Deloitte Access Economics

Corelli
BIO-INDUSTRY CONSULTING

Economic impact of a future tropical biorefinery industry in Queensland

Prepared for

qutbluebox

Deloitte.

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Glossary

ABS	Australian Bureau of Statistics
CGE	Computable general equilibrium
DAE	Deloitte Access Economics
DAE-RGEM	Deloitte Access Economics – Regional General Equilibrium Model
FTE	Full-time equivalent
GDP	Gross domestic product
GRP	Gross regional product
GSP	Gross state product
LGA	Local government area
NSW	New South Wales
QLD	Queensland
QUT	Queensland University of Technology
USA	United States of America
USDA	United States Department of Agriculture

Key points

- The commercial production of replacements for chemicals, plastics, and fuels from biobased feedstocks, using technologies such as fermentation and thermochemical conversion, is now established globally, with annual production of hundreds of thousands of tonnes.

- Queensland has a comparative advantage in bio-refining – the climate and agriculture sector ensure a large supply of biomass material that can be used to produce chemicals, plastics and fuels. The production of biobased products was identified as an area of increased focus in *Queensland's agriculture strategy*.

- This study estimates the economic impact of a sample of potentially viable new manufacturing facilities using several arid, tropical and sub-tropical crops. By 2035, the annual impact of the modelled biorefineries is estimated to be over $1.8 billion. The net present value of their contribution over the modelled period is $21.5 billion. By 2035, they support over 6,640 FTE employees, many of which are in regional Queensland.

- Biorefineries in Queensland are likely to be a viable source of economic growth and diversification. Their output can be used as inputs to domestic industries as well as generate export earnings. In addition, biorefinery industries can significantly value-add agricultural outputs, diversifying agricultural producers' revenue base.

- The economic impact analysis assumes that the biorefineries operate without government subsidisation. While production is viable without ongoing subsidies, some government facilitation would assist in industry establishment.

- There is a potential role for government in facilitating investment in the sector and ensuring policy settings do not impede private investment, for example through streamlining processes for environmental approvals. In addition, any potential biorefinery investors could make use of the services of Queensland Government agencies (including the Department of Agriculture, Fisheries and Forestry and Trade and Investment Queensland).

- International experience shows that governments can make an important contribution to attracting investment, for example through developing technology precincts and facilitating relationships between international companies and domestic industry.

- For commercial investors, this analysis supports the case for investing in the next phase of detailed design, engineering, construction cost estimation and due diligence.

Summary Report

Introduction

This report is a joint production by Deloitte Access Economics and Corelli Consulting.

qutbluebox engaged Corelli Consulting to provide the scientific information on industrial biotechnology, the case studies and potential bioproducts, presented in Chapters 2 and 3 and Appendix A of the full report.

qutbluebox engaged Deloitte Access Economics to estimate the potential economic impacts of a future tropical biorefinery industry in Queensland. This includes report content relating to economic impact analysis (including regional socioeconomic profiles, regions included in the economic impact analysis, economic characteristics of projects and discussion of computable general equilibrium modelling).

Biorefining is the process of converting biomass (organic matter) into value-added chemicals, plastics and fuels. Research into biorefineries has escalated in recent years, with a push to transition to renewable and sustainable feedstocks and reduce reliance on petrochemicals.

There are significant opportunities from biorefining for Australia, and regional Queensland in particular, including export revenues, economic growth, diversification of the agricultural sector, stimulating Australian manufacturing and climate change mitigation. Many of the potential feedstocks are the by-products of agricultural processes, or waste products that would otherwise require disposal or combustion. The various climates of Queensland (ranging from tropical to sub-tropical to arid zones) provide a diverse range of potential biological feedstocks for the production of chemicals, plastics and fuels.

Over the last decade, the ambition to secure an industrial future based on renewable resources has built significant momentum globally. The movement to sustainable chemicals and plastics manufacture has been supported by the major chemical and technology-based companies.

International experiences

Two case studies (Malaysia and Brazil) highlight key issues of the international experience in the industrial biotechnology sector. In Malaysia, a clear government vision for technology precincts has paid dividends, by attracting international businesses to Malaysia. The success of this strategy can now be measured in gross national income and new jobs generated as a direct outcome of precinct development. This success is expected to continue as Malaysia revives failing national industries and brings additional value to existing agricultural production.

As is the case with the Malaysia, the Brazil case study is built upon a national vision for the development of a new industrial sector. In Brazil, government has played a role in attracting international companies and facilitating collaboration of those companies with national industries, particularly those that supply feedstock for chemicals and plastics production.

Malaysia

Malaysia is home to two major biorefinery precincts, each based on key local feedstocks, designed to attract international chemical and polymer manufacturers. Kertih Biopolymer Park, reportedly Asia's largest biorefinery complex, was launched as a collaboration between Malaysia's national, regional, and state governments. This biorefinery precinct is planned to initiate a cellulosic feedstock-based chemical manufacturing sector that could generate US$6.14 billion in income and create 2,500 new jobs by 2020. Two keystone participants are the joint venture between South Korea's CJ CheilJedang Corporation and France's Arkema for the feed additive methionine (80,000 tonnes per annum, or tpa) and the US-based technology company Gevo, which will be producing the solvents bio-isobutanol, butanediol and ethanol at the 60,000-tpa scale by 2015.

The second precinct, Bio-Xcell, was initiated as a partnership between two palm oil plantation firms (Felda Global Ventures Holdings and Sime Darby Bhd) and Malaysia's national government. The keystone participant is US technology firm GlycosBio, to manufacture isoprene, used in synthetic rubber, to support Malaysia's rubber industry. Bio-Xcell could be the basis of a biorefinery model that would revitalise the biodiesel industry by transforming 20 palm oil-based biodiesel plants into economically viable biochemical plants.

Brazil

Brazil has leveraged its highly-developed sugarcane industry and 30 years of investment in the ethanol industry to build a global centre for bio-based plastics. The chemical giants Dow, Cargill, Evonik and Braskem have reportedly invested over US$2 billion in Brazil to date. Dow has already established a global-scale, 240,000 tpa ethanol plant (2011), and, more recently in a joint venture with Japan's Mitsui, is planning on value-adding that ethanol by converting it to ethylene and polyethylene in a biopolymers facility, worth around US$1.5 billion. Brazil's emerging global-scale biorefinery industry is established on sites selected based on access to raw material supplies, logistical connections (road and port), and proximity to local markets.

A Queensland biorefinery industry

This report examines a potential future biorefinery industry in Queensland. The projects included for discussion involve the manufacture of both fine and commodity compounds, and polymers for the global chemical and pharmaceutical sectors, derived from green or bio-based feedstocks.

This Queensland initiative is defined by multiple biorefinery facilities across the state, co-located with their agricultural, forestry and green waste feedstocks. The regional biorefineries included for discussion would generate a portfolio of fine and platform chemicals for domestic use or export: platform chemicals like succinic and levulinic acids, speciality chemicals like xylitol, the aromatic chemical furfural, phenolic resins, and biobased aviation fuel, as well as ethanol, electricity and animal feeds for local consumption.

Seven biorefinery projects were shortlisted for discussion and economic impact analysis. These include:

- Polyethylene production using greenfield sugarcane (project A)
- Resin production using green waste (project B)
- Succinic acid production using sugarcane bagasse (project C)
- Aviation fuel production using Brigalow regrowth (project D)
- Levulinic acid production using forestry residue (project E)
- Xylitol and ethanol production using sweet sorghum (project F)
- Ethanol production using sorghum stover (project G)

This set of projects does not represent the entirety of the possible future biorefinery industry in QLD, but a shortlist identified through an iterative process involving workshops with **qut**bluebox, QUT scientists, Corelli Consulting and Deloitte Access Economics. Inclusion was based on a range of factors including commercial viability, data availability, published research, export markets, feedstock availability, overseas experience and commercial scale suitability. Future advances in biotechnology will likely bring forth previously unforeseen commercial biorefining opportunities, potentially in addition to those modelled here.

As well as replacements for existing petroleum-based chemicals and plastics, the biological feedstocks suited to cultivation in Queensland, or available as by-products or waste, offer the opportunity to manufacture new chemicals not available (or not easily derived) from existing petroleum-based feedstocks. Importantly, this study demonstrates the potential for economically viable new manufacturing facilities using several arid, tropical and sub-tropical crops. The manufacturing processes largely do not compete with feedstocks used in food manufacturing or stock feed production (in some cases the bio-refinery actually increases production of stock feed as a co-output of the refinery), thus avoiding some of the issues experienced in other countries from increased competition for existing agricultural feedstocks.

The projects modelled would leverage Queensland's strengths in agriculture and industrial biotechnology, and provide benefits such as value-adding agricultural commodities. A range of different technologies suited to different climates and feedstocks suggest bio-based refineries could lay the groundwork for a state-wide industrial future. The technologies which underpin the conversion of biomass to valuable products are all well-established and suited for development into commercial-scale refineries, and provide the opportunity for Queensland to capture value from earlier publicly-funded research.

Economic impact analysis

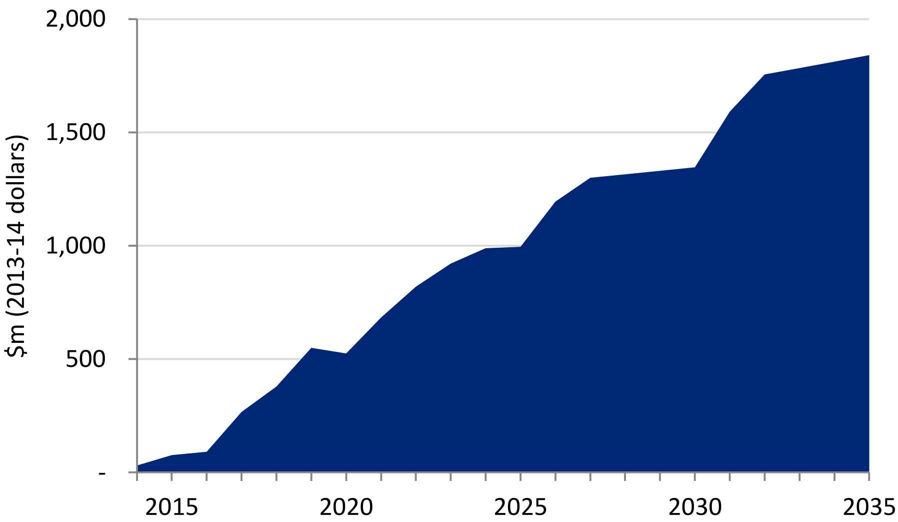
Deloitte Access Economics has used a customised version of our in-house regional general equilibrium model (DAE-RGEM) to model the estimated impacts of biorefinery construction in Queensland. The economic impact analysis compares the 'project scenario', which incorporates the proposed biorefinery construction, against a 'baseline' where the proposed construction does not proceed.

Preliminary assessment of commercial returns for each project suggests the returns are sufficient to attract private investment (however, detailed financial modelling and a full feasibility study would be needed before making any investment decisions). Thus, the only government support assumed in our economic modelling is general in nature – that government provides a stable economy that is 'open for business', with streamlined processes to minimise regulatory red tape and provide efficient environmental approvals. It is assumed that the biorefinery sector operates without explicit government subsidies, tax concessions or mandates.

The biorefinery opportunities modelled are expected to increase Queensland's gross state product (GSP) by more than $1.8 billion annually by 2035 (in today's dollars). In net present value terms, the industry's contribution over the modelled period is $21.5 billion.

This does not represent the full extent of the future size of the industry in Queensland, but rather is based on the seven prospective bio-refinery projects modelled. If these projects are successful, it is possible that Queensland could eventually be home to more biorefineries than are modelled here.

Figure 1.1 Deviation of GSP from base scenario



Source: Deloitte Access Economics

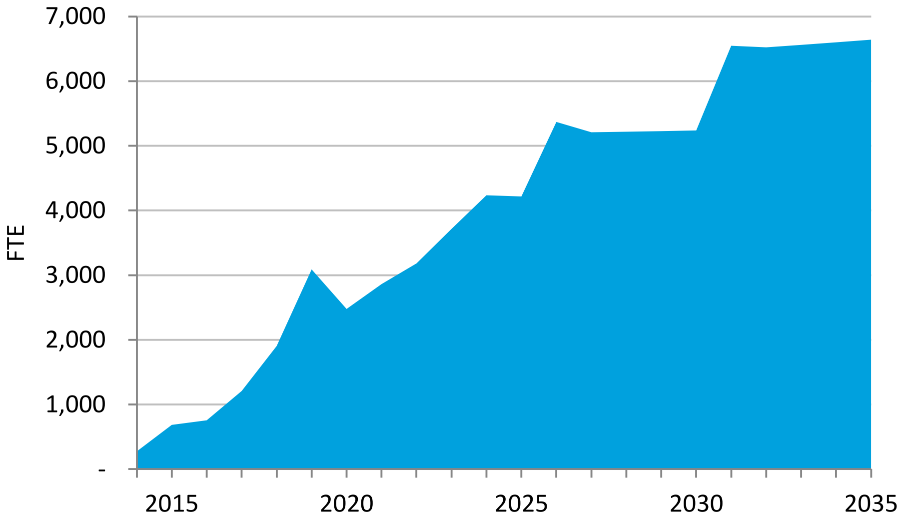
The biorefinery investment modelled is projected to increase employment across the state by 6,640 FTEs by 2035 (see Figure 1.2).

For Queensland as a whole, output and employment are expected to increase in the manufacturing, services, trade, agriculture, transport, electricity and water industries in the period to 2025. At the same time, both output and employment in the mining industry are expected to decline relative to the baseline.

In this analysis, project establishment and operations are modelled out to 2035-36. In reality, projects would very likely operate beyond 2035-36, with ongoing economic impacts.

Further, potential industry upsides have been excluded from the modelling. For example, the players in the soft drink manufacturing industry have indicated that they would pay a premium for polyethylene produced using biobased feedstocks. Also, the United States Navy, one of the major users of oil in the United States, aims to significantly increase its use of non-fossil fuel sources. Along with other applications, these higher prices for specific outputs could add to the overall economic impact of the industry, and suggests that the estimates presented in this report are conservative

Figure 1.2.Deviation of employment from base scenario



Source: Deloitte Access Economics

Conclusion

Queensland’s tropical climate and large agriculture sector produces significant volumes of biological material as by-products – often waste material available at little or no cost. This preliminary assessment indicates an opportunity to profitably convert these into chemicals, plastics, and fuels. There are technologies and feedstocks available for viable refineries to be developed in several regions – including the south west, central, coastal and tropical climate zones – each producing different bio-based products.

The development of a tropical bio-refinery industry could have a significant economic impact on the Queensland economy. The seven modelled projects alone could contribute around $1.8 billion and 6,640 FTEs over the next two decades.

This report provides sufficient proof of concept to proceed with further due diligence and a full feasibility study of the future potential and viability of these bio-refineries. Combined with government policy settings that are conducive to investment and ‘open for business’, a tropical bio-refinery industry could be an important future source of economic growth in Queensland.

