been established with an investment of €150 million including Dutch Government/Euro Fund support of €60 million. In addition BornBioFuel is constructing a US$50 million demonstration plant in Bornholm, Denmark that will produce ethanol, hydrogen, heat and power and a pellet solid fuel residue from grasses, woodchips and garden waste by wet oxidation and fermentation processes.

European initiatives also include projects with national government support, for example Choren's partnership with Shell, VW, Daimler and the German government. Choren's biomass to Fischer-Tropsch liquid fuels demonstration in Freiberg, Germany is capable of producing 15,000t of synfuel per annum and a 200,000t/yr plant is planned for commissioning in 2011. On a strictly commercial footing Europe has significant investment in Generation 1 biodiesel, a more modest investment in Generation 1 starch and sugar to ethanol plants, and a lignocellulosics to ethanol demonstration plant in Salamanca, Spain. The EU driver appears to be GHG reduction to fulfil Kyoto Protocol obligations rather than to enhance energy security.

Australia

Australian Generation 2 research activity is significant but highly fragmented. Unlike the US DOE Biomass or EU Framework programs, there is relatively little Australian RD&D coordination, with fragmentation exacerbated by competition for limited public (grant) and private funding. However the recent NCRIS initiative (Biofuels Sub-Program) has partly addressed this problem by providing funding for basic infrastructure for core RD&D activities and pilot plant facilities. Specific examples of Australian RD&D work currently in hand are briefly described below.

(a) Biomass pre-treatment and enzyme hydrolysis

Macquarie University – cloning and gene expression

Bergquist at Macquarie University is one of the pioneers of cloning and expressing cellulose and xylanase genes from extremely thermophilic organisms and other extremophiles. He has published extensively on the diversity of thermophilic fungi (e.g. Sunna & Bergquist, 2003) for cellulose and hemicellulose hydrolysis and the program continues with NCRIS support.

Monash University – biomass fractionation and cellulose saccharification

Macfarlane at Monash University, in collaboration with Upfal at Viridian Chemical Pty Ltd, have patented a novel process for pulping biomass with ionic liquids.

Queensland University of Technology (QUT) – ionic solutions

Edye and Doherty at Queensland University of Technology (QUT) have patented a novel process in which ionic liquids completely dissolve biomass and anti-solvents to separate the cellulose, hemicellulose and lignin components. Since the cellulose component is amorphous, saccharification can be achieved with greatly reduced amounts of enzymes or in dilute acid. Such processes have potential as biomass pre-treatment strategies and are potentially disruptive technologies. Their development is being funded by the Queensland Government.

Another QUT team led by Dale is involved in studies to express various cellulolytic genes in plants to facilitate their use as biomass feedstock in fermentation. This program is being carried out in collaboration with the multinational Syngenta.

Southern Cross University (SCU) – application of molecular techniques

Based on an extensive track record involving the application of a range of molecular techniques to crop enhancement and plant disease protection, Henry is focusing on their application to various biomass sources and to their use as feedstock for biofuels. Such an approach may have considerable potential in the development of indigenous biomass/energy crops unique to the Australian environment.

Sydney University – sub and supercritical fractionation of biomass

Maschmeyer at Sydney University with NCRIS support is developing a process which includes sub- and supercritical stages for biomass fractionation for fermentation and/or and direct conversion of various biomass feedstocks into liquid fuels (Licella Process).

CSIRO – biofuels research programs

CSIRO has 17 FTE research staff engaged on a sustainable biomass production research program that comprises the following research streams: sustainable biomass production, biomass conversion using enzymatic processes, lignocellulosics to crude, algal pre-feasibility, algal speciation, thermal and fluids engineering.

(b) Biomass fermentation

The benchmark for ethanol production by fermentation of carbohydrates is still the use of industrially robust strains of *S. cerevisiae* with adaption to the industrial environment including efficient conversion of sugars, ethanol and low pH tolerance, and low nutrient requirements. While bacteria such as *Z. mobilis* and genetically modified micro-organisms show considerable laboratory promise to overcome barriers to cellulosic fermentations (viz pentose fermentation and tolerance to byproducts of fractionation), their use in larger scale industrial settings has had limited success. However their large-scale use is now under evaluation by several US companies and there are significant opportunities to innovate in this field. The centres of Australian RD&D active in this field are highlighted below.

Australian Wine Research Institute (AWRI) – yeast fermentation

Varela and co-workers at the Australian Wine Research Institute (AWRI) have extensive knowledge of yeast fermentation for wine production. For example, studies on assimilable nitrogen impacts on secondary metabolite production in grape musts fermentations (e.g. Vilanova *et al*. 2007). It seems reasonable that this could be applied to biofuels production by fermentation.

Macquarie University and Microbiogen – non-recombinant yeasts

Bell and Attfield at Macquarie University and Microbiogen Pty Ltd have expertise in the genetics of industrial yeasts and are developing Saccharomyces sp. with enhanced ability to convert pentoses to ethanol. Microbiogen uses an approach that produces yeast strains that are not considered genetically modified by the Office of the Gene Technology Regulator (OGTR). They claim to have matched the rate of xylose conversion to ethanol of the best genetically modified yeasts (viz. 4 g/L/h) (Attfield & Bell, 2003 & 2006).

University of New South Wales – high productivity fermentations

Rogers and his team at the University of NSW has world-wide recognition for their pioneering work on glucose and pentose fermenting *Z. mobilis* strains which have the ability to produce ethanol faster and more efficiently than yeasts. The group has collaborated with US, European and Australian industry on this research (Rogers *et al*. 2007). Infrastructure support for further strain development and fermentation optimisation for Generation 2 processes is currently NCRIS supported.

University of New England (UNE) and NSW Dept of Primary Industry –biomass evaluations

The evaluation of a range of various raw materials for Generation 2 biofuels is the major focus of a project involving UNE, the NSW Department of Primary Industry (DPI) and UNSW currently supported by a NSW Climate Action Grant. Both agricultural and forestry residues as well as high yield energy crops are being studied to determine the optimal conditions for their enzyme hydrolysis and subsequent fermentation. Strain improvement strategies are being initiated to overcome any potential inhibitors produced in pre-treatment.

(c) Pilot scale evaluations

A pilot plant for Generation 2 process is under development by QUT in collaboration with Mackay Sugar for the conversion of bagasse to ethanol and possible higher value products. The project is supported by the NCRIS Program. In addition Ethtech, in association with Wilmot Forests, is also evaluating the pilot scale conversion of bagasse to ethanol using a patented high acid pre-treatment process which involves acid recovery using chromatographic methods.

(d) Overall process evaluations

CSIRO – lignocellulose biomass production

Evaluating the production capacity and sustainability of increased production or use of biomass resources is critical to underpin anything Australia does in this energy domain. The issues are far reaching and concern both forestry, agricuture and biological rubbish utilisation. Global research effort in transformation technologies will be relevant to Australia's technology options. However, little of the international research is directly relevant to Australian domestic feedstock resources and thus industry development in biomass utilisation. As O'Connell *et al*. (2007) say, a whole-of-agriculture and whole-of-forestry approach is required – right through the economic and environmental value chains. It is not appropriate just to evaluate chemical or gas potential of the materials or even issues such as carbon credits or soil organic matter changes. Rather, it is necessary to evaluate changes in economies such as food, forestry, environment or even tourism. It is necessary to underpin industry development in liquid fuels (and energy where feedstocks are in common) from biomass in understanding and securing supply. This has already been an issue in the ethanol from biomass fledgling industry where matters were not thought through and rushed.

The lesson has been learned and there is considerable interest from companies which utilise transport fuels in purchasing the resources which will supply future fuels either of bioethanol, biogas or lipids.

CSIRO – conversion of Australian biomass to biofuels using enzymes

There is significant effort overseas in enzymatic routes to liquid fuels. However, the biomass available in Australia for sustainable harvest is likely to be native plants that have unique distributions of lignin, cellulose and hemicellulose that need to be understood for efficient utilisation. Moreover there are some unique Australian opportunities – the protozoan *Mixotricha paradoxa* is a Trichomonadid which consumes lignocellulose, and the largest protozoan in the Australian termite (*Mastotermes darwiniensis*) gut. This is a truly voracious organism capable of transforming a large part of its bodyweight of lignocellulose into ethanol through superior cellulolytic enzymes. Forming ethanol for the e-fuel industry is the subject of some novel approaches, for example from cotton growers and other funding sources that may become available.

(e) Thermochemical processes

CSIRO and Monash – pyrolysis of lignocellulose

At Monash University, Honnery and Chun-Zhu Li are involved in the use of biomass (wood, bagasse, etc) as a renewable energy source (electricity generation, hydrogen production or bio liquid fuels as well as solid wastes as a (renewable) energy source. Their thermal cracking fluidised bed pyrolysis reactor is capable of producing up to 10 L/day of bio-crude by hydrothermal liquefaction process.

With regard to lignocellulose pyrolysis, there is increasing interest in gasification with enquiries from the aviation industry fearing pricing pressure from mineral fuels. From the standpoint of energy security also there is a desire to own the feedstocks for Fisher-Tropsch other than natural gas, hence interest in lignocellulose sustainability. Both natural gas-to-liquid (GTL) and coal-to-liquid (CTL) Fischer-Tropsch processes are proven, while GTL is practiced on a very large scale (e.g. Sasol - Qatar Petroleum). Biomass-to-liquid (BTL) has also been proven on a demonstration scale (Choren, Germany). CTL manufacturing costs well exceed those for GTL, while BTL costs are higher yet. While CTL will soon be economically viable, from the GHG emissions standpoint it is not attractive. Thus, after natural gas and coal seam methane, biomass appears to be the next most attractive gas source. Research on BTL technology to Australian biomass feedstocks (including biomass from algal biodiesel production) and on the paths from pyrolysis oils and syngas to alcohols, alkanes and other fuels should be supported. Naturally the relative GHG impacts will need to be evaluated.

5.6 BIODIESEL PROCESSES

5.6.1 Generation 1 biodiesel processes

Generation 1 biodiesel processes involve the esterification of various plant and animal oils to form fatty acid methyl ester (FAME). FAME can be used as a pure biodiesel (that is B100), but is generally blended with diesel (for example, B20 in Europe) to meet automobile fuel specifications. The main sources of such oils in Australia are canola, tallow and palm oil. However the recent dramatic rise in the prices of these components as well as food versus fuel and environmental concerns (for example expansion of palm oil production into tropical rain forest regions) has made such processes much less attractive.

5.6.2 Generation 2 biodiesel processes – microalgae

Oil from microalgae is a Generation 2 feedstock for FAME biodiesel production. Microalgae could potentially provide feedstock for ethanol (via fermentation of sugars in algal polysaccharides), synfuels (by gasification and FT reforming) and biogas (by anaerobic digestion to methane). Some microalgae species produce hydrogen.

