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Submitted via email to bioenergyroadmap@arena.gov.au

10 June 2020

RE: Queensland University of Technology (QUT) response to ARENA Bioenergy Roadmap Call for Submissions

On behalf of Queensland University of Technology (QUT), thank you for providing the opportunity to contribute to the development of the Bioenergy Roadmap. A range of QUT experts have contributed to this submission and are available to support ARENA, industry and Government in developing innovations and solutions for growth of the sector.

QUT has a major research focus on bioeconomy that includes research in bioenergy, biorefining and the production of high value bioproducts. Our staff include some of Australia's leading experts in agriculture and bioeconomy, clean energy, waste transformation, innovation systems, product design and sustainability of biobased systems. QUT also owns and operates the Mackay Renewable Biocommodities Pilot Plant – a unique publicly available facility for demonstration of bioenergy and biorefinery processes at the pilot scale. As part of our commitment to the development of sustainable bioenergy and biobased products sector, QUT has contributed to, and commissioned, the development of several key reports in this industry and two of these reports are included in our submission (Attachment 1 - Biofuels to bioproducts, 2018 and Attachment 2 - Economic impact of a future tropical biorefinery industry in Queensland, 2014).

While the ARENA bioenergy roadmap has a primary focus on bioenergy systems, we believe that this roadmap should be expanded to a 'Bioeconomy Roadmap' for Australia – to ensure that Australia has a focus and strategy for development of a broad range of both bioenergy and higher value bio-based products that will create new low carbon, sustainable, knowledge intensive and economically valuable industries of the future. Many countries around the world have, or are developing, bioeconomy strategies (GBS 2018; Figure 1) and it is critical that Australia does not get left behind in the development of this important industry.

Figure 1: Bioeconomy policies around the world (GBS 2018)

It is notable that development of the bioeconomy is important to making progress to over half of the UN sustainable development goals (Figure 2). While contributing to this global agenda, the development of a bioeconomy in Australia, including bioenergy industries, will offer many local benefits including creating regional employment, stronger regional communities and more profitable agricultural enterprises in Australia while enhancing energy security and growing our low carbon economy.

Figure 2: Contribution of the bioeconomy to the UN sustainable development goals (El Chichakli 2016)

The development of **sustainable** bioeconomy and bioenergy industries is critical to the long-term commercial growth and viability of the sector. For this reason, we support the principles outlined in the communique of the Global Bioeconomy Summit[1] and that the roadmap should be founded on bioeconomy development principles that include:

1. Responds to societies aspirations for sustainable development;
2. Based on the needs and opportunities for valorisation **and** protection of bio-resources;
3. Fostered by knowledge, science and innovation; and
4. Good governance supporting sustainable bioeconomy development.

This submission highlights some of the market and technology opportunities, industry benefits and policy options required to support and grow Australia’s bioenergy and bioeconomy industries.

[1] https://gbs2018.com/fileadmin/gbs2018/Downloads/GBS_2018_Communique.pdf

MARKETS AND TECHNOLOGY: The growing global bioeconomy is creating new economic opportunities

While bioenergy and the bioeconomy have been rapidly developing over the past decade, these industries offer a major platform for Australia's post-COVID economic recovery, with a diverse array of lucrative and sustainable opportunities for innovation-led industry development. Australia has a competitive advantage with our technologically advanced agricultural sector and a large amount of biomass available, which represents a significant economic growth opportunity for Australia and offers numerous benefits (Figure 3).

Figure 3: Benefits to Australia of growing biofuels and bioproducts industries. (Source: O'Hara, Robins, Melssen. Biofuels to Bioproducts. 2018)

Bioenergy is not only valuable for energy security, but it also serves as an important base to grow a broader bioeconomy value chain (Figure 4). Bioenergy production is generally closely located with areas of biomass production and manufacturing facilities to capitalise on waste streams which can be transformed into power, heat, fuels, materials or chemicals. Creating biorefineries that can respond to changing market forces to sustain production as well as produce higher value, lower volume products will drive economic viability.

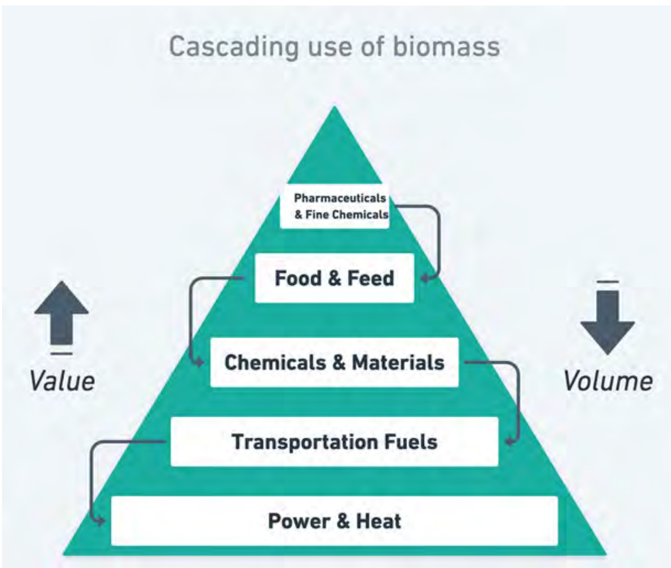

Figure 4: Cascading use of biomass value and volume in the bioeconomy (Image credit: Dr Valeri Natanelov, Postdoctoral Research Fellow, QUT).

Side products containing organic residues which can be used as fertilisers to regrow biomass or a feedstock for another product (e.g. feed, fibre, chemicals) will contribute to developing Australia's circular economy. Monetising waste turns a liability into a valuable feedstock (see for example the QUT-led 'Wastes to Profits' project that is developing technologies to valorise wastes and co-products from Australia's livestock industries (https://research.qut.edu.au/biorefining/projects/wastes-to-profits/)).

By bringing together and growing connections between research, government, industry and markets, Australia can attract large scale, international investors to establish in Australia and, in turn, grow domestic biomanufacturing capability.

Energy security: Bioenergy will play an important role in the transition to, and future of, sustainable energy supply and security in Australia and globally. Given our reliance on imports and low amounts of stored fuel coupled with international trade impacts from global events, such as the Covid-19 pandemic, bioenergy offers security to the national energy supply. Coal fired power stations in Australia are aging and, in the next 20 years, many will be decommissioned. While there is significant investment underway in renewable solar and wind electricity, bioenergy offers opportunities for dispatchable and baseload power to support the network in this energy transition and beyond.

The International Energy Agency Renewables 2018 report (IEA 2018) notes that in 2017, modern bioenergy contributed half of all global renewable energy consumption which was four-times the contribution of solar and wind energy combined. Bioenergy was also forecast to lead growth in renewable energy consumption over the period 2018-2023. In electricity production, on a global basis, bioenergy is growing at 6-8% p.a. maintaining long term growth rates. In renewable transportation fuels, biofuels account for 97% of renewable transportation fuels currently used globally with global production forecast to increase 25% over the next 5 years (pre-COVID forecasts).

Biofuels and electric vehicles are expected to emerge as complementary renewable fuel transportation options over the next several decades (IEA 2018). Biofuels are likely to continue to be the dominant renewable transportation fuel source for several decades with liquid and gaseous fuels vehicles (including hybrids) expected to continue to account for over 75% of the global light duty vehicle stock in 2050 (EIA 2019). Biofuels remain the only viable renewable fuel transportation option for the hard to decarbonise sectors or heavy transport, marine and aviation.

In the short term, bioenergy can support the transition of coal-based power generation through biomass co-firing. Regional production of biogas will also be valuable in behind the meter electricity generation, biogas to CNG networks, as a transportation fuel (i.e. for passenger vehicles, medium and long-haul trucks, rail, off road, aviation and maritime). QUT, through the support of ARENA is currently undertaking a demonstration trial of the production of biogas-produced biomethane for use as a transportation fuel in Australia (https://research.qut.edu.au/biorefining/projects/biogas-from-sugarcane/).

Bioenergy can also play an important role as a baseload and dispatchable power resource and, in doing so, support hydrogen industry development. For some scenarios, feedstock is already at a central location, with available waste thermal energy to assist in refinement (E.g. ARENA project Hydrogen Process Research & Development - https://arena.gov.au/projects/qut-hydrogen-process-research-and-development/.)

Decarbonisation of energy supply: Bioenergy will contribute to decarbonising the industrial and transportation sectors and strengthen Australia's liquid fuel security. The organic component of bioenergy is effectively carbon neutral, utilising carbon from the atmosphere to produce organic matter which can then be converted into energy whether through combustion, gasification, fermentation, transesterification, pyrolysis and anaerobic digestions. The capacity for bioenergy 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 lignocellulosic feedstocks and sugar from sugarcane may generate energy savings up to 75% and 80% respectively (Deloitte and Corelli 2014).

> **Transport fuels**: Coordinating the production of fuels that can be produced from several different supply routes, which is preferably liquid at standard pressure and temperature, and capable of being utilised in a range of different engines (fuel cells, combustion engines, etc.) will underpin the bioenergy economy and market uptake.
>
> **Thermal energy**: Heat generated from bioenergy production can be used to deliver the thermal energy required in places like food processing facilities, abattoirs and dairy producers (all of whom need steam and hot water for their manufacturing); commercial glasshouses, hospitals and aquatic centres (for space and water heating); and industrial manufacturers such as plywood and MDF manufacturers, and cement producers.

Bioenergy supply chains: In developing the bioenergy sector, the associated supply chains will require a high level of inherent flexibility and resilience (Figure 5). The processing technologies which are impacted by the specific biomass composition, volume, and timing/transport/proximity requirements need to be considered for the type of energy supply. This, in addition to weather uncertainty, biomass perishability and potential competing usage, requires a systematic approach to building the bioenergy supply chain.

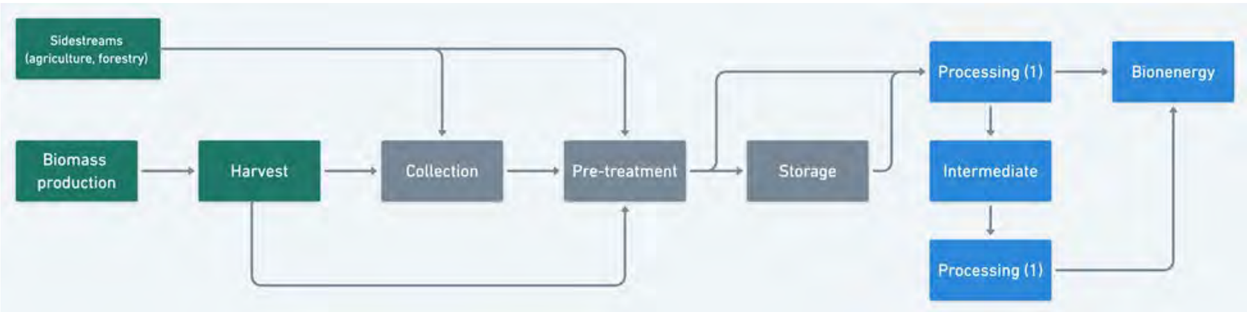

Figure 5: Schematic of a simplified bioenergy supply chain. The arrows are indicative of both transport requirements and the interdependencies between different steps. Image credit: Dr Valeri Natanelov, Postdoctoral Research Fellow, QUT).

RESOURCES: There are a range of potential sources of biomass for future biofuels production

Australia has the advantage of having access to a great diversity of resources which can be used for producing energy, fuels and materials. This offers the benefit of increased resilience in times of crisis, market shocks, and shifting trade arrangements, and a greater potential to distribute economic benefits across sectors and geographic regions.

Crops: Potential sources of biomass for future bioenergy and bioproducts (including future food, feed and fuel products) include low-grade and surplus crop products, such as low-grade wheat and sorghum, molasses and low-grade vegetable oils from oilseed crops. There are several new agricultural crops that offer significant potential, including for biofuel production from lower-quality agricultural land, including crops like *Agave tequilana* (blue agave), sweet sorghum, energy grasses, and short-rotation forestry crops.

A competitive advantage for Australia is our existing and robust sugarcane growing and processing industry and its associated physical and knowledge infrastructure. Sugarcane is one of the best performing biomass feedstocks for bioproduction in terms of fossil energy ratios (FER) (MJ out/MJ in) and greenhouse gas (GHG) abatement (de Vries, van de Ven et al. 2010; Hoefnagels, Smeets et al. 2010; Wang, Han et al. 2012).

Value-adding waste streams: Crop residues, agricultural waste, including stover, sugarcane bagasse, cane trash, grape marc and other horticultural residues, and forestry residues, can be used to produce second-generation biofuels such as bioethanol (O'Hara et al. 2018).

Increasingly, organic wastes such as municipal solid wastes and food wastes are also emerging as feedstocks for the production of bioenergy, biofuels and bioproducts. These sources of biomass are waste residues or by-products of farming in the northern, southern and western grain regions of the states of Queensland, Victoria, New South Wales, South Australia and Western Australia, and in the western, eastern and southern high-rainfall regions in Western Australia, South Australia, Queensland, New South Wales, Victoria and Tasmania (Figure 6). Establishing biorefineries to produce biofuels and bioproducts will create new income streams for farming communities in these regional areas (Herr et al. 2012).

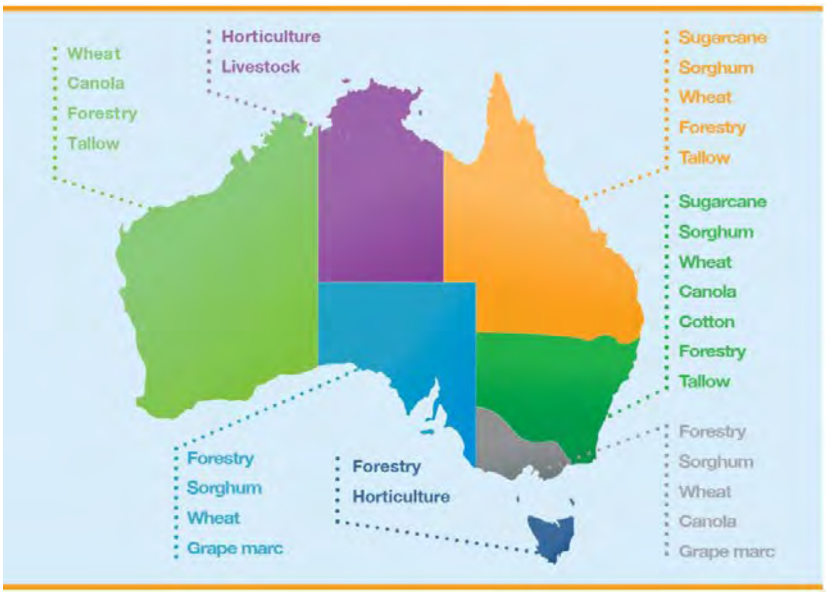

Figure 6: Industries with waste residues and by-products for biofuels and bio-based products (Source: O'Hara et al. 2018)

Associated bioproducts can also produce chemicals for use in fibres for clothing, detergents, oils and other products. This delivers economic benefits to resources that would generally be considered as end-of-life products and can contribute towards a reduction in landfill and other waste product storage. Incorporating these co-products into the supply chain will enhance the economic feasibility of bioenergy production.

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 (Deloitte and Corelli 2014).

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 (Deloitte and Corelli 2014).

Environmental impacts: In relation to the dedicated agricultural production of biomass feedstock for bioenergy feedstock, there is a very mature body of research and knowledge about the environmental impacts of agricultural crops and changes agricultural systems.

In particular, the environmental life cycle assessment (LCA) community in Australia has been very active in the development of LCA methods and data specifically for agricultural systems over the last decade. This has resulted in the Australian Life Cycle Inventory (AusLCI) (http://auslci.com.au/), which compile datasets and methods needed to conduct agricultural LCAs, and which has facilitated a large body of LCA for Australian agricultural crops (Renouf, Wegener et al. 2010; Cowie, Eckard et al. 2012; Eady, Grant et al. 2013; Eady, Grant et al. 2014; Grant, Cruypenninck et al. 2014; Grant, Eady et al. 2014; Renouf, Eady et al. 2014). However, a consolidation of this past research is needed to gain a clearer picture of the potential scale of environmental impacts of benefit that may result from the use and / or expansion of agricultural crops for bioenergy.

In relation to the use of agricultural residues for bioenergy, the environmental impacts associated with the feedstock displacement effects need to be considered, i.e., when an agricultural by-product / co-product / waste is diverted from its current use to instead be a bioenergy feedstock. One example is if feedstock is diverted away from use in animal feed formulations, then the animal feed industry will need to source a replacement from elsewhere, which may involve expanded agricultural production of something else, with the associated additional environmental impacts (water use, fertiliser and pesticide pollution to water, etc.). A second example is if agricultural residues which would otherwise stay on the fields are recovered for bio-energy there can be implications for the sustainability of the agricultural production, perhaps leading to more water use, more nitrogen use, more sediment runoff, etc.

Understanding land use implications of expanded agricultural production for bioenergy feedstock, and the associated displacement effects in markets and the economy needs to be properly evaluated. Once land use change and displacement effects are predicted, it would then be possible to evaluate the environmental sustainability of those changes (on land resources, soil health, water scarcity, water pollution, GHG emission), using techniques such as environmental life cycle assessment (LCA), material flow analysis (MFA), environmentally-extended economic input-output (EOI) assessment.

A broad review of sustainable biomass feedstock production (Renouf 2016) using sugarcane-based bioproduction as an example found that the key attributes are:

- use of land with low initial carbon stocks such as degraded land, and that will not displace an existing activity to land with high carbon stocks;
- use of land free of conditions and soil types that are prone to high nitrous oxide (N_2O) emissions;
- crops that can deliver good yields of substrate (i.e., sucrose, cellulose, oil, etc.) on marginal lands to minimise the energy inputs per unit of substrate;
- crops with perennial growing characteristics enabling multiple harvests so that cultivation energy inputs are reduced; and
- low demand for nitrogen (good nitrogen use efficiency) to minimise the embodied emissions of fertilizer production and losses of N_2O.

PUBLIC POLICY: Government policies support the growth of the biofuels industries and the bioeconomy

International policies: Around the world, government policies have been instrumental in supporting and securing feedstock supply, infrastructure and logistics; promoting access to technology and early-stage investment support; and improving demand (O'Hara et al. 2018).

