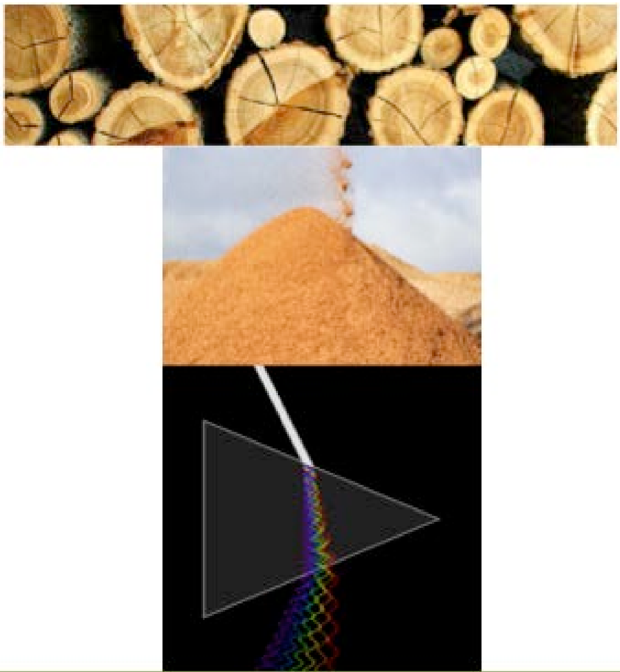
Opportunities for Australian forest growers from the development of a biorefinery and/or biomaterials industry within Australia.

Prepared for Forest Wood Products Australia

Parratt & Associates



Heat, Power, Fuels, Chemicals, Materials, Food, Feed

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Forest&Wood Products Australia
Knowledge for a sustainable Australia

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Chapter 1. Executive Summary

The development of biorefineries in Australia lags considerably behind many developed and developing countries. The recent studies undertaken on behalf of the DIISRTE (Commonwealth Department of Industry, Innovation, Science, Research and Tertiary Education)[1] confirmed that establishing biorefineries value chains in Australia would be beneficial on many levels:

- jobs security for the forest and chemical industries;
- food security;
- energy security;
- regional development; and
- sustainable farming and forestry practices.

This was confirmed further by a subsequent report undertaken by CSIRO on behalf of Enterprise Connect[2] that examined the potential value chain for utilising forest biomass in the SW region of Victoria. This options paper draws from the studies. These same studies identified that there exists key opportunities, at a general level to add value to biomass by:

- ensuring an adequate price is provided to the producers;
- enhancing the efficiency of transport;
- ensuring supply of biomass is year round and is consistent in quality and quantity;
- co-ordination across governments and the sectors of the value chain;
- improving the innovation framework for chemical and plastics sector in Australia;
- accessing international technology and best practice for the development of biorefineries for both fuel and chemicals;
- providing adequate skills development and training across the value chain to ensure Australian workers can meet the demands of growing industry;
- provide a long-term sustainable future for the forest and pulp industries, and
- linkages between the development of the chemicals, bioenergy, forest and farming sectors.

The options available to the forestry industry to develop biorefineries are limited in the current environment of low prices for forest products delivered for export or to saw mills or paper mills. The move toward biorefineries will require a whole-of-value chain approach. This will need to be brokered at all levels of government and industry. There are significant opportunities for Australian forestry and chemicals industries to collaborate to develop sustainable models of integration across the value chain from biomass growing to end-user products. It is unlikely the industry will develop in isolation and without government assistance.

There are a number of examples where wood or lignocellulosic biomass is being utilised in small to large-scale biorefineries to produce biofuels, biochemical and bio-based materials. However, there are a number of areas requiring research and development for the creation of successful biorefineries. However, with the exception of the areas directly related to growing, harvesting (including aggregation and densification) and transporting most of the research, development and innovation in the creating biorefineries will and needs to occur further down the value chain. The question does arise as to the appetite of the forest grower's to participate in such options. Arguably it is unlikely a biorefinery industry will develop without greater co-ordination and investment across the value chain in Australia. Forest biomass in Australia is currently above prices being paid for equivalent resources internationally and new business models providing benefits for foresters will need to be developed.

The development of the value chain from biomass to speciality chemicals has now become an area of intense study, research, development and publications. The sources and amounts of information available are vast. The challenge is to be able sift through the volumes of data, research and recommendations. However, the Commonwealth Government through DIISRTE, the International Energy Agency (IEA) and the USA Department of Energy have produced a number of reports and undertaken a vast number of studies over the past 10 years that a easily accessible.

1.1 Opportunities in Research, Development and Innovation

There are a number of opportunities for the forestry growers and industry to impact on the development of biorefineries within Australia either directly or via organisations such as FWPA.

1. FWPA could provide a role in brokering and supporting the development of the value chain. Innovation and commercialisation in biorefineries is proceeding at apace internationally. For the Australian forestry industry to capture some of the benefits of the change will require new partnerships and alliances to be formed. Though there is a willingness on behalf of the chemical and plastics industry in Australia to be part of the renewable bio-based product developments there is uncertainty on how to approach the development in Australia.

2. There is demand internationally and locally for access to bio-based products by users and consumers. A number of industry end-users have indicated a willingness to pay a premium for renewable bio-based products, such PET based bottles. There is a recognised shortage occurring in some of the building block chemicals in Australia. However, rather than exploring the opportunity to access renewable biomass as a source companies are either moving offshore or looking to import.
3. FWPA in association with other RDCs, ARC and Departments of Innovation could facilitate significant new research and innovation to create market pull for lignocellulosic bio-based products.
   - The chemical and plastics industry in Australia want certainty of quantity and supply of platform chemicals and quality. There is considerable research and development work to be undertaken to guarantee that this can be delivered. This is primarily substituting 'like for like' chemicals.
   - Research and development is also required to create new materials from renewable biomass. A stand out example of this is carbon fibre from lignin or cellulose.
   - The Pulp and Paper Industry Strategy Group recommended the development of a Biorefinery Institute in 2011 along the same lines as the Solar Institute. The research sub-group of the Council held initial consultations and a workshop in late 2011. The re-invigoration of this initiative would be useful for the industry.
   - Research and product development can proceed prior to developing a full-scale biorefinery. Skills and expertise would need to be developed along the value chain in unison with the development of biorefineries.
   - Previous reports have indicated the need for increased innovation and increased productivity in the forest and related industry. Education is a critical component to overcoming these shortcomings. The Commonwealth's RD &E strategies are placing greater emphasis on the Rural Development Corporations to increase education outcomes and to look for synergies across sectors. The development of biorefineries could be an area for increased investment.

4. Though there a range of process technologies (biochemical or thermolysis) that are in development there is still no clear pathway to the best-integrated model of a biorefinery. This may not occur. Australia is lagging behind on the application of platforms of technology to the transformation of biomass. It is unlikely that either the investment or the will exists to create a full-scale 'greenfield' biorefinery in Australia. Two clear alternative exist: retrofitting pulp and paper mills linked to capturing low cost biomass and/or importing technology from overseas. There are some start-up companies doing innovative research on bioenergy and renewables however these are yet to reach demonstration plant scale. The industry should increase its efforts to help identify and attract significant platform providers to Australia.

5. Overcoming the problems of aggregation, densification and transportation of forest materials is a significant and on-going area for the forestry industry. The costs of transport can represent up to 50% of the f.o.b. cost of export or delivery to central process sites. This is an area that offers considerable opportunity for pre-competitive research and development. Theoretically, the ability to aggregate and pre-process forest material could add significant competitive advantages to the establishment of biorefineries. Pre-treatment of lignocellulosic biomass is being investigated by a number of groups internationally. Previous attempts to import some of these technologies have not been successful due to a lack of industry backing and government support.

6. Undoubtedly the biggest challenge and therefore potentially the biggest opportunity for the forestry industry in the development of biorefineries is the design and implementation of a business model that will enable the private industry players to capture value along the supply chain. Bringing together foresters, transport operators, the downstream processors, governments and communities will be necessary to establish this new industry. Governments and government-sponsored organisations need to de-risk the development for each of the critical stakeholders.

7. Entry into biorefineries and value chains for woody biomass transformation is not without its challenges. A number of financial, regulatory and market hurdles need to jumped. However, as is detailed in this options paper there are a number of participants in Europe, the Americas and Asia that are overcoming these hurdles at a much greater rate than Australia. A significant factor in the development of the industry, particularly in the USA has been the large ownership by biomass producers. In 2007 over 50% of ethanol production in the USA was farmer owned.

Chapter 2. Introduction

Forest Wood Products Australia requested that Parratt & Associates prepare an options paper describing the opportunities available for Australian forest growers from the development of a bio-refinery and /or materials industry in Australia. The paper was to:

1. Review the current status of the use of timber and other resources as biorefinery feedstock
2. Report of the major processing technologies currently in use in biorefineries and an indication of the research needs and forecast outcomes.
3. Characterisation of the major products produced from biorefineries and, an assessment of current and future market demands and pricing, where known.
4. Assessment of alternate products and materials that can be commercially produced from cellulosic and lignin precursors extracted from woody biomass.
5. Recommendations regarding areas in which the Australian forest and wood products industry should prioritise R&D investments and description of the likely outcomes and benefits associated with those investments.

2.1 What is a Biorefinery

Biorefinery classification tends to cover a range of industrial activities and is often used differently by different industry participants. However, the key concept is the conversion of biomass into different product streams (bio-products may include: biofuels, materials, chemicals, food, feed) via the integration of different technologies and processes. The following definition, as developed by International Energy Agency (IEA) Bioenergy Task 42[3] is generally accepted as suitable working definition for a biorefining: "Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy". This concept includes the management of all sustainability issues, including environmental, economic and societal factors. The Biorefinery Euroview project states that "Biorefineries could be described as integrated bio based industries using a variety of technologies to make products such as chemicals, biofuels, food and feed ingredients, biomaterials, fibres and heat and power, aiming at maximising the added value along the three pillars of sustainability (Environment, Economy and Society)."

Utilising biomass, as a renewable resource is the **only** way to provide replacement carbon to that currently derived from fossil biomass sources in the manufacture of chemicals, materials and fuels. Numerous studies[4] have concluded that to create bio-based products that are competitive with fossil oil and gas 'similars' will require an integrated biorefinery strategy that will efficiently and effectively gain maximum added value from the entire biomass stream generating zero-waste. This implies collaboration and a level of integration across the supply chain.

There are several types of biorefineries currently in planning and, in some cases operational. What differentiates biorefineries is the platform of technology utilized to undertake the primary conversion of biomass to a product.