Proponents of microalgae claim the feedstock has advantages over terrestrial plants, for example oilseeds, including significantly higher land yields, more efficient carbon fixation and, most importantly, greatly reduced competition with food for arable land. Commercial microalgal culture is already a well established industry but mostly dedicated to higher value commodities than fuels (e.g. *Spirulina* sp. for foods and nutraceuticals and *Dunalialla* sp. for β-carotene). Since commercial *Spirulina* from open ponds costs about $5/kg, it is generally held that algae biodiesel is still far from economic. However in April 2008 Petrosun apparently commenced production of some 17 ML/yr from 445 ha of saltwater ponds in Rio Hondo, Texas.

Although open-pond microalgae massive cultures have been practiced and researched for more than 50 years there are still significant opportunities for RD&D of microalgae-to-liquid fuels. Unlike other Generation 2 biofuels that are close to market or have well-defined technical and economic barriers, the technical and economic challenges of microalgae-to-liquid fuels are largely unresolved. Strain selection, optimising microalgae yield, lipid yield, lipid composition, down-stream processing and the development of co-products remain as lively issues. Australia has natural advantages and the research community, with continued support, is well-positioned in terms of human capacity and infrastructure to deliver valuable outcomes.

Commercially successful microalgal biofuels will depend on robust cost-effective production processes that can compete with fossil fuels; to date not achieved despite numerous claims. Bottlenecks associated with cost, scale, reliability, yield and harvesting still stand in the way of commercial feasibility. RD&D is challenged by complex technical hurdles at the interphases of each transformation process.

Collectively these challenges are biological, chemical and engineering. They include:

- optimising native microalgal strains that are robust and stable with high lipid and growth yields;
- developing efficient algal production systems optimised for nutrient and carbon uptake for given climatic conditions;
- designing low cost harvesting, dewatering and lipid extraction systems,
- developing cost effective transesterification processes producing fuel that meets quality specifications and standards;
- designing a customised biorefinery approach able to recover high value co-products and byproducts; and
- developing economic production processes that are competitive with production from crude oil.

Despite the foregoing challenges to commercial biofuels from algae, Australia clearly has significant natural and geographic advantages including the extraordinary biodiversity of microalgae in its oceans and estuaries, suitable temperatures, high levels of solar radiation, an abundance of saline water and land unsuited to conventional agriculture. Worldwide research is significant and growing, including in Australia. Nevertheless Australian RD&D, certainly in the promising domain of algal biodiesel, appears to be fragmented, lacking a clearly articulated and coherent national strategy. The following paragraphs give highlights of the key centres and objectives of current Australian research activities.

CSIRO – algal selection and organisation

Blackburn at CSIRO is currently conducting a scoping study to estimate the realistic potential of its contribution to Australia's transport fuels mix and to place bounds on microbial biomass production under different land-use scenarios and process technologies. The project also aims to quantify the GHG abatement attributable to biodiesel production from algae. In a parallel study the CSIRO microalgae collection is being assessed for growth, oil productivity and lipid profile.

CSIRO – oil separation from microalgae
This project directed by Liffman concentrates on scale-up using CSIRO's fluid mechanics expertise to seek improvements in processing oil-rich algae. The work focuses on separating oil from water formed in the process and will learn from the algal selection and organisation project and CSIRO drying expertise.

Flinders University – biodiesel from microalgae
Biofuels research has been carried out since early 2005 by the Materials and BioEnergy Group of Flinders University, leading to formation of the BR Energy Group in 2007 (directed by Clarke) being awarded funding by the SA Premier's Science and Research Fund (PSRF) for a project to develop Generation 2 microalgae biodiesel and the biorefinery concept in collaboration with Thomas and Nayar of SARDI and the Flinders Medical Biotechnology Department. Currently an MOU is being prepared between Flinders University and BPPT (Indonesia) to carry out collaborative *Jatropha curcas* biodiesel research.

Murdoch University – bioreactors for microalgae
Murdoch University researchers under Borowitzka have published a technical and economic assessment of microalgae production systems (Borowitzka 1999). Recently the Murdoch team received a $1.89 million grant from the Department of the Environment, Heritage and the Arts for an international collaborative project with China (South China Institute of Technology) and India (Parry Nutraceuticals) to develop and oversee large-scale open ponds or 'photo-bioreactors of algae in saline ponds' in Australia, China and India as part of Australia's commitment to the Asia-Pacific Partnership on Clean Development and Climate. In reporting on the project Borowitzka has noted that at present algae costs $12/kg, but must be brought down to $1/kg to be commercially successful. He also observes that to produce one per cent of Australia's biodiesel from algae would require 100 square kilometres of otherwise low productivity; compared say to canola feedstock which would need some 2000km^2 for equivalent production from good quality arable land.

Queensland University – photosynthetic architecture of microalgae
Hankamer and colleagues at the University of Queensland, in collaborating with German scientists, are using biotechnology to investigate and alter the photosynthetic architecture of microalgae, *inter alia* to improve light penetration in high density cultures and improve yields from hydrogen-producing species (Mussgnug *et al.* 2007).

South Australian Research and Development Institute (SARDI) – process development for microalgae
Thomas and Nayar at SARDI are developing a demonstration scale microalgal biodiesel production facility in Adelaide, funded through the National Collaborative Research Infrastructure Strategy (NCRIS). The facility can be accessed by the Australian research community to study and optimise production of microalgal feedstock for biofuel production. It will comprise a state-of-the-art relocatable laboratory with instrumentation systems selected to monitor, in real time, the photophysiological parameters of the algae in the photobioreactor systems and thereby allow manipulation of control parameters to optimise the algal biomass and overall lipid yield. The facility will also comprise 15 to 20 L fully-automated photobioreactors, 200 L to 3.5 kL tubular photobioreactors, both upright and lay-flat bag systems, small raceway ponds and demonstration scale photobioreactors of 10 to 50 kL.

University of Western Sydney
Tran, Milev and Kannangara are developing catalysts for producing hydrogen from biodiesel and algal products as well as catalysts for hydrogenation using nanomaterials.

5.7 BIOREFINING – VALUE-ADDED PRODUCTS

Liquid biofuels production should not be considered in the absence of co-production of other biobased products, described in this report as Generation 3. Even with ethanol from grains the economics are significantly enhanced by the value of co-products. Indeed the point can be reached where the value of co-products can exceed that of the biofuel; here industry strategy becomes one of biorefining or total biomass utilisation with optimised conversion efficiencies and maximised return on investment. Like mineral oil refining, biorefining includes fractionation and reforming of biomass feedstocks into multiple product streams. These are not limited to liquid biofuels (ethanol, biodiesel, hydrocarbon-like oils) but can include agricultural chemicals, food ingredients, nutraceuticals, pharmaceuticals and bio-commodities identical or functionally similar to those from the petrochemical industry. It is beyond the scope of this report to list all possible product streams but, for comparison, the petrochemical industry produces over 70,000 different products and continues to expand. From a technical viewpoint potential biorefined products could match that. However, unlike petroleum refining, biorefineries are firstly unconstrained by finite feedstock resources and secondly can offer reduced GHG emissions. A biorefinery industry that can produce liquid fuels, electricity and commodity chemicals from a renewable source in regional communities while meeting accepted sustainability criteria appears to be a compelling mission for Australia.

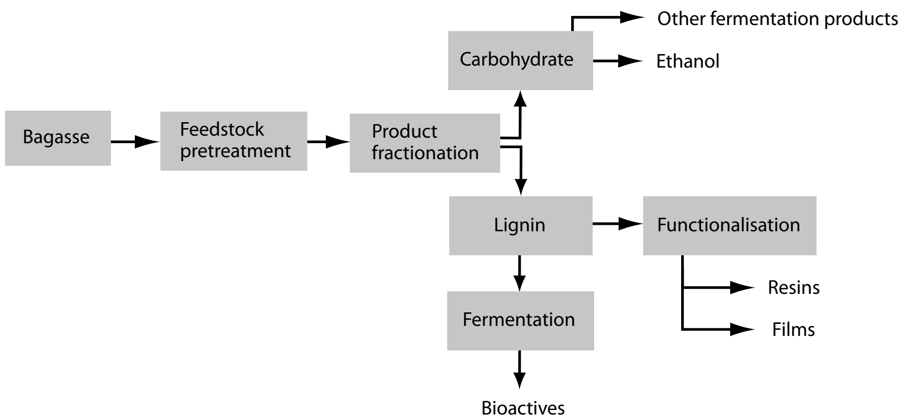
Rural Industries Research and Development Corporation – a framework for research and development

The Rural Industries Research and Development Corporation (RIRDC) commissioned a report entitled *Bioenergy, Bioproducts and Energy: a Framework for Research and Development* (O'Connell *et al*. 2007). The report recognises the strong links between transport biofuels, bio-commodities and heat and power generation from biomass. The RIRDC report is one of a series from CSIRO which review issues related to developing bio-based industries. Another such RIRDC report (Haritos 2007) identifies Australian companies marketing bio-based products. These reports note that, even at an international level, biorefinery concepts are at a relatively early stage of RD&D. Moreover this is particularly so for more sophisticated concepts that could accept a range of feedstocks and flexibly produce a mix of products to meet market demand. These reports also observe considerable cooperation among OECD nations to identify and overcome biorefinery technical barriers and reduce market risk. It is therefore pleasing to note that Australia, through Bioenergy Australia, has joined the IEA Bioenergy Task 42 Biorefineries, effective from January 2009.

Queensland University – total utilisation of sugarcane biomass

Edye, Doherty, Hobson and Bullock at QUT have conducted economic and technical feasibility assessments of models for total utilisation of sugarcane biomass and developed biorefinery processes and

Figure 5-2 Biorefinery model for sugarcane bagasse value-adding



products. In these sugarcane biorefinery models the processing facility still produces crystalline sugar, but greater significance is placed on other product streams such as electricity cogeneration, ethanol, biodiesel, hydrocarbon-like oils, agricultural chemicals, food ingredients and bio-commodities that are identical or functionally similar to those produced by the petrochemical industry; see Figure 5-2. Process and product development has focused on value adding to the lignin obtained by fractionation of bagasse, the lignocellulosic residue of sugar manufacture. QUT, in collaboration with the Australian sugar industry, is constructing a pilot plant to demonstrate bagasse fractionation and produce lignin for application testing. NCRIS funding is extending the capability of this facility to include cellulose saccharification, fermentation and distillation.