Given the significant benefits resulting from the development of biofuels and bioproduct industries and the use of these products, many countries have implemented policy frameworks supporting the growth of these industries. Biofuel blending mandates are in effect in more than 64 countries around the world, including the USA, Canada, Europe, India, China, the Philippines, and Thailand (for more detail, see Biofuels to Bioproducts, O'Hara et al. 2018 pp. 24-29; Figure 7). Australia is yet to have a national mandate supporting the inclusion of biofuels in petrol or diesel products sold in Australia. In the absence of a national biofuels mandate in Australia, several states have introduced policy measures to support the growth of the biofuels and bio-based products sectors (for more detail, see Biofuels to Bioproducts, O'Hara et al. 2018 p. 31).

One effect of a biofuels policy is to build a foundation for a bioeconomy. Infrastructure that supports the production and up-take of biofuels will promote cost reductions through the supply chain that enable further value-adding to produce bio-based chemicals, plastics and biomaterials.

Globally, government policies have been implemented to:

- Support and secure feedstock supply, infrastructure and logistics;
- Promote access to technology and early-stage investment support; and
- Improve demand (e.g. through blending mandates, taxation measures and consumer education).

Detailed information on policies from the USA, Canada, European Union, India, Thailand, China and the Philippines are available in Biofuels to Bioproducts (O'Hara et al. 2018).

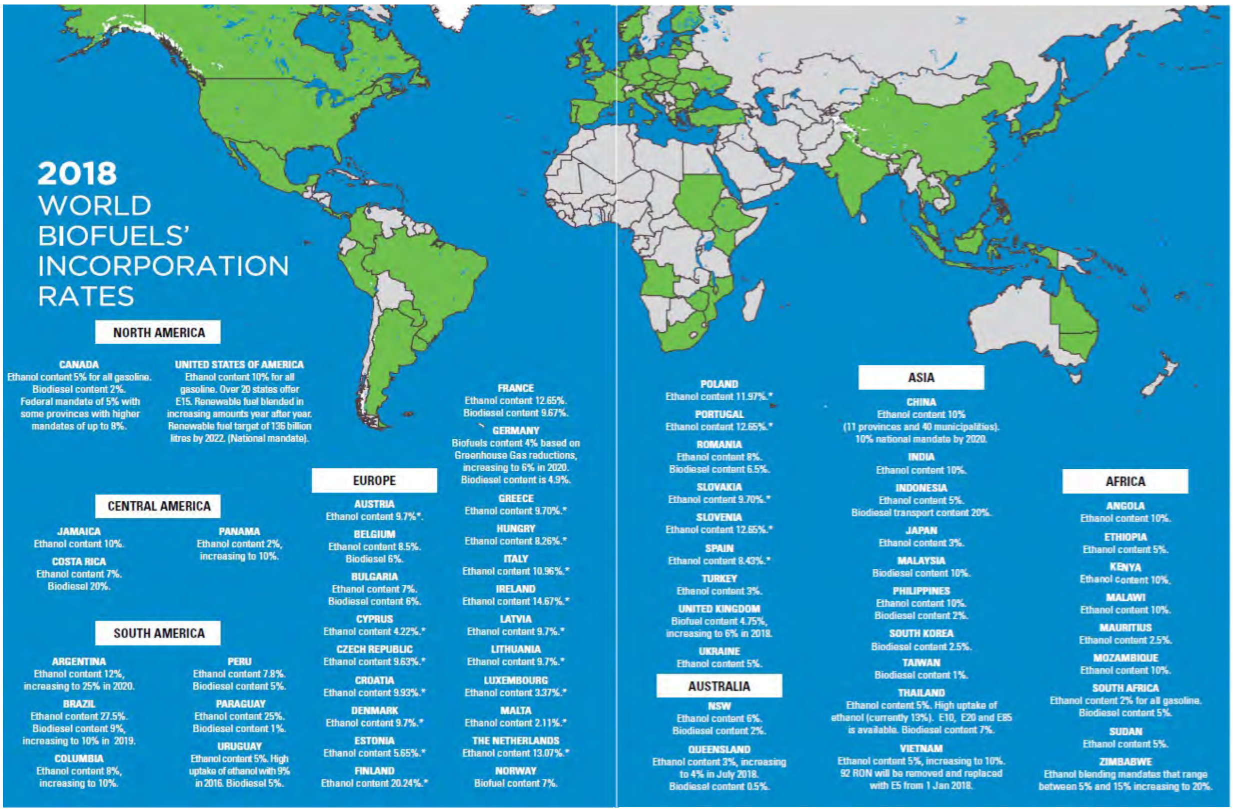

Figure 7: World biofuel incorporation rates 2018 (O'Hara et al. 2018, pp25-26).

The limited growth in Australian biofuels production over the past two decades highlights that the policy environment in Australia has been inadequate, and that a better enabling environment with more effective policy implementation is required.

Policy framework for Australia: Having clear regulatory policies and initiatives designed to support the development of the bioeconomy and, in particular, the bioenergy base will facilitate investment and uptake. In the discussion paper, *Biofuels to Bioproducts* (O'Hara et al. 2018), the authors detailed a five-point plan to establish an enabling policy environment for biofuels and bio-based products in Australia (Figure 8 and summarised below. For more detail, see *Biofuels to Bioproducts*, O'Hara et al. 2018 pp. 33-34).

Figure 8: Five-point plan to create an enabling policy environment for biofuels and bioproducts in Australia (Source: O'Hara, Robins, Melssen. Biofuels to Bioproducts. 2018)

The plan promoted in this report specifically focussed on biofuel policy as a precursor for biobased industry sector development but could be generalised to a wider bioenergy focus. The plan includes:

1: "*Develop a national biofuels, bio-based products and bioeconomy strategy*". The ARENA Bioenergy Roadmap provides a once in a generation opportunity to foreshadow a national bioeconomy strategy for Australia and articulate the vision for the sector, describe the policy implementation (including legislative framework), create ministerial champions, establish departmental facilitation programs, and provide a pathway to implementation through industry growth centres and other supporting structures.

2: Implement a national biofuels mandate supporting the introduction of higher quality fuels. In every jurisdiction where biofuels policy has been successfully implemented, the key policy framework has included a biofuels mandate for bioethanol and bio-based diesel (including biodiesel). A national biofuels mandate (or similar market formation policy measure) will also serve to harmonise biofuels blending and reporting requirements across Australia, minimising the cost to business and ensuring efficient application of biofuels mandates (O'Hara et al. 2018).

3: Provide supporting mechanisms – education, incentives and infrastructure. Effective supply-and-demand side mechanisms are essential in building public support, through the establishment phase of a biofuels mandate. These mechanisms should include public education and awareness campaigns to increase consumer understanding of the benefits of biofuels and excise incentives towards reducing the cost of ethanol-enhanced fuels at the pump.

To assist with the implementation of a mandate, it is critical to ensure the establishment of infrastructure required for blending and distribution of biofuels. At the wholesale level, this will require the widespread availability of biofuels-blending infrastructure. In addition to fuel infrastructure, incentivising or regulating vehicle manufacturers to place flex-fuel vehicles (capable of utilising varying and high-ethanol blends) into the vehicle market will help to create the vehicle capability for higher biofuel blends in the future.

4: Establish policy frameworks to grow new industries – advanced and drop-in biofuels, biochemicals and bio-based products. These will support Australia to join other countries at the forefront in creating low-carbon industries with global market potential. One of the most significant policy measures to increase the adoption of advanced and drop-in biofuels for aviation, military, marine and other markets would be the creation of a clean (or low-carbon) fuel standard, such as that introduced in California and proposed for Canada.

Likewise, the introduction of biochemical and bioproduct incentive programs, supporting the creation of manufacturing capacity in biochemicals and bio-based products, will assist in creating regional industries for markets beyond the fuels sector.

5: Support commercial developments through industry and research collaboration. Industry and research collaboration is essential in building the technical, economic and human capacity to grow the biofuels and bio-based products sector.

Governments have the ability to enhance collaboration through focusing existing and new funding programs on this sector. Providing collaboration opportunities through ARENA, Cooperative Research Centres, Australian Research Council and other programs with industry growth centres will help ensure the benefits of the biofuels and bio-based products sectors can be realised.

Energy from waste: In order to capitalise on negative cost feedstocks, consistency of regulation of beneficial reuse and end of use codes for organic residues and wastes and increase investor confidence. This can be complemented by increased waste levies which will continue to drive companies towards a circular economy. Policies that encourage collaboration between industry sectors across the bioeconomy will also be important. To facilitate this, ease of regulatory approval for contained large scale engineered microorganism use and release of non-viable side products (e.g. treated yeast biomass for animal feed)

SOCIAL LICENCE: develop long-term trust

Studies have shown support for economic benefits, safety, and impact assessments as triggers for social licence. Meaningful, trusting relationships that enable open discussions about risk and benefits alongside an understanding of the context for bioenergy can maximise social licences. Further, how organisations work together may also influence acceptance. In these terms, trust in organisations and people are critical. Trust must be treated in more specific terms, examining its antecedents and its influences, bring it into a more central role. Trust may be the connecting force as social licences change or are re-negotiated.

Highly transparent and objective appraisal of the impacts and benefits of bioenergy across economic, social and environmental dimensions, so that the inevitable trade-offs that emerge between them can be clearly seen and then negotiated, will be crucial for long-term market trust. New bioenergy products and supply chains will need to be underpinned by evaluation of sustainability performance (preferably with quantified metrics) across its three dimensions – economic, environmental and social.

The negotiation of priority bioenergy pathways and sustainability performance standards for bioenergy should be via highly structured and agreed set of values and performance criteria that is co-developed with key stakeholders and the public. This could best occur at the region level (eg. State level) in order to account for the important regional contexts and specificities that would influence values and performance criterial

Evaluation: Methods and data for evaluation and verification of environmental and social safeguards are emerging, internationally and nationally, particularly those based on environmental life cycle assessment (LCA) as well as social LCA. In Australia, the bioenergy industry can be well supported in this regard by the Australian-specific databases for agriculture, namely AusAgLCI (Eady, Grant et al. 2013; Eady, Grant et al. 2014) and methods for environmental impact assessment (Renouf, Grant et al. 2018) that align with internationally recognised methods, but regionalised for Australia.

RESEARCH: The contribution of research to developing Australia's bioeconomy

Research remains critical to the development of sustainable bioeconomy industries in Australia. The roadmap should consider opportunities to better connect industry, government and research organisations to rapidly expand the development of new knowledge and technology innovation to enhance Australia's competitiveness and commercial attractiveness as an investment destination.

Research is integral to developing Australia's bioenergy industries: Continued investment in research is critical to underpin the development of the sector. Focussed support through schemes such as Cooperative Research Centres (CRC), dedicated research funding through ARENA and sponsoring and enabling industry-government-research collaborations will continue to link advances in science and technology as effectively as possible to applications in industry. Enabling end-user driven research partnerships between publicly funded researchers and end-users to address challenges will improve the competitiveness, productivity and sustainability of Australian industries in bioenergy and the broader bioeconomy.

Research facilities for scale up and demonstration: Government investment to develop physical and virtual hubs for collaborative and/or synergistic bioeconomy opportunities across multiple technologies will generate benefit to the sector through the combination of additional knowledge and enhancing work-ready skills. International experience shows that governments can make an important contribution to attracting investment, through developing pilot plants and demonstration sites and facilitating relationships between international companies and domestic industry. Providing access to infrastructure and bringing together researchers and multiple industry partners can bridge the gap for confidence in capital investment which has been an issue for businesses in the bioenergy space. These hubs progress technology integration, and connect markets, consumers and suppliers.

QUT strongly supports the development of a 'Bioeconomy Roadmap' (including bioenergy) for Australia and note again the significant opportunity that the development of sustainable bioeconomy industries offers for Australia.

On behalf of QUT and the Institute for Future Environments, I thank you, again, for providing QUT with the opportunity to contribute to the development of the Bioenergy Roadmap. Should you have any questions regarding this submission please feel free to contact Professor Ian O'Hara (i.ohara@qut.edu.au or (07) 3138 1551).

Yours sincerely,

KaWilson

Professor Kerrie Wilson
Executive Director
Institute for Future Environments

Attachments:

1. Biofuels to bioproducts, 2018
2. Economic impact of a future tropical biorefinery industry in Queensland, 2014

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BIBLIOGRAPHY

Beate El-Chichakli, Joachim von Braun, Christine Lang, Daniel Barben & Jim Philp. Policy: Five cornerstones of a global bioeconomy. Nature 535, 221–223 2016.

Cowie, A., R. Eckard and S. Eady. 2012 Greenhouse gas accounting for inventory, emissions trading and life cycle assessment in the land-based sector: a review. Crop and Pasture Science 63(3): 284-296.

Deloitte Access Economics and Coreli Bio-industry Consulting. 2014 Economic impact of a future tropical biorefinery industry in Queensland pp58

de Vries, S. C., G. W. J. van de Ven, M. K. van Ittersum and K. E. Giller. 2010 Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. Biomass & Bioenergy 34(5): 588-601.

Eady, S., Grant, T., and S. Winter. S. 2013 AusAgLCI – the business case for investment in national lifecycle inventory for Australian agriculture to support industry development and competitiveness. 8th Australian LCA Conference, 16-18th July 2013. Sydney.

Eady, S., T. Grant, H. Cruypenninck, M. Renouf and G. Mata. 2014 AusAgLCI - a Life Cycle Inventory Database for Australian Agriculture, RIRDC Project No PRJ-007363, Publication No 14-045. Canberra. Available at www.rirdc.gov.au/publications, Rural Industries Research and Development Corporation (RIRDC).

EIA (2019). International energy outlook. https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf. Energy Information Agency

GBS 2018. Bioeconomy Policy (Part III) Update report of National Strategies around the World. German Bioeconomy Council. 2018

Grant, T., H. Cruypenninck, S. Eady and G. Mata. 2014 AusAgLCI Methodology for developing life cycle inventory, RIRDC Project No PRJ-007363, Publication No 14-046. Canberra. Available at www.rirdc.gov.au/publications, Rural Industries Research and Development Corporation (RIRDC)

Grant, T., S. Eady and M. A. Renouf. 2014 Development of an Agricultural LCI database. 3rd LCA AgriFood Asia. Bangkok, Thailand, AgiFood Asia Network.

Herr, A., O'Connell, D., Farine, D., Dunlop, M., Crimp, S., Poole, M. 2012 Watching grass grow in Australia: Is there sufficient production potential for a biofuel industry? Biofuels, Bioprod. Bioref., 2012. 6: p. 257 – 268

IEA (2018). *Renewables 2018: Analysis and Forecasts to 2023*.

O'Hara, I.M., Robins, K. Melssen, B. 2018 Biofuels to bioproducts: a growth industry for Australia. QUT Discussion Paper

Oil Change International. Fossil Fuel Subsidies: Overview. 2017; Available from: http://priceofoil.org/fossil-fuel-subsidies/

Patel, A., Koen Meesters, K., den Uil, H., de Jong, E., Blok, K and M. Patel, M. 2012. Sustainability assessment of novel chemical processes at early stage: application to biobased processes. Energy Environ. Sci. 5: 8430-8445

Renouf, M. A. 2016 Greenhouse gas abatement from sugarcane bio-energy, bio-fuels and bio-materials. Sugarcane Based Biofuels and Bioproducts. I. M. O'Hara and S. G. Mundree. Hoboken, New Jersey, John Wiley & Sons: 408.

Renouf, M. A., Eady, Grant, S.T., Grundy, M. and Brandao, M. 2014 Representing soil function in agriculture LCA in the Australian context. LCAFood 2014. R. Schenck and D. Huizenga. San Francisco, USA. 8-10 October, American Centre for Life Cycle Assessment (ACLAS): 1086-1091.

Renouf, M. A., Grant, T., Sevenster, M., Logie, J., Ridoutt, B., Ximenes, Bengtsson J., Cowie, A., and Lane, J.2018 Best Practice Guide for Life Cycle Impact Assessment (LCIA) in Australia. Version 2. www.alcas.asn.au, Australian Life Cycle Assessment Society.

Renouf, M. A., Wegener M.K., and Pagan R.J. 2010 Life cycle assessment of Australian sugarcane production with a focus on sugarcane growing. International Journal of Life Cycle Assessment 15(9): 927-937.

Wang, M., J. Han, J. B. Dunn, H. Cai and A. Elgowainy. 2012 Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. Environmental Research Letters 7(4): Article 045905

Biofuels to bioproducts:
a growth industry for Australia

Discussion Paper | 2018

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Endorsed by:

Contents

Executive summary

With the world production of energy from biofuels and wastes accounting for 10.4 per cent of the total global energy production and the market for bio-based products expected to reach US$1128 billion by 2022, a successful bioeconomy has become a global reality.

The bioeconomy is built upon the use of sustainably derived, low-value feedstocks and wastes to produce high-value bioproducts including biofuels, biomaterials, biochemicals and bioplastics. With a technologically advanced agricultural sector and a large amount of biomass available, the bioeconomy represents a significant economic growth opportunity for Australia.

This discussion paper summarises the status of the biofuels and bioproducts sectors; and describes the opportunity for Australia to grow a bioeconomy – founded on biofuels and expanding to the production of renewable bio-based products that meet consumer expectations on sustainability while also providing job opportunities in regional areas associated with feedstock supply and advanced manufacturing.

The first step in developing a successful bioeconomy in Australia is to build a strong foundation by growing the bioethanol and other biofuels industries. The potential benefits of growing the biofuels and bioproduct industries in Australia are outlined in Figure 1 – Benefits to Australia of growing biofuels and bioproducts industries.

Figure 1 – Benefits to Australia of growing biofuels and bioproducts industries

Biofuels and bioproduct industries create rural jobs and investment.
Growth in the use of 10 per cent ethanol-blended petrol (E10) alone across Australia could:

- **Create 2080 direct jobs and up to 6570 indirect jobs;**
- **Attract A$1.56 billion of investment; and**
- **Generate more than A$1.1 billion of additional revenue per year in regional communities.**

Potential additional farm revenue from biomass-based industries is between A$3.9 billion and A$7.8 billion per year currently, and A$5.7 billion to A$11.4 billion per year in 2050.