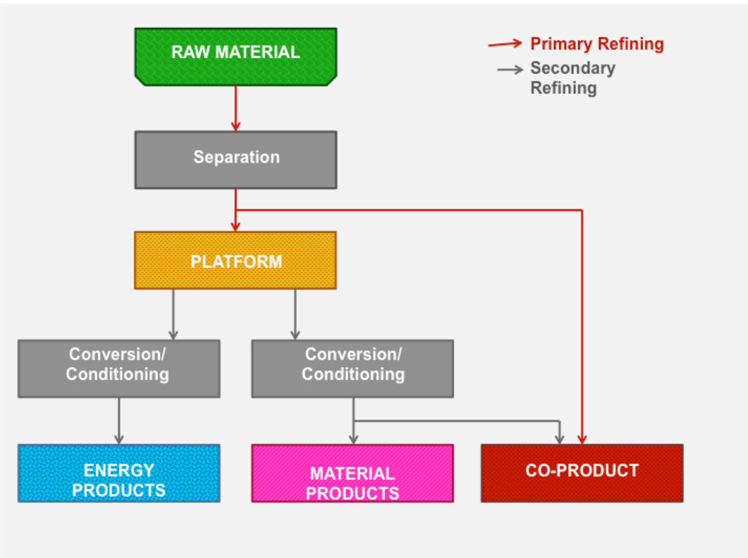


Figure 1: Basic structure of a biorefinery[5]

The platform maybe created from plant or algae or pyrolysis oils, municipal waste, syngas, biogas, lignin organic solutions or a combination of these across a biorefinery. Though this report restricts itself primarily to lignocellulose platforms there are other platforms in use or under investigation. There could be benefits of co-location and development of multiple platforms as one biorefinery (e.g. capturing waste products such as CO2 for algae production).

Lignocelluloses crops may be quite variable and opportunities exist to use multiple feedstock that are similar in basic structure e.g. softwood, hardwood, cereal stubble to ensure supply. Wood biomass is also varies between different species of trees or the type of forest residue. However, woody biomass is generally less variable than the range of crude oils that are currently processed in refineries. This is mainly due to the different origins of the crude oil, age and conditions experienced in the oil reservoir, fraction of the crude recovered and means of recovery. Products from a petrochemical refinery are controlled by the type of process units used (pyrolysis, catalytic cracker, hydro-former, etc.) the operating conditions, catalysts and the sequences of units as well as the blend of crude feeds used.

Likewise, the choice of process for a Biorefinery is normally driven by a combination of the desired end products, the process scale and economics and any locality and economic factors (i.e. availability of water to operate the process) as well as any local legislation (e.g. carbon tax, water use and discharge requirements, restrictions on volatile emissions and particulates).

In conventional petroleum / petrochemical refineries the crude is distilled to produce the fractions normally used as different fuels, lubricants and petrochemical process feedstock. The heavier residues are normally then processed in a fluidized catalytic cracker (FCC) to break them down to lighter fractions that are then separated into the valuable components or sent back to the FCC if they are still too large. Crude oil is conventionally broken down to simple building blocks before it is then, via the petrochemical industry, built up, functionalized or rearranged to produce more valuable materials.

More recently with the emergence of biorefineries in Europe and America there has been a step change in the way biomass is treated to produce value added materials. More consideration is being given to making use of the complex biomass to determine what can be made from this essentially purer, more consistent mixture of woody biomass available to the Biorefinery. This has resulted in biomass processing that does not always reduce the biomass to the smallest building blocks, instead focusing more on minimal, selected conversion processes to yield more valuable materials with minimum energy input. This has meant with new biorefineries the investment can be made in non-conventional process units and consequently there is a number of biorefineries that have on site chemical, thermolysis and biocatalytic processing units. However, some biorefineries simply pre-treat the biomass to produce bio-crude oil that can be fed to conventional petroleum refineries, thereby reducing the level of new infrastructure investment required.

The biorefining processes are likely to evolve and be further developed as a result of increased economic and social drivers for the use of biomass for fuels and chemicals. This has resulted in a significant increase in research and development investment by governments, private investors and companies in a number of countries to develop biorefinery processes, as well as new applications for biorefinery products.

Recently there has been a significant shift in interest in biorefineries away from the production of biofuel or bioenergy alone, more towards chemicals, plastics and related downstream added value products. This has been evident from new investment, company press releases, private and public sector R&D and presentations at conferences such as the World Industrial Bio conference.

2.2 Examples of Existing Lignocellulose Biorefineries

The following four examples of biorefineries in action. Though there are other examples of cellulosic biorefineries (ethanol from corn stover or miscanthus or starch or straw) these four are based predominately on the conversion of lignoclellulosic material to energy and chemical products. Borregaard is arguably one of the most advanced and profitable wood based biorefinery in the world.

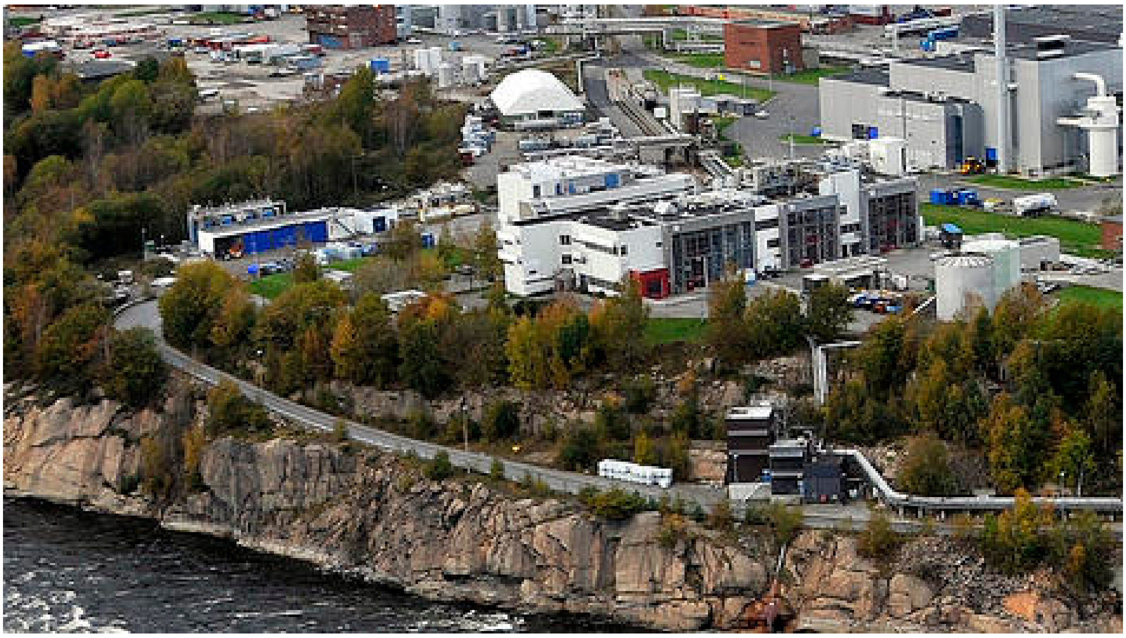
2.2.1 Borregaard (www.borregaard.com) Norway.

Borregaard is organised in three business areas accordibng to market and product type:

- Performance chemicals , including Lignotech
- Specialtiy cellulose, including Borregaard Chemcell
- Other Buisness : Vanillin, Fine Chemicals and basic chemicals

Revenues in 2012 were 3,941M NOK or A$656M was broeken down to

- 42.9% from Performance chemicals
- 41.0% from speciality cellulose
- 18.1% from Vanillin, fine chemicals and basic chemicals.



2.2.2 INEOS – New Plant Bioenergy, USA

INEOS New Planet Bioenergy (INPB) in Florida has reached another milestone and is now producing renewable power using INEOS Bio's feedstock flexible Bioenergy technology. The facility is producing renewable power for the facility and for export to the local community.

Indian River Bioenergy Centre August 2012

INEOS Bio and its joint venture partner, NPE Florida, have invested millions of dollars to build the Bioenergy Center and bring clean energy jobs to the Treasure Coast region of Florida. The Indian River County Bioenergy Center, near Vero Beach, Florida, is designed to produce eight million US gallons of advanced biofuels per year from renewable biomass including yard, wood and vegetative wastes. The facility also generates clean renewable power for export to the local market. The total project investment is more than $130 million and created 400 direct and indirect jobs (including 300 construction jobs) during the 2011-12 project development phase. The Centre will employ 60 full time jobs once the Bioenergy Centre becomes operational.

2.2.3 KiOR (www.kior.com), USA

Based in Columbus, Mississippi KiOR began construction of its first commercial scale facility, located in Columbus, Mississippi, in the first quarter of 2011. The facility produces environmentally friendly gasoline and diesel blend stocks from Southern Yellow Pine woody biomass. The plant is fully funded, and KiOR has already established purchase agreements for the site's entire fuel output.

The company states that it chose the Columbus location due to the site's proximity to abundant, locally grown woody biomass and access to shipping infrastructure. The facility was designed as an initial scale commercial facility processing 500 bone dry tons (b.d.t.) of sustainably harvested woody biomass per day. Once fully operational, it is to be expanded to produce approximately eventually 13 million US gallons of gasoline, diesel, and fuel oil blend stocks annually. KiOR has fuel offtake agreements in place with Hunt Refining, Catchlight Energy (a joint venture between Chevron Corporation and Weyerhaeuser Company), and FedEx Corporate Services. KiOR and Catchlight Energy also have a feedstock supply agreement for the facility. The engineering, procurement and construction firm in Columbus is KBR. The approximately $222 million facility is expected to create several hundred direct, indirect, and induced jobs during operation, and over 500 jobs on site during peak construction. Full production is scheduled to commence in the second half of 2013. Production of second-generation biofuel began as planned in 3rd Quarter 2012. Production is targeted initially at 272 litres per b.d.t. and 49M litres annually from the 180,900 b.d.t.

2.2.4 Zeachem (www.zeachem.com), USA

Lakewood, Colorado based biorefinery developer. ZeaChem has begun production of commercial grade cellulosic chemicals and ethanol at its 250,000 gallons per year (946,000 litres per year) biorefinery in Boardman, Oregon. According to the company the facility is among the first operational cellulosic biorefineries in the world, and showcases the scalability of its process as well as serving as a key stepping stone toward large-scale commercial production.

Products and markets
ZeaChem explained that in a similar fashion to the way a petrochemical refinery that makes multiple fuels and chemicals, its demonstration facility is employing its C2 (two-carbon atom) platform to produce cellulose based ethanol and intermediate chemicals such as acetic acid and ethyl acetate.

Chapter 3. Review of the current status on the use of timber and other resources as biorefinery feedstock

Biofuels Digest provides a database[6] on biorefinery projects currently listed worldwide. These data were compiled as of July 2012. On a simple review there are some errors in the database, for example MBD in Australia is not working with bagasse. Also, a number of the projects are in planning rather than in construction or production. With these cautions the following summary tables provide some insights into the current status on the use of timber and other resources.

Of the 167operations that reported and were verified the following provides a breakdown of the percentage using different feedstocks. The actual feedstock quantities being utilised are not reported on a consistent basis thus making comparisons between technologies and processes difficult.