Cost-effective pre-treatment of various biomass sources into their component C5 and C6 sugars, together with their residual lignin, provides opportunities to produce a range of higher-value chemicals and lignin derivatives which are now produced from food – or hydrocarbon-based raw materials. Furthermore, the application of modern biotechnology techniques (e.g. metabolic engineering, gene cloning /over-expression) as evidenced by current R&D on *Zymomonas mobilis* by Rogers and his group at the University of NSW are likely to enhance this shift. These opportunities have been highlighted in recent US Government Reports:

- *Top Value Added Chemicals from Biomass: from Sugars & Synthetic Gas* (August 2004) www.eere.energy.gov/biomass/pdfs/35523.pdf; and
- *Top Value Added Chemicals from Biomass; Biorefinery Lignin* (October 2007) www1.eere.energy.gov/biomass/pdfs/pnnl/16983.pdf

5.8 LINKED RESEARCH ACTIVITIES

Linked research is leading to more energy efficient biomass conversion unit processes (e.g. improved reactor designs with higher conversion efficiencies, lower energy inputs and higher processing rates per unit cost), development of energy integration strategies (e.g. improving heat recovery through pinch analysis) and development of improved waste-treatment processes. Efficient reactors with better heat recovery and waste treatment lead to improved LCAs (see Chapter 6) through lower energy inputs and higher biomass conversion efficiencies. Engineering research with novel and obvious links to biofuel production technologies is commended.

5.9 RD&D ROADMAP

The following RD&D Roadmap draws on the conclusions of recent US and European Biomass Roadmaps and IEA Report and focuses on areas where RD&D in Australia might have its most significant impacts. It also sets out timeframes which provide industry with projections for future planning and investment.

5.10 AUSTRALIAN RD&D FUNDING

5.10.1 The NCRIS Biofuels Sub-Program

Within the Australian context the $14 million NCRIS Biofuels Sub-Program (2006–11) is managed by Ausbiotech on behalf of the Federal Government. This program, which co-ordinates access to facilities on a marginal cost basis, has focused on providing infrastructure funds for some of the key RD&D needed for the near and medium-term bioprocess development as set out in Table 5-2. Funding has been provided for the following activities:

- a pilot plant for ethanol production from bagasse with funds of $6.5 million to the Queensland University of Technology (QUT) and Mackay Sugar Pty Ltd;
- a micro-algal photobioreactor facility for production of biodiesel components with funds of $5 million to the South Australian Research and Development Institute (SARDI); and

Table 5-2 RD&D Roadmap – key bioconversion technology priorities

Near term (0-3 years)	Medium term (3-5 years)	Long term (5-10 years)
THERMOCHEMICAL PROCESSES		
1 Syngas technologies: evaluate various biomass sources in pilot scale/medium-size plants. Improve catalyst efficiencies and clean-up technologies for syngas. **2** Pyrolysis liquids: evaluate biomass in pilot scale/medium-size plants. Characterise fuel quality.	**1** Syngas technologies: demonstrate co-gasification of biomass and coal; carbon capture and storage. **2** Pyrolysis liquids: characterise environmental impacts, transportability and storage issues.	
BIO-PROCESSES		
1 Establish pilot and medium-scale processes using biomass from residues and non-GM energy crops. **2** Evaluate alternative biomass pre-treatment at lab/pilot scale e.g. ionic liquids, supercritical methods. **3** Reduce enzyme and pre-treatment costs; develop improved microorganisms for all C5/C6 sugars. **4** Develop laboratory-scale processes for efficient harvesting of algae and recovery of lipids and hydrocarbons.	**1** Develop pilot-scale processes for advanced biofuels (e.g. butanol). **2** RD&D on range of higher value fermentation products from biomass hydrolysates and lignin residues (integrated biorefineries). **3** Evaluate pilot and medium-scale biofuel production using algae; also potential higher value products. **4** Evaluate feasibility of microbial hydrogen production.	**1** Evaluate processing characteristics of biomass from new GM 'energy crops'. **2** Evaluate possible integration of thermochemical and fermentation processes from multiple feedstocks and with multiple products.
RESEARCH COLLABORATION		
1 Develop collaboration among researchers across value chain. **2** Identify linked research, and establish engineering and design improvement targets. **3** Integrate economic and policy analysis activities into biofuels R&D program. **4** Identify and evaluate economic benefit of research with potential niche IP outputs in biorefining (e.g. novel processes and products). **5** Prioritise research activity areas according to sustainability, life-cycle inventory, economic feasibility and risk.	**1** Accelerate priority research areas. **2** Promote RD&D collaboration with fuels and chemicals industry multinationals.	**1** Demonstrate technologies based on priority research outcomes.

- an integrated RD&D program on Generation 2 process development with total funds of $2.15 million to the University of Sydney (supercritical and other biomass pre-treatment strategies), Macquarie University (high activity thermophilic enzymes) and the University of NSW (microbial strain improvement and fermentation optimisation).

However these funds are mainly for equipment and pilot plant construction. Additional government and industry funding is needed for future specific projects as identified in the RD&D Roadmaps set out in Tables 4-1 and 5-2.

5.10.2 The Department of Resources, Energy and Tourism's Second Generation Biofuels Research and Development Program

To this end the Department of Resources, Energy and Tourism's $15 million for a Second Generation Biofuels Research and Development Program (Gen-2) over three years from 2008-09 to 2010-11 is particularly timely. At the time of report preparation details of the scheme were not available; however it is clear that significant focus will be placed on RD&D associated with lignocellulosic and algal feedstocks.

5.10.3 Rural Industries Research and Development Corporation (RIRDC) Bioenergy, Bioproducts and Energy Research Portfolio

The Federal Government agency RIRDC supports and manages bioenergy and biofuels research though a competitive grant program. RD&D funding is currently modest (about $1.6 million) but RIRDC hopes to expand this in the near future. Several biofuels-related projects are supported, mainly related to feedstocks including algae.

5.11 TOWARDS A NATIONAL BIOFUELS INSTITUTE

The RD&D Roadmaps set out in Tables 4-1 and 5-2, if adopted as national targets, represent an exceptionally challenging task for Australia. It is therefore critical to consider how best the resources available for the task – financial, institutional and personal – can best be mobilised, managed and motivated to achieve the optimum outcomes. Effective synergies, needed to leverage the funds available and attract additional industry funding, demand an imaginative, focused and bold approach.

Currently the major biofuels RD&D funding comes from the $14 million NCRIS Biofuels Sub-Program; the Department of Resources, Energy and Tourism's $15 million Second Generation Biofuels Research and Development Program; Australian Research Council grants and a range of other smaller grants and industry special purpose support funding. While significant in the overall context of Australian RD&D, these resources, for which there is vigorous competition, are still relatively modest in the context of the opportunities identified, the benefits to be gained and the commitment levels of comparable developed countries. Moreover such competition for scarce resources can, it is observed, lead to fragmentation where, in the national interest, long-term collaboration and cross disciplinary interaction is clearly needed.

Some consideration has been given, and continues to be given, to more effective clustering and collaborative engagement of researchers and end users through the well-tried Cooperative Research Centre (CRC) model. Another model is that of the CSIRO Flagships, established for the very purpose of achieving big audacious goals in the national interest.

Based on early consultations with likely stakeholders, ATSE believes that consideration is warranted for a broadly embracing and nationally focused Biofuels Institute. Such an Institute would be modelled on the lines of the Global Carbon Capture and Storage Institute or, perhaps more appropriately, the Australian Solar Institute which is currently being formed. At this stage the proposal has been discussed and endorsed by the Project Steering Committee only. ATSE recognises that considerably more discussion is needed with all potential stakeholders, including government departments and agencies, the RD&D community and the biofuels industry. Nevertheless on the basis of formative discussions and contributor input up to the time of report submission, ATSE submits this proposal as a core recommendation of its report.

Importantly the Institute concept has a strong political framework with the very recent establishment of the Institute for Carbon Capture and Storage. A Biofuels Institute, much like a CRC but stronger and nationally embracing, could provide the 'glue' that the biofuels RD&D diaspora so clearly lacks. Inter alia it could assist in managing and protecting IP, attracting and leveraging industry funds and other grants, undertaking (perhaps with ATSE support) future specialist studies, managing and nurturing relationships with industry bodies, and developing and managing linkages with the Institute for Carbon Capture and Storage and the CSIRO Energy Transformed Flagship. It would naturally have close working linkages with the RIRDC and with Bioenergy Australia.

The Biofuels Institute would integrate appropriate existing resources and expertise into a coherent and integrated program of research, development and demonstration that covers feedstocks, processing technologies and bioproducts. Given the very significant overseas funding levels that Australia cannot conceivably match the Institute should, where appropriate, conduct much of its work in focused partnerships and/or joint ventures with appropriate international agencies. ATSE believes funding in the region of $15 million per annum for five years would be necessary but the interest in this field should be such that growing industry support would be likely.

ATSE would see the notional Biofuels Institute as perhaps having a similar style of parentage, structure and Government support as the other energy-related Institutes. CSIRO would clearly be a cornerstone member and hopefully the Institute would include all the biofuels RD&D universities and other RD&D centres. It could, for example, be the focal point for Australia's membership of the Global Bio-Energy Partnership (GBEP) if this recommendation is adopted.

The Institute would focus on delivery of the Roadmap objectives set out in Tables 4-1 and 5-2, perhaps through three core RD&D 'streams':

- feedstocks – for example, algae for Generation 2 biodiesel; lignocellulosics for Generation 2 bioethanol;
- process technologies – for example, algae photobioreactors; thermo-chemical and bio-chemical (e.g. fermentation) processes for Generation 2 bioethanol, lignocellulosic feedstock conversion; and
- bioproducts – for example, enzymes for faster lower cost breakdown of raw materials; chemicals which may now be produced more cheaply from renewable carbohydrates than from hydrocarbons including biopolymers, organic acids and lignin derivatives, as well as related issues associated with storage, safe handling and infrastructure integration.

ATSE holds itself ready, if invited to do so, to contribute to creation of the Biofuels Institute through wide but independent consultation with all potential stakeholders.

6 Assessing the Impacts of Biofuels

- Robust life-cycle analysis (LCA) using universally acceptable consistent metrics, embodying key externalities, is needed for Australian biofuels, Generation 1 and 2, for reliable economic and environmental analysis and comparison. CSIRO could contribute to this objective.
- There is a need to better understand the science and life-cycle analysis of N_2O emissions associated with biofuel agriculture.
- Water use efficiency (WUE) evaluation is a crucial LCA element.
- International cooperation is commended for improved understanding of more complex pollutants.
- A thorough analysis of Australia's unique biodiversity is recommended, including in the biofuels domain; an analysis that CSIRO or RIRDC might be well placed to undertake.

6.1 INTRODUCTION

This chapter discusses in broad outline the key economic and environmental issues associated with production and use of transport biofuels. They include:

- energy consumption;
- emissions (GHG and others);
- land use;
- water consumption;
- eutrophication
- biodiversity; and
- air quality.

These impacts need to be evaluated with robust metrics for each supply chain alternative using tools such as life-cycle analysis (LCA). While experienced consultants and wide ranging LCA software is available it must be recognised that many impacts, generally called 'externalities', remain subjective and outside conventional economic analysis. The Academy is currently conducting a parallel study aiming to build a rational basis for assessing such externalities.

Typical externalities, hard to quantify, are environmental and social impacts. Job creation, social equity, wealth distribution, health, biodiversity and environmental changes come to the fore. Biofuel demand, especially if artificially stimulated, can lead to unexpected 'winners' and 'losers'. Winners may be rural poor of developing countries, mainly farmers. Losers may be urban poor, vulnerable to increased food prices. Such issues are beyond LCA unless externalities are quantified to an agreed economic basis. Thus to a considerable extent LCA and other tools for economic analysis lie in the realm of available policy instruments for equitable management.