Bioethanol is the cleanest alternative for increasing the octane content of petrol.

Biofuels use at up to 10 per cent in petrol and diesel in Australia can reduce total greenhouse gas emissions by 8.9 million tonnes CO_2eq per year.

E10 use reduces vehicle exhaust particulate emissions by 26 per cent, with associated health benefits.

Job-creation, investment and other benefits are significantly enhanced by creating advanced biomanufacturing industries producing biofuels, biochemicals and other value-added bioproducts.

The substitution of 10 per cent of Australia's petrol consumption with domestically produced bioethanol has the potential to improve Australia's balance of trade by about A$1 billion annually and reduce petrol imports by up to 18 per cent.

Around the world, government policies have been instrumental in supporting and securing feedstock supply, infrastructure and logistics; promoting access to technology and early-stage investment support; and improving demand. National strategies have been developed to provide stable political environments and guidance for investors and other relevant stakeholders in the bioeconomy.

Based on the potential benefits to Australia of establishing a successful bioeconomy, a five-point plan has been developed (see Figure 2 – Five-point plan to create an enabling environment for biofuels and bioproducts in Australia).

The development of a vibrant bioeconomy in Australia offers a significant economic growth opportunity that will help diversify Australia's economy and create regional and rural jobs. It is critical that Australia acts now to capture this opportunity.

Figure 2 – Five-point plan to create an enabling policy environment for biofuels and bioproducts in Australia

1. Introduction

Biofuels are transportation fuels produced from renewable, biologically derived materials such as agricultural crops, crop residues, and organic wastes. They differ from traditional fuels such as petrol (gasoline) or diesel, which are produced from non-renewable, fossil-based crude oil. Biofuels are widely used around the world, with large-scale industries established in North and South America, Europe and across Asia.

First-generation biofuels such as ethanol and biodiesel are produced from sources such as starch, sugar, animal fats and vegetable oils. These biofuels have created global supply chains, increased markets, and the technologies for their production are well-established. Second-generation (or advanced) biofuels are typically produced from agricultural, municipal and forestry wastes, and the technologies for these fuels are maturing, with recent commercial-scale developments around the world. Furthermore, recent technology and policy advancements are leading to commercial-scale production of low-oxygen, bio-based drop-in fuels that can be used in the aviation, marine and military sectors.

As both the production and markets for biofuels and bio-based products grow, a bioeconomy is developing which will be a feature of world trade throughout the next decade. The bioeconomy is built upon the utilisation of sustainably derived, low-value feedstocks and wastes to produce high-value bioproducts including biofuels, biomaterials, biochemicals and bioplastics. The bioeconomy will produce products that meet consumer expectations on sustainability, while also providing job opportunities in regional areas associated with feedstock supply and advanced manufacturing technologies.

This discussion paper summarises the status of biofuels and bioproduct technologies and policies; and describes the opportunity for Australia to build a bioeconomy – founded on biofuels and expanding to the production of renewable bio-based products. The development of a vibrant bioeconomy in Australia offers a significant economic growth opportunity that will help diversify Australia's economy and create sustainable regional and rural jobs.

1.1. Biofuels – a global perspective

In 2014, bioenergy accounted for 10.4 per cent of the total global energy demand of 13,700 million tonnes of oil equivalent (Mtoe). Global biofuels production in 2014 was 126 billion litres and has grown at an annual rate of 15 per cent since 2000. Of the total amount of biofuels produced around the world, 62 per cent was bioethanol, 24 per cent biodiesel and 14 per cent advanced biofuels[1].

The United States of America and Brazil account for 70 per cent of the total amount of biofuels produced globally[1] and supply both domestic and export markets. In these countries, biofuel producers operate in established markets, supplying more than 95 billion litres per year. The successful integration of bioethanol into the transportation fuels market in Brazil has been attributed to several factors – affordable ethanol prices, established fuel specifications, accessible ethanol-blended fuel bowsers at petrol stations, and progressive sales of flex-fuel vehicles[2]. In the US, federal and state government programs have promoted biofuels to address issues of energy security, sustainability and regional jobs creation.

In 2005, the European Union (EU) mandated that renewable fuels (including biofuels) make up 10 per cent of total transportation fuels by 2020. Sweden leads the EU countries in renewable energy, particularly in the transport sector, where biofuels make up about 20 per cent of the total fuel market[3]. Most vehicles in Sweden use blended biofuels produced from hydro-treated vegetable oils, fatty acid methyl esters, ethanol and biogas. Nearly all petrol sold in Sweden contains 5 per cent bioethanol[4], which corresponds to about seven million vehicles using 5 per cent ethanol-blended (E5) petrol[2]. In 2011, there were 222,000 flex-fuel vehicles on the road in Sweden[5].

Many countries in Asia are implementing mandates for biofuels and other policy measures to encourage development of the industry[2]. China has mandated E10 and this policy is accelerating the transition to biofuels. Beijing is expecting to complete implementation of this target by 2020[6]. It is predicted that three million tonnes of bioethanol capacity will be added to the Chinese market in 2018. India is proposing to replace 10 per cent to 20 per cent of its petrol with bioethanol.

The development of a vibrant bioeconomy in Australia offers a significant economic growth opportunity that will help diversify Australia's economy and create sustainable regional and rural jobs.

Thailand has a target to replace 25 per cent of fossil fuels used in transportation with biofuels by 2036, with the target driven by the benefits of a bioeconomy[7].

In the next several decades, an increase of electric vehicles into the global passenger vehicle fleet is expected. While challenges remain to be overcome in driving range and recharge time, improvements in technology and cost reduction will see the number of electric passenger cars increase throughout the next several decades. New technologies – such as the Nissan ethanol solid oxide fuel cell[8,9] – use ethanol as a liquid fuel to power fuel cells, resulting in vehicles with similar environmental and health benefits to battery electric vehicles but with a comparable driving range and refuelling time to conventional petrol-fuelled vehicles (see case study 1 – Ethanol fuel cell vehicles). This technology leverages the global petrol station infrastructure that has been built up throughout the past century. However, while electric vehicle use will increase in the passenger fleet, the transition is likely to take several decades. Even with increasing demand, electric vehicles are projected to account for only 8 per cent of the global vehicle fleet by 2040[10].

In addition, biofuels are the only viable low-carbon technology for heavy transport, freight, aviation, defence and shipping applications. Technology has been developed for the conversion of first-generation biofuels (such as ethanol) into jet fuels, and the production route for this has been recently certified for use in commercial aviation. Sectors such as aviation provide large long-term markets and will be a key market opportunity for future biofuels industries in Australia (see case study 2 – Aviation biofuels).

Case study 1 – Ethanol fuel cell vehicles

To power electric vehicles, a fuel cell that uses bioethanol as its source of hydrogen is being developed by Nissan. Nissan is planning to launch this technology to the market in 2020[9].

The electricity is generated by a solid oxide fuel cell system. In this system, hydrogen is produced from bioethanol, stored in the vehicle's fuel tank, through a reformer and then reacted with atmospheric oxygen to produce electricity to charge the car's battery[8].

Conventional fuel cells require pure hydrogen to produce electricity. Hydrogen is expensive to generate and expensive infrastructure is required for storage and fuelling. The use of bioethanol eliminates the need for this investment as it is cheaper to produce, safer to store, and the refuelling infrastructure is already available. Vehicles with solid oxide fuel cell technology will offer comparable driving ranges and refuelling times as conventional petrol vehicles but with similar environmental and health benefits of electric vehicle technology.

Case study 2 – Aviation biofuels

The aviation industry produces approximately 2 per cent of global greenhouse gas emissions. In 2008, the airline industry through the International Air Transport Association (IATA) agreed on emissions control targets for the sector, including carbon-neutral growth from 2020 and a 50 per cent reduction in carbon emissions by 2050 (compared to a 2005 baseline). It was considered that these targets would be attainable with the design and manufacture of fuel-efficient aircraft and engines, and the use of sustainable aviation biofuels[11].

There are currently five aviation biofuel production routes certified for use in commercial aircraft. The most recently certified production route uses a technology that converts alcohols into jet fuel (known as alcohol-to-jet technology)[12].

Major airlines and airports are also taking definitive steps to support the transition to aviation biofuels. Over twenty-two airlines have flown more than 100,00 commercial flights with aviation biofuels since the first certified biofuels were produced. Refuelling with aviation biofuels at Oslo Airport in Norway began in January 2016. In the US in March 2016, United Airlines became the first commercial airline to commence daily flights from Los Angeles International Airport using aviation biofuels[13].

In Australia, Qantas undertook a test flight on aviation biofuels in April 2012, flying an Airbus A330 from Sydney to Adelaide[14]. In March 2016, Virgin Australia and Air New Zealand issued a Request for Information seeking the procurement of aviation biofuels in Australia[15]. In October 2017, Virgin Australia announced a partnership with US based technology company Gevo Inc. to supply alcohol-to-jet derived aviation biofuels through the Brisbane Airport fuel supply system. Also in October 2017, Qantas announced plans to buy 36 million litres of renewable jet fuel from US-based company SG Preston for use in aircraft operating from LA to Australia.

1.2. Biofuels in Australia

In contrast to the US and Brazil, where supportive policy environments have led to sustained growth in biofuels production and consumption over the past several decades, the biofuels industry in Australia has not developed to the same extent. There are currently only three commercial producers of bioethanol in Australia, with five more proposed facilities at varying stages of development (see table 3 – Existing and proposed ethanol plants in Australia). There are several small producers of biodiesel in Victoria, New South Wales, Queensland and Western Australia (see table 4 – Biodiesel plants in Australia).

The largest ethanol producer in Australia is Manildra Ethanol Pty Ltd (Manildra Group), which manufactures ethanol from starch, a by-product of their wheat milling process. There are two other ethanol producers, both based in Queensland: Dalby Bio-Refinery (United Petroleum) and Sarina Distillery (Wilmar BioEthanol (Australia) Pty Ltd), manufacturing ethanol from sorghum and molasses. Other valuable by-products from these milling processes are high-protein animal feeds, fertilisers, and CO2. While the total capacity for ethanol production from these plants is 436 megalitres (ML), the total ethanol production for 2016 was estimated to be about only 250ML[16].

In Australia, the production of biofuels is supported by a mandate in New South Wales that commenced in 2007, and a recently legislated mandate in Queensland that commenced in 2017. As of 2015-16, average nation-wide ethanol blending in petrol stood at 1.1 per cent[17] of the total volume of petrol sold. With the introduction of the mandate in Queensland and recent changes to the mandate framework in NSW, the demand for ethanol-blended petrol in these states is expected to increase.

Biodiesel in Australia is mainly produced from tallow and waste cooking oil, although vegetable oil, poppy seed oil (Tasmania) and palm oil (Northern Territory) have also been used[18]. However, domestic biodiesel demand decreased by 90 per cent in 2016[19] and a large proportion of the biodiesel production was displaced when the largest biodiesel producer in Australia, Australian Renewable Fuels (with production plants in Victoria, South Australia and Western Australia), entered voluntary administration. The company cited the rapid fall in oil prices and increased prices for feedstocks as the main reasons for insolvency[20].

The Queensland Government has made a commitment to a future biofuels and bioproducts industry with the Advance Queensland Biofutures 10-Year Roadmap and Action Plan[21]. This plan outlines the Queensland Government's strategy of working with Queensland's agricultural and waste industries to create a biofutures sector worth A$1 billion by 2026. One of the outcomes of this commitment has been the construction and commissioning of a A$16 million advanced biofuels pilot plant in Gladstone, by Southern Oil Refining Pty Ltd[22]. The plant aims to produce one million litres of advanced biofuels in the next three years, using sugarcane bagasse, other non-food plant biomass, and waste tyres as feedstocks to produce bio-based diesel and aviation fuels. If successful, a A$150 million commercial refinery will be built to produce up to 200 million litres of advanced biofuels per year. These biofuels will be suitable for military, marine, aviation and other heavy transport industries.

Table 3 – Existing and proposed ethanol plants in Australia

Name	Location	Feedstock	Capacity (ML)	Status
Manildra Group	Nowra, NSW	Starch	300	Operational
United Petroleum Dalby Biorefinery	Dalby, Qld	Sorghum	76 (100)*	Operational (Expansion)*
Wilmar Bioethanol	Sarina, Qld	Molasses	60	Operational
Renewable Developments Australia**	Pentland, Qld	Sugarcane	350	Proposed
Dongmun Greentec	Deniliquin, NSW	Wheat	~115	Proposed
Austcane	Mona Park, Qld	Sugarcane	~100	Proposed
North Queensland Bioenergy	Ingham, Qld	Sugarcane	30 – 90	Proposed
MSF Sugar Biorefinery***	Atherton Tableland, Qld	Sugarcane	55	Proposed

Source: [23] except *[24], **[25], ***[24]

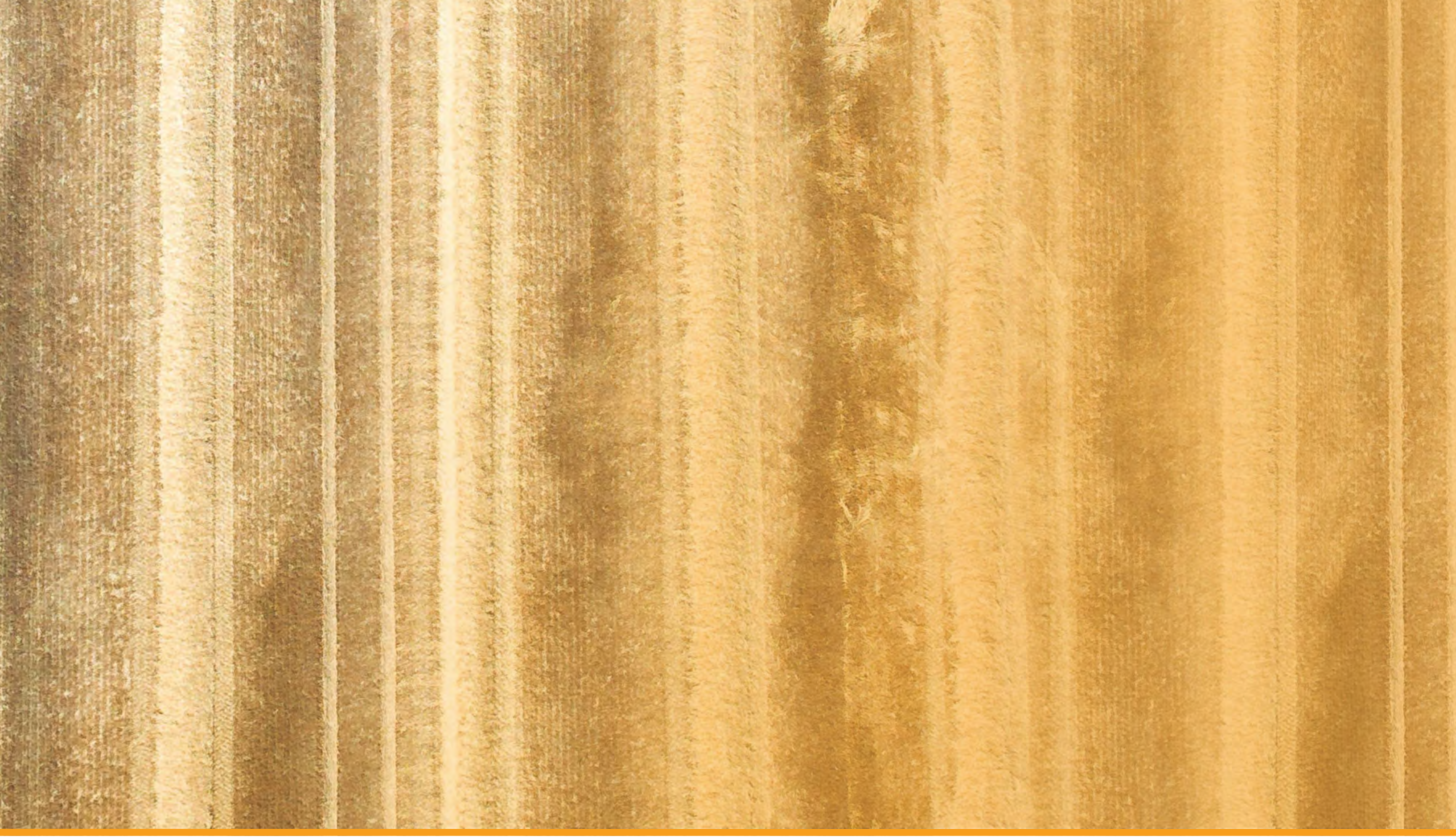
Table 4 – Biodiesel plants in Australia

Name	Location	Feedstock	Capacity (ML)	Status
Biodiesel Industries Australia	Rutherford, NSW	Used cooking oil, vegetable oil	20	Operational
Ecotech Biodiesel	Narangba, Qld	Tallow, used cooking oil	30	Operational
Macquarie Oil	Cressy, Tas	Poppy seed oil, waste vegetable oil	15	Operational
BioWorks	Henderson, WA	Mustard oil	4	Operational
Ecofuels Australia	Echuca, Vic	Canola oil	2	Operational
Australian Renewable Fuels (3 plants)	Barnawartha, Vic, Largo Bay, SA, Picton, NSW	Tallow, used cooking oil	150	In administration

Source: [18]

Figure 3 – Second-generation biorefineries

Source: Novozymes



1.3. Bioproducts – a growing industry

In 2014, the global market for bio-based products was worth US$438 billion and is expected to reach US$1128 billion by 2022[21].

Biorefineries convert biomass and organic wastes into biofuels, bioenergy, biochemicals and other bio-based products using a range of technologies and processes[26] (see Figure 3 – Second-generation biorefineries). Biorefineries are typically located near areas of feedstock production (e.g. agricultural crops) and therefore boost regional economies, create jobs in rural communities, and provide additional income streams for farmers. The development of second-generation technologies is improving process economics by utilising biomass residues, from agriculture and forestry and organic wastes, as lower-cost feedstocks.