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1 Introduction

Biorefining is the process of converting biomass (organic matter) into value-added chemicals, plastics and fuels. Research into biorefineries has escalated in recent years, with a push to transition to renewable and sustainable feedstocks and reduce reliance on petrochemicals.

A biorefinery is similar to a petro-chemical refinery, to the extent that a range of high value products may be generated from a variety of inputs, depending on market demand. Biorefinery outputs may be a replacement for an existing product within a well-established market, a functionally-improved product which delivers new value into an existing market, or a new product for innovative applications (Corelli Consulting 2010).

There are significant opportunities from biorefining for Australia, and regional Queensland in particular, including export revenues, economic growth, diversification of the agricultural sector, stimulating Australian manufacturing and climate change mitigation (Corelli Consulting 2010).

In Queensland, potential feedstocks include sugarcane bagasse, sorghum and sweet sorghum, Brigalow regrowth and other forestry residue, and some types of green waste. Due to the bulky nature of the feedstocks, the biorefineries often need to be co-located with the sources of biomass.

The Queensland University of Technology (QUT) conducts research and development into tropical crop biotechnology and bioprocessing, with a particular focus on the utilisation of crops and crop wastes for the production of biofuels and other value-added bioproducts. Bluebox Pty Limited (**qut**bluebox) is the innovation and knowledge transfer company for QUT.

qutbluebox engaged Deloitte Access Economics and Corelli Consulting jointly to conduct a study assessing the potential benefits of future tropical biorefinery industries to Queensland's economy and provide information on industrial biotechnology (including international case studies and market information).

The remainder of this report is organised as follows. Chapter 2 provides background information on biotechnology, including case studies of Brazil and Malaysia. Chapter 3 discusses a range of bioproducts that may be produced in Queensland's biorefinery industry. This chapter includes discussion of markets, technologies, and the specific projects modelled in this report. Chapter 4 contains the methodology and results of the economic impact analysis, including information on the impact in different regions of Queensland and on different industries.

2 Background

2.1 Industrial Biotechnology

Industrial biotechnology represents the third wave in biotechnology, following innovation in the medicine and agricultural sectors (Erickson, Nelson et al. 2012).

Industrial biotechnology is capable of producing a multitude of product types from renewable or agricultural raw materials. Bioproducts may be an exact replacement for an existing product with a well-established market, a functionally-improved product which delivers new value into an existing market, or a novel product for new and innovative applications.

Bio-based manufacturing processes impose a lower environmental burden, and incur lower production costs in terms of energy, water and capital cost by operating at lower temperatures and pressures, and milder conditions than traditional processes. By using biomass as a feedstock, industrial biotechnology has the potential to significantly value-add agricultural products.

Industrial biotechnology applies the tools from life sciences to transform traditional industrial processes for the manufacture of bio-based products (such as fuels, chemicals and plastics) from renewable feedstocks, such as the sugars, oils and proteins in agricultural biomass. The life sciences approach harnesses the capacity of an array of diverse and complex biological pathways to transform fermentable sugars in biomass into bulk niche or fine chemicals or polymers, in place of strictly chemical syntheses based on petrochemical feedstocks. A key element of the roadmap for biobased production of chemicals and polymers are integrated biorefineries, which generate a mix of bulk or specialty chemicals as co-products with biofuels and bioenergy. Just as a conventional oil refinery converts crude oil into fuels and an array of chemicals, a biorefinery delivers multiple bio-based products and value streams from biomass. Diversity of revenue generated by a portfolio of valuable products from one feedstock is the basis of the biorefinery's economic and environmental sustainability (Kircher 2010).

Both the process technologies and the products generated by means of industrial biotechnology have wide application within the chemical, aviation, manufacturing, agricultural, pharmaceutical, nutraceutical, cosmetic and food industries.

Chemical industry: the engine room of global development

The chemicals sector is a huge industry with global reach. The chemicals industry today is responsible for the manufacture of an estimated 143,835 chemicals, generating revenues of US$4.1 trillion, and is expected to continue to grow at 3% per year to 2050 (United Nations Environment Programme 2012). Within this framework, the current global market for biobased and renewable chemicals is already worth an estimated $3.6 billion (Ravenscroft 2013).

In a recent review, the EC's World Economic Forum estimated that by 2020 the market for biofuels, biobased bulk chemicals and plastics, and biomass-derived power and heat would approach US$160 billion, based on projected revenues of US$80 billion for biofuels, US$10-15 billion for bio-based bulk chemicals and bioplastics, and US$65 billion for power and heat (World Economic forum 2010, Ravenscroft 2013).

Demand from the industrial biotechnology sector would impact the entire biomass supply chain, from crop development, biomass production, logistics, to bioprocessing enzyme production, with revenues stimulated across collateral industries to US$150 billion. Therefore, the total impact of industrial biotechnology on the global economy may be as high as US$310 billion by 2020 (World Economic Forum 2010).

The Organization for Economic Co-operation and Development projects that worldwide plastic consumption will grow from 250,000 kilo tonnes currently to about 1 million kilo tonnes by 2020 (Erickson, Nelson et al. 2012). Currently, global bioplastics consumption represents 1,000 kilotonnes, or 0.4% of total plastics consumption. However, the bioplastics industry expects to grow rapidly, to reach a market share of 10-20% by 2020 (Kircher 2010).

Up to 15 - 20% of all bulk chemicals, the majority of speciality chemicals such as amino acids, and almost all of the production of new industrial chemicals, such as 1,3-propanediol and lactic acid, will be produced using biobased technologies (Kircher 2010, Ravenscroft 2013).

Major players within the global chemical industry recognise the value of implementing innovation, investing in both in-house R&D programs and by in-licensing, joint venture or acquisition to maintain continued strong growth and competitive advantage. These industries have invested significantly in both demonstration and commercial scale facilities for the production of biobased chemicals and polymers (see Appendix A for greater detail).

The drivers for innovation in the chemical industry are threefold: economic, environmental, and social – “the three pillars of sustainability” (Ravenscroft 2013). Industrial biotechnology is an effective means to reduce the chemical industry’s dependence on fossil fuels, while reducing manufacturing’s environmental footprint: bio-based bulk and fine chemicals could be produced with significantly less water consumed and at least 50% less CO_2 emission. Some biobased chemicals, such as succinate, consume CO_2 in their manufacture (McKinlay, Vielle et al. 2007, De Jong, Higson et al. 2012).

The capacity for bio-based approaches to provide very substantial reduction in non-renewable energy use is considerable (Patel, Koen Meesters et al. 2012): cradle-to-factory gate processes with current technology based on maize are estimated to generate energy savings of 30%, while those based on lignocellulosic feedstocks and sugar from sugarcane may generate energy savings up to 75% and 80% respectively.

In addition, alternate economic feedstocks are sought to replace or reduce those derived from crude oil, as petrochemical costs increase and supplies become unreliable, and, arguably, increasingly limited (Rhodes 2014).

As a consequence of these drivers, the chemicals industry is turning to industrial biotechnology as a route to new commercial opportunities to maintain their future market position, by delivering significant improvement in process profitability and potential for considerable market growth in the future.

> *For many years, (industrial biotechnology) was really about a technology vision, and that's now translated into commercial reality...Real substantive advancements ... show that this industry is starting to get on its feet and have a real commercial impact*
>
> *Christophe Schilling, CEO and founder of Genomatica (San Diego) (2014)*

Competitive landscape

Internationally, recognition of the future value of investing in industrial biotechnology has been evidenced by a number of large, well-financed national initiatives. The US government in particular sees the development of industrial biotechnology nationally as a key strategic objective: in 2004, the U.S. Department of Energy invested in a program to identify 30 simple chemicals, prioritised to a short list of 12, to be produced from the sugars in biomass as replacements for petroleum products (Werpy and Petersen 2004). The European Commission, EU member states, and European industry have invested €3.8 billion (US$5.0 billion) in a biobased industries initiative, "Biobased and Renewable Industries for Development and Growth", to start January 2014 and run to 2020 (Ravenscroft 2013).

> *The emerging biobased industry sector is set be the game changer for stimulating smart, sustainable, and inclusive growth in Europe. By finding commercially viable ways of generating fuel and other products from plants and waste, it will significantly reduce our dependency on oil, help us meet climate change targets, and lead to greener and more environmentally friendly growth*
>
> *Michael Ravenscroft, Senior Editor, IHS Chemical Week (Ravenscorft 2013)*

Market observers predict that North America will emerge as the leader in industrial biotechnology. Currently, North America ranks fourth in global capacity, but will dominate by 2017 as US-based technology start-ups like Gevo build plants at home (Lane 2013). Part of the reason for America's surge is the support the US government now provides biobased chemical manufacturers in accessing feedstock, in what is considered a ground-breaking industry. Most notably, the recently introduced Qualifying Renewable Chemical Production Tax Credit Act of 2013 (US Congress 2013) provides renewable chemical producers access to production tax credits currently only available for renewable energy and biofuels producers. In addition, the US government provides financial assistance for biorefineries (Voegele 2013), particularly those established in rural communities (US Dept of Agriculture 2012). In the US, approximately 3,000 companies either manufacture or distribute an estimated 20,000 biobased products and have created around 100,000 new jobs annually (Lerro 2012). US-based biorefineries that process sustainable biomass are projected to produce 700,000 jobs and US$88.5 billion in economic activity, primarily in rural areas where economic development is greatly needed (US Dept of Agriculture 2010).

The advantages of product manufacture from bio-based feedstocks have not escaped some of the large international chemicals companies. Investment by the chemicals industry in commercial scale operations for the 10 to 100,000 tonne per annum (tpa) production of bio-based chemicals has increased significantly in recent years. Those companies taking a position in the industrial biotechnology sector are the chemical majors (DuPont, Dow, BASF, Degussa, Braskem, Wacker), smaller, technology-driven companies (Gevo, Verdezyne, LanzaTech), and agricultural majors like Cargill and Archer Daniels Midland (see Appendix A).

Impacts of industrial biotechnology

There are several implications from increasing the scope of biorefining in Australia, particularly through growth in tropical biorefineries in Queensland. There are likely to be impacts for the economy, agriculture, and fuel supply.

Development of biorefineries in Queensland is expected to positively contribute to the Queensland economy, and the wider Australian economy. While the industry is small on a world scale, its operations contribute towards the outputs and employment of the chemical and plastics manufacturing industry.

These outputs provide inputs into other Australian manufacturing and industrial sectors, including fuel, pharmaceuticals and construction. High-value products may also be suitable for export.

In terms of employment, biorefineries directly employ staff in their operations, and indirectly contribute to employment in upstream (agriculture and forestry) and downstream industries (chemical industries, sales).

Supporting transport and logistics infrastructure may be required, depending on the size of the industry and the biorefinery locations, which may have construction and employment implications for parts of regional Queensland.

The biorefinery industry creates greater demand for agricultural and forestry production. In some cases, feedstocks may be whole crops which are planted for the purposes of refining. Even where this is not the case, the presence of a domestic biorefinery industry would diversify farming's customer base, with potential benefits for price and price variability. Feedstocks can also be waste products from crop production (e.g. stubble or processing waste) or forestry residues. These waste products may otherwise require (potentially costly) disposal if they were not utilised.

The use of clean feedstocks also has implications for the environment, with lower carbon emissions from biofuels compared with petrol.

Currently, Australians spend around $50 billion on energy each year, with 35% being transportation costs. Sugarcane bagasse (dry waste after juice extraction) has the potential to supply 14% of Australia's gasoline requirement through ethanol, with this estimated to be a $700 million market in Queensland and NSW alone (Proactive Investors Australia 2012).

These global activities are indicative of the burgeoning trend toward commercial-scale industrial biotechnology, and are indicative of the dimensions of the opportunity to establish a world-first integrated industrial biotechnology facility with multiple manufacturers located in one site and utilising common bio-based feedstocks. This opportunity is one for Australia to seize to position itself as a significant participant in the global industrial biotechnology sector.

2.2 Case Studies

Recent experiences with biotechnology investment in Malaysia and Brazil are discussed below. They demonstrate the potential for varied and significant industrial development around biotechnology. And while the governments in these, and other, countries have provided industry with some assistance (subsidies, capital, etc.), this does not necessarily imply anything about the optimal policy mix for Queensland or Australia.

However, both case studies highlight key policy and planning issues for Australia. The central theme of the Malaysian case study is that a government vision for technology precincts has paid dividends, by attracting international businesses to Malaysia. The success of this strategy can now be measured in gross national income and new jobs generated as a direct outcome of precinct development. This success is expected to continue as Malaysia revives failing national industries and brings additional value to existing agricultural production.

As is the case with the Malaysia, the lesson within the Brazil case study is essentially the critical role of a national vision in the development of a new industrial sector. In Brazil, government has played a role in attracting international companies and facilitating collaboration of those companies with national industries, particularly those that supply feedstock for chemicals and plastics production.

Malaysia

The Malaysian government has proactive national strategies to attract quality investments and strategic partnerships in targeted economic sectors. Consequently, Malaysia has invested in two industrial biotechnology precincts, Kertih Biopolymer Park and Bio-XCell, to drive the country's industrial biotechnology economy.

The Kertih Biopolymer Park, in Malaysia's Terengganu State, is a joint initiative between Malaysia's national biotechnology investment agency BiotechCorp, ECERDC (East Coast Economic Region Development Council), and the Terengganu State government. The Biopolymer Park is a national initiative driven by BiotechCorp to advance the Commercialization Phase of Malaysia's National Biotechnology Policy. BiotechCorp is the lead development agency for the biotech industry in Malaysia, providing a single central government contact point for industry. BiotechCorp actively engages with global industrial biotechnology companies, especially those from the US, Europe, Korea and Japan, to relocate their cellulosic-based chemical manufacturing facilities in Malaysia. The Biopolymer Park anticipates housing up to eight foreign companies by 2015, bringing M$6.8 billion (US$2.05 billion) of foreign investment. By 2012, Malaysia's BiotechCorp had invested M$170 million (US$53.3 million) in the biorefinery complex, reportedly Asia's largest, which is forecast to generate significant value for Malaysia. In total, the overall project is expected to generate income of M$20.4 billion (US$6.14 billion) by 2020, and to produce 2,500 new jobs nationally. Malaysia's strategic vision is to create a biorefinery industry which will drive the shift from fossil fuels to more sustainable bio-based production (BiotechCorp 2012, De Guzman 2012).

To ensure feedstock and energy security for the 1,000 hectare Biopolymer Park site, the Malaysian government has set aside 30,000 hectares of land for feedstock plantations to produce 10.5 million tpa of woodchips, with renewable energy generated from cellulosic feedstock instead of natural gas (BiotechCorp 2012, De Guzman 2012). In addition, Kertih Biopolymer Park is co-located with the Kertih Integrated Petrochemical Complex, to allow for cross-supply of products between both complexes, while providing economies of scale for utilities and logistics (Malaysian Investment Development Authority 2012).