Australian Study: Biofuels and Greenhouse Gases

In July 2003, the Australian Government commissioned a report from the CSIRO, jointly with the Bureau of Transport and Regional Economics and the Australian Bureau of Agricultural and Resource Economics (CSIRO, BTRE and ABARE 2003) on the appropriateness of maintaining an objective that biofuels, produced in Australia from renewable resources, contribute at least 350 ML to the total fuel supply by 2010.

The report found that on a fuel life-cycle basis there can be GHG saving of up to five per cent from the use of ethanol E10. In contrast, the use of 100 per cent biodiesel made from waste oil can achieve 90 per cent GHG benefits compared with diesel, because a waste product does not have any life-cycle emissions (also known as 'exbodied' or 'well-to-wheel' emissions) associated with it.

Other land, water and biodiversity impacts from production, distribution and use of biofuel appear not to be significant, provided that distillery wastes are disposed of using established best practice.

The study considered the case of moving to 350 ML in 2010, compared to a base stage of 115 ML by 2010. Under the scenario considered, the additional 235 ML of biofuels is assumed to comprise 205ML of ethanol and 30 ML of biodiesel. The ethanol is assumed to be produced using C Molasses (60 ML) and whole cereal grains (145 ML). The biodiesel is assumed to be produced from UCO (another 30 ML).

Under the target scenario, GHG emissions were estimated to be 0.268Mt lower in 2010 (about 0.3 per cent of transport GHG emissions). The total cost in 2010 in terms of lost GDP was estimated between \$265 to \$277/t CO_2-e in 2003 dollars.

Based on the scenario used in the report, the replacement of an equivalent volume of petrol and diesel by Generation 1 biofuels would result in a net CO_2-e emission reduction of some 32 per cent for ethanol replacement (based on E10 molasses and cereal grains), all some 90 per cent by biodiesel replacement (from waste oil, BD100). It should be noted that reliable data is not available to develop estimates of the net GHG replacement for Generation 2 biofuels

6.2 LIFE-CYCLE ANALYSIS (LCA)

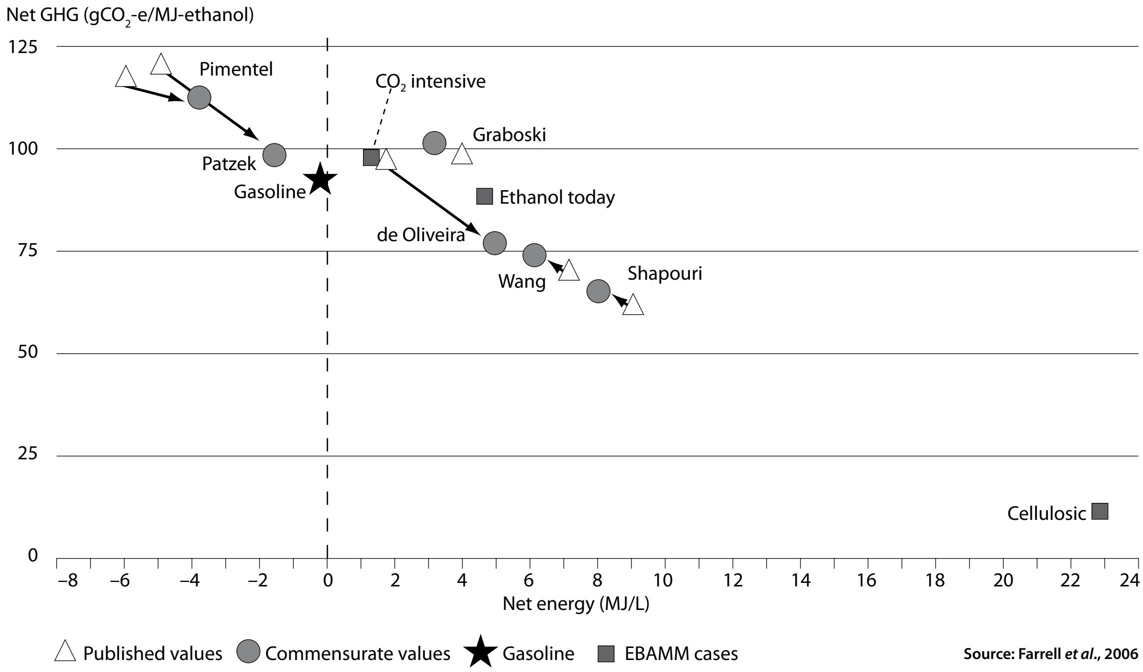
LCA is an established methodology for evaluating natural resource requirements and environmental impacts from the whole life-cycle of products and services (ISO 2006). LCA inputs can be voluminous, especially for biofuels. The range of alternative feedstocks; their supporting resources of land, labour and materials – especially water and fertilisers; conversion technologies both natural and man-made; routes to market; co-products and related services; airborne and waterborne emissions and solid wastes differ very widely, challenging conventional evaluation.

Thus any apparently viable 'field to fuel' supply-chain option, whether employing current agricultural or conversion technologies or still in the realm of advanced research, requires universally accepted data sets for all identifiable variables to avoid issues of imbalance or skewed analysis. It is recommended that CSIRO, which has strong capability in this domain, be tasked to define data sets acceptable for harmonised universal LCA application. A wealth of international material is available and CSIRO or any other Australian agency would need to work cooperatively, probably through the IEA, to ensure international database consistency. Without such a unifying approach the potential for specious or biased argument in the biofuels debate is profound.

Such work is being undertaken by the Global Bio-Energy Partnership (GBEP), a G8 initiative. Australia is not yet in GBEP; membership is recommended.

Underlying several necessary metrics, for example land carbon sinks and GHG emissions from soils, the suitability of new biomass sources and the like still require significant research to provide reliable inputs for LCA evaluation.

Figure 6-1 Summary of life cycle analyses from several studies



Source: Farrell *et al.*, 2006

Sustainability criteria for LCA

The sustainability criteria of most concern in biofuels LCA are:

- the GHG balance of biofuels production chains; and
- competition between food and energy crops for arable land.

Unfortunately some published LCA reports on biofuel production chains reflect the subjectivity of the authors and the political agendas of their funding providers. LCAs cited by industry peak bodies and lobbyists often, in the absence of robust and transparent criteria, reflect the interests of the industry. Considerable knowledge and ability is needed to examine LCA models critically and this ability exists in the Australian scientific community, especially CSIRO.

Biofuels LCA has attracted considerable attention over the past two decades. In that time LCA methodology and standards have evolved considerably. While some authors assert that there is little agreement on the LCA outcomes for biofuels, the reality is that, with the exception of studies by Pimental and Patzek (2005), there is reasonable agreement that biofuels can deliver significant GHG reductions and are energy positive, reference Figure 6-1.

It is instructive to note the dramatic potential for lignocellulosic materials, further borne out in the 2008 report of the German Institute for Energy and Environment entitled *Cost and Life-Cycle Analysis of Biofuels*. This exhaustive study, canvassing a wealth of current literature, concludes that Generation 2 biofuels (e.g. synthetic biofuels such as BTL and Bio-SNG as well as bioethanol from lignocelluloses), while still significantly higher in cost, offer higher energy yields per unit area (GJ/ha); greater GHG reductions per equivalent litre (kgCO_2-equivalent/litre); and higher GHG reductions per unit area (kgCO_2-equivalent/ha).

Outcomes of LCA work conducted by Sheehan *et al.* (2004) are provided in Table 6-1. This complex analysis examined the corn stover-to-ethanol route to determine if carbon recycling and fossil energy avoided could be balanced against the opportunity lost for sequestering health improving carbon in soil, consequently determining the optimum proportion of stover that could be harvested sustainably. The

Table 6-1 Fossil fuel inputs and greenhouse gas emissions for petrol and petrol/ethanol blends

Fuel	Fossil energy input (MJ/km)	GHG emissions (g CO_2-e/MJ)
Petrol	3.78	94
E85 corn starch-to-ethanol	2.21	81
E85 switchgrass-to-ethanol	1.12	28
E85 corn stover-to-ethanol	0.54	n.a.

Source: Sheehan, 2002

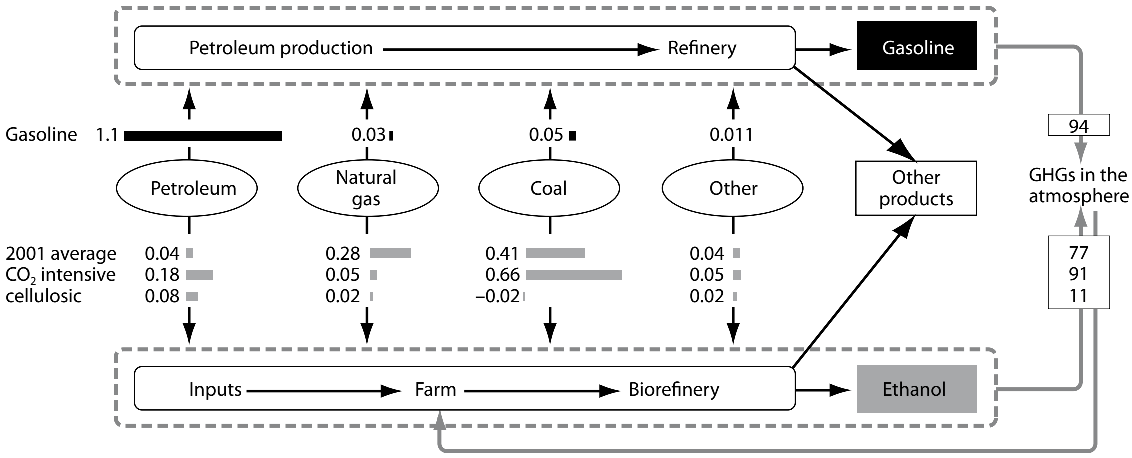
analysis was based on 11 new processing facilities across Iowa, USA, which convert corn stover to ethanol via dilute acid pre-treatment, enzymic hydrolysis and fermentation. Each is strategically positioned near existing farms where low or no-till practices were in place to minimise transportation. The analysis used an E85 ethanol blend and measured net CO_2 emissions as a function of stover removal across all farm soil types. It concluded that 40 to 50 per cent of stover could be harvested sustainably but that soil responses were highly variable.

Sheehan also compared fossil fuel inputs of various E85 blends to that of petrol. His data, expressed in Btu/mile, is converted to MJ/km in Table 6-1. The analysis for corn starch-to-ethanol production system is based on averaged data for existing installations. The scenario for switchgrass-to-ethanol was not provided. Presumably natural gas (fertiliser and electricity) and coal (electricity) inputs are included in this analysis. It is also assumed that fuel efficiency data for a flexible fuel vehicle (FFV) running on E85 is reliable and compared to a similarly fuel efficient petrol driven vehicle. GHG emissions were calculated for E85 from data provided by Dale (2007) which are averages for petrol, ethanol from corn starch and ethanol from switchgrass. Ethanol from corn stover is not included. Dale's analysis is shown in Figure 6-2.