Table 1: Summary of Feedstock and Processes currently used in emerging biorefineries

Feedstock	Percentage of Biorefineries	Process Technology	Platform Type as a Percentage
Algae	22%	Trans-esterification	8%
Animal Residue	1.3%	Fermentation	21%
Bagasse	3.4%	Hydro-processing	10%
Black Liquor	1.3%	Extraction	4%
Camelina	1.3%	FT	4%
Cellulose	4.0%	EH	26%
CO2	4.0%	BLG	1%
Corn	10.7%	Solar	2%
Corn Stover, Cobs	10.1%	Plant Cell Culture	2%
Ethanol	2.0%	Catalysis	2%
Hardwood	1.3%	CBP	1%
MacroAlgae	0.7%	Gasification	6%
Miscanthus	1.3%	Methanol Synthesis	4%
Mixed Biomass	5.4%	AH	2%
Mixed Cellulose	4.0%	Pryolysis	5%
Municipal Solids and Waste	10.7%	Undefined	2%
Palm Waste	2.7%		
Wood and Wood Waste	13.4%		

Abbreviations: Renewable Drop in Fuel (RDIF), Fischer-Tropsch (FT), Consolidated Bioprocessing (CBP), Enzymatic Hydrolysis (EH), Acid Hydrolysis (AH), Black Liquor Gasification (BLG)

There is potential overlap in some of the technologies being used and some processes maybe used in combination to create multiple streams of products. Ethanol production from corn and sugar are the current major activities by a significant amount. Though the figures above suggest that the process and feedstock may be more evenly distributed the current ethanol production in USA, Brazil, India and China dominates product output.

Of the second generation fuels and feedstock the technology and biomass sources are more evenly distributed though the major target remains biofuels with only emerging activity in the chemicals area. Lignocellulose biorefineries to produce bio-products are classed as second generation or advanced biofuels.

Table 2: Breakdown of current and target products from emerging biorefineries.

General Product	Percentage of Operations
Chemical	9.9%
Butanol	11.1%
Ethanol	34.6%
Biodiesel	15.6%
RDIF	13.6%

3.1.1 Further developments from current uses of timber in biorefineries.

1. Validation of data, companies and technologies:

   The current data is restricted and subject to significant errors in the press and industry digest. There are dynamic shifts occurring as various stakeholders alter their alliances. The most significant factor will be any emerging trends in the shifts of feedstocks to lignocellulosic sources.

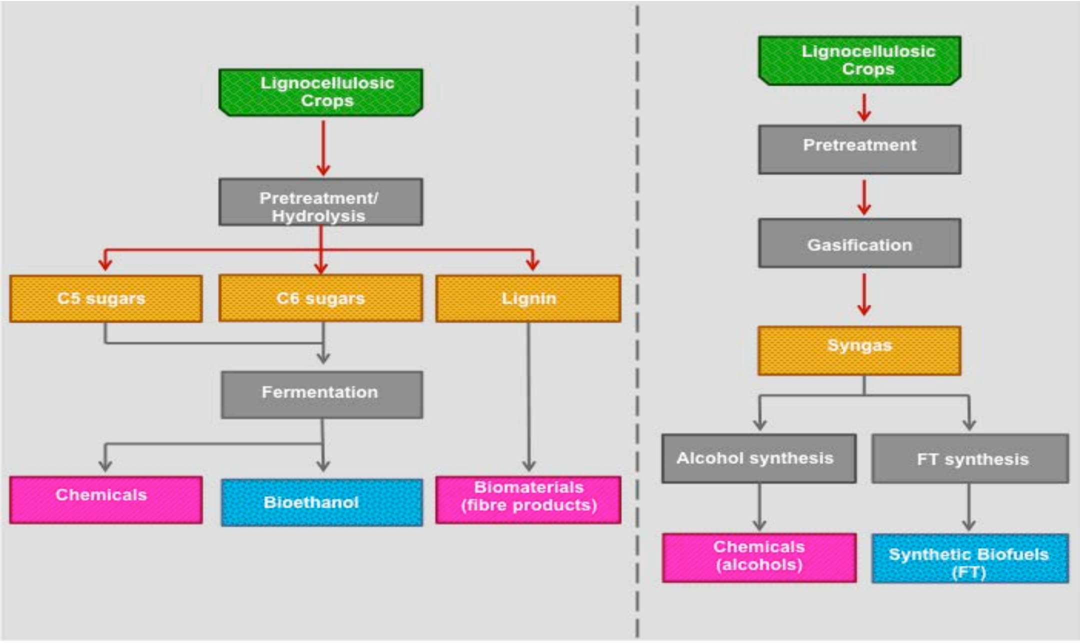
   FWPA could monitor current trends and provide industry with early data suggesting changes in trends. This analysis would need to be linked to the detailed analysis of potential technologies and markets for products from Australian timber in biorefineries.

2. As will be discussed later, there is a need to better understand the processes and chemistry for separation and purification of lignin, hemicellulose and cellulose.

Chapter 4. Lignocellulosic Biorefineries

Two clear approaches exist to the as platforms for lignocellulosic transformation: biochemical and thermochemical. There are variations on each platform, particularly the thermochemical platform.

Figure 2 provides a schematic overview of the two approaches. The biochemical approach is to initially fractionate the lignocellulose material into three streams: cellulose, hemicellulose and lignin. The thermochemical approach uses heat and/or pressure to convert the lignocellulose feedstock in to syngas or bio crude. The syngas can be converted to biofuels or chemicals.



FT = Fischer-Tropsch Process

Figure 2: Schematic diagram of the biochemical approach (LHS) and the thermochemical approach (RHS)

An integrated biorefinery development could provide an opportunity to:

- redefine and reconnect the role of agricultural, natural resources and sustainable energy and carbon based materials production;
- identify commercial drivers and likely areas of impact (such as improved land management practices and environmental services) to realign or commence research;
- develop decision frameworks to address land and water use trade-offs across human food, animal feed, water yield, fibre, energy and environmental service needs;
- move Australia and the world 'from fossil biomass to current biomass';
- stimulate both the agricultural and manufacturing / chemical industries in Australia through synergies in the value chain (i.e. the waste from agriculture become a valuable feedstock for the chemical industry);
- use of locally grown biomass for the fuel and chemical industry will stimulate employment in both rural and metropolitan contexts; and
- the use of locally grown biomass for fuel and chemicals will act as strong driver for import replacement and so assist Australia's balance of payments.

Zakzeski[7] offered the following model for an integrated lignocellulosic biorefinery focussed on the lignin stream and utilising on both biochemical and thermochemical transformation of biomass.

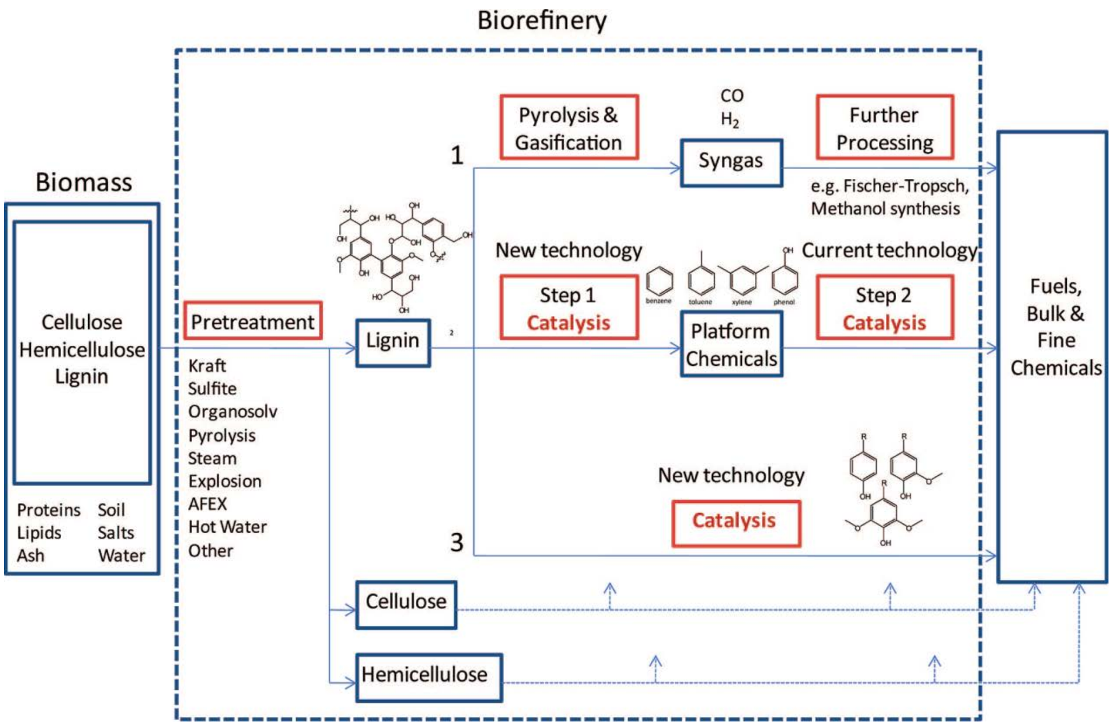


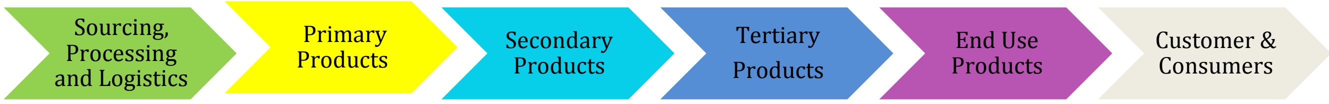
Figure 3: Lignocellulosic biorefinery scheme with an emphasis on the lignin stream[8].

Three strategies are considered in this representation. In the first strategy biomass is gasified or degraded by pyrolysis to a mixture of molecules that can be then used to produce chemicals similar to those produced by the petroleum industry. In the second strategy functional groups present on lignin yield aromatic compounds such as phenol, benzene, toluene and xylene. These platform chemicals (see Chapter 5) are converted using current petroleum-based technologies for the production of bulk and fine chemicals. The third strategy is best suited to fine chemical production with a high degree of functionality.

A number of research projects and companies are developing innovative processes (pyrolysis and thermochemical) to turn a wide range of biomass (forestry residues, crop residues, waste paper and organic waste) into stable, concentrated bio-oil (biocrude) that is compatible with existing refinery technology and can be converted into advanced biofuels. For example, in the HTU® (hydrothermal upgrading) process, originally developed by Shell, biomass is treated with water at high temperature and pressure (300-350°C & 120-180 bar) to produce bio-crude. This can be separated by flashing or extraction to heavy crude (suitable for co-combustion in coal power stations) and light crude, which can be upgraded by hydrodeoxygenation (HDO) to advanced biofuels. Licella, in Australia utilises a similar proprietary process create bio-crude.

Parratt, O'Shea and Graichen[9] examined the value chain for forest biomass to a biorefinery for the SW region of Victoria. They developed a potential value chain model as shown in Figure 4 below. The products in the value chain have been classified according to their relationship to the output of a "biorefinery".