To date, the Biopolymer Park has attracted the Korean chemical firm CJ CheilJedang, France-based Arkema, and the US-based Gevo Inc. Joint venture partners CJ CheilJedang and Arkema have invested M$3.2 billion to establish an 80,000 tpa facility to manufacture the speciality chemical bio-methionine and for feeds, largely for export to the EU and South America. Gevo, the world's largest producer of bio-isobutanol, will be operating a 60,000 tpa bio-isobutanol, butanediol and ethanol production facility by 2015, as part of Gevo's US$500 million investment in the precinct (Gevo Inc 2012).

Bio-XCell is a second dedicated biotechnology park in Johor, Malaysia (Bio-XCell) which is home to both MYBiomass, headquartered in Selangor, Malaysia, and US-based GlycosBio. MYBiomass is a special purpose vehicle under the Malaysian biomass initiative, to manufacture isobutanol, butanediol and ethanol from palm oil waste. The biorefinery, with a production capacity of 1.2 million tpa of biomass to produce 60,000 tpa of isobutanol, involves an investment of between M$300 - 400 million (US$93.4 - 124.6 million) and is expected to commence production by the end of 2016. The MYBiomass biorefinery is a collaboration between the Malaysian government and plantation giants Felda Global Ventures Holdings Bhd and Sime Darby Bhd; each industry partner is taking a 40% stake, with Malaysian Industry-Government Group for High Technology (MIGHT) holding 20%. Both Felda and Sime Darby bring access to ample oil palm biomass feedstock from their vast plantations, and financial strength, to the venture. In addition, the Malaysian government envisages the MYBiomass biorefinery as a prototype for the transformation of 20 currently idle, palm oil-based biodiesel plants, with an installed production capacity of 2.6 million tpa, which could also be converted into biochemical plants across the country (Adnan 2012, Saidak 2012).

Within the Bio-XCell precinct, GlycosBio is planning an isoprene plant from glycerol and other low value renewable feedstocks, with completion of the commercial-scale plant in 2016. Isoprene is a key building block molecule used in the production of synthetic rubber and other polymers. At Bio-XCell, GlycosBio will be well-positioned to support the local Malaysian rubber industry as well the emerging regional synthetic rubber market.

Brazil

Brazil's highly developed sugarcane industry and substantial national investment in ethanol has attracted additional and growing corporate investment in industrial biotechnology, particularly bio-based plastics (World Economic Forum 2010). The Brazilian government has been a driving force in building sector value, by providing "soft" loans to sugarcane growers to establish ethanol factories, directing significant funding at closing the gap between research and commercial development, in order for biorefineries to achieve commercial scale (EuropaBio 2011), and creating strong market demand for the domestic consumption of bio-based products manufactured nationally (Blanco-Rosete and Webb 2008, Brehmer and Sanders 2009). The Brazilian national development bank, BNDES, and research financing agency, Finep, have reserved US$988 million for investment in a short list of projects in bio-based chemicals and biofuels, to be allocated 2012-2014. Consequently, Dow Chemical, Cargill, Evonik and Braskem have initiated projects in Brazil, collectively worth more than US$2 billion. Previously, the two financial organizations invested US$493 million in research on second generation cellulosic ethanol production, gasification, and other approaches to value-add sugarcane (Lux Research 2013).

Dow Chemical and Japan's Mitsui formed a joint venture in 2011 to build and co-own a global-scale, 240,000 tpa ethanol plant at Dow's existing sugarcane operation at Santa Vitória, Brazil, to be expanded into a biopolymers facility at a projected cost of US$1.5 billion. The joint venture harvests its own sugarcane from 50,000 acres of sugarcane and has built an ethanol plant with capacity to process 2.7 million tonnes of cane annually, with plans for a second stage ethanol-to-ethylene and biopolymers plant. The scale of production is sufficient to generate bio-based ethylene to meet Brazil's domestic market demand for polyethylene used in footwear and other manufacturing, as well as for export (Dow 2007a, 2007b).

Germany's Evonik, a world leader in specialty chemicals, has invested €55 million (US$69 million) in a 50,000 tpa oleochemicals facility in Sao Paulo, Brazil, scheduled for 2014, for applications in cosmetics, personal care and household care. The portfolio will include specialty surfactants, conditioning agents, emollients, emulsifiers, thickeners, and fabric softening ingredients. Evonik has also co-located a biobased lysine production facility with Cargill at Castro in Brazil. Cargill has invested R$500 million (US$211 million) in a corn-based integrated biorefinery at the Castro site, at which Cargill manufactures starches and sweeteners for dairy products, candies, confectionery, beverages, bread, the paper and cardboard industry, and animal nutrition (de Guzman 2013, Evonik 2014). The biorefinery sites were all selected because of access to raw material supplies, logistical connections (road and port), and proximity to local markets.

Braskem, Brazil's largest chemical manufacturer and world's largest producer of bioplastics, has established a 450,000 tpa plant to produce polyethylene from sugarcane-derived ethanol in 2011, and announced plans in 2013 for a second 200,000 tpa plant. India-based JBF Industries has announced plans for 500,000 tpa facility in Sao Paulo to produce ethylene glycol for Coca-Cola's partially bio-based PlantBottle PET, and sugarcane-based low-density polyethylene (LDPE) for Tetra Pak by 2014 (Watson 2012, Etra Pak 2013).

3 A Queensland biorefinery industry

This chapter describes major bioproducts that are expected to make up part of Queensland's industrial biotechnology industry. Each section, corresponding to a different bioproduct, includes discussion of current and future markets, the technology used, and the project(s) modelled that produce each output. Greater detail on project characteristics can be found in Appendix D.

The biorefinery industry envisaged for Queensland avoids some of the challenges or risks that have affected the viability of petrochemical refineries and manufacturing in Australia. While traditional refineries use relatively expensive inputs, the cost of which is directly dependent on currency movements, biorefineries make use of comparatively much cheaper feedstocks available domestically. In one case (resin production in North Queensland), the biorefinery could actually be *paid* to remove the feedstock, which is green waste that cannot be processed using current infrastructure.

Importantly, the viability of biorefineries in Queensland is contingent on the nearby availability of feedstocks. The biorefineries included in this study experience a comparative advantage as they are able to leverage off the specific climate and biobased feedstocks available nearby.

Prospective projects are located in regions that can supply appropriate feedstocks in sufficient quantities. Each biorefinery project is modelled within one of five regions, each of which is an aggregation of local government areas (LGAs) defined by the Australian Bureau of Statistics. Each project occurs in one region, but they can have impacts across the state (and Australia). Table B.1 details the LGAs making up each region.

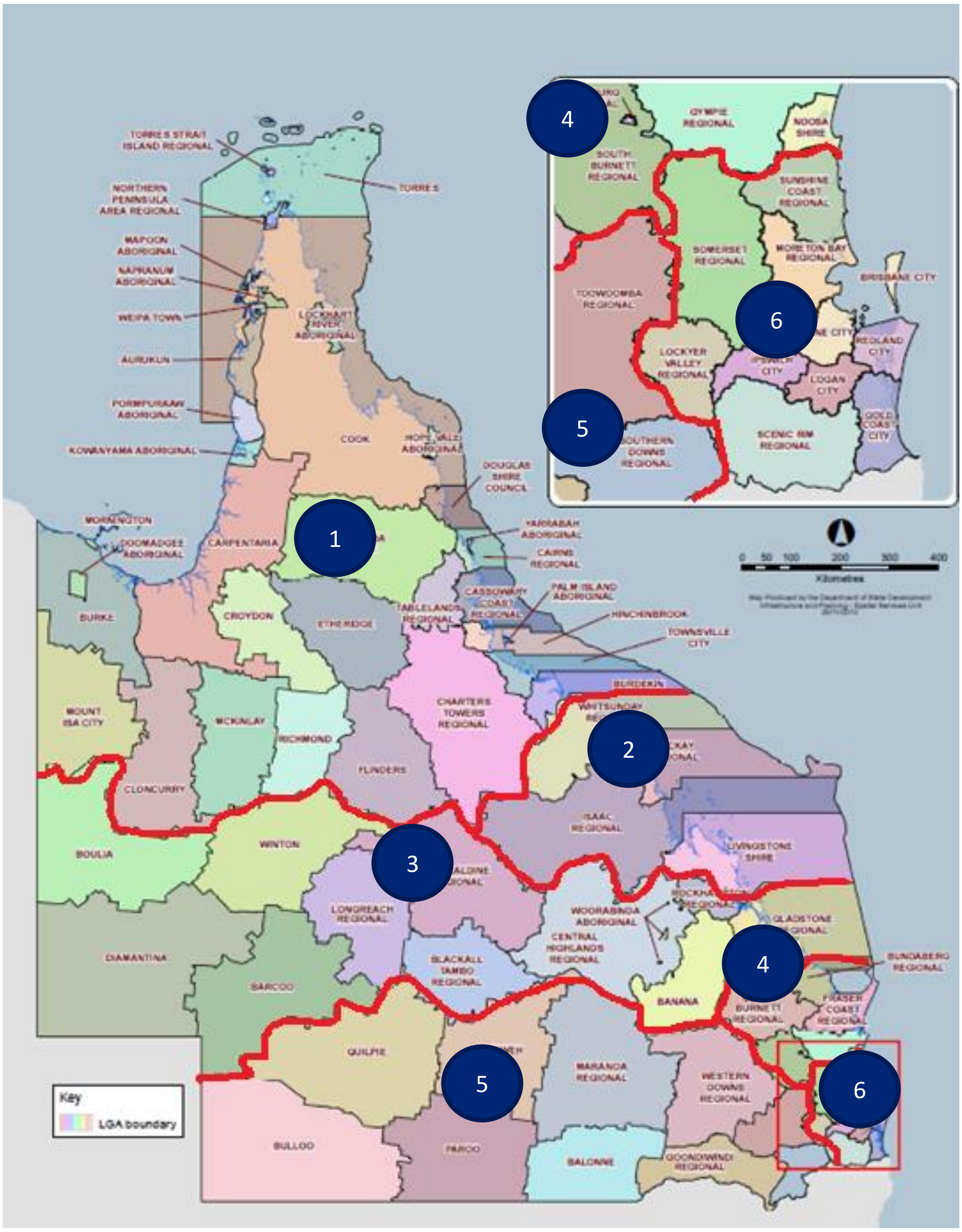
Table 3.1: Potential Queensland biorefineries modelled

Project	Primary output	Input	Region
A	Polyethylene	Sugarcane	North Queensland (1)
B	Resins	Green waste	North Queensland (1)
C	Succinic acid	Sugarcane bagasse	Whitsunday (2)
D	Aviation fuel	Brigalow regrowth	Central Queensland (3)
E	Levulinic acid	Forestry residues	Wide Bay Burnett (4)
F	Xylitol and ethanol	Sweet sorghum	Wide Bay Burnett (4)
G	Ethanol	Sorghum stover	Darling Downs/South West (5)

The geographic boundaries of the regions used are displayed in Figure 3.1 (numbers in Table 3.1 correspond to numbers in Figure 3.1).

A sixth region, South East Queensland, completes the regional breakdown of Queensland. While no project is located in South East Queensland, because the DAE-RGEM models the movement of resources within the economy, there are still impacts in the region which contribute to the overall impact of the biorefinery industry scenario.

Figure 3.1 Queensland regions used in this analysis



Source:http://www.dsdip.qld.gov.au/resources/map/local-government-area-boundaries.pdf, regions defined by DAE

3.1 Polyethylene

Market

Up to 82-90% of the plastics and fibres currently on the market could be substituted by biobased plastics (Shen, Haufe et al. 2009). A significant manufacturing advantage of biobased plastics is that they are chemically identical to their petrochemical-derived counterpart and, as such, use the same conventional processing technologies as are used for fossil-based plastics. In 2011, 3.5 million tonnes of biobased polymers were produced worldwide, compared to 265 million tonnes of traditional, fossil-based plastics (PlasticsEurope 2011). Biobased plastics have seen exponential growth rates in the past few years, with some recent estimates suggesting that production may reach 12 million tonnes by 2020 (Nova Institute 2013).

The outstanding market for biobased plastics to date has been for biodegradable applications, however, non-biodegradable polymers (such as polyethylene terephthalate, polypropylene and polyethylene) are anticipated to dominate the market for biobased plastics. Of the top 3 polymer types, polyethylene is the market leader (29%) (PlasticsEurope 2011). As for conventional polyethylene, biobased polyethylene is derived from ethylene, a significant building block for many other chemicals and plastics, produced in volumes exceeding 140 million tpa (International Renewable Energy Agency 2013).

The market for biobased plastics is driven not only by process efficiencies and feedstock sustainability for the manufacturers, but also by end-user demand. Braskem and Dow, both major producers of biobased polyethylene (PE) (see Appendix A), have remarked that "green PE easily draws a premium of 40% or more from clients eager for an enviro-marketing edge" (Erickson, Nelson et al. 2012, Moser 2013). The world's largest beverage company, Coca-Cola is making strategic replacement of all of its plastic bottles made from fossil fuels with 100% bio-based materials by 2020. Coca-Cola already produces a fully recyclable high density polyethylene plastic bottle derived from biobased ethylene for juice brand products, as well as 10 billion PlantBottle™ containers in 20 countries worldwide (Coca Cola).

Technology

The production pathway for biobased polyethylene from renewable feedstocks involves the relatively simple and well-established technologies of fermentation and dehydration. The process starts with ethanol produced from agricultural biomass, such as sugarcane, or lignocellulosic biomass such as wood or straw. Biobased ethanol is produced from sugarcane juice and bagasse using conventional yeast fermentation technology. The cane sugars are readily converted to ethanol; the sugars in the cellulosic bagasse need to be released following pre-treatment with acid hydrolysis. Bioethanol is then purified ready for dehydration to ethylene using an alumina or silica alumina catalyst (International Renewable Energy Agency 2013). The biobased ethylene so produced is then ready for polymerisation to polyethylene, and is chemically identical to the petrochemical-based polymer. Bagasse is also burned to provide process energy and heat, and to generate electricity, a valuable process by-product.

Ethylene production from renewable feedstocks can significantly reduce the environmental impact of manufacture of this bulk chemical. Life cycle analysis of the production of bio-ethylene from sugarcane estimates a saving of up to 150% of process energy, based on the production of electricity and heat as co-products from sugarcane bagasse. The reduction in greenhouse gases is estimated at 120% from sugarcane. The land required for ethylene production using sugarcane is 0.48 hectares per tonne of ethylene (Patel, Crank M et al. 2006, International Renewable Energy Agency 2013). In addition, as with other comparable biobased production systems such as succinic acid and xylitol, biobased ethylene and polyethylene production using local agri-resources can reduce national dependence on imported petrochemical energy and plastics, as well as stimulate regional economies.

Potential Queensland production

Project A represents a major greenfield investment in new irrigated land in the North Queensland region to produce polyethylene. The modelled project involves a capital expenditure program worth over $660 million (in 2013-14 dollars), spread over three years from 2018-19.

Sugarcane provides the feedstock. The project envisaged could process four million tonnes of sugarcane each year, converted into nearly 190 thousand tonnes of polyethylene worth over $330 million. This development also has potential for conversion of the platform biobased ethylene into other important high volume plastics: polyvinyl chloride (PVC), polystyrene and polyethylene terephthalate (PET) (PlasticsEurope 2011).