The comparison of inputs to petrol and to E85 blends shows that, under specific scenarios, biofuels can make a real contribution to GHG mitigation and fossil fuel savings. Included here it illustrates the complexity and the site and technology specific nature of LCA. It would be tempting, but probably incorrect, to conclude that ethanol produced from cereal straws under Australian conditions would have values similar to corn stover.

Australian analyses of similar complexity have yet to be performed. Thorburn *et al.* (2006) conducted detailed economic modelling of sugarcane field trash harvesting but the impact studied was limited to the

Figure 6-2 Comparison of LCA for ethanol and petrol



Source: Dale 2007, revised version of a figure originally published by Farrell *et al.*, 2006 relationship between crop yield and soil moisture retention attributable to the trash blanket. Underpinning the economic analysis are significant mass and energy balances reportable in LCA format.

Australian researchers have contributed strongly to LCA. Cowie *et al.* (2004 & 2007) used LCA methodology to comment on the impact of the Mandatory Renewable Energy Target (MRET) scheme on competition for biomass. Cowie is Australia's leader for the IEA Bioenergy Task 38 – Greenhouse Gas Balances of Biomass and Bioenergy Systems. Beer *et al.* (2002) are authors of several LCA studies including the 2001 study comparing transport fuels. The Australian Life Cycle Assessment Society (ALCAS) was established in 1999 to promote and foster the appropriate application of LCA in Australia and the responsible development of LCA methodology. Since 2006, ALCAS has worked with CSIRO to develop an Australian Life Cycle Inventory database. DEST supported a CRC for Greenhouse Accounting from July 1999 to June 2006. RIRDC has funded development of the Bioenergy Atlas for Australia and the Australian Greenhouse Office provides guidance and information on LCA methodology.

LCA is a critical element of value creation in any enterprise exposed to government policies seeking to reduce GHG emissions (e.g. through a cap-and-trade or tax mechanisms). For biofuels, soundly evaluated LCAs based on accepted international standards will significantly strengthen business cases for agro-industrial enterprises that require multi-million dollar investments, while government policy should distinguish and promote enterprises with highest GHG mitigation benefits.

LCAs are often industry- funded to establish 'green credentials' by demonstrating abatement activities. Such analyses require critical independent expert review.

6.3 BIOFUELS AND GREENHOUSE GAS EMISSIONS

Greenhouse gases such as methane, carbon dioxide and nitrous oxide and other complex volatile organic compounds (VOCs) are emitted throughout each of the alternative supply chains. They are impacted by agricultural practices and processes, including fertiliser use, agronomy, harvesting, conversion and distribution.

■ Soil carbon and carbon sinks

CO_2 emissions from converting land types, particularly those that are large carbon sinks, need to be evaluated. Studies show that the net land carbon sink, including soils and vegetation, is approximately 1.5Gt/yr carbon and takes up some 20 per cent of current human CO_2 emissions (Royal Society 2008). Serious consequences in terms of CO_2 emissions have arisen from the drainage of peat lands in South East Asia, in many cases for the planting of palm oil plantations or deforestation by logging. While evidently attractive to the farmer the CO_2 balance is seriously negative, not as a direct consequence of biofuel demand.

■ Nitrous oxide (N_2O) from biofuels

The IPCC notes that GHG nitrous oxide has a global warming potential 296 times greater than CO_2 (Royal Society 2008). This arises from nitrogenous fertilisers and natural mineralisation. Indeed the largest single source of atmospheric N_2O globally arises from industrial fertilisers. Australia, with its poor soils, is a case in point.

When new land is cultivated for biofuels it is possible that regular fertiliser application will soon be needed, leading to increased atmospheric emission. Thus analysis of biofuel cropping needs improved understanding of the nitrogen cycle and its interaction with cropping systems. Such research is probably proceeding internationally; Australia must draw upon this to gain the best knowledge available.

The IPCC estimates that one per cent of added nitrogen is returned to the atmosphere through activities that result in the mineralisation of soil organic matter. However, the Royal Society report notes that based on recent research, it is more likely that the amount of nitrogen returned to the atmosphere as N_2O is in the range of three to five per cent.

This larger range of N_2O emissions could significantly reduce the currently assumed GHG emission gains from replacing conventional fossil fuels with biofuels. There is a need to improve our understanding of the scientific basis for N_2O release from different biofuel crop productions systems and land types.

6.4 LAND USE

The growing competition for good quality land – for food, conservation, biodiversity, urban development, recreation and other human uses – is one of the more complex inputs to life-cycle analysis. The impact of biofuel production on food prices in particular is already evident in the USA and Europe. Thus there is increasing focus both on low productivity land with which Australia is abundantly endowed and on co-production of food and non-food products. Nevertheless these impacts spread more widely than land use alone; socio-economic, water, energy and environmental impacts are far reaching and require no less rigorous analysis and focused research. Biofuels policy needs to be especially sensitive to these issues.

■ Land use comparison

An energy metric in common international use compares land used by different biofuels and other sources of biomass in terms of delivered energy per unit land area (MJ/ha/yr). However this is a complex assessment, requiring clear distinction between primary biomass energy and the useful energy contained in the derived transport fuels. Some authorities have undertaken and published comprehensive delivered energy analyses for a wide range of primary feedstocks although not, it is believed, for the Australian environment.

■ Energy resource depletion and GHG emissions savings

The evaluation of biofuels GHG emissions (and the ratios of primary energy inputs to delivered energy outputs) must be set in the context of the fossil transport fuels they are intended to replace. International analyses, especially the IPCC (2001), indicate significant differences between biofuel pathways from less than 50 per cent to over 100 per cent. The latter figure arises from the avoidance of GHG emissions from central power generation when electricity is co-generated from byproducts. Considerable potential exists to improve the conversion efficiencies of some conventional feedstocks, especially where the wastes can be put to profitable use.

6.5 WATER USE

Water is crucial to Australia. Needed through the entire biofuel supply chain its availability varies significantly with location, land quality and season. Competition is intense and likely to increase; partly due to population increase. A recent Academy report, *30/50 – The Technological Implications of an Australian Population of 30 Million by 2050* (ATSE 2007), forecast the impact of population growth on a host of factors including climate variability and change, water, energy, transport, waste disposal, infrastructure and policy implications to meet future challenges. The need for long-term planning for water availability was highlighted.

Of critical importance in planning is the need to understand and develop reliable data on the factors that impact water use efficiency (WUE). WUE depends upon many factors including precipitation, evaporation and transpiration, in turn dependent on climatic variables including CO_2 levels, solar insolation and wind. Clearly these vary widely between crops and regions. Different root stocks have quite different water extraction capabilities. WUE evaluation is a crucial LCA element.

6.6 OTHER POLLUTION ISSUES

From feedstock through to conversion and end use, the entire biofuel chain has a wide range of pollution impacts. Each requires evaluation if a meaningful picture is to be gained on life-cycle impact of the multiplicity of 'field to fuel' alternatives.

Feedstock production – isoprenes

Some crops release VOCs such as isoprene which contribute to ozone formation. VOCs from biofuel plants play important atmospheric chemistry roles. Isoprene release varies with temperature and light conditions, for example summer heatwaves, and may increase as climate change leads to higher temperatures. Isoprenes are particularly attributable to conifers, meaning that forestry feedstocks need to be evaluated carefully. However no known database exists, highlighting a potential area for international cooperative research. This should help understand why and through what mechanisms plants emit isoprenes, as well as its mitigation potential.

Feedstock production – fertilisers and pesticides

Feedstocks can require artificial fertilisers and pesticides with adverse pollution impacts, notably eutrophication where nutrient runoff (nitrogen and phosphorus) triggers rapid algal bloom growth, especially with drought reduced river flows. With bacterial breakdown dissolved oxygen can reduce to the point below which life can be sustained. International interdisciplinary cooperative research is warranted in this critically important region spanning agricultural, energy and water domains.

Feedstock storage and conversion

Feedstock storage, preparation and conversion create dust and noise. Biological processes have fermentation waste streams and micro-organisms, waste gases and reagents used to purify alcohols. Acids and residues from reactions such as hydrolysis have to be disposed of. Thermal gasification creates noise, odour, waste water, tar, ash and exhaust gases such as carbon monoxide. All these pollutants, including management and disposal challenges, need to be better understood; again an area for potential international collaboration.

Biofuels end use

Transport biofuels suffer pollutant emissions including formaldehyde, acetaldehyde and others with proportions varying between different biofuels. Better pollutant profiles are needed for each fuel type to provide for improved evaluation.

6.7 BIODIVERSITY

Over centuries human activity has led to irreversible biodiversity loss, accelerating over the past 50 years with conversion of natural forests to croplands, advancing human habitation and infrastructure. Biofuel agro-ecosystems will further alter local habitats and affect native species, distribution and abundance. Impacts will depend on crop type, density and inputs including water and agro-chemicals. Given the vast range of potential biofuel crops, from trees to dense grasses, biodiversity impacts will vary widely, quite apart from any economic consequences. Cultivation of any new crop brings its own pests and diseases, possibly leading to more use of pesticides and herbicides with impacts on crop yields of all types. Moreover some biofuel characteristics, such as fast vegetative growth and high yields, may enable pests – such as rabbits and cane toads – to become invasive under the right conditions thus impacting in unexpected ways on water and nutrient cycles. Such potential impacts and presumed benefits need to be very carefully evaluated before commitments to new crops, for example jatropha or switchgrass, are made in Australia.

A risk assessment framework for the evaluation of potential bio-energy crops would include the following elements:

- the full life-cycle of biofuel production;
- the invasiveness of the crop;
- the potential interactive effects of the biofuel crop with other regional pressures, e.g. water shortage and drought stress;
- the impacts to ecosystems; and
- changes in these risks under any future climate scenario.

6.8 CONCLUSIONS

Throughout the entire supply chain biofuels environmental impacts must be rigorously evaluated. GHG emissions, water consumption, biodiversity, eutrophication and air pollution vary with means of production, conversion, distribution and end use. Proper quantification provides for comparing overall environmental benefits and disbenefits of the multiplicity of biofuel pathways, essential for all stakeholders.

LCA usefully compares land use impacts and GHG emissions but its application must reflect real world changes, for example in emissions when biofuels replace fossil fuels. Much LCA RD&D is needed, including development of authoritative databases on feedstocks, land use, soil carbon dynamics, nitrous oxide emissions, water consumption, biodiversity and other pollutants. Considerable research and development remains to be done to determine the credentials and viability of Australian biofuels to determine whether they are to become more than a marginal economic activity. This is an area competently addressed by the RIRDC.