←------------ Feedstock-----→ Biorefinery ←-----------------------BioProducts--------------------------→



Feedstock	**Biorefinery Products**	**Secondary Products**	**Tertiary Products**	**End Use Products**	**Customers and Consumers**
Trees (Hardwood and Softwood) Forest Waste Paper Mill Waste **Separated Into** (1) Woody Fraction (2) Terpenes (ie Eucalypt Oil and Pine Oil, paper mill waste streams)	• Gas Stream • Biocrude • Char • BioAromatics • Waste for Power Generation etc	• Polyethylene • Polypropylene • PVC • Polyamides • Plasticisers • Styrenics • Polyurethanes • Polycarbonate • PET and Polyesters • Lubricants • Phenolics • Surfactants • Additives / Stabilisers • Fuels	• Plastic films, sheets and fibres • Blow moulded products • Injection moulded products • Rotomoulded products • Resins and Emulsions • Engineering Polymers and composites	• Packaging • Carpet • Clothing • Signs • Pipe, Cable and Profiles • Electronic items & Media • Household & Recreational • Automotive & Transport • Tanks and storage • Defence Applications • Paint & Coatings	• Gov'ment • Councils • Telstra • Mining Industry • Agriculture Industry • Transport Industry • Tourism Industry • Telecommunication Industry • General Public • Exports

Figure 4: Potential Value Chain for Biomass Transformation including products

The *primary products* are those that can be derived from the wood as well as the plant secondary chemicals (terpenes) that can be extracted from the wood, bark and leaves. The processes chosen for the initial biorefinery are predominantly thermolysis and chemical processes to be compatible with current infrastructure in paper mills, fuel refineries and petrochemical plants. Through using: (i) HTU (hydrothermal upgrading) to process the wood[10] and (ii) pyrolysis to process the terpenes[11] it would be possible using known technologies with minimal re-investment to manufacture *"like for like"* products at significant volume where there are existing value chains, markets, infrastructure and customers.

As the integrated biorefinery evolves it could seek to make use of the complex nature of the woody biomass to produce other materials in the form of *"functional equivalents"* and *"new or novel"* products. This may need further investment in different process units that can make full use of thermolysis, chemical and biocatalytic processes to produce the new range of products.

There is the opportunity for the *primary products* to flow down the value chain. Some of the primary product may form an export stream to sell the materials into the world market. Parratt et al[12] had discussions with various global manufacturers who clearly viewed Australia as a potential source of renewable feedstock to supply their value chains and the associated innovation in bio-based products. This has been confirmed in ongoing discussions between CSIRO and a number of companies based in the Asia Pacific region[13]. One of these large companies, which has committed to 100% renewable feedstock, has expressed interest in purchasing, contracting or partnering with Australian biomass growers or early chain converters to supply feedstock for their chemical and plastics business.

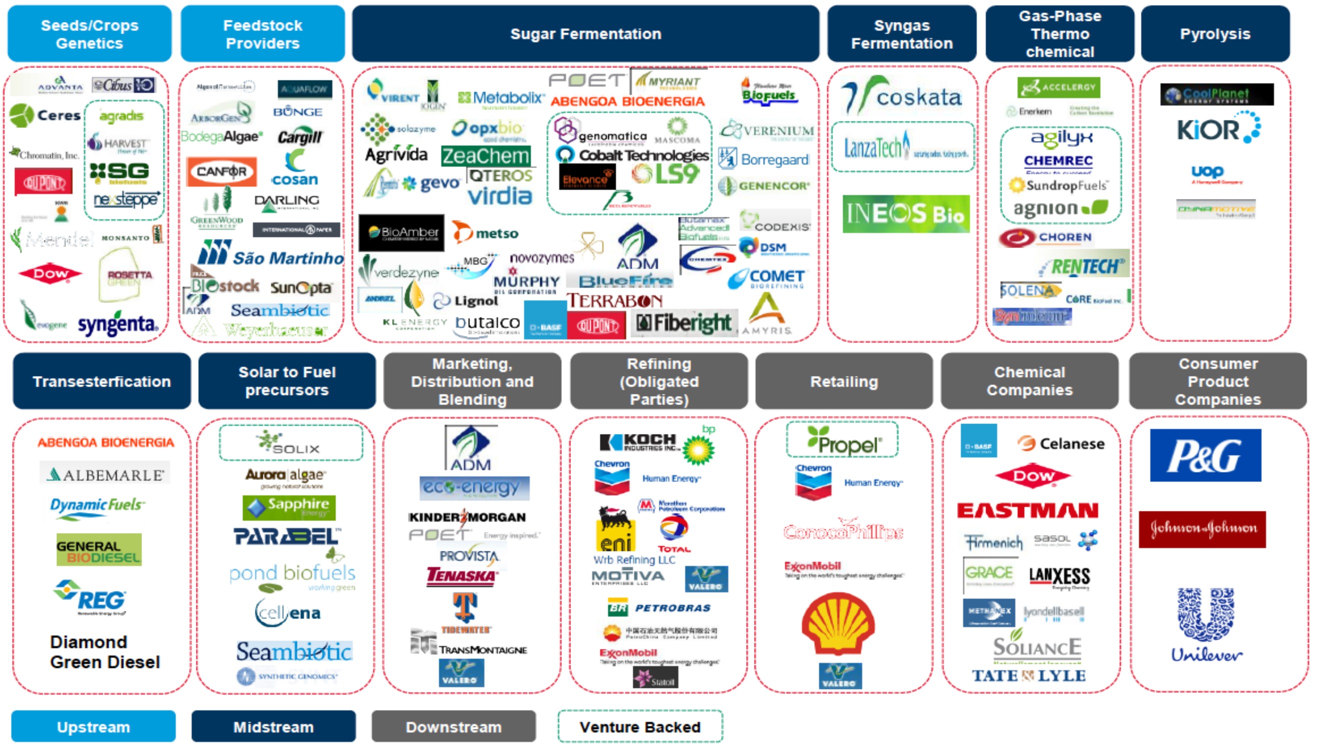
The *secondary products* identified are those that can make use of the primary biorefinery outputs to produce "*like for like*" materials for existing products in Australia. The majority of the manufacturing for these secondary products is currently undertaken in Victoria, or at least in Australia. The manufacturing industry for these secondary and other products along the value chain is currently in decline[14] mainly due to:

- cost pressures
- below world scale operation
- raw material limitations

Some of the products nominated in the value chain have been manufactured in Australia. However, globalisation has moved this manufacturing offshore. The challenge is to determine the likelihood of production being re-established in Australia. This will require links to the international supply chain with products and quantities capable of competing in the international market. It is plausible that with the availability of cheaper, sustainable feedstock in combination with the pressures due to increasing prices of crude oil and rising transport costs that there is an opportunity for the products to be manufactured in Australia once again. Green and local manufacturing is currently receiving an additional boost through the rise of consumer interest in sustainable/green products (PET bottles, PLA chip bag, bio-polyethylene from Brazil).

The value chain for the biochemical production utilising alternative platforms is growing rapidly and is complex.

Advanced Biofuel and Biochemicals Value Chain



Source: SVB and Bloomberg New Energy Finance.

The biofuels and biochemical value chain is now characterised by significant partnerships, joint ventures and technology platform companies seeking to gain value through technology licensing[15]. In the last 5 years in the USA alone in excess of US$5B was raised and invested in biofuels and biochemical production. In moves that are similar to the biotechnology industry IPOs are be used to add working capital rather than as exit strategies for founders. This does present challenges for a developing industry in Australia. There is clearly a world-view that renewables chemicals and fuels from biomass is a medium to long-term proposition as evidenced by the significant investment and developing value chain. The question remains as to which biomass, which technology, which partners and at what cost.

4.1.1 Opportunities for further development on Biorefineries

No clear technology 'winner' has emerged for the lignocellulosic transformation platform. It is unlikely that there will be one clear preferred technology. Australia on the whole is well behind on international research developments and is unlikely to be able to develop a 'greenfield' biorefinery without significant input from international companies and agencies.

1. FWPA could focus on supporting research and development that builds capacity in the key fields likely to use the outputs of biorefineries. This could include investments that ensure there is significant pull through on forest biomass to broaden the market base for the commodity. Improving the understanding of chemical, biochemical and materials engineering of transformed woody biomass will build on the knowledge base for forest and related industries.

2. Significant R&D activities[16] need to be undertaken to realise the development of a large integrated biorefinery. Some of these activities would include;
    - waste-heat recovery and exchange;
    - residue storage and handling;
    - scale compatibility between biochemical and thermochemical processing;
    - animal feed protein production as a co-product. For example, Dupont currently sends to land fall all waste solids from its 1,3 propanediol plants;
    - reduction of process water requirements; and
    - consistency of supply and characterisation of biomass pre-delivery.

The integration and optimum utilisation of all products from the conversion of pulp logs and residues to materials and chemicals could see the transformation of pulp and paper facilities into truly integrated biorefineries.

Several studies have been conducted attempting to better understand biomass value chains. Some discuss the biomass processing options as a business opportunity for the production of bioenergy and, in addition high value material products (e.g. Crucial Carbon for Sustainability Victoria, 2008[17]; Warden and Haritos, 2008[18]). Other studies focus on technologies for capturing the raw biomass material (Rose 2008[19]) and the recent Victorian State Government 'Fuelled for Growth" and the Victoria's Timber Action Plan. There are no published studies that work through the value chain in conjunction with industry partners from the growing of the biomass to the potential Australian and international end-uses.

3. FWPA could facilitate a critical pathway analysis of timber to be transformed into higher value biochemical entities. Linking foresters with those further down the value chain.
4. The current 'Cellulose Fibres Chain Study of the Green Triangle'[20] and other recent studies have identified a number of current industry dilemmas that need to be addressed for the industry to capture additional value from the forest resources. These dilemmas include:

    - productivity is lower than world standards;
    - costs of logistics and harvesting are high;
    - growth rates and density on poorer soils and with less water leads to lower yields and increased costs per hectare with lower returns compared to some international counterparts;
    - timber mill prices in Australia are no longer competitive with imports;
    - there has been an under-investment in new technology, research and development by the industry;
    - the industry is fragmented and lacks a clear vision for innovation and change;
    - there is little integration along the value chain as compared to other jurisdictions.;
    - value adding to the forest resource has not been considered a priority by the forest owners; and
    - when compared to a number of competitors there is comparatively little government assistance or subsidies provide to value chain development in Australia. The 'biofuel subsidies' in Europe, North America, South America, India and China have given significant impetus to the development of the value chain. Reducing the barriers to entry into new industries.

5. Identify which existing international stakeholders may be interested in investment in Australia. There has been a number of biomass audits and a number of government studies indicating that there is sufficient biomass resource, significant possibilities for co-location and significant potential for downstream processing.

6. Work with the existing industry stakeholders, State and Commonwealth governments and ARENA to identify opportunities for inward investment.

7. Specific areas of focus
    - Harvesting
        - The CRC for Forestry and CRC for Future Farming Systems have undertaken work in this field. The extent to which the knowledge has been adopted appears to be open to question.
    - Logistics
        - There is a large body of work that show that transport costs are a significant productivity and profit impediment for the industry and the development of biorefineries. Operations research, scale of rigs and transport networking could be offer possible solutions.
    - Pre-treatment
        - Decentralised pre-treatment of biomass to allow for densification and compaction (effectively removing the need to transport moist biomass) is a research demand.
    - Transformation
        - Several transformation technologies are emerging. Australia has world-class research in enzymology, fermentation biology, petro-chemistry and renewable chemistry resident in Universities and CSIRO but not a lot in industry. Moving this expertise to an industry focus through such activities as the ARC Industrial Transformation Hubs and Innovation Precincts offer opportunities to engage with industry. The reality is that this will require greater international participation with the value chain beyond the forest. FWPA should work to assist with this development.
    - Product Development
        - FWPA, on behalf of its forest stakeholder could help develop market pull for its timber products. This can only be achieved by proof of concept on the benefits, scale and accessibility of biomass to be transformed into new chemicals and materials.
        - Working with international chemical and materials companies is required.