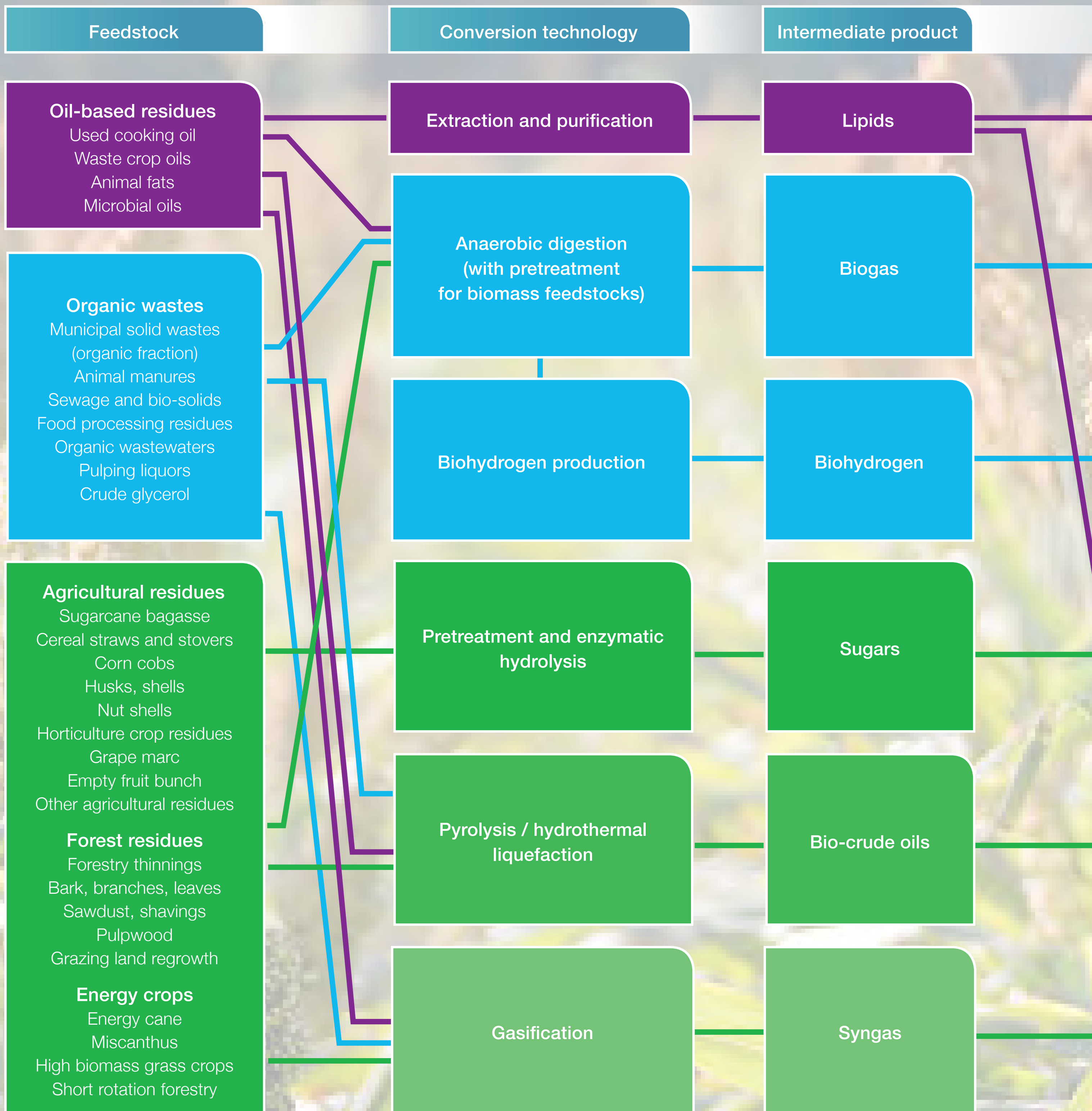
Fibre-rich biomass residues can be processed to produce fermentable sugars, oils, chars and gaseous products. There are many processing technologies that can be used, including enzymatic hydrolysis, anaerobic digestion, and thermochemical routes such as gasification and pyrolysis (see Figure 4 – Technologies for biomass conversion to biofuels). The establishment of second-generation biorefineries, (producing value-added products), benefits from the existing supply chains, infrastructure and skilled employees developed by first-generation biofuel industries. Bioethanol plants provide an excellent platform for the development of biorefineries, as additional unit operations required for new processes can be readily added to the existing plant.

In the past 10 years, large-scale biorefineries have been successfully established in Europe, Northern America and Asia for the production of organic acids such as succinic acid and lactic acid, and other chemicals such as isobutanol, polyethylene and monoethylene glycol.

Amyris is currently developing a biorefinery project in Queensland that will use sugarcane as the feedstock for the production of 23,000 tonnes of farnesene by fermentation[27]. The farnesene will be sold to the growing South East Asian market to produce vitamins, cosmetics and fragrances. Production is expected to start in 2020, with anticipated revenues of between US$60 million and US$80 million (see case study 3 – Amyris).

Other companies are also progressing with the commercial development of bioproduct technologies. Gevo is supplying both the fuels and chemicals sectors with isobutanol produced from corn syrup (see case study 4 – Gevo). Verdezyne is completing its world's first dodecanedioic acid plant in Malaysia, which will use crude palm oil and palm residues as feedstock. CorbionPurac currently produces lactic acid and lactide from sugar and cassava starch in Thailand, and are completing their first poly lactic acid (PLA) plant there. BioAmber is operating a succinic acid plant in Sarnia, Canada, using sugars as feedstock.

Figure 4 – Technologies for biomass conversion to biofuels



Source: Adapted from [26]

Case study 3 – Amyris

Californian-based company Amyris produces trans-β-farnesene (biofene) by fermentation, using sugarcane as the feedstock and a proprietary yeast that is part of their industrial synthetic biology platform.

Biofene is used to produce drop-in fuel replacements including diesel and jet fuel. The biofene-derived jet fuel was successfully tested in 2012 and is certified for blending with Jet A/A-1[28]. Biofene is also used to produce a wide range of other products like cosmetic emollients, fragrances and polymers.

Amyris has built a fermentation plant in partnership with a bioethanol and sugar company in Brotas, Brazil. The plant benefits from the established supply chain, proximity to sugar cane feedstocks, access to energy from the bioethanol plant, and trained personnel.

In 2016, Amyris partnered with Renmatix, Total New Energies USA and the US Department of Energy to commercialise a second-generation fermentation process using wood as a feedstock to produce biofene. Amyris is attempting to reduce the cost of farnesene to less than US$1/L and diversify feedstock sources, allowing production in a variety of rural areas[29].

Amyris has recently announced an intent to build a commercial-scale biorefinery to produce 23,000 tonnes of farnesene from sugarcane in Queensland. The farnesene will supply the growing Asian market with vitamins, cosmetics and fragrances[27].

Case study 4 – Gevo

Colorado company Gevo Inc is an advanced biofuel and renewable chemicals company. Gevo produces isobutanol with Gevo's Integrated Fermentation Technology via fermentation with their proprietary yeast and continuous separation of isobutanol from the fermenter broth during fermentation.

The process can use renewable feedstocks like corn, wheat, sorghum, barley and sugarcane[30]. Isobutanol can be used as a solvent or blended with gasoline to be used as a transportation fuel. It can be processed further to the jet fuel isooctane, and as a starting material for synthetic rubber, plastics and polyester production. The technology is designed to retrofit existing bioethanol plants.

Gevo have leveraged their existing assets by retrofitting a bioethanol plant in Luverne, Minnesota for their first commercial plant. They also produce ethanol and protein-rich animal feed. The capacity of the plant is 18 million litres of isobutanol per year[30]. Since 2011, Gevo has been converting isobutanol to isooctane and alcohol-to-jet synthetic paraffinic kerosene, in Silsbee, Texas[31].

2. The benefits of biofuels and bioproduct industries

The increased production and use of ethanol and other biofuels would contribute to the development of a successful Australian bioeconomy (see figure 5 – Benefits of biofuel and bio-based product industries in Australia).

Figure 5 – Benefits of biofuel and bio-based product industries in Australia

2.1. Creating jobs and investment in regional and rural communities

Around the world, biofuels industries have created jobs and investment in regional and rural communities. In 2015, the US produced 55.7 billion litres of ethanol, which created 85,967 direct jobs and 271,440 indirect and induced jobs, and contributed US$44 billion in gross domestic product (GDP) and US$10 billion in tax revenues[32]. In the European Union (EU), the bioethanol industry generates 70,000 direct and indirect jobs. By 2020, based on current growth projections, employment in the European bioethanol sector could reach up to 205,000 jobs[33]. More broadly, the EU bioeconomy generates revenue of nearly €2 trillion and employs more than 22 million people, accounting for 9 per cent of total employment[34].

Biofuel plants are generally situated close to their feedstocks, as the transportation of feedstocks is quite expensive. In Australia, wheat starch, molasses and sorghum are used for bioethanol production, with facilities located in the regional communities of Nowra in New South Wales and Dalby and Sarina in Queensland. The Wilmar bioethanol distillery in Sarina[35] directly employs 80 people in the bioethanol production process and a further 80 people in the distribution and sales of biofertiliser (dunder, which is a by-product of the molasses ethanol production process)[36].

The construction of a new bioethanol plant in Australia with a capacity of about 100ML would be expected to result in capital investment of about A$120 million and create revenue exceeding A$85 million per year, much of which would be spent on procuring feedstocks, wages for employees, and procurement contracts in local service industries. To produce ethanol at 10 per cent of Australia's total domestic gasoline consumption would require up to 13 additional bioethanol plants of 100ML capacity. Assuming that each bioethanol plant would create 160 new jobs, this growth would create 2080 direct jobs and up to 6570 indirect jobs, require A$1.56 billion of investment, and create more than A$1.1 billion of revenue per year in regional communities.

In 2014, a Deloitte Access Economics and Corelli Consulting report commissioned by Queensland University of Technology (QUT) investigated the potential impact of the establishment of biorefinery industries in Queensland. The study identified that the growth of biorefinery industries in Queensland alone could result in an increase to the Gross State Product of more than A$1.8 billion per year, and the creation of around 6640 jobs, most of which would be in regional communities[37]. The corresponding benefits resulting from growth in biorefinery industries across Australia would be greater.

The investment and job-creation benefits of biofuels have been evidenced in other regions, such as Iowa in the US (see case study 5 – The Iowa experience).

Case study 5 – The Iowa experience

The state of Iowa in the US, with a population of about 3.1 million, has a significant agricultural sector including corn and soybean production. The growth in bioethanol production has brought new revenue, jobs and investment to the state while increasing energy security and reducing motor vehicle particulate emissions.

Iowa produces 27 per cent of total bioethanol produced in the US. Forty-three bioethanol plants (including two cellulosic ethanol plants) produce about 14.35 billion litres of bioethanol annually[38,39]. These plants directly and indirectly employ nearly 47,000 people[40]. The established bioethanol industry in Iowa is providing a strong platform for biomanufacturing industries (biorefineries), which take advantage of the existing bioethanol supply chain for feedstock and can be integrated easily into existing bioethanol plants for the production of value-added advanced biofuels, chemicals, lubricants and nutraceuticals[41].

Cellulosic bioethanol plants allow the use of cheaper agricultural residues as feedstocks and have led to the development in Iowa of new biomass harvesting technologies, which are reducing supply chain costs. Commissioning of a cellulosic ethanol plant in Iowa by POET-DSM began in 2014. This plant has the capacity to produce about 95 million litres of bioethanol annually[42].

The POET-DSM cellulosic ethanol plant was built next to POET's corn ethanol plant, in Emmetsburg, so that energy, land, personnel, feedstock supply, storage and logistics could be shared. Construction of this plant generated about 300 jobs. Currently, 50 employees operate the plant with an additional 60 indirect jobs[42].

According to the Iowa Power Fund study[42], the total 20-year economic output from the POET-DSM cellulosic ethanol plant for Iowa is US$24.4 billion (mid-range scenario), with the creation of up to 13,000 jobs and US$20 million in local agricultural residue contracts annually.

Biodiesel has also had an important impact on the economy of Iowa. Iowa is the leading producer of biodiesel in the US. In 2016, Iowa's nine biodiesel plants produced 1.1 billion litres of biodiesel from tallow, soybean oil, corn oil, canola and used cooking oil[39]. The contribution of biodiesel industry to the GDP of Iowa was US$480 million, and 3800 jobs were created across the economy from biodiesel production[43].

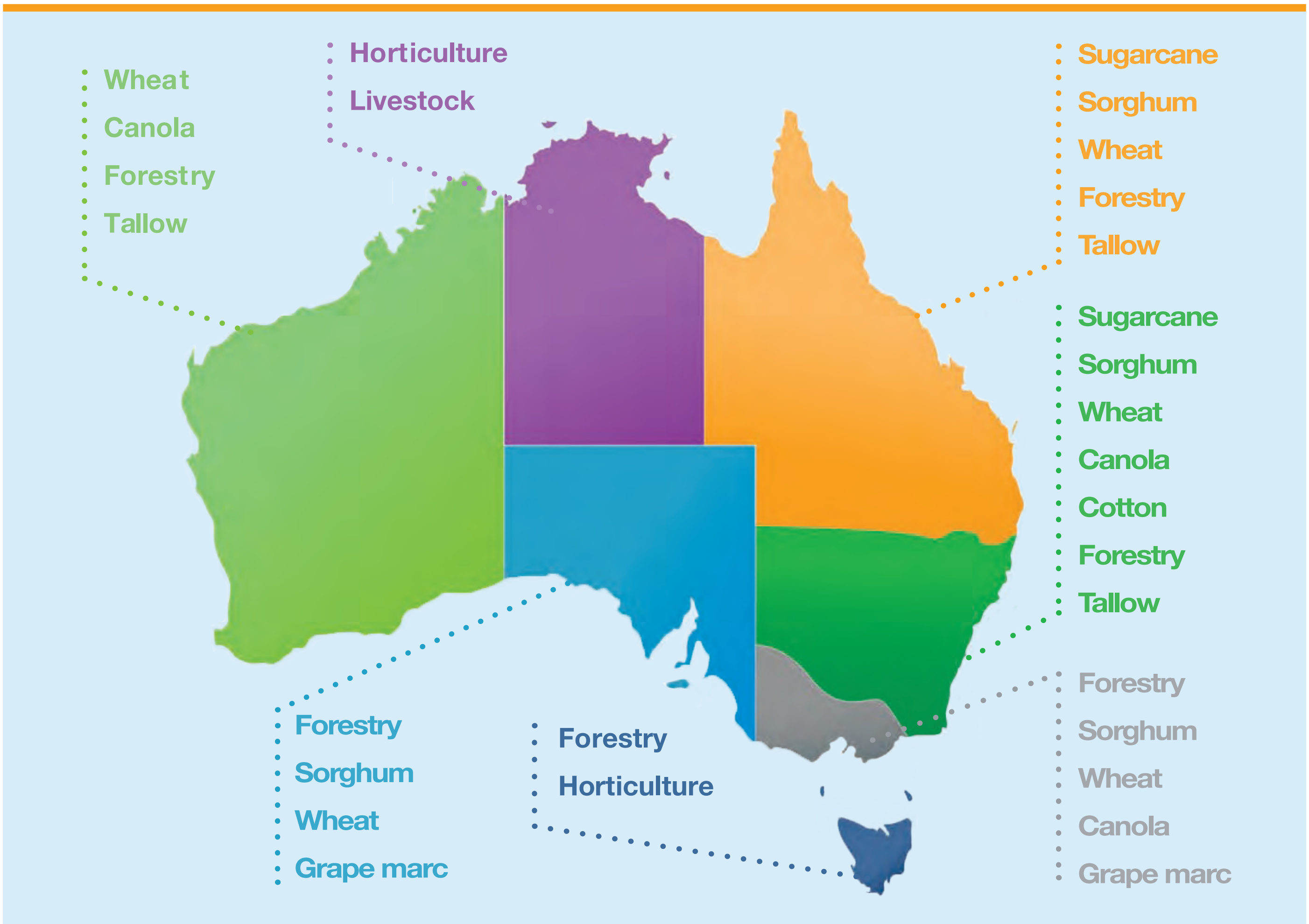
In total, the renewable fuel industry accounts for US$4.7 billion of GDP in Iowa, generates US$2.3 billion of household income, and accounts for 3 per cent of state employment[39].

2.2. Creating additional income streams for farmers

Australia is well-positioned to benefit from the growth of the bio-based fuel and chemical sector due to the large amount of biomass available in Australia. According to a recent CSIRO study[44], the total annual amount of biomass potentially available from all feedstocks in Australia is 78 million tonnes, increasing to almost 100 million tonnes in 2030 and 114 million tonnes in 2050. Assuming an average biomass price of between A$50 per tonne and A$100 per tonne, the potential additional revenue available for biomass is currently between A$3.9 billion and A$7.8 billion, rising to between A$5.7 billion and A$11.4 billion in 2050.

Potential sources of biomass for future biofuels production include low-grade and surplus crop products, such as low-grade wheat and sorghum, molasses and low-grade vegetable oils from oilseed crops. Crop residues including stover, sugarcane bagasse and cane trash, forestry residues, grape marc, and horticultural residues can be used to produce second-generation biofuels such as bioethanol[45] (see Figure 6 – Industries with waste residues and by-products for biofuels and bio-based products).

Figure 6 – Industries with waste residues and by-products for biofuels and bio-based products



There are several new agricultural crops that offer significant potential, including for biofuel production from lower-quality agricultural land, including crops like *Agave tequilana* (blue agave), sweet sorghum, energy grasses, and short-rotation forestry crops. Increasingly, organic wastes such as municipal solid wastes and food wastes are also emerging as feedstocks for the production of biofuels and bioproducts.

These sources of biomass are waste residues or by-products of farming in the northern, southern and western grain regions of the states of Queensland, Victoria, New South Wales, South Australia and Western Australia, and in the western, eastern and southern high-rainfall regions in Western Australia, South Australia, Queensland, New South Wales, Victoria and Tasmania. Establishing biorefineries to produce biofuels and bioproducts will create new income streams for farming communities in these areas[46].