7 Policy Issues

- Biofuels must be seen as a component of an overall policy for security and sustainability.
- In the short to medium term the need will be for supplementation of indigenous fuels for transport. The potential for increased production of Generation 1 biofuels from current resources is limited and thus, without significant changes, bioethanol and biodiesel will remain a small fraction of transport fuels.
- Future focus must be on Generation 2 biofuels based on bioethanol from lignocellulosic materials and on biodiesel from algae.
- There are considerable commercial and other risks in such developments. Government policies must reflect these in financial measures to ensure the development of a viable and enduring industry.
- Federal and State policies need to be better aligned.

7.1 INTRODUCTION

This chapter outlines the key policy issues relating to Australian biofuels. The synthesis report *Biofuels in Australia – issues and prospects* (O'Connell *et al*. 2007) discusses the implications of a biofuels industry in Australia. It is clear that the economic and policy environment is complex and challenging. A more detailed, supplementary report (Batten & O'Connell 2007) expands on policy issues.

In favourable economic circumstances with current technologies, agricultural land and crops, biofuels could form a small component (less than a few per cent) of Australia's transport fuel mix using waste starch, sugarcane molasses and low-value grains for ethanol and waste cooking oil and tallow for biodiesel. These feedstocks do not compete strongly with human and animal foods. However these resources are not likely to increase substantially while international demand and continuing Australian drought have lifted world prices considerably. This reduces the possibility of increased production using imported feedstocks. Thus biofuels production costs remain high and volatile.

For biofuels to contribute more than say 15 per cent of Australia's transport fuels new technologies, production crops and cultivation areas are needed. Promising 'Generation 2' technologies include ethanol or methanol from woody lignocellulosic biomass and biodiesel from algae.

Australia's land and water resources are increasingly contested for food, fibre, energy, carbon sequestration and biodiversity. Biofuels choices will have substantial implications for the economy, the environment and society. A large-scale Australian biofuels industry will have to demonstrate robust credentials in GHG emissions, land and water impacts, financial viability and social acceptability.

Policies for biofuels industry development are a component of the broader alternative transport fuels policy framework, which in turn must be linked to the overall sustainable energy policy framework.

7.2 GENERAL POLICY CONTEXT

It is necessary to set the development of biofuels in the context of concerns over global and regional energy futures. These concerns are: security and sustainability of energy supply – particularly of oil for transport, the link between combustion of fossil fuels and major climate change, and availability of technological innovations involving the introduction of more efficient systems for fossil fuels and new systems for renewable energy sources. The relative strengths of these concerns drive the attitudes of governments to support of a biofuel industry. In practice to ensure that these concerns are addressed a mix of technologies is needed. Biofuels are thus part of the energy mix and not a solution in their own right (Olz *et al*. 2008, Royal Society 2008).

The use of biofuels in transport needs to be seen as part of the broad transformation of that sector of industry. The sector overall has to become more efficient. A comprehensive approach is needed in which fuels, production methods, distribution and vehicle technologies need to be coordinated across industry and government.

A critical feature of the development of a biofuels industry is the need to create a predictable and growing market to stimulate private investment. To assist the creation of an attractive market, experience overseas clearly demonstrates that the government needs to use fiscal instruments.

Over the next five to 10 years biofuel production methods will change from Generation 1, based on fermentation of starch and sugar, to Generation 2 based on gasification of lignocellulose. This will affect the whole nature of the industry; thus government attitudes will be critical to its future in terms of the biofuels contribution expected and the incentives needed to achieve this.

The following sections discuss these issues in more detail.

7.3 ENERGY SECURITY AND MITIGATION OF CLIMATE CHANGE

Australia has very good coal or gas reserves with supplies adequate for several centuries to maintain electricity production and mineral processing. However indigenous oil supplies are in decline against the growing demand for liquid transport fuels. While this shortfall can and is being met by imports the international market is extremely volatile with recent record prices of up to US$120/bbl. High demand growth, particularly in India and China, places huge pressures on supplies and this situation will continue. The ongoing availability of liquid transport fuels at acceptable prices is a major policy issue for the Australian Government.

One option for meeting the Australian transport fuels shortfall is through conversion of indigenous reserves of coal, gas and oil shale to liquids (Trimm 2007). Current synthetic fuel costs lie in the range of US90 to 110c/L, approximately twice that of oil at US$50/bbl. An alternative for Australian transport fuels security is production of biofuels from indigenous biomass as discussed in Chapters 4 and 5. Current Generation 1 biofuels compare in cost to oil fuels with biodiesel higher, comparable to synthetic fuels. Generation 2 lignocellulosic biofuels will probably compare well with synthetic fuels.

A vital consideration for the future of fossil fuels is the reduction of emissions of GHGs given the link between combustion of fossil fuels and climate change (Royal Society 2008). There is a risk that the production of alternative liquid fuels if seen purely from a security perspective could result in increased emissions since synthetic fuels are more carbon intensive than oil fuels. Emissions can be reduced by additional expenditure on carbon capture and storage, increasing costs still further. Biofuels are more attractive in this regard. The data are scattered over a wide range but suggest that Generation 1 biofuels from cereals, straw, beet and rapeseed are likely to reduce emissions by about a half on average while Generation 2 biofuels are likely to reduce emissions still further (Royal Society 2008).

7.4 TRANSPORT FUELS AND TRANSPORT POLICY

The current production of ethanol and biodiesel in Australia constitutes only a tiny fraction of the overall national consumption of petrol and diesel. This could grow but the analysis of this report suggests that, given the variability of rainfall and the area of arable land and water needed for extensive production, biofuels will continue to make only a small contribution to the future liquid fuel needs of Australia.

Concerns have been expressed about possible petrol engine damage by ethanol. However most Australian vehicles can use a blend of 10 per cent ethanol with petrol without modification; the limit permitted by legislation. Higher blends are used overseas (up to 85 per cent) but this requires some modification of the fuel supply system to allow for materials compatibility. Blends of five per cent biodiesel with diesel are usable without modification but higher blends require some vehicle and engine adaptations. As the octane rating of ethanol is considerably higher than petrol, higher compression ratios can be used, improving engine energy conversion efficiency.

While biofuels have been justified as extending supplies of liquid transport fuels their use is complementary to other technologies aimed at improving fuel efficiency. Significant changes in social attitudes to vehicles, particularly in urban areas, are needed if congestion and air pollution are to be reduced.

Many other technologies have been demonstrated but need to be reduced in cost to be commercially viable (ATSE 2008). The use of stronger, lighter vehicle materials reduces weight and thus fuel consumption and emissions of GHGs. The industry rule is that a 10 per cent weight reduction gives a 5 per cent increase in fuel efficiency, but the use of composite materials across the vehicle can increase this to10 per cent. The benefits of weight reduction can be further realised if coupled to a hybrid or electric vehicle. Current hybrid vehicles can reduce petrol consumption by about a third. The critical technology is energy storage in either batteries or supercapacitors, both of which are being developed in performance although the electricity source and battery materials need to be carefully evaluated using LCA for overall environmental performance and energy efficiency. In the longer term, hydrogen fuel cells may power electric vehicles although a key challenge remains infrastructure for the production, distribution and storage of hydrogen. Nevertheless available data suggest that these technologies, when established, could reduce overall transport emissions more cheaply than biofuels (Royal Society 2008).

7.5 MARKETS AND SUBSIDIES

In recent years, numerous governments around the world have promoted industrial-scale production and use of liquid biofuels for varying reasons of security, reduction of emissions, reduced urban pollution and rural development. This development has been subsidised in a variety of ways along the chain from producer to user.

At the beginning of the chain are subsidies for goods and services consumed in the production process. In countries such as Brazil, the USA and the EU, the largest of these are often subsidies to producers of feedstock crops, particularly sugar and maize (for ethanol) and oilseeds (for biodiesel). In Australia little support is given in this area. Other subsidies are given to capital goods and labour used in production, and for land purchase. In Australia, subsidies to production have been in the form of grants for construction or expansion of biofuel manufacturing plants; these subsidies lower fixed costs and investment risks.

Later in the chain there are subsidies linked to output which offset fuel-excise taxes. These enable the sale of ethanol and biodiesel at retail prices roughly at parity with taxed petroleum-based fuels. The biggest element of assistance for biofuels is an excise tax rebate, provided as a per litre grant to producers which exactly offsets the A$0.38124 fuel excise duty. The grant is not available for imported ethanol but it covers both imported and domestically produced biodiesel. Currently this is due to be phased out in mid

2011. Other assistance is given through subsidies for designated consumers. In the most recent financial year (2006-07), Australian Federal and State governments spent about A$95 million supporting the production and use of biofuels and this will grow substantially in future years if maintained. Without subsidies some producers will be hard-pressed to cover production costs. Strong concerns over the efficacy of such subsidies in developing a biofuels industry have been expressed by some Australian economists (Quirke *et al*. 2008). It is believed that some of these biofuels excise issues are being considered in the Henry Tax inquiry, due to report in 2009.

Another contentious area of support is the use of mandates to guarantee markets. In 2001 the Australian Government set a non-binding target for biofuel production of 350 ML/yr by 2010 (equivalent to roughly one per cent of transport fuel consumption). In contrast to other national governments the Australian government has resisted calls from the biofuels industry to mandate particular volumes or blending ratios. However two State governments have taken a contrary view by introducing mandates to support emerging local industry. Thus New South Wales introduced a two per cent ethanol mandate at the end of last year and plans to introduce a 10 per cent ethanol mandate in 2010, although this is now in doubt with the recent change of government. Queensland plans to introduce a five per cent ethanol mandate later this year. In contrast Victoria has rejected the use of a mandate. The use of such mandates raises serious issues about supplies of biomaterials to meet required volumes. Increased grain prices resulting from biofuel production could reduce the competitiveness of grain and livestock exports.

This reflects growing concern overseas over the costs of biofuels (IEA 2007). Other critical factors in further development of biofuels are the long-term sustainability of the industry, perceived conflict between export of products for food against their use for biofuels leading to rising food costs, and the environmental degradation caused by deforestation of tropical forests to enable planting of palm oil crops for biodiesel. These are not yet major concerns in Australia although the level of public debate is rising and recently feedlot operators in Queensland have complained about the rising cost of sorghum due to its use for ethanol production.

7.6 TECHNOLOGICAL INNOVATION AND FUTURE PRODUCTION

Chapters 4 and 5 have drawn out a number of areas where technological innovation could lead to cost and emission reductions in biofuels production. Thus, to reduce costs of Generation 1 biofuels, there is a need to improve yield from conventional feedstocks through breeding and GMO techniques. The latter could also be used to reduce chemical inputs of fertilisers and pesticides.

Audits need to be conducted of the GHG emissions associated with production and use of present and future biofuels to ensure that feedstocks are being used most effectively. There is evidence to suggest that, under some conditions, the greatest CO_2 savings may be achieved by displacing coal with low emission electricity generation technologies (e.g. hydro, biomass, renewables or nuclear) coupled with advanced electric vehicles. Such scenarios will need to be tested by rigorous LCA as they evolve in the years ahead.