4.2 Economics of Biorefineries

Recent report released in 2011 provides some base cost estimates and availability of woody biomass to feed into a biorefinery. The report provided estimates of the current theoretical maximum amount of biomass available include 9.2 Mt/y crop residues, 6.5 Mt/y pulp logs, 3.1 Mt/y sawmill residues and 2.0 Mt/y harvest residues from plantations and native forests. The total amount of biomass is expected to increase by 6 Mt/y as a result of new hardwood plantations reaching harvestable age in the next 5–10 years. In the longer term, it is estimated that 10 Mt/y biomass could be produced from dedicated bioenergy plantations established on 5% of currently cleared crop and grazing land. Table 2 is adapted from Scoping Biorefineries – Temperate Forest Value Chains 2011[21].

Table 3: Estimated production and transport costs ($/t oven-dry weight) for different feedstock types and distances *

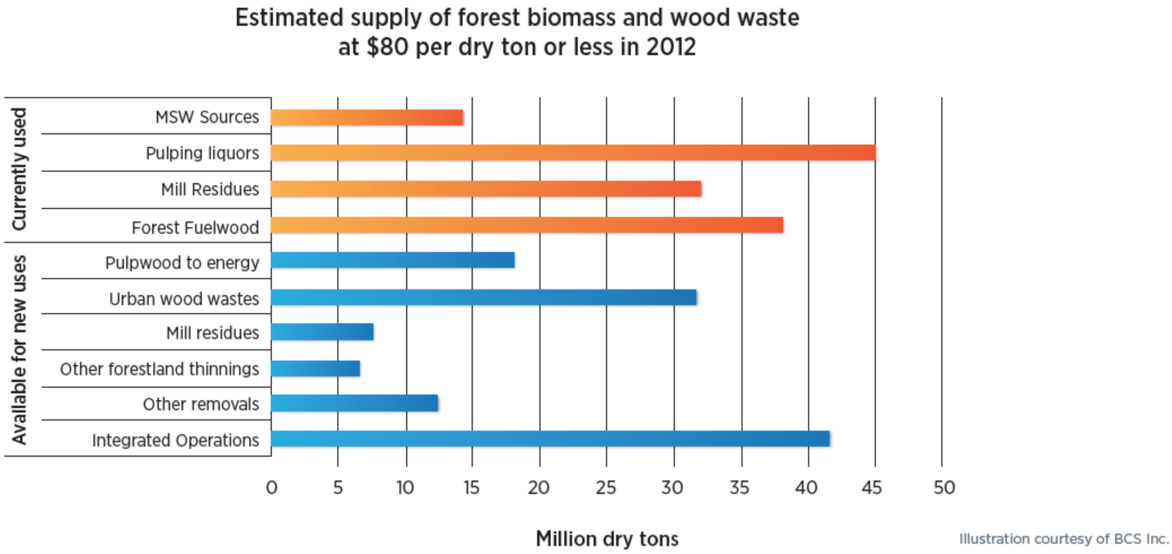
Feedstock	**Production cost ($/t ODW)**				**Transportation cost ($/t ODW)**			
					Distance (km)			
	Growing	**Harvest and collection**	**Chipping**	**Total**	**50**	**100**	**150**	**200**
Forest								
Pulp logs	$20–$60	$70–$100	$10–$20	$100–$180	$15	$25	$36	$46
Forest Residues	$10–$20	$30–$70	$20–$30	$60–$120	$14	$25	$36	$46
Sawmill Residues	NA	NA	NA	$10–$60	$12	$21	$31	$40
Bioenergy Plantations	$35	$30–$50	0	$65–$85	$12	$21	$31	$40

ODW = oven dry weight
*Table based on CSIRO derived assessments and assumptions plus data from Table 3-5 and Table 3-6 of Scoping Biorefineries – Temperate Forests Value Chains[22]

A number of factors will effect to the price of the biomass residues or pulpwood however, in summary the following variables are some of the more obvious factors that could effect pricing:

- plant growth rates;
- availability of substitutes or product (biomass) replacement e.g. woodchip for crop residues;
- transport costs (distance, densification, mode of transport, scale of transport loads, pre-treatment potential, fuel);
- fit for purpose of the biomass (e.g. specific plants oils or fractions)
- import potential of pulp as a precursor to transformation; and,
- the scale of the value add by the biorefinery (e.g. high value chemicals vs. energy vs. commodity chemicals).

These variables will change from location to location and from biomass to biomass and for the technology applied (thermo-chemical versus bio-chemical versus a combination). As a comparison current estimates for forest residues in USA[23] are presented in the figure below.



The range for supply of dry ton of biomass was from $20-$80 at roadside. The figures provided here are for project supply at US$80 per dry ton.
Significant public and private investment is occurring internationally to develop lignocellulosic technologies and commercial operations.

IEA Task 39 has recently reported on the status of 2nd Generation biofuels demonstration facilities[24]. Overall 66 projects provided data on the current state of their operations. Of theses 66 projects, 37 were classified as using biochemical transformation, 23 as using thermochemical, and 6 a hybrid of both. Pilot facilities constituted 32 production facilities, 21 of which were classified as demonstration facilities and 13 as commercial facilities. The classification based on production is; pilot mostly less than 500 t/y, demonstration (mostly under 5000 t/y) and commercial (greater than 5,000 and up to 500,000 t/y).

The average investment, range and output for each type of facility for biochemical transformation are given in Table 4.

Table 4: Capital Investment and outputs from operational and planned facilities[25]

Facility	Average	Range	Investment per Tonne
Pilot < 500 T/y	US$12.9 M	$3.5-46.2M	7.1T per Million $
Demonstration < 5,000T/y	US$49.6M	$5.0-100.0M	77.9T per Million $
Commercial < 500,000T/y	US$115.5M	$32-211.0M	1 558.2T per Million $

The values in the table are derived from the IEA report. A number of companies did not provide any financials and were not included. The average investment was US$182.6M and an output of 1,040 T per million dollars invested. However these are data based on a mix of sources and mostly provided by companies either at start up or in transition to full commercialisation. There is third party evidence to suggest that these figures are of the right order of magnitude[26].

A more recent analysis[27] by Laser and others looked at 14 different mature technology biomass refining scenarios. The modelling and analysis examined thermochemical, biochemical and hybrid biorefineries as Greenfield developments. The outputs varied depending upon design and included ethanol, power, F-T fuels (syngas), protein, demethylether (DME), rankine power. The detailed study's overall conclusions are:

- mature cellulosic biomass refinery – especially when combined with thermochemical processing offers significant advantages;
  - efficiencies equivalent to petroleum based fuels;
  - avoiding substantial GHG emissions;
  - require modest volumes of process water; and
  - can achieve production costs competitive to petroleum production at about US$30/barrel of oil.
- the best-performing scenarios involve the carbohydrate fraction being converted biologically and the lignin-rich residue being converted thermochemically.

This study examined the ability to retrofit pulp paper mills and to use the cellulose stream as a basis for biochemical transformation in to fuels or other chemicals. An integrated biorefinery intending to divert the cellulose stream for either fuel or chemical production would need to achieve similar or better returns per tonne. Certainly with subsequent processing, prices well above this are achievable[28].

4.2.1 Opportunities for further development of the economics of biorefineries.

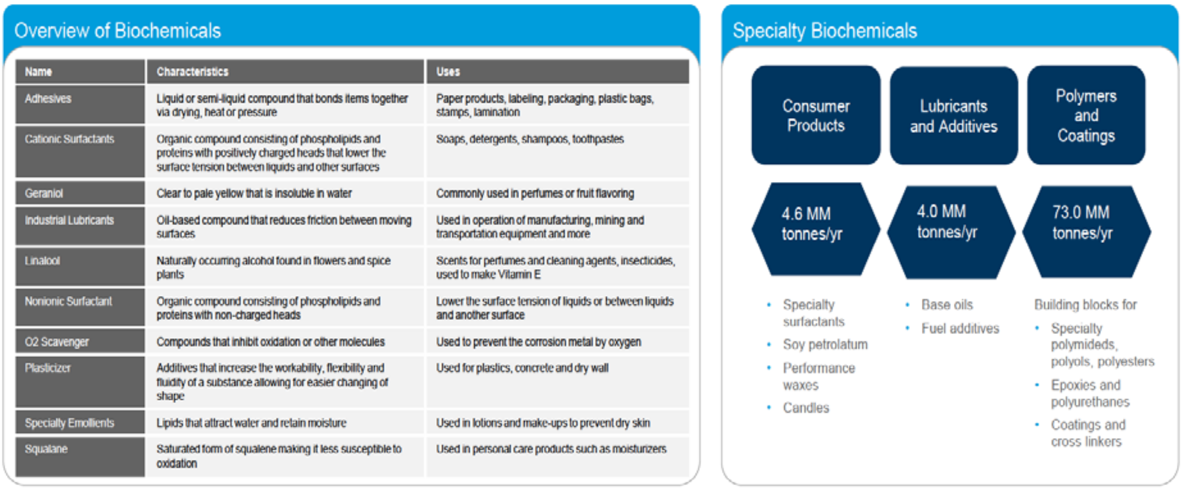
There is limited commercial data available to reliably assess the cost: benefits of developing new integrated biorefineries. This can hamper effective decision-making by new entrants and is a barrier to entry. The costs of undertaking such analyses are not trivial and can be biased by the conversion technologies, proposed location economics and supporting infrastructure both upstream and downstream. Licella P/L, a bio-oil company based near Sydney recently received $5.4M Licella from ARENA and will use the funding to conduct a de-risked feasibility study in order to produce an investment case for the company's first pre-commercial module in Australia[29].

Chapter 5. Products from Lignocellulosic Biorefineries

Lignocellulosic biomass can be converted to a wide range of products encompassing the broad categories of fuels and energy, materials, and chemicals in a manner analogous to petroleum refineries that process crude oil. Current estimates suggest 10–25% of oil company revenues are derived from chemical endpoints[30]. The top six oil companies had revenues of US$1.5T in 2009, while global shipments in chemicals were valued at US$3.7T. Significant value-add is therefore occurring between the oil refinery and the end product.