2.3. Improving fuel quality and vehicle performance

The higher the octane number of a fuel, the more compression that the air fuel mixture in an engine can withstand reducing the potential for "knocking" – an effect caused by the premature detonation of the mixture of air and fuel during combustion[47]. The use of higher octane fuels allows for the use of higher compression engines which are more fuel efficient and have reduced emissions. Ethanol, methyl tertiary-butyl ether (MTBE), and some aromatics are added to petrol to increase the octane level. Australian fuel quality standards allow up to 1 per cent by volume of MTBE, 1 per cent di-isopropyl ether and 1 per cent benzene to be present in petrol[48]. However, locally produced ethanol, with an octane rating of 113, provides a cleaner alternative for upgrading the octane content of petrol to the levels required for enhanced engine performance. Unlike ethanol, octane-enhancing additives such as MTBE and aromatics pose a risk to air and water quality and human health. MTBE and aromatics from petrol spills and leaking fuel tanks contaminate and accumulate in groundwater. Ethanol does not readily accumulate in groundwater as it is highly biodegradable, whereas MTBE and aromatics are resistant to biodegradation.

Both the low octane rating and the high sulphur content of Australian unleaded petrol limit the supply of new engine and exhaust emission control technologies into the Australian market. When 10 per cent ethanol is blended with low sulphur, low octane petrol then it is suitable fuel to power low emission, high fuel efficiency vehicles that require 95 RON petrol. This low sulphur E10 would offer a significant price differential for consumers at the bowser while allowing Australia to access the most modern and fuel efficient fleet available globally. The Australian Government's discussion paper Better Fuels for Cleaner Air[47], notes that E10 is currently cheaper than regular unleaded petrol without ethanol. The introduction of an ethanol mandate along with the withdrawal of the high sulphur 91 RON unleaded petrol from sale would result in a substantial improvement in base fuel quality in Australia allowing for the use of the latest engine technologies and resulting in improved fuel efficiency, reduced emissions and health benefits without an increase in fuel cost to the consumer.

2.4. Reducing emissions and improving health

Blending bioethanol or biodiesel with transportation fuels leads to a reduction in greenhouse gas emissions (see table 5 – Conventional transportation fuels greenhouse gas emissions and potential emission reductions with biofuel blends). The full implementation of an Australia-wide E10 and B10 mandate would correspond to a reduction of, respectively, approximately 2.6 million tonnes and 6.3 million tonnes of greenhouse gas emissions per year[48-51]. From a health perspective, ethanol-blended petrol reduces emissions of harmful carcinogenic substances, such as benzene and 1,3-butadiene and polycyclic aromatic hydrocarbons, by between 30 per cent and 70 per cent; and ultrafine particulates (<1μm) by up to 90 per cent[50]. A study undertaken at the Ford Australia node of the Advanced Centre for Automotive Research and Testing concluded that hydrocarbons, NO_x, CO_2 and particulate matter emissions from E10 petrol were, respectively, 15 per cent, 18 per cent, 5 per cent and 26 per cent lower compared to unleaded petrol[52] (see table 6 – Cumulative emissions from a vehicle running on ULP and E10). The beneficial health and health care cost impacts of using ethanol-blended petrol have been principally attributed to reduced particulate emissions from ethanol-blended fuels reducing mortality and morbidity associated with lung cancer, cardiopulmonary disease, chronic obstructive pulmonary disease, asthma and cardiovascular disease[53].

Table 5 – Conventional transportation fuels greenhouse gas (CO_2eq) emissions and potential emission reductions with biofuel blends

Fuel type	*Australian consumption (ML)	Average CO_2 emissions factor (kg of CO_2qe/L)	*Total CO_2 emissions (Mt of CO_2eq/y)	Average CO_2 emissions factor with 10% ethanol / biodiesel (kg of CO_2eq/L)	*Total CO_2 emissions with 10% ethanol / biodiesel (Mt of CO_2eq/y)	Total reduction in CO_2 emissions (Mt of CO_2eq/y)
Petrol	18,240	2.35	43.0	2.09	40.4	2.6
Diesel	26,539	2.72	72.2	2.43	65.9	6.3

Source: Calculated from [48,49], Note: * 2016/17

Table 6 – Cumulative emissions from a vehicle running on ULP and E10

Fuel type	Hydrocarbons (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	Particulate Number (#)
ULP	27.67	260.37	19.19	234.18	1.39 E+11
E10	23.44	259.98	15.78	223.34	1.03 E+11
Average emissions reduction	15%	0%	18%	5%	26%

Source: [52]

In the future, bio-based aviation fuels will contribute to a significant decrease in global CO_2 emissions. World-wide in 2015, 781 million tonnes of CO_2 was produced from flights. Biofuels can decrease the carbon footprint of jet fuel by 80 per cent, based on full life cycle assessment. An overall reduction in CO_2 emissions of 5 per cent can be expected if biofuel replaces 6 per cent of jet fuel by 2020[54].

2.5. Improving Australia's balance of trade

Ethanol production in the US in 2014 reduced the amount of refined petrol imported by 527 million barrels of crude oil — more than the amount of oil the US imported from Saudi Arabia and Kuwait combined[55]. In the same year, the EU imported more than 90 per cent of its crude oil requirements, amounting to €272 billion. In 2014, bioethanol displaced 4.8 per cent of the EU's petrol volumes, saving €1.5 billion.

The value of Australia's total petroleum imports increased to A$24.4 billion in 2015-16, accounting for nearly 10 per cent of the annual value of all imports. In 2015-16, some 55.4 million litres of petroleum products were consumed in Australia compared to domestic production of 25.8 million litres[56]. To meet the shortfall, and accounting for oil and petroleum product exports, Australia imported 52.2 million litres of crude oil and petroleum products (excluding natural gas) at a cost of A$24.4 billion from trading partners including South Korea, Singapore, Japan and Malaysia[17]. Australia's net petroleum imports have increased by 56 per cent in the past seven years (see figure 7 – Australian net petroleum imports (excluding natural gas) and are likely to continue to rise.

Australia's average ethanol blending rate stood at 1.1 per cent of the total volume of petrol sold in 2015-16[17]. As a result, the country offset approximately 180 million litres of petrol imports. By substituting 10 per cent of Australia's petrol imports with ethanol produced domestically, Australia can reduce petrol imports by about 1800 million litres annually, based on the Bureau of Resources and Energy Economics' projection of a 0.7 per cent increase in transport energy consumption[57]. This substitution would reduce imports and improve Australia's balance of trade by about A$1 billion annually.

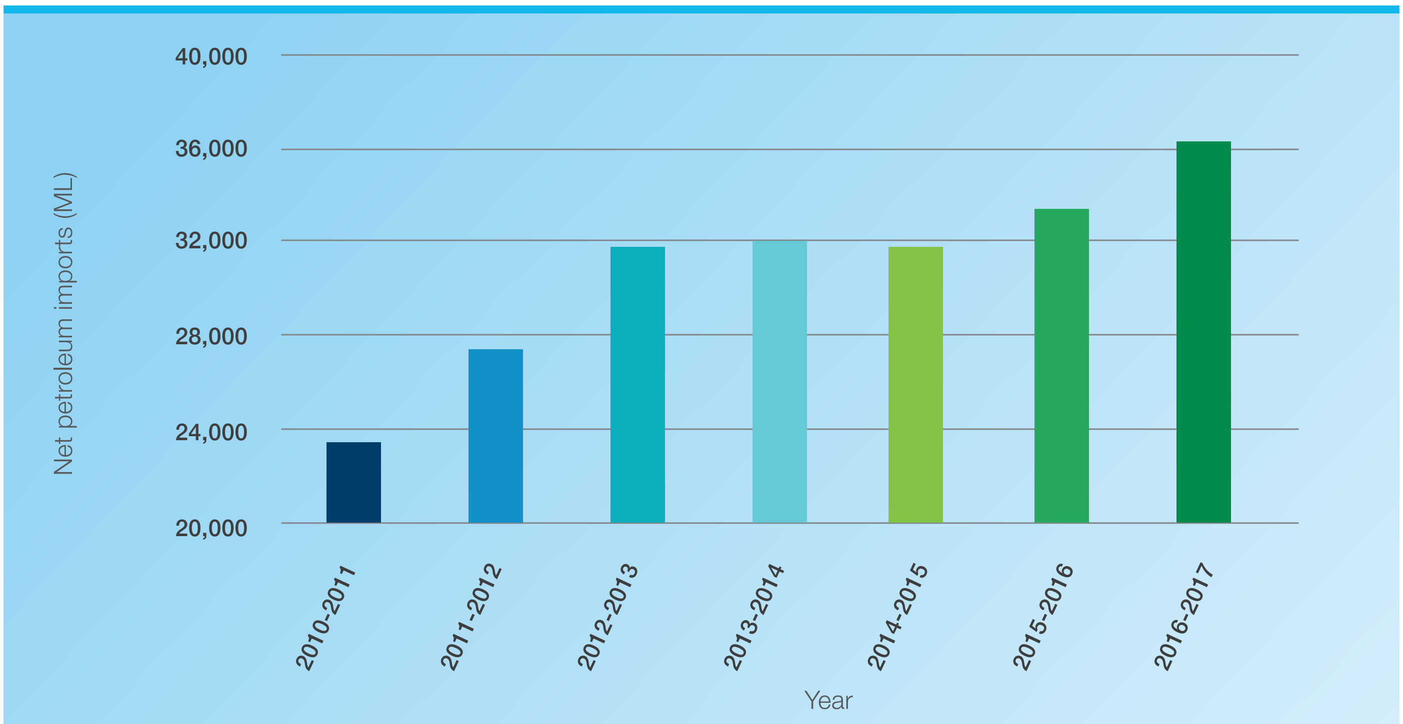
If renewable fuels produced domestically can be used across the petrol, diesel and aviation fuel sectors, an even greater contribution would be made to improving Australia's balance of trade.

2.6. Enhancing energy security

The production of biofuels in Australia can help diversify the sources of transportation fuels and decrease Australia's reliance on petroleum imports. The risks associated with transportation fuel security in Australia were highlighted in a landmark report, Australia's liquid fuel security; commissioned for NRMA Motoring and Services, by Royal Australian Air Force Air Vice-Marshal (Retd) John Blackburn AO[58].

The closure of three of Australia's seven oil refineries (in 2012, 2014 and 2015) reduced the production capacity of refined petroleum products in Australia by 45 per cent[56]. Australia now sources 85 per cent of its refined fuel products from Asia and 58 per cent of its crude oil and feedstocks from the Asia Pacific region[59]. This has increased Australia's vulnerability to potential supply disruption due to geopolitical factors[60].

Figure 7 – Australian net petroleum imports (excluding natural gas)



Source: adapted from [17]

As a member of the International Energy Association (IEA), Australia has a commitment to hold a 90-day fuel reserve in case of disruption to global supply. In 2015, Engineers Australia told a Parliamentary Senate inquiry into transport resilience and sustainability that Australia had two weeks' supply at sea, 5-12 days' supply at the refineries, 10 days' worth of refined stock at the terminals, and three days' worth at service stations – well short of the 90-day stockholding requirement[60].

While the Australian Government has announced plans to add 40 days' worth of fuel reserves, this is estimated to cost several billion dollars and take 10 years to achieve[60]. This also places Australia at a greater supply risk in case of geopolitical tensions or other supply disruptions, while offering a solution that does not contribute to regional job-creation.

The implementation of a nation-wide mandate for 10 per cent ethanol blending in petrol alone could reduce automotive gasoline imports by about 18 per cent annually, and contribute to enhanced domestic fuel security.

2.7. Creating advanced biomanufacturing industries

Biorefineries produce a wide range of products such as fuel, animal feed, food and beverage ingredients, and chemicals.

The successful creation of a bio-based chemicals industry is dependent, in part, on ready access to large quantities of biomass. Australia with its large biomass reserves is well-positioned to benefit from the growth of bio-based fuel and chemical sectors.

The biofuels infrastructure, from the feedstock supply chain to ethanol production, is a critical element for success and provides an excellent foundation for expansion of the existing biofuels plants into biochemicals production. These plants are situated in rural regions near biomass-rich areas, which ensures that rural areas benefit from job-creation and the generation of significant economic growth.

A recent report on the bio-based products sector in the US provided an assessment of the job-creation potential of advanced biomanufacturing industries (see case study 6 – Bio-based products industries in the US).

Case study 6 – Bio-based products industries in the US[61]

The US economy has benefited enormously from the bio-based products industry. The industry has value-added US$393 billion to the US economy and created 4.22 million jobs, primarily in regional areas. Every job in the industry creates 1.76 jobs in other parts of the US economy.

One of the most critical government initiatives driving the success of the bio-based products market in the US is the BioPreferred Program. The program mandates the purchase of bio-based products by federal agencies and their contractors, and supports voluntary labelling of bio-based products with US Department of Agriculture certification (USDA-certified bio-based product labels). The program has defined 97 product categories for some 14,200 products.

Bio-based products are defined as products derived from plants and other renewables. These products are produced by sectors including agriculture and forestry, biorefining, biochemicals, enzymes, bioplastic bottles and packaging, forest products and textiles (excluding the energy, livestock, food, feed and pharmaceutical industries). Bio-based products from the two sectors of forestry products and agriculture and forestry are currently the biggest contributors to the US bioeconomy. Bioproducts in the forestry sector have created almost 1.06 million jobs and directly value-added US$93.3 billion to the economy, while agriculture and forestry sector bioproducts have created 263,500 jobs and directly value-added US$15.8 billion to the economy. Bioproducts in the textiles and bio chemicals sectors have also contributed significantly to the economy, respectively creating 164,370 jobs and a direct value-add of US$9.6 billion, and 17,690 jobs and a direct value-add of US$5 billion. The top five states producing bio-based products are California, North Carolina, Texas, Georgia and Pennsylvania. The bioproducts industry directly employs between 71,000 and 145,000 people in each of these states and contributes between US$6 billion and US$10 billion to each of the local economies.

Bio-based products also benefit the US economy by reducing greenhouse gas emissions. Feedstocks for biorefineries replace a significant proportion of chemical feedstocks traditionally sourced from crude oil refineries. The US bio-based products industry saved approximately 6.8 million barrels of oil and reduced CO_2eq emissions by 10 million metric tonnes in 2014.

3. International policy frameworks for biofuels and bioproducts industry development

3.1. Policy frameworks around the world

Recent studies estimate that traditional oil, gas and coal industries continue to be supported by government subsidies exceeding US$775 billion globally. This estimate does not include the costs of externalities associated with climate change, environmental impacts, military conflicts, and spending and health impacts from fossil fuel production and use[62]. Given the significant benefits resulting from the development of biofuels and bioproduct industries and the use of these products (identified in Section 2), many countries have implemented policy frameworks supporting the growth of these industries.

Biofuel blending mandates are in effect in more than 64 countries around the world, including the US, Canada, Europe, India, China, the Philippines, and Thailand (see figure 8 – World biofuel incorporation rates 2018).

Many of these countries have benefited greatly from the development and growth of biofuels and, in particular, the bioethanol industry.

One effect of a biofuels policy is to build a foundation for a bioeconomy. Infrastructure that supports the production and up-take of biofuels will promote cost reductions through the supply chain that enable further value-adding to produce bio-based chemicals, plastics and biomaterials.

Around the world, government policies have been implemented to:

- Support and secure feedstock supply, infrastructure and logistics;
- Promote access to technology and early-stage investment support; and
- Improve demand (e.g. through blending mandates, taxation measures and consumer education).

3.2. United States of America

The US biofuel framework is underpinned by the Renewable Fuel Standard program, created under the Energy Policy Act of 2005 and further expanded as the Energy Independence and Security Act of 2007[2].

The BioPreferred Program (part of the Agricultural Act of 2014) is designed to increase the market for bio-based products. The two principal parts of the program are a mandatory purchasing requirement for federal agencies and their contractors, and voluntary labelling of bio-based products with a USDA-certified bio-based product label[63].

Several states have sub-national policy measures that operate to support and expand national measures. One important policy measure contributing to the penetration of biofuels into the market is the Californian Low-Carbon Fuel Standard (LCFS), which requires petroleum importers, refiners and wholesalers to increasingly reduce the carbon intensity of petroleum-based fuels by producing low-carbon fuel alternatives or buying credits from companies that produce or sell low-carbon fuels, such as biofuels, electricity, natural gas and hydrogen. The implementation schedule (which began in 2011) requires petroleum fuel producers and importers to reduce the carbon content of their fuels by 0.25 per cent, increasing to a 10 per cent reduction by 2020[64].

3.3. Canada

The Canadian renewable fuel strategy of 2007 (in accordance with a sub-section of the Environmental Protection Act 1999[65]) introduced 5 per cent and 2 per cent national biofuels mandates based on, respectively, volume for gasoline and diesel fuel, and heating distillate oil. Some of the provinces have increased these mandates. For example, Quebec has announced a 2017-2020 Action Plan to increase the mandates from 2020. This action plan is part of the 2030 Energy Policy targeted at reducing Quebec's dependence on fossil fuels by 40 per cent by 2030[66].

The biofuels industry in Canada, which consists of 26 renewable fuel plants, produces 1800 million litres of ethanol and 400 million litres of biodiesel annually, and contributes more than C$3.5 billion to the economy year on year. The industry has created approximately 14,000 direct and indirect jobs and continues to create more than 1000 direct and indirect jobs every year. The return on investment on the government's C$2.2 billion commitment in 2007 will be more than C$3.7 billion. Currently, the use of biofuels reduces greenhouse gas emissions by 4.2 million tonnes, which is equivalent to removing 1 million cars from the roads in Canada every year[67].

2018 WORLD BIOFUELS' INCORPORATION RATES

NORTH AMERICA

CANADA
Ethanol content 5% for all gasoline. Biodiesel content 2%. Federal mandate of 5% with some provinces with higher mandates of up to 8%.

UNITED STATES OF AMERICA
Ethanol content 10% for all gasoline. Over 20 states offer E15. Renewable fuel blended in increasing amounts year after year. Renewable fuel target of 136 billion litres by 2022. (National mandate).

CENTRAL AMERICA

JAMAICA
Ethanol content 10%.

COSTA RICA
Ethanol content 7%. Biodiesel 20%.

PANAMA
Ethanol content 2%, increasing to 10%.

SOUTH AMERICA

ARGENTINA
Ethanol content 12%, increasing to 25% in 2020.

BRAZIL
Ethanol content 27.5%. Biodiesel content 9%, increasing to 10% in 2019.

COLUMBIA
Ethanol content 8%, increasing to 10%.

PERU
Ethanol content 7.8%. Biodiesel content 5%.