Given that the potential for Generation 1 biofuels appears to be limited in Australia by availability of suitable land and adequate water, attention has to be directed now to Generation 2 biofuels based on lignocellulose materials which are not competitive for crops or food. For Generation 2 biofuels, possible feedstocks need to be evaluated and new processing technology developed. It should be possible to maximise the efficiency of output and reduce costs through development of biorefineries where co-products have considerable value. While the development work on production of feedstocks must be done under local climate conditions, soils, water supply etc, there is a strong need for links into international projects focused on Generation 2 process technology which can be adapted for Australian feedstocks. This will minimise development costs and speed up commercialisation.

However, as earlier noted, government policy has a critical role in developing and maintaining biofuel markets. There are major issues with transition to Generation 2 biofuels. For private investment the transition appears risky; government will need to consider carefully the level and type of incentives to build into new plants and related infrastructure. Energy security, sustainability and emissions reduction need to be weighed against other comparable expenditure options.

Appendices

A – TERMS OF REFERENCE

OUR TRANSPORT FUTURE – ASSESSING THE ONGOING ROLE OF BIOFUELS IN THE AUSTRALIAN TRANSPORT SECTOR

Australian Academy of Technological Sciences and Engineering
A project funded by the ARC LASP 07

Project Summary

This proposal aims to clarify what we do know in terms of the potential for biofuels (and alternative hydrocarbon fuels) to become a significant component of our transport fuels mix in the context of the range of alternatives that are available. We also need to clearly define and prioritise the remaining knowledge gaps – for example, what do we need to know – in order to map out critical research, development and adoption pathways for the emerging biofuels industry.

The significance of this project is that it will lead to a reduction of dependence on fossil fuels, and hence emission of carbon dioxide, via the development of non-fossil fuel energy systems for the future. Furthermore, strategic positioning of Australia in the sustainable production of biofuels will allow access to future markets in the European Union.

The expected outcomes of the project will be:

- identify a coherent approach to the RD&D as well as policy pathways for biofuel industry development in Australia;
- improved linkages between researchers and users of research in the area of biofuels; and
- a better understanding of the directions of world research in the areas of interest and a more focused approach in Australia.

National and community benefit

Australia is highly dependent on fossil fuels for energy generation and transport fuels in particular. Accordingly, there is a need to ensure that the impact of climate change on the environment is minimised. Furthermore, there is clearly a looming problem for Australia in terms of the impacts of climate change on water supplies, food production, coastal environments and human health. Reduction of dependence on fossil fuels, and hence emission of carbon dioxide are critical issues.

The benefits arising from this research, into the development of non-fossil-fuel energy systems for transport fuels, will lead to lower levels of emissions of carbon dioxide to the atmosphere. Furthermore, strategic positioning of Australia in the sustainable production of biofuels will allow access to future markets in the European Union. In the EU, biofuels targets are being set such that there is a strong chance that they will rely to some extent on imported biofuels and have already developed legislative frameworks to limit this market to those biofuels which can demonstrate sustainability credentials. This may lead to significant export income for Australia and assist to educe our dependency on consuming fossil fuels for transport energy.

Development of next-generation sources of transport fuels offers an opportunity for Australia to improve its quality of life and also to develop new knowledge-based industries to maintain economic growth.

By bringing senior bioenergy specialists and researchers together in structured workshops, this project will provide a unique opportunity to shape the future path of bioenergy research for transport fuels in Australia. The social and economic benefits to Australia resulting from this project will be substantial and long-lasting.

B – BIOFUELS WORKSHOPS

Three Workshops were convened at the outset of the project in July and August 2007 to gain wide-ranging views from industry, research organisations, industry and the public service on the Australian transport biofuels industry. The free-ranging discussions, recorded on the project website (www.atse.org.au), were underpinned by the Biofuels Issues Paper (Appendix C). A fourth, more focused invitation Workshop was convened in January 2008 to explore the essentials of a Biofuels Research Roadmap for Australia.

Issues Workshop – Brisbane, 30 July 2007

Prof Don Nicklin AO FTSE (Chairman)	ATSE Queensland Division
Mr Matthew Andrew	Queensland Department of State Development
Prof John Bell	Queensland University of Technology
Prof Keith Bullock AO FTSE	Queensland University
Mr Bruce Harrison	Queensland Department of State Development
Dr Brian Keating	CSIRO Sustainable Ecosystems
Mr David Lamb	CSIRO Energy Technology
Mr Keith Sharp	TFA Project Group
Mr Martin Thomas AM FTSE	ATSE

Issues Workshop – Sydney, 1 August 2007

Mr Richard Kell AM FTSE (Chairman)	Cardno MBK
Professor Robert Bilger FAA FTSE	University of Sydney
Dr Thomas Brinsmead	University of Newcastle
Dr Donald Brown AO FTSE	O'Connell Street Associates Pty Ltd
Dr Bob Durie FTSE	CSIRO
Mr Bob Gordon	Renewable Fuels Australia
Mr David Gosling	State Transit Authority
Mr Peter Gregory	Department of Industry, Tourism and Resources
Professor Cliff Hooker	University of Newcastle
Dr John Keniry AM FTSE	Ridley Corporation
Mr David Lamb	CSIRO
Mr Paul McGregor	McGregor & Associates
Mr Sydney Mills	Manildra Group
Ms Ann Morrison	Caltex
Dr Roslyn Prinsley	RIRDC
Dr Stephen Schuck	Bioenergy Australia
Mr Peter Seebacher	AusEng Pty Ltd
Mr Martin Thomas AM FTSE	ATSE
Ms Eileen Tso	Department of Industry, Tourism and Resources
Dr John Wright FTSE	CSIRO

Issues Workshop – Melbourne, 2 August 2007

Dr Paul Donaghue FTSE (Chairman)	ATSE
Dr Vaughan Beck FTSE, ATSE	ATSE
Dr Tom Beer	CSIRO
Mr Greg Burg	National Australia Bank
Mr Michael Case	RACV
Ms Michelle Graham	Australian Ethanol Limited NSW
Mr David Lamb	CSIRO
Mr Peter Laver AM FTSE	ATSE
Mr Simon Mikedis	RACV

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Dr Peter Rogers	UNSW
Dr Stephen Schuck	Bioenergy Australia
Professor Bruce Stone FTSE	ATSE
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C – ACRONYMS AND ABBREVIATIONS

ABS	Australian Bureau of Statistics
ACCC	Australian Competition and Consumer Commission
AGO	Australian Greenhouse Office
AIP	Australian Institute of Petroleum
ALCAS	Australian Life Cycle Assessment Society
ARF	Australian Renewable Fuels Limited
ATSE	Australian Academy of Technological Sciences and Engineering
AWRI	Australian Wine Research Institute
bbl	barrel
BSE	Bovine spongiform encephalopathy (mad-cow disease)
BTL	Biomass to liquid
Btu	British thermal unit (1 Btu = 1.05506 kJ)
CNG	Compressed Natural Gas
CPRS	Carbon Pollution Reduction Scheme
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTL	Coal to liquid
CQU	Central Queensland University
DCC	Department of Climate Change
DEST	Department of Education, Science and Training
DOE	Department of Environment (USA)
DPI	Department of Primary Industries
DSS	Decision Support System
EBTP	European Biofuels Technology Platform
EC	European Community
EIA	Environmental impact assessment
EU	European Union
FT	Fischer-Tropsch
GBEP	Global Bio-Energy Partnership
GHG	Greenhouse gases
GIS	Geographic Information System (online mapping)
GJ	Gigajoule (1 GJ = 10^9 J)
GM	Genetic modification (or genetically modified)
GTL	Gas to liquid
GW	Gigawatt (1 GW = 10^9 W)
ha	Hectare (1 ha = 10,000 m^2)
HTU	Hydro Thermal Upgrading
IEA	International Energy Agency
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
J	joule (SI unit of work or energy – work done by a force of 1Newton over 1 m)
kg	kilogram
L	litre
L/yr	litres per year
LCA	life-cycle analysis
LPG	Liquefied Petroleum Gas
Mbbl/day	Million barrels per day
Mha	Megahectare (1 ha = 10,000 m^2)

MJ	Megajoule
ML/yr	Megalitres per year
ML	Megalitre (1 ML = 1,000,000 litres)
Mt	Megatonne (1 Mt = 1,000,000 tonnes)
MW	Megawatt (1 MW = 10^6 W)
NERDDC	National Energy Research, Development and Demonstration Council
NCRIS	National Collaborative Research Infrastructure Strategy
NOx	Nitrogen Oxides
NREL	National Renewable Energy Laboratory (USA)
OGTR	Office of the Gene Technology Regulator
QUT	Queensland University of Technology
R & D	Research and Development
RD&D	Research, development and demonstration / deployment
RD&E	Research, development and engineering
RIRDC	Rural Industries Research and Development Corporation
RSPO	Roundtable on Sustainable Palm Oil
SARDI	South Australian Research and Development Institute
SCU	Southern Cross University
SMR	Steam-methane reforming
SRI	Sugar Research Institute
t	tonne
UCO	Used cooking oil
UNE	University of New England
UNSW	University of New South Wales
ULS	Ultra low sulphur (diesel fuel)
VOC	Volatile organic compound
WUE	Water use efficiency
W	Watt (1 W = 1 J/s)