Internationally, there is significant funding and policy support for the development of (industrial) biobased value chains. While these value chains may have initially competed with some food production, many jurisdictions are accelerating towards utilization of non-food biomass sources. An opportunity exists in Australia to do the same in niches and commodities applicable to Australia. A snapshot of global biochemical production is provided in the following diagram:

Figure 5: Overview of Biochemical Products and annual demand[31]



Name	Characteristics	Uses
Adhesives	Liquid or semi-liquid compound that bonds items together via drying, heat or pressure	Paper products, labeling, packaging, plastic bags, stamps, lamination
Cationic Surfactants	Organic compound consisting of phospholipids and proteins with positively charged heads that lower the surface tension between liquids and other surfaces	Soaps, detergents, shampoos, toothpastes
Geraniol	Clear to pale yellow that is insoluble in water	Commonly used in perfumes or fruit flavoring
Industrial Lubricants	Oil-based compound that reduces friction between moving surfaces	Used in operation of manufacturing, mining and transportation equipment and more
Linalool	Naturally occurring alcohol found in flowers and spice plants	Scents for perfumes and cleaning agents, insecticides, used to make Vitamin E
Nonionic Surfactant	Organic compound consisting of phospholipids and proteins with non-charged heads	Lower the surface tension of liquids or between liquids and another surface
O2 Scavenger	Compounds that inhibit oxidation or other molecules	Used to prevent the corrosion metal by oxygen
Plasticizer	Additives that increase the workability, flexibility and fluidity of a substance allowing for easier changing of shape	Used for plastics, concrete and dry wall
Specialty Emollients	Lipids that attract water and retain moisture	Used in lotions and make-ups to prevent dry skin
Squalane	Saturated form of squalene making it less susceptible to oxidation	Used in personal care products such as moisturizers

Utilising Australian renewable resources has the potential to impact significantly three key sectors of the economy: agriculture, forestry and the Australia's chemicals and plastics industry. The chemical and plastics sector has a turnover of approximately A$32B pa and directly employs 85,000 people. The forestry sector employs an equivalent number throughout the value chain and contributes approximately 1% to Australian GDP or $19B annually. The added value from the sector is approximately A$9.6B pa.

The extraction, dissociation and fractionation of lignocellulosic biomass may yield products either directly, or through additional processing of the three major substituents – i.e. the carbohydrates, cellulose and hemicelluloses, and the polyaromatic lignin, is summarised in Figure 5.

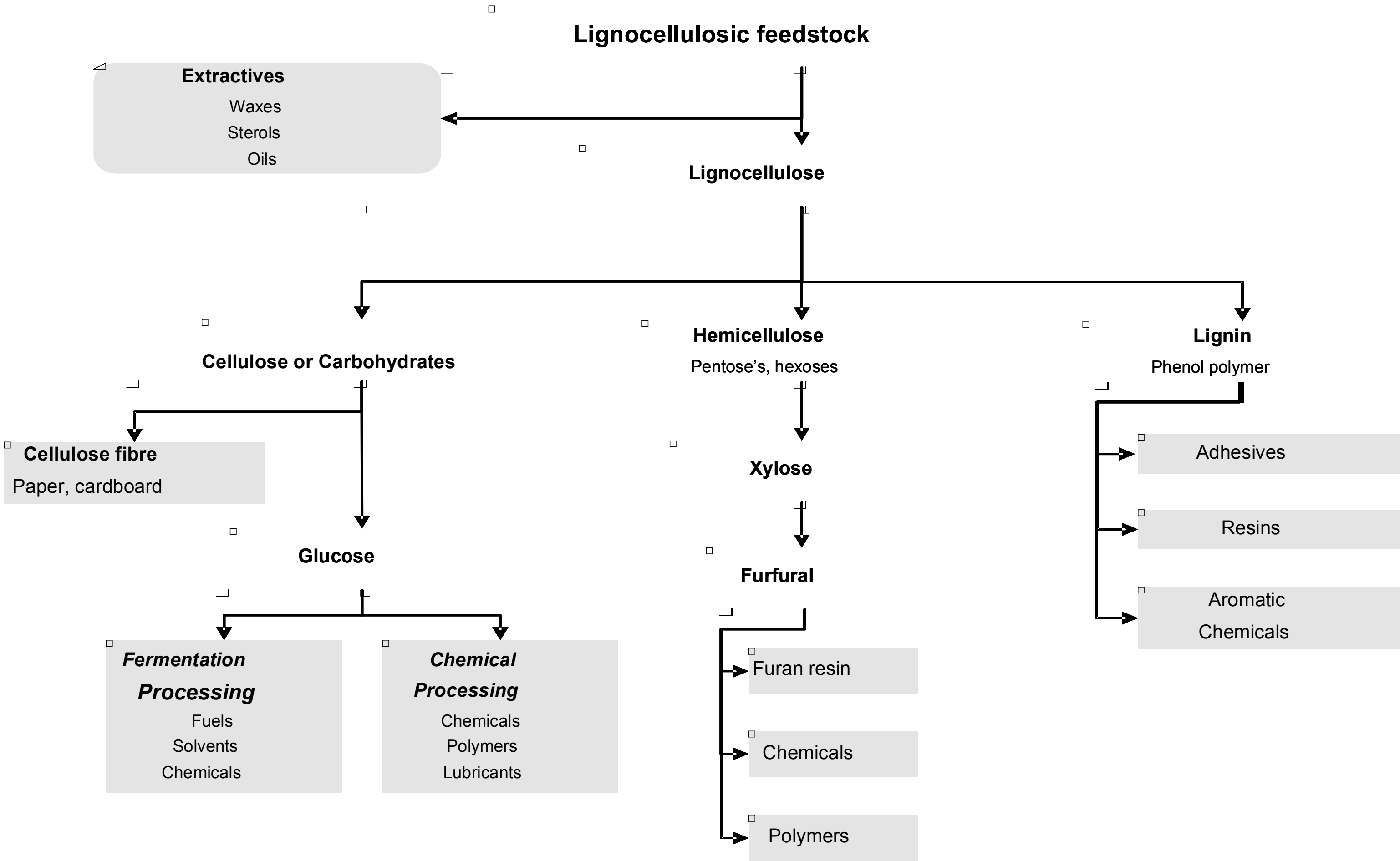


Figure 6: Example of product streams potentially available from lignocelluloses processing[32]

Of particular interest for lignocellulosic biorefineries is the utilisation of carbon 5 and 6 compounds.

C5 derived compounds	C6 derived compounds
Furfural	2,5 furandicarboxylic acid
Levulinic acid	Sorbitol
Isoprene/Farnesense (biohydrocarbons)	Lysine
Xylitol/Arabitol	Adipic acid
Furfuryl alcohol	Glucaric acid
Pentane diamine	Ascorbic acid
Itaconic acid	Phenoils from lignin

In addition there are the C*n* containing compounds like *p*-xylene and polyhydroxyalkonates. Bio-based PET bottles derived from C*n* compounds have been announced by Coca Cola and there is considerable interest from other users seeking to improve the commercial credentials of their PET based products.

Shen, et al[33] examined the potential for creating bio-plastics and the ability to deliver technical substitution on a range of products. Technical substitution is achieved when chemically identical biobased plastics replace petrochemical plastics. Shen suggests that total maximum technical substitution potential of biobased plastics and fibres is 90%, or 240M tonne of the total consumption of plastics and fibres in 2007.

Table 5: Technical substitution (%) potential of biobased man-made fibres (staple fibres and filament)

	PET	PA	Acrylic	Other Synthetic	Cellulosic
PLA	10%		5%		5%
PTT	20%	20%	5%		5%
PHA	5%		5%		5%
Biobased PET	65%				
Biobased PA6, PA66		80%			
Sum Percentages	100%	100%	15%		15%

	PET (1,000t)	PA (1,000t)	Acrylic (1,000t)	Other Synthetic (1,000t)	Cellulosic (1,000t)	Total (1,000t)	% Substitution
2007 World Fibre Consumption	30,804	3,836	2,407	575	3,081	40,703	100%
Technically replaceable volume	30,804	3,836	361	0	462	35,463	87%

PET = polyethylene terephthalate; PHA = polyhydroxyalkanoates ; PTT= Polytrimethylene terephthalate ; PA = polyamides; PLA= Polyactide ; PA6 = Polyamide; PA66=polyamide

Taking Shen's proposition to the next stage will depend on the development of platform chemicals as detailed by the US Department of Agriculture's report. The list of candidate platform chemicals was recently revised and updated in the light of intense ongoing research (Bozell and Petersen, 2010)[34]. The most prospective platform chemicals and some of their potential applications are summarised in Table 6.

Table 6: Prospective biobased platform chemicals and their application areas[35,36]

Platform Chemical	Pathway	Derivatives	Potential Application	Some Common Final Applications
Ethanol	Biochemical fermentation	Ethylene Acetic acid Ethyl acetate	Polyethylene Polyvinylchloride solvents	Plastic (shopping bag) Wide general use, fuel, clothing, electrical wire
Furans	chemical	Furfural Hydroxymethylfurfural Furan-2,5-dicarboxylic acid	Furanoic polyesters Polyamide	For bottles and films Boats, carbon fibre For nylons
Glycerol	Biochemical and chemical	Glyceric acid Polylactic acid analogues Propylene glycol 1,3-propane diol Polyesters and polyols epichlorohydrin	Novel polyesters PLA with improved polymer properties Sorona® fibre (DuPont) Polyurethane resins	Food Packaging Biodegradable plastic Carpets Films, filaments, engineering resins Textiles
Biohydrocarbons	Biochemical	isoprene	Rubber replacement	
Lactic acid	Biochemical	Polylactic acid Lactate esters Propylene glycol	PLA polymers, e.g Natureworks® Solvents Biodegradable fibres	Plastics, packaging, Textiles, appliances
Succinic acid	Biochemical	1,4-butanediol Tetrahydofuran γ-butyrolactone	Solvents, Fibres New polyesters	Housing materials, paints
Hydroxy-propionic acid	biochemical	1,3-propanediol Acrylic acid, acrylamide	Sorona® fibre (DuPont) Polymers, resins	Carpet, Food packaging plastic packaging, adhesives
Levulinic acid	Chemical	Methyl tetrahydrofuran γ-butyrolactone diphenolic acid	Fuels, Solvents, Replacement for bisphenol-A for polycarbonates	Fuels, Lunch boxes and Drink Bottles
Sorbitol	Chemical and biochemical	Isosorbide, Propylene glycol, Branched polysaccharides	PET like polymers, Antifreeze Water soluble polymers	Drink bottles, bicycles Sportsgoods, Camping gear, Protective equipment
Xylitol	Chemical and biochemical	Xylaric and xylonic acids, polyols	New polymers and polyester resins	Packaging, coatings

A recent analysis by Zakzeski explores the multitude of chemical derivatives possible from lignin[37]. The authors concluded that the realisation of an integrated biorefinery for securing the added value of lignin over and above a waste stream requires considerable research. Specifically, the authors stress the need to identify the biomass chemistry, the pre-treatment technologies and the specific catalytic technology to perform transformations.

Lignin is arguably the most undervalued resource created during the pulp and paper production. Estimates are that only approximately 2% of the lignin available from the pulp and paper industry is used commercially with the remainder burned as a low value fuel. Lignin conversion has significant potential as a source for the sustainable production of fuels and bulk chemicals. Its unique structure and chemical properties could provide a wide variety of bulk and fine chemicals, particularly aromatic compounds, as well as fuels are potentially obtainable from lignin. Indeed, lignin can be regarded as the major aromatic resource of the bio-based economy.

Since lignin is a principal component of biomass, a lignocellulose biorefinery will need to receive and processes enormous quantities of lignin, and conversion of this component also to fuels and chemicals are imperative for economic profitability.

The development of fully integrated biorefinery incorporating the realisation lignin values requires specific catalytic technology to perform the transformations. The biomass source and pretreatment method dictates the performance required of the catalyst in terms of robustness, selectivity (in terms of disrupting specific lignin linkages), activity, and recyclability. For example, dirtier feed streams require more robust catalysts, which often has implications on the types of processes that can be realistically employed. Knowledge of the types of catalysts available, their characteristics, and the types of transformations that they perform are thus essential for the development of efficient biorefineries.