PARAGUAY
Ethanol content 25%. Biodiesel content 1%.

URUGUAY
Ethanol content 5%. High uptake of ethanol with 9% in 2016. Biodiesel 5%.

EUROPE

AUSTRIA
Ethanol content 9.7%*.

BELGIUM
Ethanol content 8.5%. Biodiesel 6%.

BULGARIA
Ethanol content 7%. Biodiesel content 6%.

CYPRUS
Ethanol content 4.22%.*

CZECH REPUBLIC
Ethanol content 9.63%.*

CROATIA
Ethanol content 9.93%.*

DENMARK
Ethanol content 9.7%.*

ESTONIA
Ethanol content 5.65%.*

FINLAND
Ethanol content 20.24%.*

FRANCE
Ethanol content 12.65%. Biodiesel content 9.67%.

GERMANY
Biofuels content 4% based on Greenhouse Gas reductions, increasing to 6% in 2020. Biodiesel content is 4.9%.

GREECE
Ethanol content 9.70%.*

HUNGRY
Ethanol content 8.26%.*

ITALY
Ethanol content 10.96%.*

IRELAND
Ethanol content 14.67%.*

LATVIA
Ethanol content 9.7%.*

LITHUANIA
Ethanol content 9.7%.*

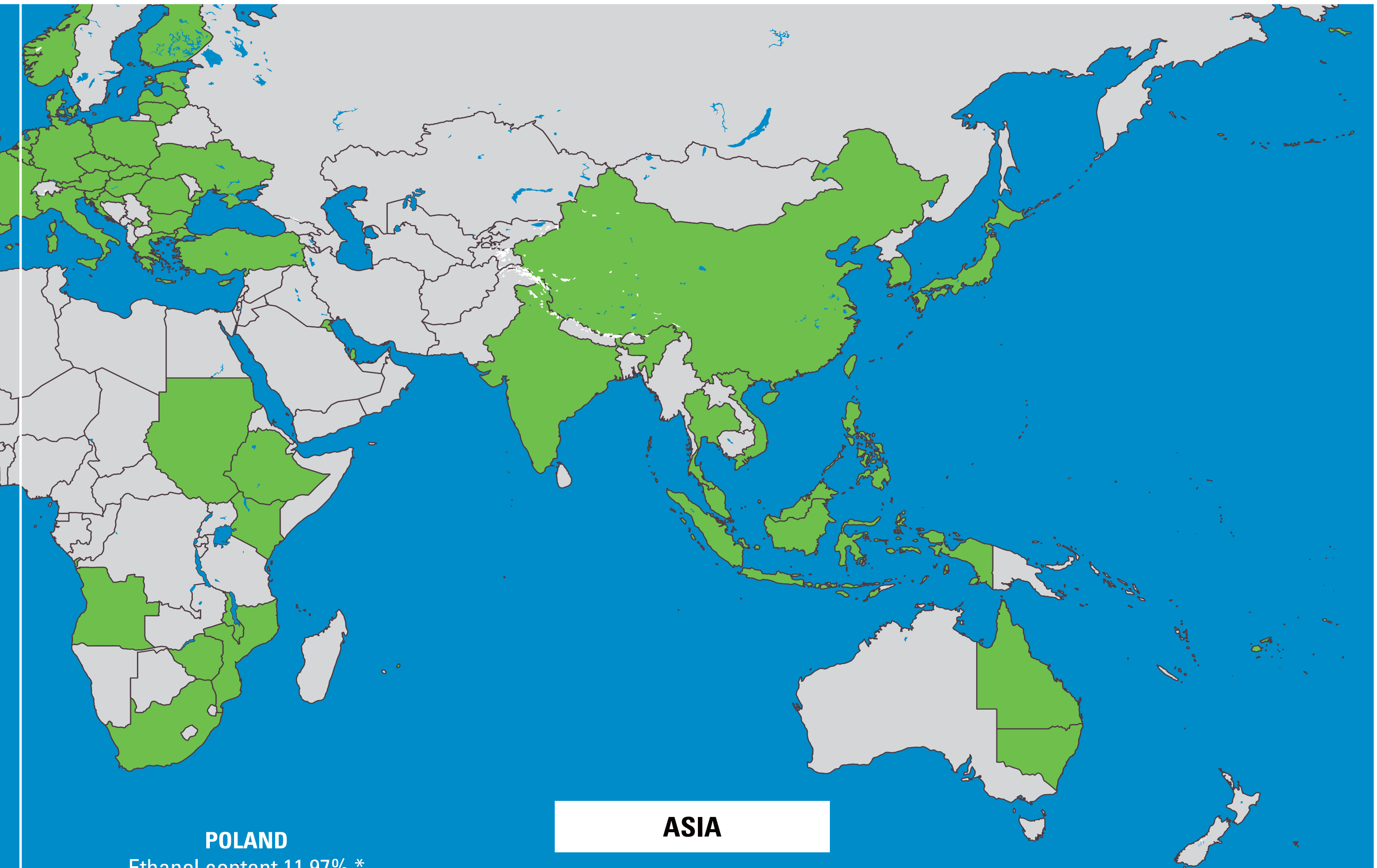
LUXEMBOURG
Ethanol content 3.37%.*

MALTA
Ethanol content 2.11%.*

THE NETHERLANDS
Ethanol content 13.07%.*

NORWAY
Biofuel content 7%.

Figure 8 – World biofuel incorporation rates 2018



POLAND
Ethanol content 11.97%.*

PORTUGAL
Ethanol content 12.65%.*

ROMANIA
Ethanol content 8%.
Biodiesel content 6.5%.

SLOVAKIA
Ethanol content 9.70%.*

SLOVENIA
Ethanol content 12.65%.*

SPAIN
Ethanol content 8.43%.*

TURKEY
Ethanol content 3%.

UNITED KINGDOM
Biofuel content 4.75%, increasing to 6% in 2018.

UKRAINE
Ethanol content 5%.

AUSTRALIA

NSW
Ethanol content 6%.
Biodiesel content 2%.

QUEENSLAND
Ethanol content 3%, increasing to 4% in July 2018.
Biodiesel content 0.5%.

ASIA

CHINA
Ethanol content 10% (11 provinces and 40 municipalities).
10% national mandate by 2020.

INDIA
Ethanol content 10%.

INDONESIA
Ethanol content 5%.
Biodiesel transport content 20%.

JAPAN
Ethanol content 3%.

MALAYSIA
Biodiesel content 10%.

PHILIPPINES
Ethanol content 10%.
Biodiesel content 2%.

SOUTH KOREA
Biodiesel content 2.5%.

TAIWAN
Biodiesel content 1%.

THAILAND
Ethanol content 5%. High uptake of ethanol (currently 13%). E10, E20 and E85 is available. Biodiesel content 7%.

VIETNAM
Ethanol content 5%, increasing to 10%.
92 RON will be removed and replaced with E5 from 1 Jan 2018.

AFRICA

ANGOLA
Ethanol content 10%.

ETHIOPIA
Ethanol content 5%.

KENYA
Ethanol content 10%.

MALAWI
Ethanol content 10%.

MAURITIUS
Ethanol content 2.5%.

MOZAMBIQUE
Ethanol content 10%.

SOUTH AFRICA
Ethanol content 2% for all gasoline.
Biodiesel content 5%.

SUDAN
Ethanol content 5%.

ZIMBABWE
Ethanol blending mandates that range between 5% and 15% increasing to 20%.

Note: Countries with no mandates are in grey

*This can be supplemented with alternate biofuels and within the European mandates, there may be minimum biofuel segmentation volumes.

3.4. European Union

The EU currently has a directive for 5.75 per cent biofuels blending for transportation fuels, which is scheduled to increase to 10 per cent by 2020[2]. The EU directive prescribes sustainability criteria for biofuels, requiring that biofuels must have at least 35 per cent greenhouse gas (GHG) savings compared to fossil fuels. The requirement will rise to 50 per cent in 2018 and 60 per cent for new production plants[68].

The EU produced 5800 million litres of ethanol in 2015 and 5.88 million tonnes of co-products including high-protein animal feed[33]. The bioeconomy in the EU generates revenue of nearly €2 trillion and employs more than 22 million people, accounting for 9 per cent of total employment[34]. The bioethanol industry generates and sustains 70,000 direct and indirect jobs. In 2014, the EU imported more than 90 per cent of its crude oil requirements, amounting to €272 billion. In 2014, EU bioethanol displaced 4.8 per cent of EU's petrol volumes, saving €1.5 billion[33].

The bioeconomy in the EU generates revenue of nearly €2 trillion and employs more than 22 million people, accounting for 9 per cent of total employment[34]

3.5. India

In December 2015, the Indian Government doubled its target of ethanol blending to 10 per cent to promote cleaner-burning fuel[69]. The current government efforts have resulted in a significant rise in ethanol bought from local sugar mills. In the sugar cane season 2015-16, oil marketing companies had contracts to buy 1036 million litres of ethanol, higher than the 5 per cent blending mandate[70].

It is estimated that India's ethanol policy could lead to foreign exchange savings of US$1.7 billion from displaced oil imports[71]. According to a recent report, India currently imports 80 per cent of its crude oil requirements, with oil imports accounting for nearly 32 per cent of total imports[72]. An analysis from Bloomberg found that the country could save about US$19.4 billion a year by replacing petrol imports with ethanol[73].

3.6. Thailand

Thailand's Alternative Energy Development Plan 2015-2036 aimed to increase the share of renewable and alternative energy from biofuel, from 7 per cent of total fuel energy use in 2015 up to 25 per cent in 2036. To accomplish this energy use goal, the government has targeted an increase of ethanol consumption from 1170 million litres in 2015 up to 4100 million litres by 2036[7]. Thailand's highly successful blending program has resulted in the participation of petrol companies in the production of fuel ethanol. Currently, gas stations in Thailand are equipped to supply E10, E15, E20 and E85 blends – with all stations supplying E10, 90 per cent also supplying E20 (approximately 3400 retail outlets), and 26 per cent suppling E85 (about 1000 retail outlets) (calculated from [7, 74]). According to the USDA, the average ethanol blending rate in Thailand stood at 12.1 per cent as of 2015[7].

An analysis of the impact of biofuels on the socio-economic development of Thailand (based on the 15-year Alternative Energy Development Plan target for 2022) showed that employment generation would increase (by an average of 15,900 - 25,500 people per year over 15 years), increase GDP by US$150 million, and result in US$2547 million savings from reduced petroleum fuels imports[75].

3.7. China

China is the largest passenger car market in the world. Until recently, ethanol accounted for only about 2% of petrol consumption in China. In September 2017, the Chinese Government announced plans to introduce an E10 mandate which will result in a dramatic increase in ethanol demand. This announcement is part of a broader policy aimed at environmental improvements[6]. Reuters has estimated, based on industry figures, that investments of more than US$1.5 billion sourced from government, private and foreign investors will flow into the north-eastern corn belt where more than 10 new ethanol plants are planned. It is predicted that most of these plants will commence production next year adding more than 3 million tonnes of bioethanol capacity in 2018. A total of 36 new ethanol plants with a 300,000 tonnes per year capacity equating to an investment of about US$5.5 billion will be required by 2020, to supply the market with the 15 million tonnes of ethanol required to fulfil this mandate

The 150 million tonne gasoline market in China is currently worth about US$4 billion per year. The E10 mandate

The use of biofuels in Canada reduces greenhouse gas emissions by 4.2 million tonnes, which is equivalent to removing 1 million cars from the roads in Canada every year[74].

would offset 15 million tonnes of gasoline imports leading to potential savings of US$400 million per year.

3.8. The Philippines

The Philippines has an E10 ethanol (and a 2 per cent biodiesel) mandate in place, which was fully implemented in 2012 following the successful implementation of the 'Biofuels Act of 2006'[2]. The mandate to use biofuels is a measure designed to develop and utilise indigenous and sustainably sourced renewable energy to reduce the dependence on imported oil, mitigate toxic and greenhouse gas emissions, create rural jobs and income and ensure availability of alternative and renewable clean energy. Another important aspect of the ethanol blending mandate in the Philippines is the replacement of MTBE as an octane booster in petrol.

The Philippines has made big strides in attracting investment and enforcing the mandate. In 2015, the Philippines blended 400,000 tons of ethanol in its fuel and this is expected to double by 2020. According to the Philippines' National Bioethanol Board (NBB), local and foreign direct investments in the sector have grown from US$206 million in 2012 to US$386 million in 2015. The Investments were projected to double to US$770 million in 2016. The bioethanol sector contributes around 6 per cent to the Philippines national GDP. Savings of about US$75 million were realized due to the displacement of fossil fuels with bioethanol in 2014, not counting their environmental contribution of reducing greenhouse gas emissions. According to Regina Martin, NBB Vice-Chairman, "nearly 420,000 hectares of land are planted with sugarcane, benefitting more than 75,000 farmers and more than 700,000 workers, of which 20,000 are working for the bioethanol sector"[76].

It is estimated that India’s ethanol policy could lead to foreign exchange savings of US$1.7 billion from avoided oil imports[71].

4. Developing an enabling policy environment in Australia

4.1. Current policy environment in Australia

Australia is yet to have a national mandate supporting the inclusion of biofuels in petrol or diesel products sold in Australia. Conversely, Australian Government regulations cap the proportion of ethanol that can be added to petrol at 10 per cent, on the basis that petrol containing higher ethanol blends may cause engine problems in some older vehicles. A national fuel quality standard for E85 exists to enable its use in cars that have been specifically built or modified to use this level of ethanol blend[77].

The taxation treatments for bioethanol and biodiesel in Australia are specified in the Excise Tariff Amendment (Taxation of Alternative Fuels) Act 2011 as amended by the Excise Tariff Amendment (Ethanol and Biodiesel) Act 2015. The rates of excise duty for fuel ethanol manufactured domestically commenced at zero, on 1 July 2015, and increase on 1 July of each subsequent year by 6.554 per cent until the final schedule rate of 32.77 per cent of the excise duty rate for petrol is attained in 2020. Imported ethanol will maintain an excise rate equivalent to that of petrol[78].

Biodiesel produced domestically currently receives a concessional rate, which commenced at zero on 1 July 2015 and will increase progressively by 3.33 per cent per year until it reaches 50 per cent on 1 July 2030[78]. Unfortunately, this concessional rate does not apply to renewable or bio-based diesel products such as hydro-processed vegetable oil. Modifications to the excise definitions are required to ensure this concessional rate can be applied to these new products and help stimulate the growth of these products in Australia.

In the absence of a national biofuels mandate in Australia, several states have introduced policy measures to support the growth of the biofuels and bio-based products sectors.

The NSW Government introduced a 2 per cent ethanol mandate in 2007, which was increased to 4 per cent in 2010 and to 6 per cent in 2011[79]. The legislation requires blending of 6 per cent ethanol in petrol by retailers, based on volumes of fuel sold at individual fuel retailers. The mandate increased demand for ethanol-blended petrol significantly in that period. Issues associated with the mandate include the exemption framework which has contributed to demand decline and reduced mandate effectiveness. Currently, the proportion of ethanol use in petrol in NSW is about 2.5 per cent [80]. Recent legislative changes to the mandate framework may see the amount of ethanol use in NSW increase.

The Queensland Government introduced a biofuel mandate from 1 January 2017, to boost the biofuel and biomanufacturing industry sector. The Queensland bio-based petrol mandate requires that 3 per cent of the total volume of regular unleaded petrol sales and ethanol-enhanced fuel sales must be bio-based petrol (ethanol). The legislation further provides that the ethanol mandate will increase to 4 per cent[81].

In 2016, the Queensland Government released the Biofutures 10-Year Roadmap and Action Plan to grow the state's bio-based industries. The plan identified a vision for a A$1 billion sustainable and export-oriented industrial biotechnology and bioproducts sector by 2026[21].

The Australian Government invests through the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC) to improve the competitiveness and increase supply of renewable energy in Australia, and to increase the flow of finance into the clean energy sector. Support is available through these programs for biofuels and bioenergy, however investment in bio-based technologies and deployment has been modest in relation to other renewable energy technologies. There are no dedicated programs for technologies available for non-energy bioproducts and biomaterials technologies.

ARENA is currently supporting the development of a national database of biomass resources for bioenergy across Australia. The A$6.27 million Australian Biomass for Bioenergy Project is supported by the Rural Industries Research Development Corporation and all state governments in Australia. This resource will be a valuable tool for future biofuel and bioproduct industry proponents seeking to develop commercial projects in Australia[82].

The limited growth in Australian biofuels production over the past two decades highlights that the policy environment in Australia has been inadequate, and that a better enabling environment with more effective policy implementation is required.

4.2. A policy framework to create an enabling environment for biofuels and bioproducts industry growth

The following policy measures have been identified as measures to foster an enabling environment for the production of biofuels and bioproducts in Australia. Based on the potential benefits of biofuels and bioproducts industries, the implementation of more effective policy measures is warranted. The following section details a five-point plan to establish an enabling policy environment for biofuels and bio-based products in Australia (see figure 9 – Five-point plan for establishing an enabling policy environment for biofuels and bio-based products in Australia).

Figure 9 – Five-point plan to create an enabling policy environment for biofuels and bioproducts in Australia

1 Develop a national biofuels, bio-based products and bioeconomy strategy

One of the key policy measures to creating an enabling environment is to establish biofuels and bio-based products as a priority growth sector for the Australian economy. This measure can be facilitated through the establishment of a national biofuels, bio-based products and/or bioeconomy strategy for Australia. This strategy would articulate the vision for the sector, describe the policy implementation (including legislative framework), create ministerial champions, establish departmental facilitation programs, and provide a pathway to implementation through industry growth centres and other supporting structures.

2 Implement a national biofuels mandate supporting the introduction of higher quality fuels

In every jurisdiction where biofuels policy has been successfully implemented, the key policy framework has included a biofuels mandate for bioethanol and bio-based diesel (including biodiesel). The biofuels mandates have been supported by long-term goals with increasing annual volumetric requirements, the placement of requirements on obligated parties, reporting conditions, and the establishment of significant penalties for non-compliance. A national biofuels mandate will also serve to harmonise biofuels blending and reporting requirements across Australia, minimising the cost to business and ensuring efficient application of biofuels mandates.