D – GLOSSARY OF TERMS

ASTM D6751: A US standard for biodiesel that establishes fuel quality requirements, such as purity and lubricity characteristics. See CEN 14214 European specifications.
Bagasse: Sugarcane processing residues.
Benzene: An aromatic hydrocarbon with a single six-carbon ring and no branches; a known carcinogen.
Biodiesel: A biofuel used in compression-ignition (diesel) engines containing mono-alkyl esters of long-chain fatty acids created by transesterifying plant animal oils with a simple alcohol (typically methanol but sometimes ethanol) as a catalyst. Modified biofuels for diesel engines (sometimes called 'synthetic', 'green' or 'renewable' diesel) can also be produced from lignocellulosic biomass using gasification and synthesis, cellulose or hydrothermal liquefaction; however the term 'biodiesel' typically applies only to those fuels derived from renewable lipid sources.
Bioenergy: Energy produced from organic matter or biomass. Biomass may either be burned directly or converted into liquid or gaseous fuel.
Biofuels: Liquid or gaseous fuels derived from organic matter, e.g. biomass.
Biomass: Organic material from plants or animals including forest product waste; agricultural residues and waste, energy crops, animal manures and the organic component of municipal solid waste and industrial waste.
Biomass residues: Residue resulting from the harvesting, processing and use of biomass. Can be divided into primary residues (generated before and at harvest – for example, the tops and leaves of sugarcane), secondary residues (generated during processing – for example, sugarcane bagasse, rice husks and black lie) and tertiary residues (generated during and after product end use – for example demolition wood and municipal solid waste).
Biomass to liquid (BTL): Thermal processes, such as gasification and Fischer-Tropsch synthesis, which convert biomass into liquid fuels.
Biorefinery: An integrated refining facility in which biomass is converted into fuel, chemicals, energy, materials and other products.
Biorefining: The process by which biomass is converted into fuel, chemicals, energy and/or biomass-based materials.
Bxx (where xx is a number – for example, B5, BI0, etc.): Biodiesel blended with petroleum diesel with biodiesel volume percentage indicated by the number.
Cellulosic biomass: Plant matter composed of linked glucose molecules that strengthen the cell walls of most plants. Next-generation biofuel conversion technologies can convert cellulosic biomass into liquids.
Cellulosic ethanol: Ethanol produced from cellulosic biomass, usually using acid –based catalysis or enzyme-based reactions to break down plant fibres into sugar which is then fermented into ethanol.
CEN 14214: A standard for European biodiesel performance, established by the European Committee for Standardisation, that sets fuel quality requirements such as purity and lubricity characteristics. See ASTM D6751 for US standards.
Clean Development Mechanism: The CDM is one of the two 'flexible' financing provisions under the Kyoto Protocol. It provides opportunities to promote biofuel development in developing countries.
Co-generation: A power station designed to generate both heat and electricity simultaneously. It delivers useful energy at efficiencies of 70 to 90 per cent compared with around 45 per cent for the best conventional (electricity only) generating plants.
Combustion: A chemical reaction between a compound (fuel) and an oxidising element (oxygen in air) that releases energy in the forms of heat and light. Compressed natural gas (CNG). Made by compressing purified natural gas (a fossil fuel composed primarily of methane) for storage in hard containers. It is frequently used to power vehicles and is considered a cleaner alternative to more carbonaceous fuels such as diesel or petroleum.

Compression-ignition engines: Also known as diesel engines. Internal combustion engines in which atomised fuel is injected into highly compressed air. The heat and pressure of the compressed air alone ignites the fuel.

Diesel fuel: A fuel processed from petroleum that contains a mix of molecules ranging from 12 to 22 carbon atoms (C-12 to C-22). Designed to run in diesel internal-combustion engines.

Dimethyl ether (DME): Sometimes called 'methyl ether' or 'wood ether'. It is gaseous ether (CH_3OCH_3) that can be manufactured as a biofuel and used as a substitute for natural gas.

Dry mill: A type of starch-ethanol mill characterised by the method of milling grains prior to fermentation into ethanol. Dried grains are ground and all pans an introduced into the production process. Proteins and fibres are usually extracted after fermentation.

Exx (where xx is a number – for example, EI0, E20, etc.): Ethanol blended with petroleum with ethanol volume percentage indicated by the number.

Energy crops: Crops grown and harvested for use as a feedstock in the production of fuels or other energy products.

Ethanol (CH_3CH_zOH): A vehicle fuel typically made from fermenting sugar derived from biomass (usually corn, sugarcane or wheat) that can replace ordinary petroleum in modest percentages (blends) in spark-ignition engines or can be used in pure form in specially modified vehicles. Nearly all ethanol is produced by fermenting plant sugars and starches (or hydrolysed cellulose or hemicellulose in the future); however, it can also be produced from fossil feedstocks. In this report ethanol refers exclusively to biomass-derived ethanol (also known as 'bioethanol').

Eutrophication: Eutrophication is an increase in chemical nutrients – typically compounds containing nitrogen or phosphorus – in an ecosystem, and may occur on land or in water. However, the term is often used to mean the resultant increase in the ecosystem's primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.

Fatty acid methyl ester (FAME): Another term for biodiesel feedstock. A material used as a raw material in an industrial process.

Fischer-Tropsch (FT) process: A biomass to liquid (BTL) method of synthesising hydrocarbons, specifically petroleum and diesel molecules, from 'syngas'. It passes hydrogen and carbon monoxide over a catalyst, either cobalt or iron, at high temperature and pressure. Named after German chemists Franz Fischer (1877–1948) and Hans Tropsch (1889–1935), the process is most often used to create FT diesel, a fuel for compression-ignition engines.

Flexible fuel vehicle (FFV): A vehicle specially designed to run on straight petroleum or any petroleum-ethanol blend up to E85 in temperate climates, and E96 in tropical climates, from a single tank.

Fossil fuel equivalent: A measure of energy potential from a given fuel or energy source relative to producing that same amount of energy with fossil fuels.

Fuel cell vehicle: A vehicle propelled by a fuel cell engine using hydrogen as a fuel (note that it is possible that on-board reformers can be used to extract the hydrogen from various fuels, such as methane, petroleum and ethanol).

Gasoline: A liquid fuel for use in internal combustion engines where the fuel-air mixture is ignited by a spark. It consists of a mixture of volatile hydrocarbons derived from the distillation and cracking of petroleum. It normally contains additives such as lead compounds or benzene to improve performance (the prevention of premature ignition) or rust inhibitors.

Gas to liquid (GTL): A route of gaseous fuel processing that results in byproducts that can include liquid fuels such as naphtha and diesel. The resulting BTL/GTL diesel can be used as a straight fuel or blended with ordinary diesel or biodiesel.

Genetically modified (GM) crops: Plants whose genetic make-up has been altered using genetic engineering technology that does not involve natural methods of reproduction. Some biomass crops, including sugarcane and corn, have been genetically modified to improve aspects of plant productivity.

Greenhouse gas (GHG): Gaseous components of the atmosphere that contribute to the greenhouse effect of gases in the Earth's atmosphere (where increased amounts of solar heat are trapped in the air). Human activity contributes to the greenhouse effect by releasing GHGs such as carbon dioxide, methane and others.
Hydrogenation: The chemical reaction that results in addition of hydrogen (H_2). The process is usually employed to reduce or saturate organic compounds and constitutes the addition of pairs of hydrogen atoms to a molecule. In the context of this report hydrogenation produces a hydrocarbon fuel.
Jatropha: An oilseed crop that grows well on marginal and semi-arid lands. The bushes can be harvested twice annually, are rarely browsed by livestock and remain productive for decades.
Knocking: A metallic rattling or pinging sound that results from uncontrolled combustion in an engine's cylinders. Heavy and prolonged knocking may cause power loss and damage to the engine.
Life-cycle analysis (LCA): An analysis that examines the environmental impact of a product or process from its inception to the end of its useful life.
Lignocellulosic feedstock: Biomass feedstock such as woody materials, grasses, and agricultural and forestry residues that contains cellulose, hemicellulose and lignin. It can be broken down in a number of ways into biofuels.
Liquefied petroleum gas (LPG): A fossil fuel extracted from crude oil and natural gas, comprised principally of propane (C_3Hs) and butane (C_4HlO). LPG turns to liquid under moderate pressure and is roughly 1/250th the volume of its gas form.
Lubricity: A measure of a substance's lubricating qualities, a property of oiliness or slipperiness. Lubricity is a concern for engine systems using liquid fuels, as many components, such as fuel pumps, depend upon fuel for lubrication.
Methanol (CH_30H): A simple alkyl also known as methyl alcohol.
Methyl ester: Another term for biodiesel.
Miscanthus: Also known as elephant grass it is a tropical and subtropical hardy perennial grass species originating in Asia and America. It is a promising biomass source due to its high growth rate.
Municipal solid waste: Total waste excluding industrial waste, agricultural waste and sewage sludge. Includes durable and non-durable goods, containers and packaging, food wastes, garden wastes and miscellaneous inorganic wastes from residential, commercial, institutional and industrial sources. Waste-to-energy combustion and landfill gas are byproducts.
Nitrous oxide (N_2O): A nitrogen oxide that is a common pollutant from burning fossil fuels or organic matter. It is a powerful GHG and a known ozone –depleting substance.
Petroleum: See definition for gasoline.
Potassium hydroxide (KOH): Commonly known as caustic potash, potassium hydroxide is a catalyst used with rapeseed oil in the process of transesterification to create rapeseed methyl ester, a biodiesel fuel.
Pyrolysis: A thermo-chemical process in which biomass is converted into liquid 'bio-oil', solid charcoal and light gases (H_2, CO, CH_4, C_2H_2, C_2H_4). Depending upon the operating conditions (temperature, heating rate, particle size and solid residence time), pyrolysis can be divided into three subclasses: slow, fast or flash.
Rapeseed: A flowering member of the Brassicacae family and a major global source of vegetable oil. Rapeseed oil is the most common feedstock for biodiesel in Europe, especially in Germany. Canola is a common North American cultivar of rape.
Rapeseed methyl ester: Biodiesel made from rapeseed oil.
Short-rotation coppice: A method of tree harvesting where the trees are harvested and the remaining tree stumps produce vigorous regrowth that is harvested after a prescribed number of years (varying by tree species and crop management priorities); three to four harvests may be possible before the trees must be replanted. Suitable trees are described as 'coppicable'.
Short-rotation hardwood forestry: A hardwood forest management strategy using short-rotation coppicing (or tree harvesting and replanting) after a prescribed number of years.

Saccharification and fermentation: A one-step process used to convert cellulosic biomass into alcohol that combines cellulase enzymes and microbes for fermentation. As enzymes break down cellulose into sugars, microbes ferment these sugars into alcohol.

Sodium hydroxide (NaOH): Commonly known as lye, this is a catalyst used to transesterify oils and an alcohol into molecules of methyl ester, or biodiesel.

Spark-ignition engines: Internal combustion engines that use an electronic spark from a spark plug to ignite a compressed mixture of fuel and air.

Steam-methane reforming: A process that converts methane and light hydrocarbons to carbon monoxide and hydrogen using steam and a nickel catalyst. The reforming reactions are endothermic (they absorb heat, rather than producing heat); as a result, heat must be supplied to SMR reactors, typically by a furnace surrounding a tube bundle packed with a nickel catalyst where the reforming reactions occur.

Switchgrass: A prairie grass native to North America that holds considerable promise as a feedstock for cellulosic conversion into ethanol.

Syngas (synthesis gas): A mixture of carbon monoxide, carbon dioxide, hydrogen and methane created during the gasification process of heating biomass in the presence of air, oxygen or steam. Syngas can be converted to a variety of fuels, including hydrogen, methanol, dimethyl ether and Fischer-Tropsch liquids.

Transesterification: A reaction to transform one ester into a different ester. This process is used to transform natural oil into biodiesel by chemically combining the natural oil with an alcohol (such as methanol or ethanol).

Vinasse: The residue liquid from the distillation of ethanol, rich in potassium and organic matter; it is used as a fertiliser and irrigation liquid to increase sugarcane crop yields.

Volatile organic compounds (VOCs): Organic compounds comprised of carbon and hydrogen that easily vaporise into the atmosphere. VOCs can pollute soil and groundwater, and in the presence of sunlight they react with NO_x to form tropospheric ozone, a respiratory irritant.

Well-to-wheels analysis: A life-cycle analysis of petroleum fuels that measures the efficiencies and impacts of various energy sources.

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Biofuels for Transport: A Roadmap for Development in Australia

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