5.1.1 Opportunities for further Product Development

Lignin Zakzeski notes significant research issues to be resolved to access greater value from lignin processing. FPWA, in association with other research bodies could invest in developing high valued products from lignin. He notes:

1. there is a general lack of detailed information regarding the performance of catalysts on the valorization of actual lignin streams.
2. lignin streams could contain proteins, inorganic salts, and other potential poisons that generally complicate catalysis.
3. the nature of biomass feedstocks ($C_n H_m O_o$), which contain high oxygen content and various ether linkages that make them more hydrophilic, differs significantly from hydrophobic petroleum feedstock ($C_n H_m$). These differences have ramifications for the development of suitable catalysts.

5.2 The International market for bio-based products.

Plastemart.com report in September 2012 that global synthetic and bio-based biodegradable plastics market was worth US$2.3B in 2011 and is expected to reach US$7.8B in 2018, growing at a compound average growth rate (CAGR) of 19.5% from 2011 to 2018, according to a new market report published by Transparency Market Research. In the overall global market, Europe is expected to maintain its lead position in terms of revenue till 2018. Europe is expected to enjoy 36.8% of global synthetic and bio-based biodegradable plastics market revenue share in 2018 followed by North America. The global synthetic and bio-based biodegradable plastics market is being driven by the growing demand for eco-friendly materials mainly in the packaging industry, cheap feedstock supply and its acceptance by the consumers.

Globally, biodegradable plastics find its major use in packaging, agriculture and transportation industries. Biodegradable plastics market is classified under two markets, synthetic (petroleum derived) biodegradable plastics and renewable (bio-based) biodegradable market. Bio-based biodegradable plastics market is segmented on the basis of its types as starch based plastics, polylactic acid (PLA) and polyhydroxyalkanoates (PHA). The market for renewable biodegradable plastics was US$1.9B in 2011 and it is expected to reach US$7B in 2018. The major geographic markets for biodegradable plastics are Europe, North America and Asia Pacific. Europe enjoys the largest market share of the worldwide synthetic & bio-based biodegradable plastics market in 2012 and is expected to lead till 2018. Asia Pacific market is expected to grow at a CAGR of 25.7% from 2011 to 2018.

The requirement for renewable chemicals produced from biomass is to satisfy a global need for sustainable development, consumer demand for green products and reduced reliance on petrochemicals as a feedstock. Although it is possible to derive chemicals from non-biomass sources e.g. gas to liquids or coal to liquids, these are not considered to be renewable sources for chemicals. The following figure shows the expected global renewable chemicals market growth over the period 2007-2014.

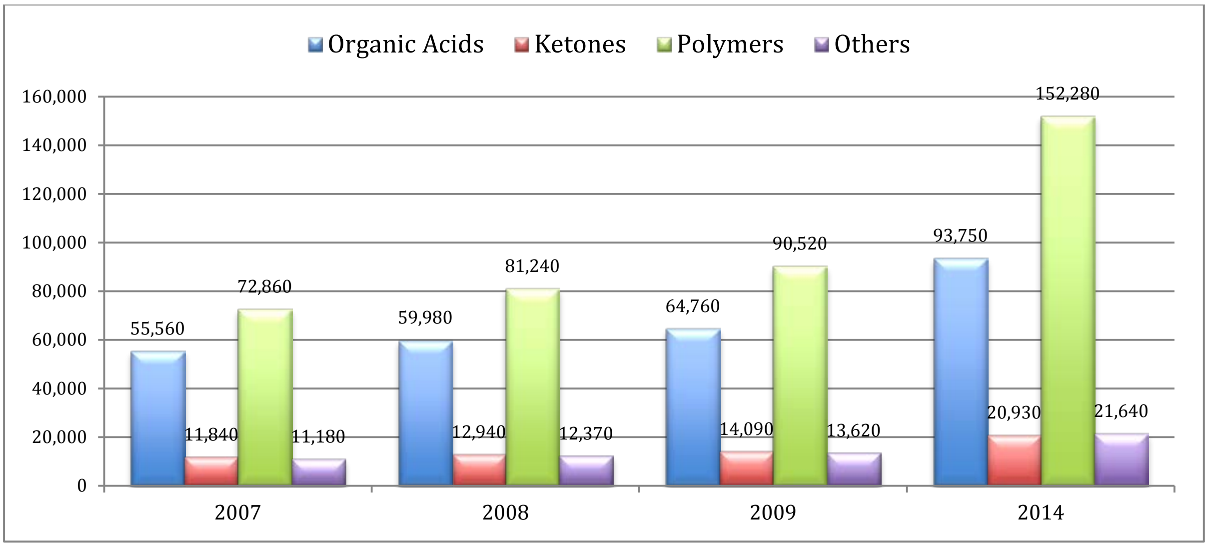


Figure 6: Summary of Global Renewable Chemicals Market 2007-2014 ($Thousands). *Source: Global Renewable Chemicals Market by Market and Markets (2010)*[38].

Alcohol maintains the largest market but it also has the lowest CAGR (Compound Average Growth Rate, i.e. year on year growth rate) of 5.3% due to expected over-capacity in the US and Europe and the recent stabilisation of crude oil prices. Polymers have the highest CAGR of 11%, due to an expected increased demand from the food and packaging industry, biodegradable and compostable plastics for the electronic and automobile industries. The overall market growth will also be driven by government pressure and consumer demand to produce more eco-friendly chemicals. The following table shows the expected growth in the platform chemical market.

Table 7: Global Renewable Platform Chemicals Market, by products, 2007-2014 ($millions)

Product	2007	2008	2009	2014	CAGR% 2009-2014
1,4-diacids	$400	$410	$470	$810	11.5
2,5-furan dicarboxylic acid	$50	$50	$70	$140	14.9
3-hydroxypropionic acid	$230	$260	$310	$600	14.1
Aspartic acid	$40	$50	$50	$80	9.9
Glucaric acid	$50	$50	$50	$90	12.5
Glutamic acid	$320	$350	$390	$630	10.1
Itaconic acid	$170	$170	$190	$280	8.1
Levulinic acid	$30	$50	$50	$160	26.2
Glycerol	$280	$310	$360	$720	14.9
Others	$20	$20	$20	$30	8.4
Total	**$1,590**	**$1,720**	**$1,960**	**$3,540**	**12.6**

Source: *Global Renewable Chemicals Market by Market and Markets (2010)*[39]

This renewable platform chemical market is set to increase significantly (CAGR of 12.6%) within the next 5 years. Broadly speaking, this is due to increases in demand for platform biobased chemicals and their derivatives. In addition the development of new processes are enabling platform chemicals to be being utilised in newer and wider fields, as well the platform chemicals processed are being used to derive other chemicals. In effect there is both product substitution and new products being delivered:

- the 26.2% CAGR for Levulinic acid is due to the derivatives being used in high volume chemicals in such areas as, additives for gasoline and biodiesel, herbicides, replacement of hazardous monomers in polycarbonate production, manufacture of pharmaceuticals, agrochemicals, plasticisers, and textile auxiliaries;
- Glycerol production is increasing as a co-product of the increased biodiesel production and is now being converted into polymers with wider commercial use;
- the Glucaric acid market is set to increase CAGR of 12.5% as its derivatives are used in high volume chemicals that are used to make nylons, detergent surfactants and new polymeric materials. New technology is expected to improve efficiency of the Glucaric acid production in the future;
- Glutamic acid production is becoming more efficient and less expensive with development of low cost-fermentation routes;
- aspartic acid derivatives have the potential to substitute for other more expensive chemicals in such products as detergents, water treatment and superabsorbent polymers;
- 3-Hydropropionic acid, derivatives have wide-ranging applications such as used in clothing, packaging, resins and speciality chemicals in both high volume and high value quantities. It can be converted to several industrial chemicals including 1,3-propanediol, malonic acid and acrylamide. Dupont produces it Serona brand polymers from 1,3 Propanediol. The market is expected to grow by 14.1% per year over the next 5 years;
- 2,5 Furan dicarboxlic acid growth of 14.1% CAGR is being driven through demand for its derivatives. These can be used for new families of products such as nylons from renewable chemicals;
- 1,4 diacids derivatives are succinic acid, fumaric and malic acid. A CAGR of 12.7% is the expected due to the varied applications of its derivatives;
- Succinic acid has its own derivatives that are used widely in the expanding pharmacology industry and has applications in varied industries such as polymers, fibres, food, detergents, surfactants, additives for flavours and fragrances and pharmaceutical industry. Biorenewable succinic acid reduces dependence on petrochemical derived-succinic acid; and
- Fumaric acid derivatives are used in food acidulant, beverage ingredient and manufacture of unsaturated polyester resins with improved mechanical properties and thermal stability, as well as artificial sweetners used in the health industry and by diabetics.

5.3 Case Studies

5.3.1 Case Study 1: Woody biomass to plastics

An opportunity exists to produce a range of "like for like" polymers from woody biomass in Australian and world industry players. This could satisfy an existing unmet need in Australia and internationally.

Polyolefins (i.e. polyethylene and polypropylene) are currently the world's highest volume polymers. Polyethylene has an annual production of approximately 80 million metric tons[40] and polypropylene of approximately 45.1 million tons[41]. They are currently derived from crude oil. Polyethylene is produce by the polymerisation of ethylene. Ethylene is produced either from processing of crude oil or by separation/steam cracking of natural gas. Polypropylene in Australian is currently produced as a by-product of gasoline manufacture. Currently the gasoline stream is shrinking in Australia due to a number of influences.

Companies such as Dow have made a commitment to produce polyethylene from sugar cane in Brazil. The Dow process involves the fermentation of sugar to produce ethanol. The ethanol is then dehydrated to produce ethylene. There are doubts to the viability of producing polyethylene from sugar cane as well as concerns over the use of the land to grow sugarcane rather than food.

A proposed alternative route to that used by Dow would allow for a broader range of polymers from the woody biomass using hydrothermal upgrading (HTU). This is based on the work that been done in Europe and Australia on developing the HTU process for the conversion of woody biomass to produce fuels and bio-crude.

Taking the scenario further it is possible to optimise yield (post-terpene extraction to produce bio-aromatics and other functional terpenes) when processed by HTU to give a gas stream rich in alpha-olefins (e.g. ethylene, propene, butene and pentene) and hydrogen. The hydrogen from the gas stream is usable as a fuel or could be utilised in a reformer unit in a petroleum oil refinery or even utilised elsewhere in a biorefinery to produce other chemicals. The alpha olefin gas stream could then be utilised for the applications shown in Table 8, and the putative value chain is summarized in Figure 7 below. The data in Table 8 were determined using the data obtained by CSIRO as part of another study[42]. These data do not assume optimised production processes. Current world prices for ethylene and propylene are US$1000/mt and US$1340/mt respectively. In theory, this provides a potential 6-fold lift in value before costs.