The implementation of a national biofuels mandate will support the adoption of higher quality fuels with a minimum 95 RON (without the use of toxic additives such as MTBE and aromatics) and the phasing out of low octane, high sulphur 91 RON unleaded petrol while not increasing costs to the consumer. This will provide access for Australian consumers to the most modern and fuel efficient fleet available globally reducing fuel use and tailpipe emissions.

3 Provide supporting mechanisms – education, incentives and infrastructure

Effective supply-and-demand side mechanisms are essential in building public support, through the establishment phase of a biofuels mandate. These mechanisms should include public education and awareness campaigns to increase consumer understanding of the benefits of biofuels and excise incentives towards reducing the cost of ethanol-enhanced fuels at the pump. To assist with the implementation of a mandate, it is critical to ensure the establishment of infrastructure required for blending and distribution of biofuels. At the wholesale level, this will require the widespread availability of biofuels-blending infrastructure. At the retail level, the requirement is to ensure that all service stations are equipped with biofuels bowsers and infrastructure necessary to support consumer access to biofuels.

In addition to fuel infrastructure, incentivising or regulating vehicle manufacturers to place flex-fuel vehicles (capable of utilising varying and high-ethanol blends) into the vehicle market will help to create the vehicle capability for higher biofuel blends in the future. Flex-fuel vehicles can utilise ethanol fuel blends from E10 to E85. Establishing a requirement for E85-compatible vehicles in the marketplace provides opportunities for growing the market for ethanol beyond E10 or E15 levels. The long changeover time for vehicles in the national fleet requires that policy mechanisms supporting the introduction of flex-fuel vehicles need to lead the wide-scale use of these higher ethanol blends.

4 Establish policy frameworks to grow new industries – advanced and drop-in biofuels, biochemicals and bio-based products

Through the introduction of policy frameworks supporting the introduction of advanced and drop-in biofuels, biochemicals and bio-based products, Australia can join other countries at the forefront in creating low-carbon industries with global market potential. One of the most significant policy measures to increase the adoption of advanced and drop-in biofuels for aviation, military, marine and other markets would be the creation of a clean (or low-carbon) fuel standard, such as that introduced in California and proposed for Canada. It is critical that Australia recognises and acts on the development and introduction of these technologies.

Likewise, the introduction of biochemical and bioproduct incentive programs, supporting the creation of manufacturing capacity in biochemicals and bio-based products, will assist in creating regional industries for markets beyond the fuels sector.

5 Support commercial developments through industry and research collaboration

Industry and research collaboration is essential in building the technical, economic and human capacity to grow the biofuels and bio-based products sector. Governments have the ability to enhance collaboration through focusing existing and new funding programs on this sector. Providing collaboration opportunities through ARENA, Cooperative Research Centres, Australian Research Council and other programs with industry growth centres will help ensure the benefits of the biofuels and bio-based products sectors can be realised.

5. Conclusions and summary

This discussion paper has summarised the biofuels and bioproduct technologies and policies globally, and highlighted the opportunity for Australia to build a thriving bioeconomy founded on biofuels and renewable, bio-based products. This discussion paper also focuses on the needs for production of biofuels and other bio-based products to meet consumer expectations on sustainability, while also creating job opportunities in regional areas associated with feedstock supply and advanced manufacturing technologies.

Given the investment and policy momentum in other countries, biofuels and bioproduct industries will develop in Australia only with the creation of an enabling environment. This paper has highlighted a five-point plan, which will lead to substantial growth in these sectors. The development of a vibrant bioeconomy in Australia offers a significant economic growth opportunity that will assist to diversify Australia's economy and create regional and rural jobs. It is critical that Australia act now to capture this opportunity.

Biofuels and bioproduct industries create rural jobs and investment. Growth in the use of 10 per cent ethanol-blended petrol (E10) alone across Australia could:

Generate more than A$1.1 billion of additional revenue per year in regional communities.

Create 2080 direct jobs

6570 indirect jobs

Attract A$1.56 billion of investment

Potential additional farm revenue from biomass-based industries is between A$3.9 billion and A$7.8 billion per year currently, and A$5.7 billion to A$11.4 billion per year in 2050.

Bioethanol is the cleanest alternative for increasing the octane content of petrol.

Biofuels use at up to 10 per cent in petrol and diesel in Australia can reduce total greenhouse gas emissions by 8.9 million tonnes CO_2eq per year.

E10 use reduces vehicle exhaust particulate emissions by 26 per cent, with associated health benefits.

Job-creation, investment and other benefits are significantly enhanced by creating advanced biomanufacturing industries producing biofuels, biochemicals and other value-added bioproducts.

The substitution of 10 per cent of Australia's petrol consumption with domestically produced bioethanol has the potential to improve Australia's balance of trade by approximately A$1 billion annually and reduce petrol imports by up to 18 per cent.

6. References

1. Shankaar, A.V. *World Bioenergy Association publishes global bioenergy statistics 2016*. 21 June 2016; Available from: http://www.besustainablemagazine.com/cms2/wolrd-bioenergy-association-publishes-global-bioenergy-statistics-2016/.
2. United Nations Conference on Trade and Development. *The state of the biofuels market: Regulatory, Trade and development Perspectives.* September 2014; Available from: http://unctad.org/en/PublicationsLibrary/ditcted2013d8_en.pdf.
3. Andersson, K. *Sweden surpasses 20 percent biofuels in transportation first half of 2017.* 18 August 2017; Available from: https://www.svebio.se/en/press/press-releases/sweden-surpasses-20-percent-biofuels-transportation-first-half-2017/.
4. European Biofuels Technology Platform. *Biofuels in the Sweden.* 2015; Available from: http://www.etipbioenergy.eu/images/EBTP_Factsheet_Sweden_582afadab45bc.pdf.
5. SEKAB. E85 – How Sweden got the most biofuel in Europe. Available from: http://www.sekab.com/sustainability/what-weve-done/e85-how-sweden-got-the-most-biofuel-in-europe/.
6. Reuters. *China set for ethanol binge as Beijing pumps up renewable fuel drive.* 13 Sept 2017; Available from: http://www.reuters.com/article/us-china-biofuels-policy/china-set-for-ethanol-binge-as-beijing-pumps-up-renewable-fuel-drive-idUSKCN1BO17W.
7. Preechajarn, S., and Prasertsri, P. *Thailand Biofuels Annual.* 2016; Available from: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bangkok_Thailand_7-22-2016.pdf.
8. Wong, J. *Nissan developing bio-ethanol fuel-cell for electric vehicles.* 15 June 2016; Available from: http://www.caradvice.com.au/453676/nissan-developing-bio-ethanol-fuel-cell-for-electric-vehicles/.
9. Newman, J. *Ethanol Powers New Fuel-Cell Technology for Nissan* 14 June 2016; Available from: https://www.cars.com/articles/ethanol-powers-new-fuel-cell-technology-for-nissan-1420684800729/.
10. International Energy Agency, *World Energy Outlook.* 2016: Paris, France.
11. IATA. *IATA Sustainable Aviation Fuel Roadmap.* 2015; Available from: http://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf.
12. Haq, Z., and Kostova, B. *Biofuels in Defense and Aviation.* 8 March 2017; Available from: https://energy.gov/sites/prod/files/2017/03/f34/day_3_plenary_haq_aviation_overview.pdf.
13. IATA. *Fact Sheet Alternative Fuels.* Nov 2016; Available from: http://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf.
14. QANTAS. *Creating a sustainable future with aviation biofuels.* Available from: https://www.qantas.com/travel/airlines/sustainable-aviation-fuel/global/en.
15. Australia Aviation. *Air New Zealand, Virgin Australia progress biofuel bid.* 16 March 2017; Available from: http://australianaviation.com.au/2017/03/air-new-zealand-virgin-australia-progress-biofuel-bid/.
16. GAIN. *Australia Biofuels Annual 2016.* 15 July 2016; Available from: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Canberra_Australia_7-15-2016.pdf.
17. Office of the Chief Economist. *Australian Petroleum Statistics.* 2017; Available from: http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Australian-petroleum-statistics.aspx.
18. Biofuels Association of Australia. *Biodiesel in Australia.* 2016; Available from: http://biofuelsassociation.com.au/biofuels/biodiesel/biodiesel-in-australia.
19. APAC Biofuels Consultants. *Australian Biofuels 2017.* April 2017; Available from: http://www.eccoaustralia.com/biofuels.html.
20. Kauppila, I. *Australian Renewable Fuels enters into voluntary administration.* 22 Jan 2016; Available from: http://biofuels-news.com/display_news/10109/Australian_Renewable_Fuels_enters_into_voluntary_administration/.
21. Advance Queensland. *Queensland Biofutures - 10-Year Roadmap and Action Plan.* June 2016; Available from: http://www.statedevelopment.qld.gov.au/resources/plan/biofutures/biofutures-10yr-roadmap-actionplan.pdf.
22. The Queensland Cabinet and Ministerial Directory Queensland Government. *Giant step forward for new biofuels.* 2016; Available from: http://statements.qld.gov.au/Statement/2016/3/29/giant-step-forward-for-new-biofuels-industry-in-queensland.
23. Houston, G., Quach, B., and Turner, S., . *Maximum price for wholesale fuel-grade ethanol.* 2016; Available from: https://www.ipart.nsw.gov.au/files/sharedassets/website/shared-files/pricing-reviews-section-12a-submissions-review-of-a-maximum-price-for-wholesale-ethanol-issues-paper/online_submission_-_manildra_group_-_k._beavon_-_1_aug_2016_200900000.pdf.
24. Minister for State Development and Minister for Natural Resources and Mines. *Media Release: $60M FNQ biorefinery to create 130 jobs.* 10 July 2017; Available from: http://statements.qld.gov.au/Statement/2017/7/10/60m-fnq-biorefinery-to-create-130-jobs.
25. Australian Renewable Energy Agency. *Media Release: ARENA supporting Australia's largest bio-energy project.* 29 April 2016; Available from: https://arena.gov.au/news/arena-supporting-australias-largest-bio-energy-project/.
26. Arup and URS Consortium. *Advanced biofuel feedstocks – An assessment of sustainability.* 2014; Available from: https://lb-net.net/wp-content/uploads/2014/07/feedstock-sustainabilityE4H.pdf.
27. Biofuels Digest. *Two Up: Amyris, Queensland gamble on farneses for SE Asia.* 22 June 2017; Available from: http://www.biofuelsdigest.com/bdigest/2017/06/22/two-up-amyris-queensland-gamble-on-farnesene-for-se-asia/.
28. Biomass Magazine. *Amyris ships first commercial order of Biofene from Brazil plant.* 7 Feb 2013; Available from: http://biomassmagazine.com/articles/8610/amyris-ships-first-commerical-order-of-biofene-from-brazil-plant.
29. World of Chemicals News. *Amyris bags contract to produce cellulose-derived farnesene.* 9 Aug 2016; Available from: http://www.worldofchemicals.com/media/amyris-bags-contract-to-produce-cellulose-derived-farnesene/10276.html.
30. Chemicals-Technology. *Gevo Bio-Based Isobutanol Plant, Luverne, Minnesota, United States of America.* 2017; Available from: http://www.chemicals-technology.com/projects/gevo-isobutanol-plant-minnesota-us/.
31. Johnston, G. *Alcohol to Jet. 2017*; Available from: https://www.icao.int/Meetings/altfuels17/Documents/Glenn%20Johnston%20-%20Gevo.pdf.
32. Renewable Fuel Association. *Fueling A High Octane Future – 2016 Ethanol Industry Outlook.* 2016; Available from: http://www.ethanolrfa.org/wp-content/uploads/2016/02/RFA_2016_full_final.pdf.
33. ePure. *European renewable ethanol industry annual statistics report 2016.* 2016; Available from: http://epure.org/media/1461/160922-press-release-european-renewable-ethanol-industry-annual-statistics-report-2016.pdf.
34. ePure. *European renewable ethanol promotes jobs and growth.* Available from: http://epure.org/media/1125/epure-factsheet-jobs-growth.pdf.
35. Daily Mercury. *Fuelling Mackay's job market into the future.* 3 Sept., 2015; Available from: https://www.dailymercury.com.au/news/fuelling-mackays-job-market-into-the-future/2761731/.
36. Playne, M.J., *Increased digestibility of bagasses by pretreatment with alkalis and steam explosion.* Biotechnology and Bioengineering, 1984. **26**(5): p. 426-433.
37. Deloitte Access Economics Pty Ltd and Corellli. *Economic impact of a future tropical bio-refinery industry in Queensland.* 2014; Available from: https://cms.qut.edu.au/__data/assets/pdf_file/0004/482728/ife-biorefinery-report.pdf.
38. Iowa Corn. *Ethanol plants.* 2017; Available from: http://www.iowacorn.org/corn-uses/ethanol/ethanol-plants.
39. ABF Economics. *Contribution of the renewable fuels industry to the economy of Iowa.* 26 Jan 2017; Available from: http://iowarfa.org/wp-content/uploads/2016/04/2017-Iowa-Economic-Impact-Study.pdf.
40. Iowa Corn. *Iowa Corn 300.* 2017; Available from: http://www.iowacorn.org/corn-uses/ethanol/iowa-corn-300.
41. Biofuels Digest. *The Iowa Renaissance.* 16 March 2017; Available from: www.biofuelsdigest.com/bdigest/2015/03/16/the-iowa-renaissance.
42. Office of Energy Efficiency & Renewable Energy. *POET-DSM: Project Liberty.* Available from: https://www.energy.gov/eere/bioenergy/poet-dsm-project-liberty.

43. Iowa Biodiesel Board. *Economic Impacts of Biodiesel in Iowa 2017;* Available from: http://www.iowabiodiesel.org/en/biodiesel_resources/economic_impacts_of_biodiesel_in_iowa/.

44. Crawford, D.F., et al., *A spatial assessment of potential biomass for bioenergy in Australia in 2010, and possible expansion by 2030 and 2050.* Global Change Biology Bioenergy, 2016. **8**: p. 707-722.

45. CSIRO and Rural Industries Research and Development Corporation. *Biofuels in Australia - an overview of issues and prospects.* 2007; Available from: http://biomassproducer.com.au/wp-content/uploads/2013/11/BiofuelsinAustralia_CSIRO.pdf.

46. Herr, A., et. al., *Watching grass grow in Australia: Is there sufficient production potential for a biofuel industry?* Biofuels, Bioprod. Bioref., 2012. **6**: p. 257 - 268.

47. Australian Government. Better fuel for cleaner air. Discussion paper. December 2016. https://www.environment.gov.au/system/files/consultations/f3f4acc3-f9e6-4cc3-8a1e-a59a6490cffd/files/better-fuel-cleaner-air.pdf

48. Australian Governement Department of the Environment and Energy. *Australian Petroleum Statistics July 2017.* 2017; Available from: http://environment.gov.au/energy/publications/petroleum-statistics-july-2017.

49. Australian Government Department of Environment and Energy. *National Greenhouse Accounts Factors – July 2017.* Available from: https://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/national-greenhouse-accounts-factors-july-2017.

50. *Biofuels Association of Australia. Ethanol and emission reductions.* 2016; Available from: http://biofuelsassociation.com.au/biofuels/biodiesel/effect-of-biodiesel-on-emissions/.

51. *Biofuels Association of Australia. Effect of Biodiesel on emissions.* 2016; Available from: http://biofuelsassociation.com.au/biofuels/biodiesel/effect-of-biodiesel-on-emissions/.

52. *Brear, M. Comparison of emissions and fuel consumption of a passenger vehicle on two fuels.* 2016; Available from: https://www.ipart.nsw.gov.au/files/sharedassets/website/shared-files/pricing-reviews-section-12a-submissions-review-of-a-maximum-price-for-wholesale-ethanol-issues-paper/online_submission_-_manildra_group_-_k._beavon_-_1_aug_2016_200800000.pdf.

53. Orbital and CSIRO, *Evaluating the health impacts of ethanol blended petrol.* 2008, Report to Department of the Environment, Water, Heritage and the Arts.

54. ATAG. *Facts & Figures.* May 2016; Available from: http://www.atag.org/facts-and-figures.html.

55. Renewable Fuel Association. *Fueling a High Octane Future, Ethanol Industry Outlook 2016.* Available from: www.ethanolrfa.org/wp-content/uploads/2016/02/RFA_2016_full_final.pdf.

56. Office of the Chief Economist. *Australian Energy Update 2016.* 2016; Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aes/2016-australian-energy-statistics.pdf.

57. Syed, A. *Australian Energy Projections to 2049 - 50.* November 2014; Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aep/aep-2014-v2.pdf.

58. Blackburn, J. *Australia's liquid fuel security: A report for NRMA Motoring and Services.* 2013; Available from: https://sitwww.mynrma.com.au/about/australias-liquid-fuel-security.htm.

59. Sun, J.X., et al., *Isolation and characterization of cellulose from sugarcane bagasse.* Polymer Degradation and Stability, 2004. **84**(2): p. 331-339.

60. Sutton, M. *Defense White Paper 2016: Dependency on fuel imports 'a risk' amid South China Sea tensions.* 24 Feb 2016; Available from: http://www.abc.net.au/news/2016-02-24/fuel-imports-a-risk-amid-south-china-sea-tensions-nrma-advisor/7149648.

61. United States Department of Agriculture. *An Economic Impact Analysis of the U.S. Biobased Products Industry.* 2016; Available from: https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf.

62. Oil Change International. *Fossil Fuel Subsidies: Overview.* 2017; Available from: http://priceofoil.org/fossil-fuel-subsidies/.

63. U.S. Department of Agriculture. *What is biopreffered.* Available from: https://www.biopreferred.gov/BioPreferred/faces/pages/AboutBioPreferred.xhtml.

64. California Energy Commission. *Low Carbon Fuel Standard.* Available from: http://www.energy.ca.gov/low_carbon_fuel_standard/.

65. Canada, J.L.W. *Renewable Fuels Regulations.* 3 July 2017; Available from: http://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-189/FullText.html.

66. Renewable Industries Canada. *Statement regarding the Quebec Government's 2017 - 2020 Action Plan under the 2030 Energy Policy.* 26 Jun 2017; Available from: http://ricanada.org/statement-regarding-quebec-governments-2017-2020-action-plan-2030-energy-policy/.