3.2 Resins

Market

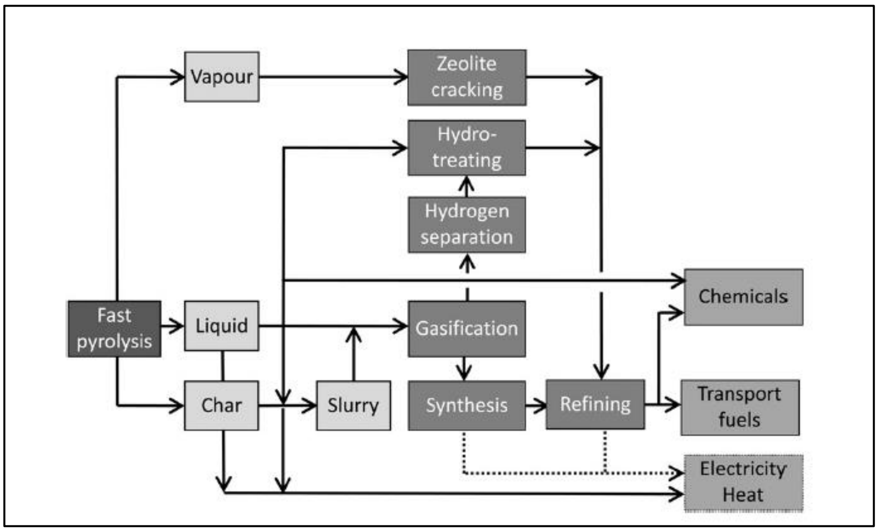
Phenolic resins (or phenol-formaldehyde resins) are synthetic thermosetting resins invented in 1907 (Bakelite) as the first plastic. The global volume for the phenol-formaldehyde resins market is expected to reach 16 million tonnes by 2016, with a compound annual growth rate of 12.1%. The US currently accounts for the highest share of the global market, with India and Japan recording the fastest growth rate for uptake of these resins.

Phenolic resins are extensively and globally used in industry because of their cost effectiveness, ease of use and high temperature (up to 300-350°C), water and chemical stability (European Phenolic Resins Association). Phenol-formaldehyde resins are widely consumed in the metals, construction and transport industry: as bonding adhesives imparting water resistance to composite wood panels for exterior applications; in the manufacture of abrasives, friction materials (brakes/clutch linings), foams, laminates, and as a reinforcing resin to modify the strength and flexibility of rubber (European Phenolic Resins Association). Phenol-formaldehyde resins are the product of the reaction between phenol and formaldehyde catalysed by alkali to provide a thermosetting polymer called resole. Other phenolic compounds, such as resorcinol, can also react with formaldehyde to generate a range of polymers which vary in adhesive reactivity and cost. Pyrolysis-derived phenol has been incorporated during the manufacture of phenol-formaldehyde resins and found by industry to be equivalent to conventional fossil-derived adhesive with respect to the resin's reactivity and performance (Athanassiadou, Tsiantzi et al. 2002).

Technology

Consistent with the key concept of the biorefinery as a producer of multiple product stream, pyrolysis is a long-established thermochemical technology within both the chemical industry and bioenergy sector, used predominantly for the generation of biofuels, but also for the production of chemicals and biochar from biomass (Figure 3.2). Pyrolysis is adaptable in terms of feedstock and a wide variety of fibrous and woody biomass resources are suitable, including; forest waste, (sawdust and bark), agricultural waste, (sugarcane bagasse, straw, olive pits and nut shells), energy crops (miscanthus and sorghum), forestry wastes (bark) and solid industrial and municipal wastes (sewage sludge and leather wastes) (van den Berg, Kay et al. 2010, Bridgwater 2012).

Figure 3.2 Fast pyrolysis-based biorefinery



Source: Bridgewater (2012)

The pyrolysis of organic waste materials has become well-established in Europe and Japan (Bridgwater 2012), backed by government support and policies over the past 20 years (van den Berg, Kay et al. 2010). Canada is home to several large scale plants and two major pyrolysis companies: Dynamotive and Ensyn. Other countries investing in pyrolysis for the production of fuels and chemicals include Finland, Germany, UK, USA, Netherlands, and Australia, motivated by climate change policies and increasing energy prices (van den Berg, Kay et al. 2010).

Of particular interest for chemicals production is fast pyrolysis, which is the rapid thermal decomposition of organic compounds in the absence of oxygen to produce liquids, char, and gas. When applied to cellulosic biomass, fast pyrolysis disintegrates that biomass and the liquid fraction (bio-oil) which results is a rich mixture of complex and potentially valuable compounds. Fast pyrolysis is notable for its fast reaction times of up to 2 seconds, operating at atmospheric pressure and moderate temperatures (400-500°C) and yielding up to 75% by weight of bio-oil. Bio-oil is a low viscosity fluid, with potential applications directly as a combustion or transportation fuel, as a feedstock for power generation, and for the extraction of an array of chemicals for adhesives and resins (van den Berg, Kay et al. 2012, Bridgwater 2012).

The bio-oil produced from fast pyrolysis consists of depolymerised biomass plus compounds including phenols, acids, alcohols, hydroxyls, esters, aldehydes and unsaturated hydrocarbons. The yield of phenols is high, at up to 17% of the pyrolysis oils (Athanassiadou, Tsiantzi et al. 2002), and can be fractionated out of the bio-oil using such separation technologies as supercritical fluid extraction (Patel, Bandyopadhyay et al. 2005). Pyrolysis-derived phenol has been incorporated during the manufacture of phenol-formaldehyde resins and found by industry to be equivalent to the conventional fossil-derived adhesive with respect to the resin’s reactivity and performance (Athanassiadou, Tsiantzi et al. 2002).

There are several kinds of fast pyrolysis reactors in industrial operation globally, made up of multiple modular units, each with biomass feedstock capacity of up to 100,000 tonnes per year (Bridgwater 2012).

Potential Queensland production

Resin production in a future Queensland biorefinery industry is represented by project B, a plant located in the North Queensland region. The project involves three years of capital works commencing in 2015-16, with capital expenditure worth over $19 million in 2013-14 dollars.

The feedstock for this project is green waste sourced from the Cairns Regional Council. This waste cannot be processed in the Cairns Advanced Resource Technology Facility, and because there is a cost to disposing of the material, the biorefinery will receive payment for removing it in the order of $20 per tonne. This is a percentage of the per tonne price the Council Regional Council currently pays to have this green waste removed.

It is anticipated that 150 kilograms of resin will be produced for every tonne of green waste. This output is priced at $2,000 per tonne, so annual revenue is over $5.9 million annually.

3.3 Succinic acid

Market

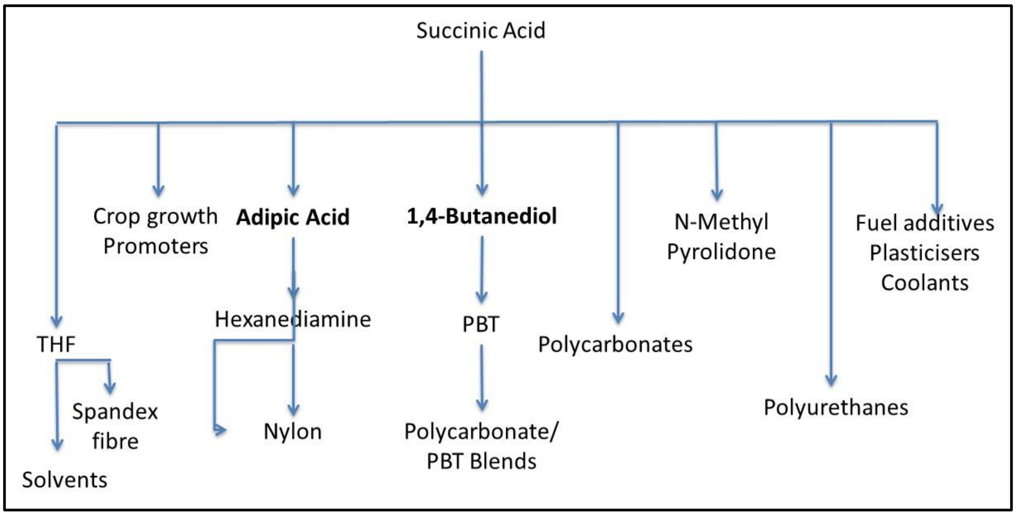
Succinic acid is a significant, small chemical building block or platform chemical used in the manufacture of polymers, resins, food and pharmaceuticals, among other products. Fossil fuel-derived succinic acid was considered a speciality chemical, but as a result of price competiveness and renewable feedstocks, bio-based succinic acid is now addressing a larger volume commodity market (De Jong, Higson et al. 2012).

The global succinic acid market is about 90,000 tpa, of which two thirds is expected to be produced from renewable feedstocks (De Jong, Higson et al. 2012). Demand for bio-succinic acid, driven by applications such as intermediates, solvents, polyurethanes, and plasticizers and coatings, is anticipated to grow strongly. The addressable market for bio-succinic acid could be worth up to US$7.5 billion in new and existing applications, and production capacity has been expanding from 3,000 tpa in 2011 to 50,000 tpa in 2013 (see Appendix

A). While Europe has been the dominant market, accounting for 35% in 2010, Asia-Pacific is expected to be the fastest growing jurisdiction as a result of significant demand from key markets such as China, Japan and India (Myriant Corp , Ravenscroft 2013).

The value chain for succinic acid (Figure 3.3) is based on a position as a starting material for new industrial applications for biodegradable polymers such as polybutylene succinate, fuel additives, novel plasticisers, solvents, spandex fibres, thermoplastic polyurethanes, and fine and speciality chemicals (De Jong, Higson et al. 2012). In addition, biobased succinic acid can serve as a starting material for adipic acid, 1,4-butanediol and tetrahydrofuran, all significant platform chemicals (2014). The estimated potential market size for the polymers, polysuccinate esters and polyamides that can be synthesized from succinic acid is up to 27 million tonnes per year (Song and Lee 2006).

Figure 3.3 The value chain for biobased succinic acid



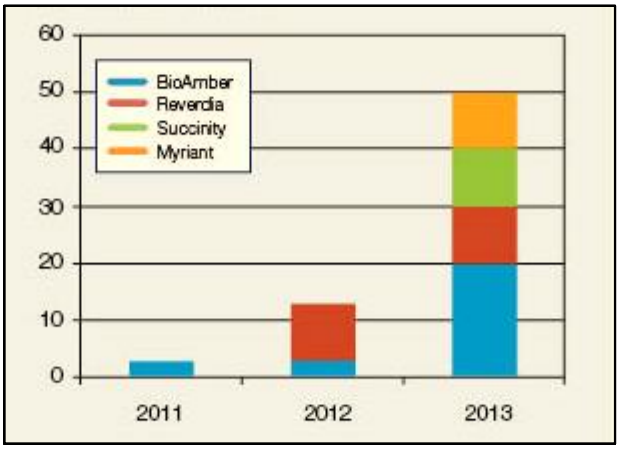
Note, THF stands for tetrahydrofuran and PBT stands for polybutylene terephthalate.

Bio-succinate is produced from glucose or starch by fermentation by bacteria or yeast, with a significantly higher energy efficiency compared to the traditional petrochemical method. It is also one of the first bio-based processes to sequester carbon dioxide (CO_2) in the production process (Myriant Corp). Initial commercial scale production uses sugar or starch as feedstock, with the longer term strategy to switch to second generation cellulosic feedstock.

Commercial production of biobased succinic has attracted a number of industry players from among the chemical majors, and commercial scale manufacture of bio-succinic acid is now on stream. BioAmber was the first commercial producer of biobased succinic acid at an integrated biorefinery in Pomacle, France, which is owned by Agroindustries-Recherches et Developpements (ARD), the French agricultural consortium, and built at a cost of €21.0 million. In addition, BioAmber and Mitsubishi Chemicals have a plant of 30,000 tpa initial capacity in Sarnia, Canada, which will eventually be expanded to 50,000 tpa by 2016. Plans for two additional facilities in Thailand and North America/Brazil to give a total cumulative capacity of 165,000 tpa have been announced (BioAmber , De Jong, Higson et al. 2012).

The Roquette and DSM joint venture, Reverdia, announced production of 10,000 tonnes bio-succinate per year from starch feedstock from 2010 (DSM).

Figure 3.4 Production of biobased succinic acid reaches commercial scale



Source: Ravenscroft (2013)

Note, capacity in kilotonnes.

The US-based technology firm Myriant Corp and Germany's ThyssenKrupp Uhde have been developing a commercial-scale process for bio-succinic acid since 2009 (Myriant Corp), and Myriant started large-scale production in mid-2013. ThyssenKrupp Uhde is a division of the German chemical major, ThyssenKrupp, a relatively new entrant into industrial biotechnology, and area seen by that corporation as its future growth strategy. In July 2013, the company announced the launch of Europe's first multi-purpose fermentation plant for the continuous production of bio-based chemicals, specifically the starting materials for biodegradable plastics such as polylactic acid and polybutylene succinate (ThyssenKrupp 2013).

Lactic acid producer Purac and BASF have formed a joint venture, Succinicity, which is building a plant near Barcelona with a capacity of 10,000 tpa of bio-succinic acid, scheduled to be on stream late 2013 or early 2014. A second plant is planned with a capacity of 50,000 tpa (Ravenscroft 2013).

Technology

Conventionally, succinic acid is produced from maleic anhydride in a chemical process which uses liquefied petroleum gas (LPG) or petroleum oil as a starting material. Succinic acid is mostly produced by the chemical process from n-butane through maleic anhydride. The high cost of conversion of maleic anhydride to succinic acid, and the significant cost of maleic anhydride as an intermediate, has limited the use of chemically-produced succinic acid for its wide range of applications (Song and Lee 2006).

Fermentative production of succinic acid by industrial yeast (Efe, van der Wielen et al. 2013) or bacteria (Song and Lee 2006) from renewable resources, including sugarcane (Efe, van der Wielen et al. 2013) can be more cost-effective than the petroleum-based processes. The rumen bacterium *Mannheimia succiniciproducens* is one candidate for the commercial production of succinic acid, with high productivity and high yield from renewable resources. *M. succiniciproducens* can produce a yield of as much as 91% of succinic acid from glucose under reducing environments (Lee, Lee et al. 1999). A further process advantage is offered by *M. succiniciproducens* in the efficient use of xylose, which makes it possible to use the untreated hydrolysate of wood or sugarcane bagasse as a feedstock to reduce the raw material cost.

The consumption of the greenhouse gas CO_2 provides additional environmental benefits. While purification of fermentation products can equate to 60% of overall production costs, simple and more cost-effective methods using reactive extraction (Song and Lee 2006) followed by crystallization (Efe, van der Wielen et al. 2013) have been developed to purify succinic acid from other by-products.

The cost of producing succinic acid from unprocessed cane sugar are significantly reduced by integrating the succinic fermentation plant with the sugar plant and transferring concentrated juice to succinic acid production. In addition, integration of the two plants provides the opportunity for the two operations to share process heat (generated by the succinic process (Efe, van der Wielen et al. 2013) and electricity (from burning bagasse during sugar refining), with mutual cost benefits.