Table 8: Estimated conversion of Woody Biomass to Gas Streams for the production of Ethylene and Propene etc,

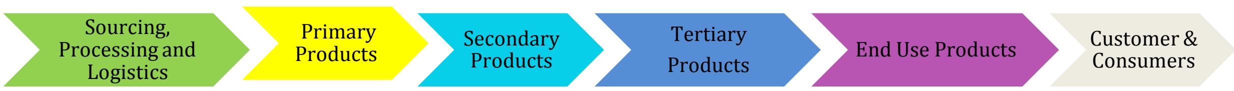
Component	Tons woodchip required to produce 1 ton target material	Target tons for estimated Market (tpa)	Amount of biomass required to produce target (tpa)	Ha of Oil Mallee required to produce target (Ha)	Application
(A) Ethylene (B) Ethylene and Ethane*	50.63 10.12	400,000	22.50 M 4.50	3.214 M 0.643 M	• Polyethylene (PE) • Vinyl Chloride (PVC) • Ethylene Glycol • Polyethylene Glycol • Co-monomer for PP
(A) Propylene (B) Propene and Propane*	13.28 9.60	400,000	5.90 M 4.27	0.843 M 0.609 M	• Polypropylene (PP) • Acrylic acid • Paint and coating resins • Super-absorbent polymer

Note *:It is possible to convert the saturated compounds through to the alpha olefins (i.e. convert ethane to ethylene).

However the preference is to produce a stream rich in the alpha olefins using the first HTU process rather than using subsequent steam cracking steps. The data presented in Table 8 show that enough ethylene and propene to meet the needs for the current Australian production of polyethylene and polypropylene would take less than 1 million hectares of oil mallee. It would be possible to grow this amount of mallee around the grain crops in approximately 10 years. However, the required amount of wood to supply the Australian production of polyethylene, PVC and polypropylene and acrylic resins could by provided from pulp logs and pulp and paper waste from the SW region of Victoria, now. It is also feasible that the Australian production of these materials could be grown to an amount to replace the current level of import of the above-mentioned materials. Figure 7 depicts a potential the range of products that could be produced through the value chain. Caution is required, as ethylene production based on shale oils has been forecast to increase significantly43 and this may result in reduced prices in the near term.

There are a number of researchers in Australia that could provide useful input to the development of the technology required to convert biomass to the gas streams. Alternatively it could be possible to licence appropriate HTU technology and adapt/refine/optimise it to suit the woody biomass feedstock as well as the required process products. It is highly probably the optimal solution may require a combination of locally developed technology as well as licensed technology. It is important to point out that Ignite Energy (the part owner of Licella) is the first company world-wide to come up with a commercial HTU process to upgrade coal as well as to produce bio-crude and chemicals from woody biomass.

←------------ Feedstock----→ Biorefinery ←-----------------------------BioProducts------------------ →



Feedstock	**Biorefinery Products**	**Secondary Products**	**Tertiary Products**	**End Use Products**	**Customers and Consumers**
Woody Fraction	***HTU of Wood*** • Gas Stream • C2-C4 • -Ethylene • -Propene • -Butene • -Pentene • Hydrogen (fuel) • Water	• Polyethylene • Polypropolyene PVC • Arcylic Paint resins • PET (ethylene glycol component) • Lubricants	• Packaging sheets and fibres • Blow moulded products • Injection moulded prodcuts • Fibreglass resins	• Packaging • Carpet • Pipes • Household & Recreational • Automotive & Transport • Defence Applications • Industrial Paints	• Gov'ment • Councils • Telstra • Mining Industry • Agriculture Industry • Transport Industry • Tourism Industry • Telecommunication Industry • General Public • Exports

Figure 7: Case Study 1: Conversion of Woody Fraction via HTU into Gas Stream and onto chemicals and plastics

5.3.2 Case Study 2: Woody biomass to biocrude

An alternative to the production of a predominately gas rich product is to optimize the HTU process to produce a greater proportion of the bio-crude liquid stream. The bio-crude stream could be utilized as a feed to conventional petroleum and petrochemical refineries. This means that the bio-crude can be used as a supplement/replacement for current crude oil. This also means that the bio-crude could be used to make fuel and could still be used to produce the gas feedstock required to produce the polyethylene and polypropylene using existing catalytic cracking processes.

The composition of the bio-crude will be different to that of conventional crude oil. Thus, it is likely that the ideal refinery units to produce the desired products from the bio-crude will be different from those used for conventional crude. It is also likely that the proportions and specific make-up of the products will be slightly different than that obtained with conventional crude oil. The proposed route to convert woody biomass to bio-crude to conventional fuels, chemicals and plastics may not be as energetically or economically favourable as the routes to some of materials shown in the Case study above.

It is relevant here that conventional crude oils have a reasonably wide range of compositions (i.e. ranging from light, "sweet" low sulphur crudes such Gippsland crude through to some of the heavy tar sand crudes from Alberta and Venezuela) and so it may be possible to relatively easily supplement bio-crude for conventional crude and still obtain the desired products when using the conventional refineries. Chevron is currently investigating processes to introduce biomass into a conventional refinery[44].

←------- Feedstock-→ Biorefinery ←-------------BioProducts-------------------------------------→

Feedstock	**Biorefinery Products**	**Secondary Products**	**Tertiary Products**	**End Use Products**	**Customers and Consumers**
Woody Fraction	***HTU of Wood*** • "Bio-Crude" • (Feed to conventional Petroleum or Petrochemcial refinery) • "Can make same products as current crude oil" • Hydrogen (fuel) • Water	• Polyethylene • Polypropylene • PVC • Polyamides • Plasticisers • Styrenics • Polyurethanes • Polycarbonate • PET and Polyesters • Lubricants • Phenolics • Surfactants • Additives / Stabilisers • Fuels	• Plastic films, sheets and fibres • Blow moulded products • Injection moulded prodcuts • Rotomoulded products • Resins and Emulsions • Engineering Polymers and composites	• Packaging • Carpet • Clothing • Signs • Pipe, Cable and Profiles • Electronic items & Media • Household & Recreational • Automotive & Transport • Tanks and storage • Defence Applications • Paint & Coatings	• Gov'ment • Councils • Telstra • Mining Industry • Agriculture Industry • Transport Industry • Tourism Industry • Telecommu nication Industry • General Public • Exports

Figure 6: Case Study: Conversion of Woody Fraction Via HTU into Gas Stream and onto chemicals and plastics

Chapter 6. Potential Barriers to Entry

Barriers to entry into any emerging industry can be daunting and impact significantly the opportunity to realise the benefits economically and socially. Creating and capturing new value chains for biomass to biorefineries and bio-products is no exception.

The 2011 DIISR[45] study identified significant challenges that could impact on the development of biorefineries and biomass value chains. These challenges reflect some of the barriers to entry to the development of viable biorefineries but they also offer insights in to potential areas of R&D and commercialisation. The

- access to and competition for biomass in sufficient quantities to ensure long-term viability;
- defining sustainable practices appropriate for the growth and collection of biomass;
- development of logistics systems to ensure efficient collection, delivery and storage of biomass;
- accessing sufficient capital investment to establish new biorefineries of sufficient scale or to retrofit existing pulp mills utilising temperate biomass;
- overcoming the low level of R&D by Australian companies across the value chain and by research institutions into development of biobased products from biomass transformation;
- identification of biobased products capable of direct substitution or replacement in the Australian chemical industries;
- overcoming the inertia in Australian chemical industries to look at import replacement strategies;
- perceptions and concerns by some sections of the community and governments over the environmental impacts of biomass collection either from forests or from farms;
- limited understanding by governments, researchers and communities of the potential role biorefineries could play in the establishment of new industries, new jobs and regional development and
- valuing biomass for biobased products such renewable chemicals and plastics could place pressure on existing uses of the biomass e.g. pulp production or co-generation of energy in pulp mills.

Undoubtedly, the greatest barriers to entry for new or existing industry participants, not necessarily in order of priority as these may vary, will be:

- Access to adequate biomass at a consistent quality and with long term supply;
- Access to appropriate efficient technology;
- Access to sufficient capital and/or the development of new business models of innovation and commercialisation; and
- Access to markets particularly for product substitution over existing petrochemical based sources.

This appears a daunting list of challenges and barriers, however important steps have been taken to progress the potential development of an industry. For example the recent finalisation of the Carbon Tax program, the development of ARENA, a renewed interest by a number of multi-national chemical companies in procuring bio-based products. In a perverse way the decisions on closure of Leading Synthetics PET facility in Vic, the closure of the plant at Millicent in SA and the closure of the Petrie Cardboard Mill in Qld point to the need for the industry to re-think and re-position itself.

Chapter 7. Conclusions

Several studies reported elsewhere[46] indicate ultimate scale of the biorefinery the optimum end point scale would be 1-2M bdt with scope to increase to 3-4M bdt of biomass. The former could be delivered by a combination of rail and road from within the region to one location. Increasing the scale to 3-4M bdt would require access and probably co-location with a port facility.

In Australia there are limited options for the location and development of biorefineries. In many ways these options are similar to those facing decisions in the location of paper and pulp mills. For example currently only two locations within the SW region of Victoria would satisfy most requirements, Geelong and Portland. Portland has a strategic advantage of being located close to the Green Triangle and larger plantation reserves. Geelong has strategic advantages from the co-location with a number of primary, secondary and tertiary product companies and easy access to the business hub of Melbourne, the technology hubs of Geelong and Melbourne.

The figure below[47] provides a working model for a three-phase development of a biorefinery. This also fits well with the evolution of product development and business model framework proposed in Figure 4. Phase 1 corresponds to the emphasis on revenues from commodity products, Phase 2 product replacement by molecular equivalents is the major route of new products to market and Phase 3 sees product diversification and business from new functionally equivalent products and specialty chemicals.

In Phase 3 the emphasis is on optimisation of product delivery systems and value maximization for a diversified range of products with a strong margins-centric approach across a product portfolio of biobased chemicals and materials.

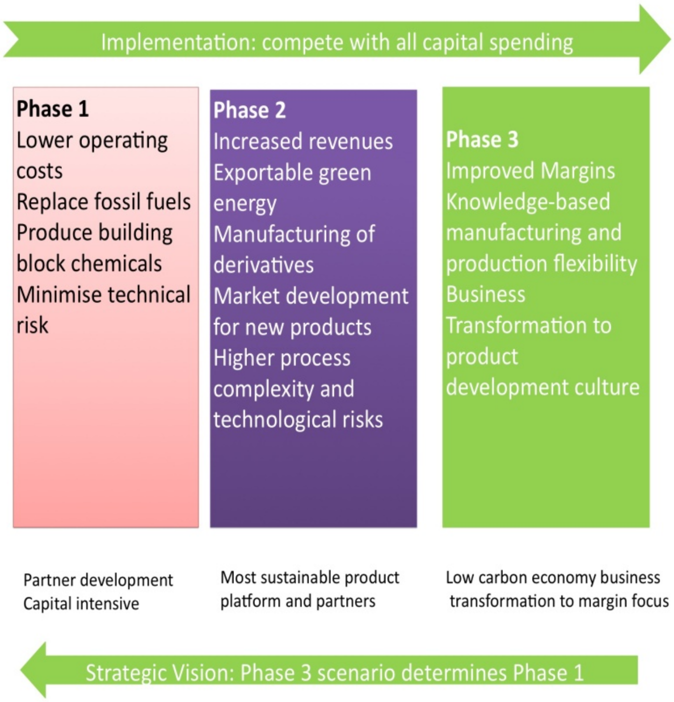


Figure 7: Potential Biorefinery Implementation Strategy

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