Potential Queensland production

This potential project could be located in the Mackay area of the Whitsunday region (Project C). The project is modelled as involving three years of capital expenditure, commencing in 2014-15 and in total worth $391 million in today's dollars.

The feedstock for the project is sugarcane bagasse, sourced from surrounding areas. At full scale production, 600,000 tonnes of feedstock would be used each year. It is anticipated that the facility will employ 45 full time equivalent employees.

It is anticipated that the project will produce 110 thousand tonnes of succinic acid worth over $260 million each year.

3.4 Aviation Fuels

Market

The global consumption of jet fuel is around 830 million litres per day, with the US responsible for the largest share (37%) of that volume (Organisation for Economic Co-operation and Development 2012). The airline industry has strong incentives to shift to the use of alternative sources of fuel. Not only is the cost of petrochemical-based jet fuel subject to large fluctuations, but fuel has risen from representing around 15% of airline operating costs in 2003 to approximately 27% in 2007 (Air Transport Department 2008). The aviation industry is also under pressure to reduce its GHG emission or buy CO_2 credits on the open market which would add billions of dollars to airlines' costs (Organisation for Economic Co-operation and Development 2012). As a result, alternative biobased jet fuel is now seen as a strategic necessity for the aviation industry as an approach to significantly lower the industry's GHG emissions but also provide a long-term sustainable substitute for petroleum-based jet fuel.

Globally, the drive towards production of sustainable aviation fuel has intensified, with consortia formed in Europe, Russia, United Arab Emirates, Abu Dhabi, Qatar, China, Malaysia, Singapore, Japan, Australia, Canada, Brazil, Mexico and the US as discrete international centres for strategic acceleration of the roll out of renewable jet fuels. Internationally, commercial interest in sustainable aviation fuels is represented by Neste Oil (Finland), Altair Fuels (US), Amyris (US), UOP (US), Dynamic Fuels (US), GEVO (US), SkyNRG (Netherlands), Rentech (US), Solazyme (US), Solena (US) and Virent (US) (Organisation for Economic Co-operation and Development 2012). In the EC, Airbus, along with leading European airlines (Lufthansa, Air France/KLM, & British Airways) and key European biofuel producers (Neste Oil, Biomass Technology Group and UOP), have launched an initiative locally to stimulate the commercialisation of aviation biofuels, targeting the annual production of 2 million tonnes of sustainably produced biofuel for aviation by 2020 (European Biofuels Technology Platform, Organisation for Economic Co-operation and Development 2012).

In the US, motivated by the need for energy security and environmental sustainability, the Commercial Aviation Alternative Fuels Initiative (CAAFI) was formed as a coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants and US government agencies. CAAFI has taken the lead in the development and deployment of alternative jet fuels for commercial aviation. In 2013, the US Department of Defense invested US$16 million with three technology companies to support facilities for production of bio jet fuels for fighter jets and destroyers by 2016, as part of the Advanced Drop-In Biofuels Production Project (Defence Production Act) (European Biofuels Technology Platform).

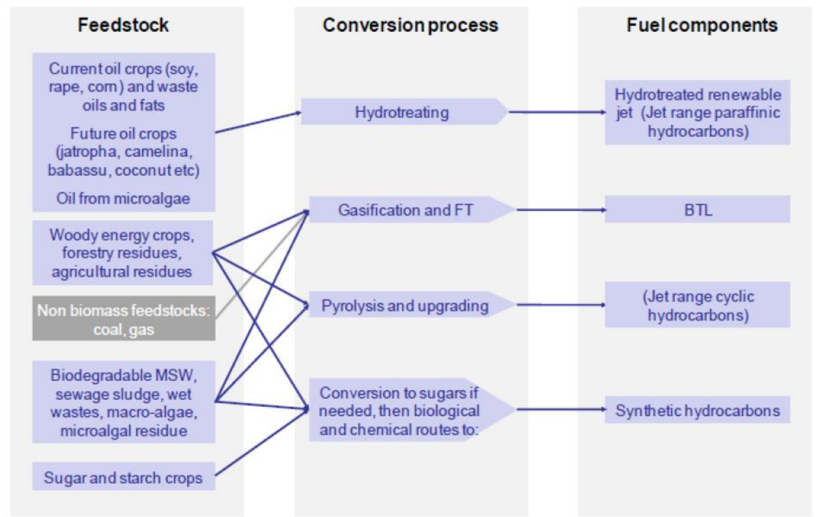
Demonstration flights using biojet fuel commenced in 2011 and continue with Porter Airlines, All Nippon Airways, Qantas, LAN Colombia, Air Canada, Azul Brazilian Airlines all having carried out successful demonstration flights using biojet fuel (European Biofuels Technology Platform).

Consistent with the proposed biojet biorefinery in Fitzroy based on Brigalow biomass, a recent proposal for the production of sustainable jet fuels in Australia from native and plantation forest biomass has an initial production target of 5% of Australia’s jet fuel requirements or 470 million litres in 2020, with production capacity building gradually over 25 years (Booth, Raison et al. 2014).

Technology

One approach to the generation of sustainable jet fuel or synthetic paraffinic kerosene is the production of biojet fuels from biomass and plant oil feedstocks. Biomass can be converted into biojet fuel (biomass to liquid fuel or BTL) by means of a number of technologies, biological or thermochemical, including pyrolysis, gasification, anaerobic digestion, distillation, fermentation (see Figure 3.5).

Figure 3.5 Feedstock conversion pathways to renewable aviation fuel



Source: Organisation for Economic Co-operation and Development (2012)

Pyrolysis and gasification followed by the Fischer–Tropsch synthesis is considered one of the best approaches currently available commercially (Liu, Yan et al. 2013), and has the advantage of flexibility of almost any biomass feedstock. Shell and Sasol are the current leading producers of biojet fuel using this approach (Organisation for Economic Co-operation and Development 2012). Alternatively, cellulose-based feedstocks from sugarcane have been converted into biojet using biological means. Sugars from sugarcane bagasse can be fermented by commercially developed strains of yeast to produce a renewable hydrocarbon, farnesene, which is then processed into a drop-in renewable jet fuel. Lifecycle analysis indicates that renewable jet fuel produced in this way in Brazil by the US technology company Amyris may reduce greenhouse gas emissions by at least 80% when compared to conventional fossil-derived jet fuel (Amryis 2014).

Potential Queensland production

This potential project could be located in the Central Queensland region (project D). The project is modelled as commencing capital works in 2016-17, with further expansion occurring every five years over the modelled period (the project is envisaged as involving significant capital expenditure beyond this period as well). This capital expenditure program is worth over $470 million in 2013-14 dollars.

The feedstock for this project is Brigalow regrowth. With a plan to harvest on a 10 year rotation, clearing activities are outside the scope of the *Environmental Protection and Biodiversity Act 1999* (Brigalow regrowth). It is anticipated that at full scale the project will process five million tonnes of feedstock per annum.

Over 1.5 billion litres of aviation fuel will be produced annually once the project is at full scale. The input data for this project are consistent with published CSIRO work on the economics of a project like this in the Fitzroy region of Queensland (Hayward et al. 2013).

3.5 Levulinic, formic, and acetic acids and furfural

Market

Levulinic acid is a valuable platform chemical which is one of the US DoE's top 12 bio-derived platform chemicals (Werpy and Petersen 2004). Levulinic acid can be used as a solvent, antifreeze, food flavouring agent, for plastic synthesis, and to generate liquid fuels (Galletti, Antonetti et al. 2012). In addition, due to its highly reactive chemistry, levulinic acid is a platform chemical, able to generate a vast range of industrial derivatives. Two such derivatives are diphenolic acid and levulinic acid esters. Diphenolic acid is a direct replacement for bisphenol A in polycarbonates, epoxy resins, polyarylates and other polymers, and has applications in lubricants, adhesives and paints. Levulinic acid esters have significant potential as blend components in diesel formulations, as replacements of kerosene as a home heating oil and as a fuel for the direct firing of gas turbines for electricity generation.

The co-product, formic acid, has direct application as a commodity chemical. Formic acid is used extensively in textile dyeing and finishing, in leather tanning, and in the manufacture of drugs, dyes, insecticides, refrigerants and catalysts. In 2000, the world consumption of formic acid amounted to approximately 415,000 tonnes. A Biofine plant processing 300 dry tonnes of feedstock per day would produce approximately 9,000 tpa of formic acid per year (assuming a cellulose content of 40%).

Acetic acid is a significant industrial building block for the production of a large number of chemical compounds, with global demand of 6.5 million tpa. Acetic acid has wide application in the production of plastics including PVA, film, bottles and fibres, as a food ingredient and an industrial solvent. Recently, US-based ZeaChem Inc. produced bio-based acetic acid by fermentation at comparable purity to the traditional product, and the company has successfully demonstrated the commercial scalability of the fermentation process (Erickson, Nelson et al. 2012).

Furfural is generated from the hemicellulosic pentose fractions of the biomass. Furfural is used as a solvent directly or in the production of furfuryl alcohol, tetrahydrofuran (THF) and levulinic acid. Furfuryl alcohol is a monomer for furan resins, used mainly as foundry binders. The global production of furfural in 2001 was around 225,000 tpa; approximately 40,000 tpa of furfural was consumed in Europe in 2000, furfuryl alcohol being the major market. A commercial-scale Biofine plant processing 300 dry tonnes of feedstock per day would produce around 13,000 tonnes of furfural per year, meeting the requirements of a third of the European market. Furfural conversion products, THF or levulinic acid and their downstream products, may therefore present more marketable final products than furfural itself in large biorefinery schemes, especially if the fuel additive market is explored (Hayes, Fitzpatrick et al. 2008).

Technology

Lignocellulosic feedstocks such as wood and wood wastes are abundant and far less costly than other feedstocks (crude oil, natural gas, corn kernels, and soy oil) based on energy content (Zhang 2008). Chemical technologies that fractionate recalcitrant lignocellulosic feedstocks can inexpensively generate a range of chemicals and fuels that are currently competitive only from petrochemical reserves. The Biofine Process is one of these technologies and provides high yields of levulinic acid, furfural and formic acid, by a continuous, and chemically-based technology using biobased renewable feedstocks (Hayes, Fitzpatrick et al. 2008).

The Biofine process is a hydrothermal conversion which uses dilute sulphuric acid to break down the complex chemistry of lignocellulose. The feedstock is shredded then mixed with recycled dilute sulphuric acid. The process has two distinct stages: the first plug flow reactor rapidly (12 seconds) hydrolyses the carbohydrate polysaccharides to soluble intermediates (e.g. 5-hydroxymethyl-2-furaldehyde HMF). The second reactor has a longer residence time (~20 minutes) and uses milder conditions. The 5- and 6-carbon sugars which result undergo multiple acid-catalysed reactions to give the platform chemicals, levulinic acid and furfural among the final products. Furfural and other volatile products tend to be removed at this stage; levulinic acid is recovered under reduced pressure, and refined to a purity of 98%. The acid used for the initial feedstock hydrolysis is recovered in the final stage, for reuse in subsequent operations (Hayes, Fitzpatrick et al. 2008).

The Biofine process, due to its process efficiencies, achieves yields of levulinic acid from cellulose of 70-80% of the theoretical maximum, representing the conversion of about 50% of the 6-carbon sugars in the cellulose feedstock to levulinic acid, with 20% being converted to formic acid. The yield of furfural from 5-carbon sugars is also approximately 70% of the theoretical value, equivalent to 50% conversion. An additional advantage of the Biofine process is the flexibility for a wide range of heterogeneous lignocellulosic feedstocks, including sawdust, paper mill sludge, municipal solid waste, and sewage (Hayes, Fitzpatrick et al. 2008, Galletti, Antonetti et al. 2012).

Potential Queensland production

This potential project could be located in the Wide Bay region (project E). Facility construction is modelled as occurring in 2017-18, worth approximately $13 million in 2013-14 dollars.

The feedstock for the facility is forestry residue. The availability of forestry residues in the area, due to the significant forestry industry in the Wide Bay region, is an important factor influencing the location of the facility. Understanding of feedstock availability is based on information on forestry activity in the Gympie area as well as QUT scientist expertise on the forestry industry.

Levulinic acid is the main output of the facility (2,270 tonnes per annum), but other products are also made. These include formic acid, furfural and acetic acid. Revenues are anticipated to be over $10 million per annum.

3.6 Ethanol

Market

To date, biomass-based biorefineries globally are dominated by those designed to produce ethanol as a biofuel. The World Economic forum estimates that the market for ethanol and other biofuels will meet revenue targets of US$80 billion by 2020, exceeding the return on bulk chemicals and plastics alone (World Economic Forum 2010). Consequently, the economics of biorefineries is favoured by a mixed product portfolio of chemicals, plastics and energy and power.

Ethanol is now accepted as a conventional transportation fuel at varying concentrations in unleaded petrol from 10% ethanol (E10) to 85% ethanol (E85). Ethanol can be used in combustion engines as a standalone fuel, fuel-extender in petroleum blends, or as an additive to increase the fuel octane rating, replacing benzene. The use of ethanol as a biofuel is recognised as a sustainable alternative to petrochemical fuels, with broad environmental benefits in terms of toxic and particulate emissions (Albertson, Wong et al. 2013).

Technology

Ethanol is produced globally at the industrial scale by the fermentation of sugars, largely using the commercially available yeast, *Saccharomyces cerevisiae*. This yeast is a well-established, well understood industrial microorganism that has been used for centuries. The entire sweet sorghum plant, juice, grain and fibre, can be used to generate high yields of ethanol from both the naturally occurring sugars in sweet sorghum juice as well as the sugars liberated from enzymatic hydrolysis of sweet sorghum bagasse and grain. Optimised operating conditions for maximum ethanol yields for the sweet sorghum have already been reported for pilot fermentation studies at the Mackay Renewable Biocommodities Pilot Plant, with ethanol yields of up to 94.5% obtained on the juice (Albertson, Wong et al. 2013).

To increase ethanol recovery from sweet sorghum, additional fermentable sugars are released from the bagasse by conventional treatments: pre-treatment with steam explosion followed by enzymatic hydrolysis using commercial cellulase mixtures. Steam explosion weakens the bonds within the fibrous structure of bagasse, allowing improved access by hydrolytic enzymes to release sugars from the cellulose polymer. The final step of the process is fermentation of the combined sugars to alcohol in a batch fermenter vessel, then recovery of the ethanol by distillation (Albertson, Wong et al. 2013).

Potential Queensland production

Two modelled projects have ethanol as their primary output. The first (project F) is located in the Wide Bay Region, and involves three years of capital works commencing in 2016-17 and worth $240 million in 2013-14 dollars. Sweet sorghum would provide the feedstock for this facility. Both the grain and the lower-priced stalk would be utilised. The facility modelled is designed to process one million tonnes of feedstock annually.

The second project modelled (project G) that has ethanol as its primary output is located in the Darling Downs region. The project commences capital works in 2016-17 which continue for two years, with spending worth $91 million in 2013-14 dollars. The feedstock for this project is sorghum stover, which is priced at a significant discount to sorghum grain. This project will diversify sorghum producers' customer base, with feedlots currently major buyers in the region. Taking in over 200,000 tonnes of sorghum stover per annum, the plant will be able to produce 48 million litres of ethanol per annum, worth $38 million at a price of $0.80 per litre.

3.7 Other products

3.7.1 Xylitol

Market

The sugar alcohol, xylitol, is the first rare sugar to have established a global market, with applications in the food industry as a sugar substitute and as an inexpensive starting material for the production of other rare sugars. Xylitol was one of the promising biobased specialty chemical targets identified by the US DoE in 2004 and 2010 (Werpy and Petersen 2004, De Jong, Higson et al. 2012). Xylitol is conventionally synthesized from the pentose sugars, using metal catalysts at elevated temperature and pressure. The fermentation of the pentose sugar uses bacteria and yeast, is a cost-effective and environmentally-friendly process, and avoids the need for purification of xylose, which is the major cost-intensive step in conventional catalytic processes (Girio 2012). The annual world market for xylitol, which is priced at $4–5 per kilogram, is estimated to exceed US$500 million.

The relatively high value makes biobased xylitol an attractive proposition for commercialization, and the largest manufacturer internationally is the Danish company, Danisco (now a part of DuPont) using hardwoods and maize as feedstock, with several other suppliers based in China. The market for xylitol is driven partly by recognition of the health benefits of xylitol in food, dental and pharma products, but also as a platform chemical used to produce ethylene glycol and 1,2 propanediol. Ethylene glycol is used in the production of poly(ethylene)terephthalate (PET) for plastics in packaging, car manufacture and textile fibres for such companies as Toyota, Danone and Coca Cola; 1,2 propanediol (or propylene glycol) is used widely in fragrance, cosmetics and personal care applications, food and flavourings, pet and animal feeds and in pharmaceutical formulations, as well as industrial resins, solvents paints and coatings (De Jong, Higson et al. 2012).

Rare sugar specialist manufacturers, Xylitol Canada and zuChem are both launching new production processes for xylitol. Xylitol Canada completed pilot demonstration of its cellulosic xylose process in 2013, with a commercial-scale facility planned to produce up to 10,000 tonnes of xylose per year from sustainably harvested North American hardwoods. US-based zuChem Inc. and India-based Godavari Biorefineries Ltd. have entered into a global partnership for the production and commercialization of sweeteners and renewable sugar-derived ingredients as food ingredients from a variety of cellulosic feedstocks at 380,000 litre scale (Rao Ravella, Gallagher et al. 2012, Lane 2013).

A number of studies consider the coproduction of xylitol with ethanol from cellulose feedstock (for example rye straw). Xylitol has a higher economic value than ethanol so co-production of xylitol increases the profitability of a lignocellulosic ethanol plant. This is significant in terms of the economic viability of cellulolytic ethanol plants, which have been estimated at capacity of 2000-4000 tonnes per day (Aden 2002) requiring a US$200m commitment. Hence co-production of xylitol may be required for the economic viability of smaller facilities (Rao Ravella, Gallagher et al. 2012).

Technology

Xylitol is conventionally synthesized from the pentose sugars released from the acid hydrolysis of hemicellulose from hardwoods and agri-industrial residues such as sugarcane bagasse, straw, seed husks, and pulp and paper waste streams, using metal catalysts at elevated temperature and pressure (Domínguez, Salgado et al. 2012). The industrial biotechnology approach to xylitol production still uses acid hydrolysis of the hemicellulose fraction to release xylose, but then transforms the sugar to xylitol by fermentation of the xylose sugar using bacteria or yeast. One naturally-occurring yeast strain, *Rhodotorula* sp, converts xylose to xylitol at high yield: (61% of theoretical) (Bura, Vajzovic et al. 2012), while another improved yeast strain of *Candida* yields 100% xylitol from xylose (Ko, Kim et al. 2006). The fermentation approach to xylitol production is a cost-effective and environmentally-friendly process, and avoids the need for purification of xylose, the major cost-intensive step in conventional catalytic processes (Girio 2012).

Potential Queensland production

In addition to ethanol, project F will be able to produce xylitol worth nearly $30 million annually.

3.7.2 Animal feeds

Market

In 2013, the total world volumetric production of compound animal feed was approximately 1 billion tonnes, of which about 300 million tonnes was produced directly by on-farm mixing or feedlot. Global commercial feed manufacturing generates an estimated annual turnover of over US$370 billion at a compound annual growth rate of 3.7% (International Feed Industry Federation 2013.). Animal feeds represent a significant portion (70%) of the production costs of livestock, with impact on the output of meat, eggs and milk.

Two major challenges in the animal feed industry in Australia are the prohibition against the use of bovine by-products in ruminant feeding (dairy and beef cattle) and the need to avoid species-to-species feeding issue (for example, poultry feeds derived from processed poultry wastes). Therefore, the generation of protein- and vitamin-enriched yeast biomass as a by-product of ethanol production (Feedipedia – Animal Feed Resources Information System) provides added value to local animal industries in the vicinity of the biorefinery, by meeting growing industry demands for alternative protein sources for both commercial and feedlot feeds.

Technology

Biomass of the yeast *Saccharomyces cerevisiae* is collected at the end of the fermentation process, inactivated by heat treatment or with organic acids, and then dewatered for inclusion at up to 80% in animal feed as concentrated stillage (Feedipedia – Animal Feed Resources Information System). This biomass from ethanol production is widely used as an animal feed as rapidly perishable wet distiller's grain, or the more stable dried distiller's grain (O'Hara 2013).

Potential Queensland production

Projects F and G are both modelled as producing animal feed in addition to their primary outputs of ethanol.

3.7.3 Electricity

Market

Energy is a potentially very valuable co-product for integrated sweet sorghum biorefineries. In a recent report, the World Economic Forum estimates that the market for bio-based power and heat will reach US$65 billion by 2020, providing valuable additional revenues streams to agricultural-based biorefinery of various scales (World Economic Forum 2010).

Technology

Combustion of fibrous crop biomass in water tube boilers is well-established in the agricultural sector for co-generation of heat and power. Combustion releases energy as heat which is then used to convert water into steam inside the boiler to drive the processing of the crop, e.g. sugarcane, for electricity generation. The yield of electricity produced from agricultural biomass is largely dependent of the efficiency of the conversion processes (Albertson, Wong et al. 2013). Surplus biobased electricity can be exported locally at a wholesale power price into the electricity distribution network, delivering revenues by means of Renewable Energy Certificates (RECs) produced under the Australian Government Renewable Energy Target (O'Hara 2013).

Potential Queensland production

Project F is modelled as generating revenue from electricity production of $4 million per year.

4 Economic impact analysis

This chapter provides the methodology for the economic impact analysis, information on the six regions identified as potential locations for the seven biorefineries modelled, and the modelling results.

4.1 Methodology

Deloitte Access Economics has used a customised version of our in-house CGE model (DAE-RGEM) to model the estimated impacts of biorefinery construction in Queensland. Further detail on the model is in presented in Appendix D.

The model is customised in that Queensland has been broken down into six regions to reflect the potential sourcing of inputs and location of the potential projects modelled. For example, projects F and G, which utilise sorghum as an input are located in areas of large (or potentially large) sorghum production. Project E, which makes use of forestry residues, is located in a region with significant forestry activity.

Table 4.1 summarises the socioeconomic characteristics of the six modelling regions. More detailed discussion of this data for the six aggregated regions is presented in Appendix C.

In the modelling component, the economic impact analysis compares the 'project scenario', which incorporates the proposed biorefinery construction, against a 'baseline' where the proposed construction does not proceed. The base scenario forms the reference point, or counterfactual, against which the impacts of changes in economic variables due to the construction are compared. The project scenario specifically looks at the impacts of the proposed project on capital expenditure and production.

QUT scientists drew on their expertise and relevant literature to provide project information including the level and profile of capital expenditure, inputs and outputs of biorefineries, and their prospective location. The regional breakdown of Queensland is based on where biorefinery feedstocks would be drawn from, itself a function of climate and other environmental characteristics. Deloitte Access Economics undertook a sense-check of the model inputs, but has not independently verified the costings. Detail on project characteristics is available at Appendix D.

The economic impact analysis employs the assumption that these are commercial projects, operating without government subsidies, but also that government provides a stable operating environment that does not place unreasonable limitations on the technologies used.

Foreign governments (and therefore taxpayers) have in some cases contributed significant funds to the biorefinery sector. While this does undoubtedly provide the sector with a boost, it distorts the allocation of resources in the economy, and means scarce public funds are captured mostly by owners of the subsidised businesses. Sound public policy principles would recommend against this type of intervention.

Note that various potential upsides have been excluded from the modelling. For example, players in the soft drink manufacturing industry have indicated that they would pay a premium for polyethylene produced using biobased feedstocks. Also, the United States Navy, one of the major users of oil in the United States, aims to significantly increase its use of non-fossil fuel sources. Any impact these or other initiatives could have on output prices or the size of potential markets has not been included in the analysis.

Table 4.1: Regional summary statistics

	Region	Population	Indigenous population (%)	Unemployment rate (%)	Labour force participation rate (%)	Employed in agriculture (%)	Employed in manufacturing (%)	Land area used for production (%)
1	North Queensland	539,171	12.2%	6.0%	70.8%	11.3%	14.2%	86.9%
2	Whitsunday	171,297	4.1%	3.6%	74.2%	9.9%	16.0%	93.0%
3	Central Queensland	229,552	5.2%	4.3%	73.1%	12.0%	19.7%	92.4%
4	Wide Bay Burnett	279,201	4.0%	8.8%	64.6%	22.0%	24.6%	84.1%
5	Darling Downs/South West	246,097	4.5%	4.5%	73.6%	24.8%	18.9%	96.2%
6	South East Queensland	3,008,780	1.8%	6.2%	72.5%	2.0%	19.0%	60.2%
	Queensland	4,474,098	3.6%	6.1%	72.0%	6.2%	18.6%	88.0%

Source: ABS 2013

4.2 Modelling results

Gross state product

In Queensland, the construction of the seven biorefineries is expected to result in an increase in gross state product (GSP) (relative to the baseline) of $31 million in 2014; by 2035 the increase is estimated to grow to over $1.8 billion above the baseline. The net present value of the modelled biorefineries' contribution over the modelled period is $21.5 billion.

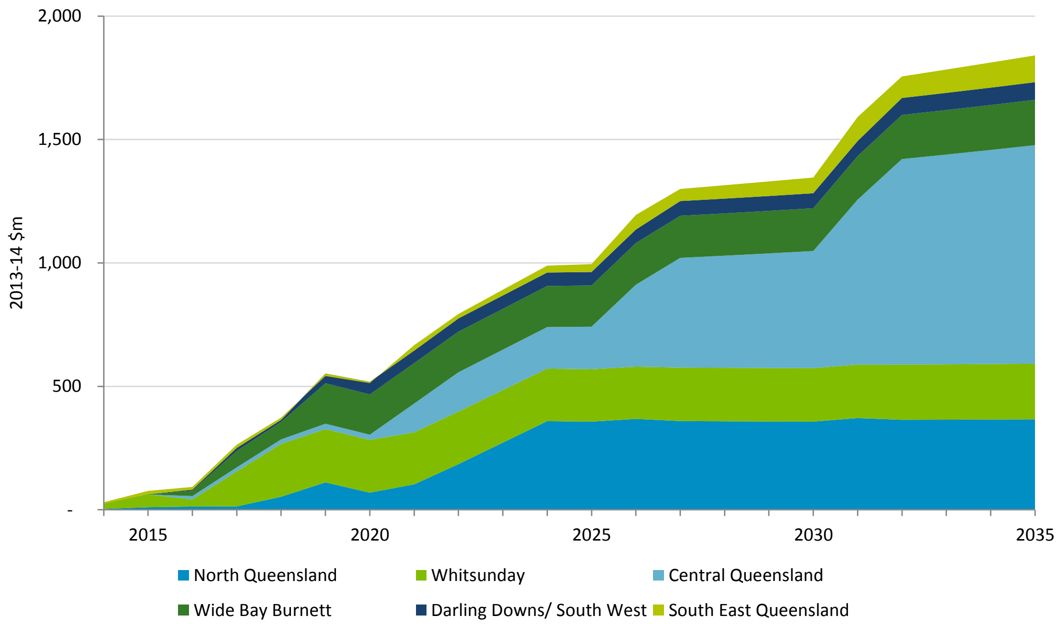
In this analysis, project establishment and operations are modelled out to 2035-36. In reality, projects would very likely operate beyond 2035-36, with ongoing economic impacts.

Within Queensland, gross regional product (GRP) is expected to increase relative to the base scenario for all regions by 2035. As Chart 5.1 illustrates, Central Queensland is expected to experience the greatest increase, with a projected deviation of $885 million in 2035. This reflects the significant nature of the investment in Central Queensland, with capital expenditure of nearly $2 billion and construction expected to continue out to 2036-37.

It should be reiterated that the set of projects modelled (including their location) do not represent a definitive vision of the future biorefinery industry (and therefore its impacts) in Queensland. The total size and regional distribution of impacts will likely be different in reality – these modelling results demonstrate that biorefinery investment can have significant impacts throughout Queensland, particularly in regional areas. That said, the modelling does produce projections of impacts in the regions defined for this analysis:

- In North Queensland, GRP is expected to increase by $367 million (0.7%) compared to the base scenario in 2035.
- In the Whitsunday region, GRP is expected to be $226 million (0.7%) higher under the project scenario than the base scenario by 2035.
- A fast ramp up in GRP deviation is estimated for the Wide Bay Burnett region, with deviation of GRP under the project scenario more than doubling from $71 million in 2018 to $164 million in 2019. By 2035, the project scenario is estimated to result in GRP being $184 million (2.9%) higher than the under the counterfactual.
- In 2035, GRP in the South East Queensland region is projected to positively deviate from the base scenario by $109 million (1.2%).
- The Darling Downs/South West region is forecast to have a GRP $71 million higher (0.3%) than under the base scenario in 2035.
- In South East Queensland, GRP under the project scenario is expected to be $109 million (0.04%) higher than baseline.

Figure 4.1 Deviation of GSP from base scenario by region



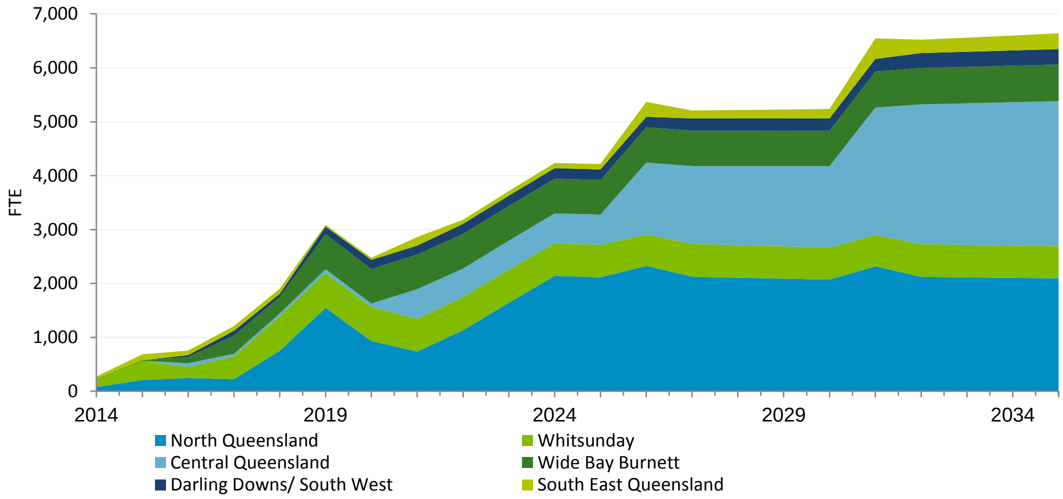
Employment

Compared to the base scenario, employment in Queensland under the project scenario is projected to be higher by 276 FTE employees in 2014, growing to 6,640 FTEs by 2035.

As is the case for increases in GRP, Central Queensland and North Queensland are expected to experience the largest share of this absolute growth relative to baseline, as shown in Chart 5.2. Employment in Central Queensland is projected to increase by 2,694 FTEs (2.0%) in 2035 (relative to baseline) and in North Queensland by 2,095 FTEs (0.36%) in 2035 compared with baseline.

- In the Wide Bay Burnett and Whitsunday regions, employment under the project scenario is expected to be higher than the baseline by 679 FTEs (0.6%) and 595 FTEs (0.5%) respectively, in 2035.
- Darling Downs/South West and South East Queensland are expected to experience growth relative to the base scenario of 286 (0.2%) and 292 FTEs (0.02%) respectively.

Figure 4.2 Deviation of FTE employment from base scenario by region



Source: Deloitte Access Economics

Industry impacts

Under the project scenario, the output of related Queensland industries is generally expected to increase relative to the base scenario in 2025.

- Biorefinery production directly and indirectly increases output and employment in the manufacturing industry. Output from the manufacturing industry is expected to be $849 million higher than under the base scenario in 2025, and employment is expected to be higher by 996 FTEs.
- For the services industry, employment under the project scenario is estimated to be higher by 1,489 FTE employees in 2025, while output will be $296 million higher.
- Trade is projected to be $181 million higher relative to baseline, with 951 more FTE employees in 2025. This reflects the output from biorefineries that may be exported.
- For agriculture, demand for feedstock is expected to contribute to an increase output of $104 million relative to the baseline, with 583 more FTE employees in 2025.
- Production from biorefineries is expected to increase demand for transport. By 2025, output from the transport industry is expected to be $14.7 million higher than the baseline, with 110 additional FTEs.
- For the electricity and water industry, output is projected to grow by $6.1 million relative to baseline, and employ 30 more FTEs than in the absence of construction.
- In contrast, output from mining is projected to decline relative to the base scenario, with a decline of $30 million, and a loss of 33 FTEs by 2025. This may be attributable to the output and employment shifting to other industries.

These estimated impacts on output and employment are summarised in the following table.

Table 4.2: Output and employment impacts of the modelled biorefinery industry in

Industry	Output ($ million)	Employment (FTE)
Agriculture	104.0	583
Mining	-30.6	-32
Manufacturing	849.0	996
Electricity and water	6.1	30
Trade	181.4	951
Transport	14.7	110
Services	295.6	1,489

On a regional level, the industries are expected to have different experiences under the project scenario relative to baseline.

- The trade and services industries are expected to experience increases in both output and employment from the base scenario across all six regions in 2025.
- Manufacturing output and employment are projected to be higher under the project scenario in all regions except for South East Queensland, where a decrease is projected.
- In 2025, output and employment are both expected to be higher under the project scenario in the agricultural industry, for all regions. The largest absolute increase in employment is expected in North Queensland.
- In contrast, output and employment in mining are expected to be lower than the base scenario in 2025 for all regions except North Queensland, where a slight positive increase in output is forecast relative to baseline.
- Output and employment for the transport and electricity and water industries are projected to be above the base scenario in 2025 for all regions except Whitsunday, which is expected to be below the base scenario in output, and South East Queensland, which is projected to experience lower output and employment than baseline.

Conclusion

Queensland's tropical climate and large agriculture sector produces significant volumes of biological material as by-products – often waste material available at little or no cost. This preliminary assessment indicates an opportunity to profitably convert these into chemicals, plastics, and fuels. There are technologies and feedstocks available for viable refineries to be developed in several regions – including the south west, central, coastal and tropical climate zones – each producing different bio-based products.

The development of a tropical bio-refinery industry could have a significant economic impact on the Queensland economy. The seven modelled projects alone could contribute around $1.8 billion and 6,640 FTEs over the next two decades.

This report provides sufficient proof of concept to proceed with further due diligence and a full feasibility study of the future potential and viability of these bio-refineries. Combined with government policy settings that are conducive to investment and 'open for business', a tropical bio-refinery industry could be an important future source of economic growth in Queensland.

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Appendix A: Commercial scale production of biobased chemicals

Carbon number	Bio-based Chemical	Laboratory, Pilot, Demonstration Scale	Commercial-Scale Production	Feedstock	Application
C2	Ethylene	Dow Chemical/Mitsui	Braskem: 200,000 tpa Dow Chemical/Mitsui: 350,000 tpa plant, onstream 2015.	ethanol from sugarcane	plastics
C2	Ethylene glycol		Greencol Taiwan: 100,000 tpa, India Glycols: 175,000 tpa	ethanol from sugarcane	polyethylene terephthalate (PET) plastic
C2	Acetic acid	Wacker: 500-tpa pilot plant; LanzaTech: 5 tpa demo plant (end 2014)	Zeachem: 250,000 gallons per yea	fermentable sugar; CO_2	industrial solvent, synthetic fibres & textiles, inks & dyes, rubbers & plactics, pesticides
C3	Propylene	Braskem, Dow, Global Bioenergies	Braskem: 30,000–50,000 tpa plant (in planning)	ethanol from sugarcane	thermoplastic resin in automotive and other industries
C3	Propylene glycol	Senergy Chemical, from glycerin	Archer Daniels Midland: 100,000 tpa	glycerine	Food, cosmetic and pharmaceutical, liquid detergents, engine coolants, industrial heat-transfer fluids, polyester resins
C3	1,3-Propanediol	Metabolic Explorer, 8,000 tpa	DuPont and Tate & Lyle Bio Products, 45,000 tpa	corn starch	personal care, performance coatings, ink jet ink and high performance elastomers
C3	Epichlorohydrin	Dow	Solvay: 10,000-tpa plant (EU), 100,000-tpa plant (Thailand), 100,000-tpa capacity (China, 2014)	glycerine; corn-derived sorbitol	epoxy resins used in paints & coatings, composites, adhesives, electronics; non-epoxy applications, eg pulp & paper, water treatment & healthcare products.
C3	Lactic acid		Cargill: > 150,000 tpa	sugar	bioplastics, textiles, molded plastic parts, foams & films
C3	Acetone	TetraVitae Bioscience: acquired by Eastman Renewable Materials 2011	Cathay Industrial Biotech; Jiangsu Lianhai Biological Technology Co.		Industrial solvent
C3	Acrylic acid		OPX Biotechnologies/ Dow (50,000 liters pa by 2014), Arkema, BASF, Cargill, Metabolix, Myriant, SGA Polymers	glycerine; lactic acid; sugars	Superabsorbent polymers
C4	Isobutene	Gevo/Lanxess; Global Bioenergies	Lanxess: 10,000 tpa, Brazil	isobutanol from sugars	synthetic rubber
	isobutanol		Gevo: 50,000 tpa, plans to increase to 1 million tpa by 2015	sugars	speciality chemicals, gasoline & jet feedstock, plastics, fibres rubber & other polymers
C4	Succinic acid		BASF/Purac, Succinity: 10,000 tpa (EU); plans to add 50,000-tpa; BioAmber: 3,000 tonne (France); 30,000-tpa plant (Canada) online 2014, plan to add 20,000 tpa; planning 100,000 tpa plant for BDO & succinic acid (Thailand); Myriant: 13,500 tpa construction 2013, second plant 64,000 tpa for 2015;	fermentable sugars	solvents, polyurethanes, and plasticizers
C4	1,4-Butanediol	BioAmber, Genomatica/Chemtex, Genomatica/Tate & Lyle, Metabolix: 8,000 tpa Myriant/DPT Genomatica/Toray five-week BDO run, 2,000 tonne (Apr 2013)	BASF / Geonomatica: to increase to 650,000 tpa Novamont/Genomatica: 18,000 tpa under constructn (2013)	succinate from sugar; fermentable sugars	spandex fibers & other performance polymers, resins, solvents & printing inks for plastics
C5	Isoprene	Amyris, Genencor/Goodyear,	Glycos Biotechnologies to start production 2014		
C6	2,5-Furandicarboxylic acid (FDCA)	Avantium, 20-tpa pilot plant; partnership with Solvay	Avantium: engineering stage for a 50,000-tpa plant	sugars	nylon, thermoplastics, polyesters, polyamides & polyurethanes, coatings, resins, plasticizers
C6	Adipic acid and other nylon precursors	BioAmber/Celexion, Draths (now Amyris), Genomatica, Rennovia	Verdezyne demonstration trials of 1,000 tonnes pa (2014)	sugar or plant oil	nylon, plastics and foams

Source: Ravenscroft (2013), company websites.

Appendix B: Modelling regions

There are 74 LGAs in Queensland. For the purposes of this analysis, six regions were defined and the LGAs were assigned to these regions (see Table 3.1, page 15). The LGAs associated with each of the modelling regions are presented in Table B.1 below.

Table B.1: LGAs and modelling regions

Modelling region	Region name	Queensland LGA
1	North Queensland	Aurukun (S)
		Burdekin (S)
		Burke (S)
		Cairns (R)
		Carpentaria (S)
		Cassowary Coast (R)
		Charters Towers (R)
		Cloncurry (S)
		Cook (S)
		Croydon (S)
		Doomadgee (S)
		Etheridge (S)
		Flinders (S)
		Hinchinbrook (S)
		Hope Vale (S)
		Kowanyama (S)
		Lockhart River (S)
		McKinlay (S)
		Mapoon (S)
		Mornington (S)
		Mount Isa (C)
		Napranum (S)
		Northern Peninsula Area (R)
		Palm Island (S)
		Pormpuraaw (S)
		Richmond (S)
		Tablelands (R)
		Torres (S)
		Torres Strait Island (R)
		Townsville (C)
		Weipa (T)
		Wujal Wujal (S)
		Yarrabah (S)
2	Whitsunday	Isaac (R)
		Mackay (R)
		Whitsunday (R)

3	Central Queensland	Banana (S) Barcaldine (R) Barcoo (S) Blackall Tambo (R) Boulia (S) Central Highlands (R) Diamantina (S) Gladstone (R) Longreach (R) Rockhampton (R) Winton (S) Woorabinda (S)
4	Wide Bay Burnett	Bundaberg (R) Cherbourg (S) Fraser Coast (R) Gympie (R) North Burnett (R) South Burnett (R)
5	Darling Downs/South West	Balonne (S) Bulloo (S) Goondiwindi (R) Maranoa (R) Murweh (S) Paroo (S) Quilpie (S) Southern Downs (R) Toowoomba (R) Western Downs (R)
6	South East Queensland	Brisbane (C) Gold Coast (C) Ipswich (C) Lockyer Valley (R) Logan (C) Moreton Bay (R) Redland (C) Scenic Rim (R) Somerset (R) Sunshine Coast (R)

Appendix C: Socioeconomic profiles

North Queensland (including Far North Queensland)

This modelling region spans from Torres LGA in the north and is bounded by Mount Isa, Flinders and Burdekin LGAs.

Population

In 2011, the population of the North Queensland region was around 539,200 (ABS 2013). Of the population, 12.2% of residents identified as being Aboriginal or Torres Strait Islander peoples, significantly higher than 3.6% statewide.

Of the total population aged 15 years and over in this region, 52.6% had post-school qualifications, compared with 54.3% in Queensland (ABS 2013).

Employment and income

The working age population accounts for 67.6% of people in the North Queensland region. Of these people, there is a labour force participation rate of 70.8%. Unemployed persons make up 6.0% of the labour force, similar to 6.1% across Queensland (ABS 2013).

Agriculture, fishing and forestry are important employers in the region, with 11.3% of people employed in this industry compared with 6.2% in Queensland. On the other hand, manufacturing accounts for 14.2% of employment in this region, below 18.6% across the state.

Income per capita, from all sources other than Government pensions was $23,704 in 2010 (ABS 2013).

Land use

The North Queensland region, as defined in this analysis, spans approximately 71.7 million hectares. Of this area, conservation and natural environments account for 11.3% of land area, while 86.9% of land area was used for production. Production includes both dryland and irrigated agriculture and plantations, as well as including production from relatively natural environments (such as grazing).

Whitsunday

The Whitsunday region defined for this analysis includes the Whitsunday, Isaac and Mackay LGAs.

Population

In terms of population, the Whitsunday region has the lowest number of people (approximately 171,300 in 2011). 4.1% of this population identified as Aboriginal or Torres Strait Islander peoples in the 2011 Census. Across the region, 52.3% of people aged 15 years and over had post-school qualifications (ABS 2013).

Employment and income

The Whitsunday region had the highest working age population of the regions, with 69.2% of its residents between the ages of 15 and 64. In addition, the region has a low unemployment rate of 3.6%, compared with the state average of 6.1%. The labour force participation rate in the Whitsunday region is 74.2% (ABS 2013).

Agriculture, fishing and forestry accounts for 9.9% of employment in the region and manufacturing employs 16.0% of workers in the area. This region has the highest income per capita of those defined here, at $30,338 per person.

The Whitsunday region had the highest total personal income per capita (excluding Government pensions), estimated at $30,300 per person in 2010 (ABS 2013).

Land use

This is the smallest of the regions by land area, covering 9 million hectares. Of this area, 4.5% is classified as conservation and natural environments, while 93% is used for production (ABS 2013).

Central Queensland

The Central Queensland region spans across the state, from Boulia and Diamantina LGAs in the west to Gladstone LGA in the east.

Population

In 2011, the Central Queensland region had a population of 229,600 (ABS 2013). Aboriginal or Torres Strait Islander peoples accounted for 5.2% of the total population. Approximately half (50.2%) of all residents aged 15 years or over had post-school qualifications.

Employment and income

In the Central Queensland region, the working age population accounted for 66.9% of the total. The labour force participation rate is slightly higher than average, at 73.1% compared with 72.0% statewide.

The manufacturing industry is a key employer in the region, accounting for 19.7% of workers, while agriculture, fishing and forestry employs a further 12.0% of people (ABS 2013).

Total personal income per capita (excluding Government pensions) was estimated at $25,800 per person in 2010 (ABS 2013).

Land use

This region covers over 51.3 million hectares. 91.0% of the land area is used for production from relatively natural environments (e.g. grazing), with a further 1.3% used in dryland agriculture and 0.2% of land area under irrigated agriculture. Conservation and natural environments cover 6.3% of land area in this region (ABS 2013).

Wide Bay Burnett

Modelling region 4 is located to the east of the state and includes the LGAs of Bundaberg, Cherbourg, Fraser Coast, Gympie, North Burnett and South Burnett.

Population

In 2011, the estimated resident population of the Wide Bay Burnett region as defined in this analysis was 279,200 persons, of which 4% reported being Aboriginal or Torres Strait Islander peoples. This region had the lowest proportion of residents with post-school qualifications (47.4% of people aged 15 years and over) (ABS 2013).

Employment and income

The region has a low working age population, with only 60.9% of residents aged between 15 and 64 years, compared with a state average of 67.2%. The region also has a low labour force participation rate (64.6%) and a high unemployment rate (8.8%) relative to the rest of the state (72.0% and 6.1% respectively) (ABS 2013).

This is a significant region for agriculture and manufacturing, with almost half of all regional employment (46.6%) in these two industries alone (22.0% and 24.6% respectively).

In Wide Bay Burnett, total personal income per capita excluding Government pensions was estimated at around $17,000 per person in 2010 (ABS 2013). This is the lowest across the six regions.

Land use

One of the smaller regions by area, the Wide Bay Burnett region covers around 4.9 million hectares. Dryland agriculture and plantations account for 4.4% of land use, with a further 3.2% attributable to irrigated agriculture and plantations. This is the highest proportion of land under agriculture across the six regions. In total, 84.1% of land is used for production, including grazing land. 11.5% of land is designated as conservation land and natural environments.

Darling Downs/South West

The Darling Downs/South West region was defined along in the south of the state and along the NSW border, bounded by Bulloo, Quilpie, Toowoomba and Southern Downs LGAs.

Population

The population of the Darling Downs/South West region was 246,100 persons in 2011, of whom 11,000 (4.5%) were Aboriginal or Torres Strait Islanders. Of the population aged 15 years and over, 48.7% of the resident population had post-school qualifications.

Employment and income

In this region, the working age population accounts for 63.1% of the total. The unemployment rate in the region was estimated at 4.5% in 2011, with a labour force participation rate of 73.6% (ABS 2013).

As with Wide Bay Burnett, agriculture and manufacturing are significant industries of employment. Almost a quarter of all employees (24.8%) were employed in agriculture, fishing or forestry, and a further 18.9% were employed in manufacturing.

Excluding Government pensions, total personal income per capita for this region was estimated at $20,800 per person in 2010 (ABS 2013).

Land use

The region covers over 33.8 million hectares, with 96.2% of this land used for production, the highest of all the regions. This comprises 91% of land used for production from relatively natural environments (such as grazing), 4.3% used for dryland agriculture and 1.0% under irrigated agriculture. This region had the lowest proportion of its land under conservation and classified as natural environments, at just 1.9% of total area (ABS 2013).

South East Queensland

The South East Queensland region is bounded by Somerset and Sunshine Coast LGAs in the north, Lockyer Valley LGA in the west, the NSW border to the south and the Queensland coastline.

Population

While the smallest geographically, this region has the highest population. At over 3 million residents, the population of South East Queensland is almost six times as large as the other regions in this analysis, with this mostly attributable to the capital city (Brisbane) and other major regional centres (Gold Coast and Sunshine Coast). The Aboriginal and Torres Straight Island population account for 1.8% of the total.

This region also has the highest proportion of residents aged 15 years or over with post-school qualifications (55.9%) (ABS 2013).

Employment and income

In South East Queensland, the working age population is 68% of the total population. The unemployment rate is in line with the state average (6.2% compared with 6.1%). Similarly, the labour force participation rate (72.5%) is only slightly higher than statewide (72.0%).

Agriculture, fishing and forestry have a relatively low contribution to employment in this region, only accounting for 2.0% of employed persons, compared with 6.2% statewide. On the other hand, employment in manufacturing (19.0% of employment) is similar to the state average of 18.6%.

Total personal income per capita (excluding Government pensions) was estimated at $25,800 per person in 2010 (ABS 2013).

Land use

This region covers approximately 2.2 million hectares. 5.3% is built-up area, significantly higher than all other regions which have less than 0.5% of their total land area in this category. That said, only 53.5% of land in South East Queensland is categorised as conservation areas and natural environments. Dryland and irrigated agriculture account for 3.9% and 2.9% of land area respectively (ABS 2013).

Appendix D: Project economic profiles

Table D.1 below provides information on the economic characteristics of the modelled projects. All dollar values are millions of 2013-14 Australian dollars.

Project establishment and operations out to 2035-36 are modelled, with zero terminal value at that date. In reality, projects would very likely operate beyond 2035-36, and would have some non-zero terminal value at 2035-36 if they did not. This means that the economic impact analysis, and apparent viability of projects, is conservatively represented in this report.

The projects are indicative technologies with the potential to be viably manufactured in Queensland. The exact timing and location would depend on individual project proponents – these projects were selected for the purpose of estimating the potential future impacts of the industry.

The projects have been based on technical and scientific inputs from **qut**bluebox, QUT scientists and Corelli Consulting. We have not independently verified the viability of each project.

The major factor driving the viability and benefit cost ratios of these projects is the discrepancy between the unit costs of feedstocks and the value of the outputs. This difference represents the value of novel technologies that provide new ways of using resources.

While Project A (polyethylene production using sugarcane in North Queensland) has a benefit-cost ratio below one, it has still been included in modelling of the economic impact of a Queensland biorefinery industry. This is because of the high assessed likelihood that a project of this type, using this type of technology will be viable in Queensland, especially at higher oil prices (increasing input costs for petrochemical-based polyethylene production).

Table D.1: Economic characteristics of modelled projects

Project	Start date	Capital expenditure	Revenue	Costs	Benefit-cost ratio	Internal rate of return
A	2018-19	$663	$1,631	$1,568	0.73	N/A
B	2015-16	$19	$48	$11	1.56	16.6%
C	2014-15	$391	$2,158	$1,217	1.34	19.7%
D	2016-17	$473	$3,883	$3,063	1.10	16.6%
E	2017-18	$13	$77	$37	1.57	31.6%
F	2016-17	$240	$1,269	$640	1.44	22.7%
G	2016-17	$91	$356	$177	1.33	17.0%

Note, all dollar values are millions of 2013-14 Australian dollars.

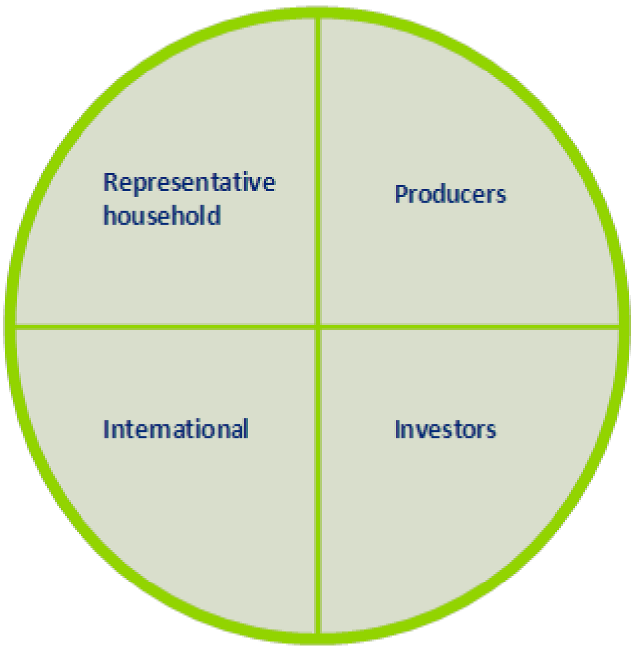
Appendix E: CGE modelling

The Deloitte Access Economics – Regional General Equilibrium Model (DAE-RGEM) is a large scale, dynamic, multi-region, multi-commodity computable general equilibrium model of the world economy. The model allows policy analysis in a single, robust, integrated economic framework. This model projects changes in macroeconomic aggregates such as GDP, employment, export volumes, investment and private consumption. At the sectoral level, detailed results such as output, exports, imports and employment are also produced.

The model is based upon a set of key underlying relationships between the various components of the model, each which represent a different group of agents in the economy. These relationships are solved simultaneously, and so there is no logical start or end point for describing how the model actually works.

Figure E.1 shows the key components of the model for an individual region. The components include a representative household, producers, investors and international (or linkages with the other regions in the model, including other Australian States and foreign regions). Below is a description of each component of the model and key linkages between components. Some additional, somewhat technical, detail is also provided.

Figure E.1: Key components of DAE-RGEM



DAE-RGEM is based on a substantial body of accepted microeconomic theory. Key assumptions underpinning the model are:

- The model contains a 'regional consumer' that receives all income from factor payments (labour, capital, land and natural resources), taxes and net foreign income from borrowing (lending).

- Income is allocated across household consumption, government consumption and savings so as to maximise a Cobb-Douglas (C-D) utility function.
- Household consumption for composite goods is determined by minimising expenditure via a CDE (Constant Differences of Elasticities) expenditure function. For most regions, households can source consumption goods only from domestic and imported sources. In the Australian regions, households can also source goods from interstate. In all cases, the choice of commodities by source is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.
- Government consumption for composite goods, and goods from different sources (domestic, imported and interstate), is determined by maximising utility via a C-D utility function.
- All savings generated in each region are used to purchase bonds whose price movements reflect movements in the price of creating capital.
- Producers supply goods by combining aggregate intermediate inputs and primary factors in fixed proportions (the Leontief assumption). Composite intermediate inputs are also combined in fixed proportions, whereas individual primary factors are combined using a CES production function.
- Producers are cost minimisers, and in doing so, choose between domestic, imported and interstate intermediate inputs via a CRESH production function.
- The model contains a more detailed treatment of the electricity sector that is based on the 'technology bundle' approach for general equilibrium modelling developed by ABARE (1996).
- The supply of labour is positively influenced by movements in the real wage rate governed by an elasticity of supply.
- Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. A global investor ranks countries as investment destinations based on two factors: global investment and rates of return in a given region compared with global rates of return. Once the aggregate investment has been determined for Australia, aggregate investment in each Australian sub-region is determined by an Australian investor based on: Australian investment and rates of return in a given sub-region compared with the national rate of return.
- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions, and minimises costs by choosing between domestic, imported and interstate sources for these goods via a CRESH production function.
- Prices are determined via market-clearing conditions that require sectoral output (supply) to equal the amount sold (demand) to final users (households and government), intermediate users (firms and investors), foreigners (international exports), and other Australian regions (interstate exports).
- For internationally-traded goods (imports and exports), the Armington assumption is applied whereby the same goods produced in different countries are treated as imperfect substitutes. But, in relative terms, imported goods from different regions are treated as closer substitutes than domestically-produced goods and imported composites. Goods traded interstate within the Australian regions are assumed to be closer substitutes again.

- The model accounts for greenhouse gas emissions from fossil fuel combustion. Taxes can be applied to emissions, which are converted to good-specific sales taxes that impact on demand. Emission quotas can be set by region and these can be traded, at a value equal to the carbon tax avoided, where a region's emissions fall below or exceed their quota.

Households

Each region in the model has a so-called representative household that receives and spends all income. The representative household allocates income across three different expenditure areas: private household consumption; government consumption; and savings.

The representative household interacts with producers in two ways. First, in allocating expenditure across household and government consumption, this sustains demand for production. Second, the representative household owns and receives all income from factor payments (labour, capital, land and natural resources) as well as net taxes. Factors of production are used by producers as inputs into production along with intermediate inputs. The level of production, as well as supply of factors, determines the amount of income generated in each region.

The representative household's relationship with investors is through the supply of investable funds – savings. The relationship between the representative household and the international sector is twofold. First, importers compete with domestic producers in consumption markets. Second, other regions in the model can lend (borrow) money from each other.

- The representative household allocates income across three different expenditure areas – private household consumption; government consumption; and savings – to maximise a Cobb-Douglas utility function.
- Private household consumption on composite goods is determined by minimising a CDE (Constant Differences of Elasticities) expenditure function. Private household consumption on composite goods from different sources is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.
- Government consumption on composite goods, and composite goods from different sources, is determined by maximising a Cobb-Douglas utility function.
- All savings generated in each region are used to purchase bonds whose price movements reflect movements in the price of generating capital.

Producers

Apart from selling goods and services to households and government, producers sell products to each other (intermediate usage) and to investors. Intermediate usage is where one producer supplies inputs to another's production. For example, coal producers supply inputs to the electricity sector.

Capital is an input into production. Investors react to the conditions facing producers in a region to determine the amount of investment. Generally, increases in production are accompanied by increased investment. In addition, the production of machinery, construction of buildings and the like that forms the basis of a region's capital stock, is undertaken by producers. In other words, investment demand adds to household and government expenditure from the representative household, to determine the demand for goods and services in a region.

Producers interact with international markets in two main ways. First, they compete with producers in overseas regions for export markets, as well as in their own region. Second, they use inputs from overseas in their production.

- Sectoral output equals the amount demanded by consumers (households and government) and intermediate users (firms and investors) as well as exports.
- Intermediate inputs are assumed to be combined in fixed proportions at the composite level. As mentioned above, the exception to this is the electricity sector that is able to substitute different technologies (brown coal, black coal, oil, gas, hydropower and other renewables) using the 'technology bundle' approach developed by ABARE (1996).
- To minimise costs, producers substitute between domestic and imported intermediate inputs (governed by the Armington assumption) as well as between primary factors of production (through a CES aggregator). Substitution between skilled and unskilled labour is also allowed (again via a CES function).
- The supply of labour is positively influenced by movements in the wage rate governed by an elasticity of supply (assumed to be 0.2). This implies that changes influencing the demand for labour, positively or negatively, will impact both the level of employment and the wage rate. This is a typical labour market specification for a dynamic model such as DAE-RGEM. There are other labour market 'settings' that can be used. First, the labour market could take on long-run characteristics with aggregate employment being fixed and any changes to labour demand changes being absorbed through movements in the wage rate. Second, the labour market could take on short-run characteristics with fixed wages and flexible employment levels.

Investors

Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. The global investor ranks countries as investment destination based on two factors: current economic growth and rates of return in a given region compared with global rates of return.

- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions, and minimises costs by choosing between domestic, imported and interstate sources for these goods via a CRESH production function.

International

Each of the components outlined above operate, simultaneously, in each region of the model. That is, for any simulation, the model forecasts changes to trade and investment flows within, and between, regions subject to optimising behaviour by producers, consumers and investors. Of course, this implies some global conditions that must be met, such as that global exports equal global imports and that global debt repayment equal global debt receipts each year.

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Contact us

Deloitte Access Economics
ACN: 149 633 116

Level 1
9 Sydney Avenue
Barton ACT 2600
PO Box 6334
Kingston ACT 2604 Australia

Tel: +61 2 6175 2000
Fax: +61 2 6175 2001

www.deloitteaccesseconomics.com.au