67. Canada, R.I. *Driving Canada's low carbon economy.* 2016; Available from: http://ricanada.org/industry/background/.

68. ePure. *Enabling Innovation and Sustainable Development - State of the industry 2015.* 2015; Available from: http://epure.org/media/1215/epure_state_industry2015_web.pdf.

69. Reuters. *India doubles ethanol blending target to help sugar mills.* 2015; Available from: http://in.reuters.com/article/india-ethanol-idINKBN0U51JU20151222.

70. Business Standard. *After 3 years, India to achieve 5% ethanol-petrol blend target.* 2017 14 August 2017]; Available from: http://www.business-standard.com/article/economy-policy/after-3-years-india-to-achieve-5-ethanol-petrol-blend-target-116042000808_1.html.

71. Biofuels Digest. *India set to implement E10 mandate from October, reducing up to $1.7 billion in forex for oil imports.* 2015; Available from: http://www.biofuelsdigest.com/bdigest/2015/08/11/india-set-to-implement-e10-mandate-from-october-reducing-up-to-1-7-billion-in-forex-for-oil-imports/.

72. Deorukhkar, S., Garcia-Herrero, A., and Xia, L.,. *India is becoming key for world energy demand: What are the main opportunities and challenges?* 8 Oct 2014; Available from: https://www.bbvaresearch.com/en/publicaciones/india-is-becoming-key-for-world-energy-demand-what-are-the-main-opportunities-and-challenges/.

73. Bloomberg New Energy Finance. *Next-generation ethanol: What's in it for India.* 2011; Available from: http://www.novozymes.com/en/-/media/Novozymes/en/sustainability/transparency-and-accountability/Documents/bnef-13-05-2011-next-generation-ethanol-in-india.pdf?la=en.

74. PTT, *PTT annual report 2016.* 2016.

75. Kumar, S., Abdul Salam, P., Shrestha, P. and Ackom, E. *An assessment of Thailand's biofuel development.* Sustainability 2013; Available from: https://www.researchgate.net/publication/258052980_An_Assessment_of_Thailand%27s_Biofuel_Development.

76. Biofuels International. *Bioethanol investments in Philippines may double next year*. 12 Aug 2015; Available from: http://biofuels-news.com/display_news/9502/Bioethanol_investments_in_Philippines_may_double_next_year/.

77. 55th Parliament Utilities, S.a.I.C. *Liquid Fuel Supply (Ethanol and Other Biofuels Mandate) Amendment Bill 2015.* Nov 2015; Available from: http://www.parliament.qld.gov.au/documents/tableOffice/TabledPapers/2015/5515T1680.pdf.

78. Australian Taxation Office. *Fuel-Excise: Biofuels.* 2016; Available from: https://www.ato.gov.au/Business/Excise-and-excise-equivalent-goods/Fuel-excise/Biofuels/.

79. Office of the Chief Economist Department of Industry, I.a.S. *Australian Petroleum Statistics.* Sept 2016 242]; Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aps/2016/Australian_Petroleum_Statistics_242_September2016.pdf.

80. Australian Petroleum Statistics: Table 3B August 2017 - Sales of petroleum products by state marketing area

81. Department of Energy and Water Supply. *Queensland biofuel mandate.* 5 July 2017; Available from: https://www.dews.qld.gov.au/biofuels/mandate.

82. ARENA. *National bioenergy database to create new job opportunities.* 7 Jan 2016; Available from: https://arena.gov.au/news/national-bioenergy-database-to-create-new-opportunities/.

Abbreviations

ARENA	Australian Renewable Energy Agency
B10	10 per cent biodiesel-blended diesel
CEFC	Clean Energy Finance Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
E5	5 per cent bioethanol-blended petrol
E10	10 per cent bioethanol-blended petrol
E15	15 per cent bioethanol-blended petrol
E20	20 per cent bioethanol-blended petrol
E85	85 per cent bioethanol-blended petrol
ETBE	ethyl tertiary-butyl ether
EU	European Union
FAME	fatty acid methyl esters
GDP	Gross Domestic Product
HEFA	hydro-processed esters and fatty acids
IATA	International Air Transport Association
IEA	International Energy Association
LCFS	Low-Carbon Fuel Standard
MTBE	methyl tertiary-butyl ether
NO_x	nitrous oxides
PLA	poly lactic acid
QUT	Queensland University of Technology
US$	American dollars
ULP	unleaded petrol
USDA	US Department of Agriculture

Units

CO_2eq	carbon dioxide equivalent
g	grams
kg	kilograms
km	kilometres
L	litres
mg	milligrams
ML	megalitres
Mt	megatonnes
Mtoe	million tonnes of oil equivalent
y	year

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

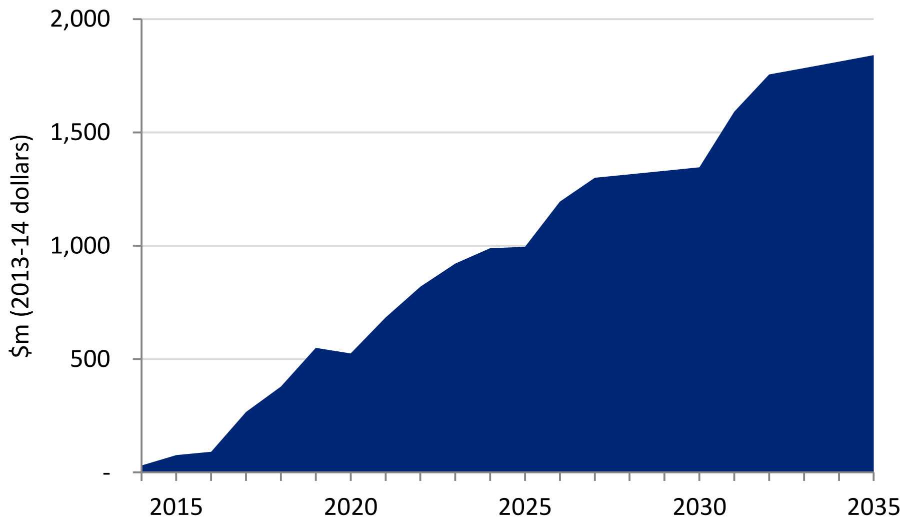
Deloitte Access Economics has used a customised version of our in-house regional general equilibrium model (DAE-RGEM) to model the estimated impacts of biorefinery construction in Queensland. The economic impact analysis compares the 'project scenario', which incorporates the proposed biorefinery construction, 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

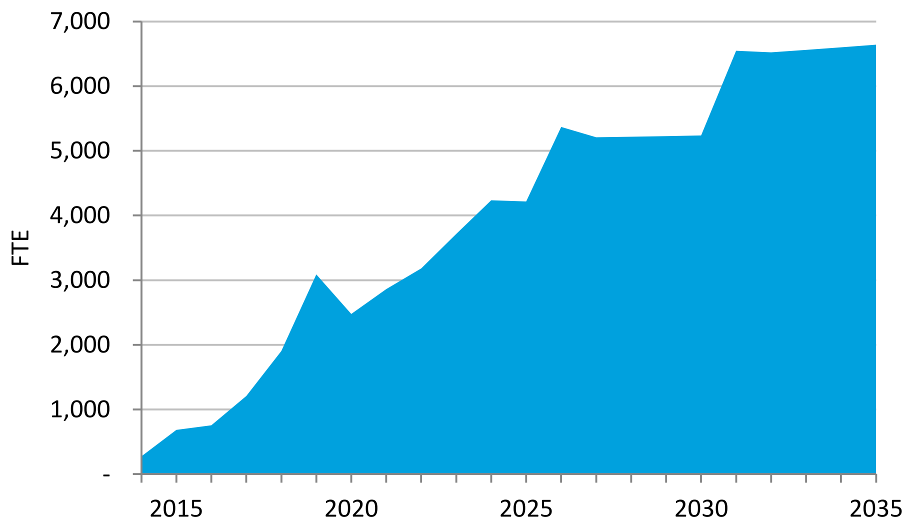
The biorefinery investment modelled is projected to increase employment across the state by 6,640 FTEs by 2035 (see Figure 1.2).

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.

Deloitte Access Economics
Corelli
BIO-INDUSTRY CONSULTING

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.

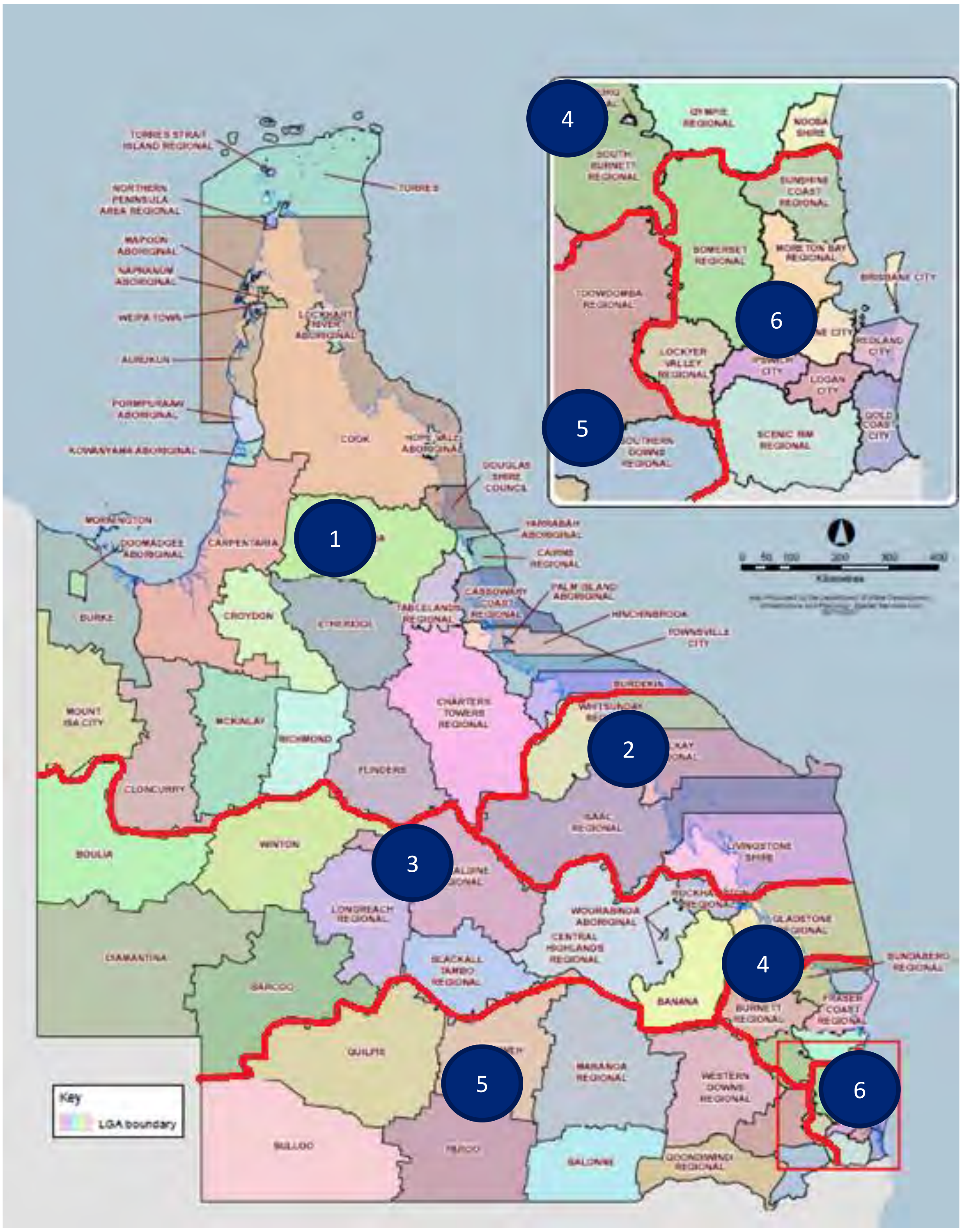
Table 3.1: Potential Queensland biorefineries modelled

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

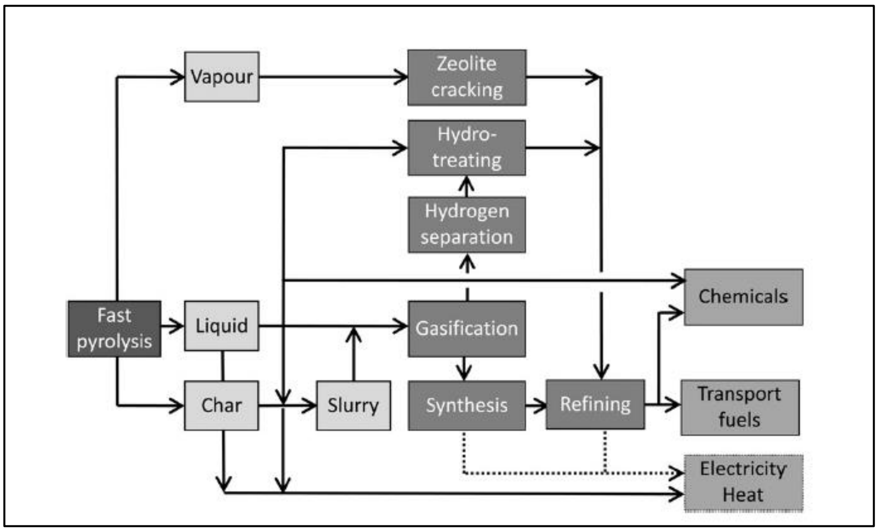
Phenolic resins (or phenol-formaldehyde resins) are synthetic thermosetting resins invented in 1907 (Bakelite) as the first plastic. The global volume for the phenol-formaldehyde resins market is expected to reach 16 million tonnes by 2016, with a compound annual growth rate of 12.1%. The US currently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

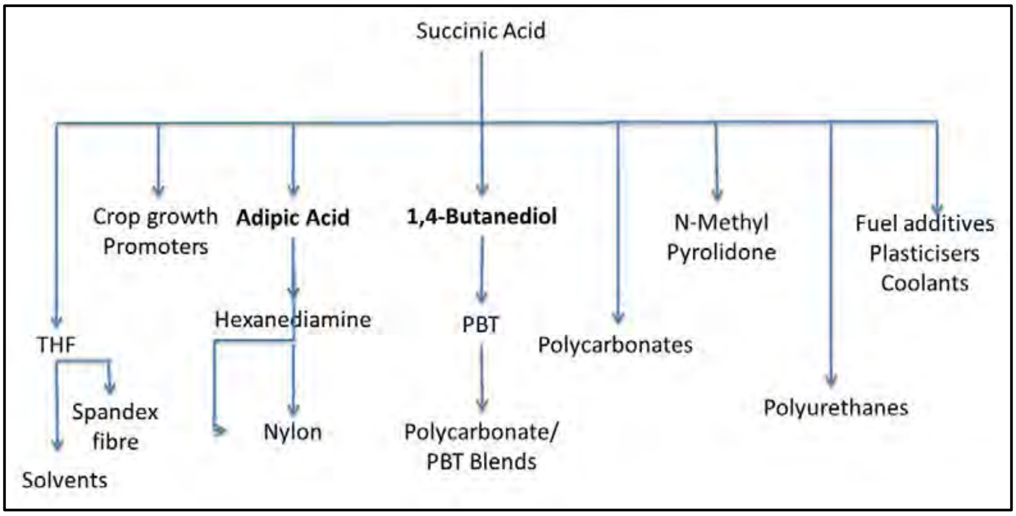
Succinic acid is a significant, small chemical building block or platform chemical used in the manufacture of polymers, resins, food and pharmaceuticals, among other products. Fossil fuel-derived succinic acid was considered a speciality chemical, but as a result of price competiveness and renewable 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



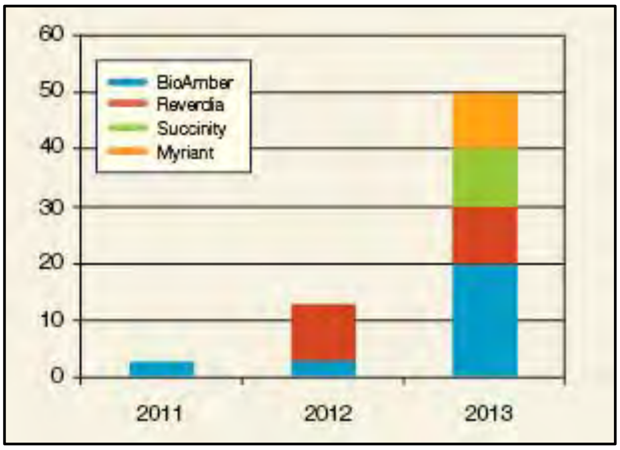
Note, THF stands for tetrahydrofuran and PBT stands for polybutylene terephthalate.

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).

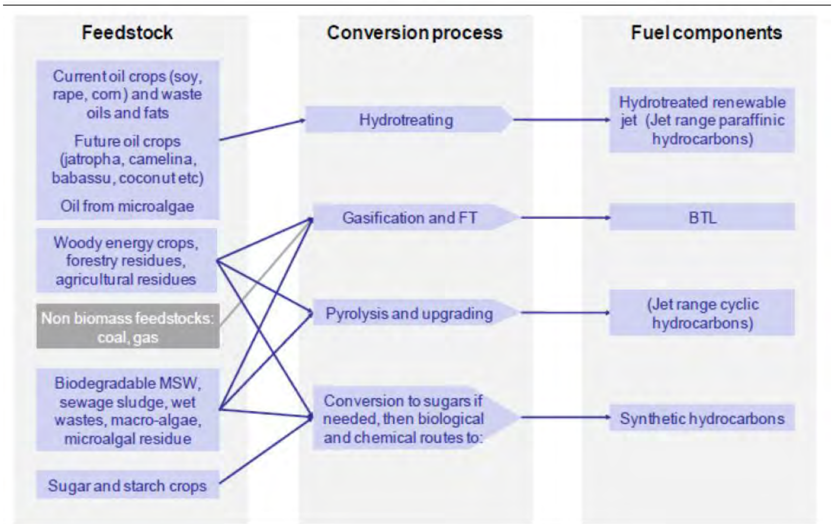
Demonstration flights using biojet fuel commenced in 2011 and continue with Porter Airlines, All Nippon Airways, Qantas, LAN Colombia, Air Canada, Azul Brazilian Airlines all having carried out successful demonstration flights using biojet fuel (European Biofuels Technology Platform).

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.

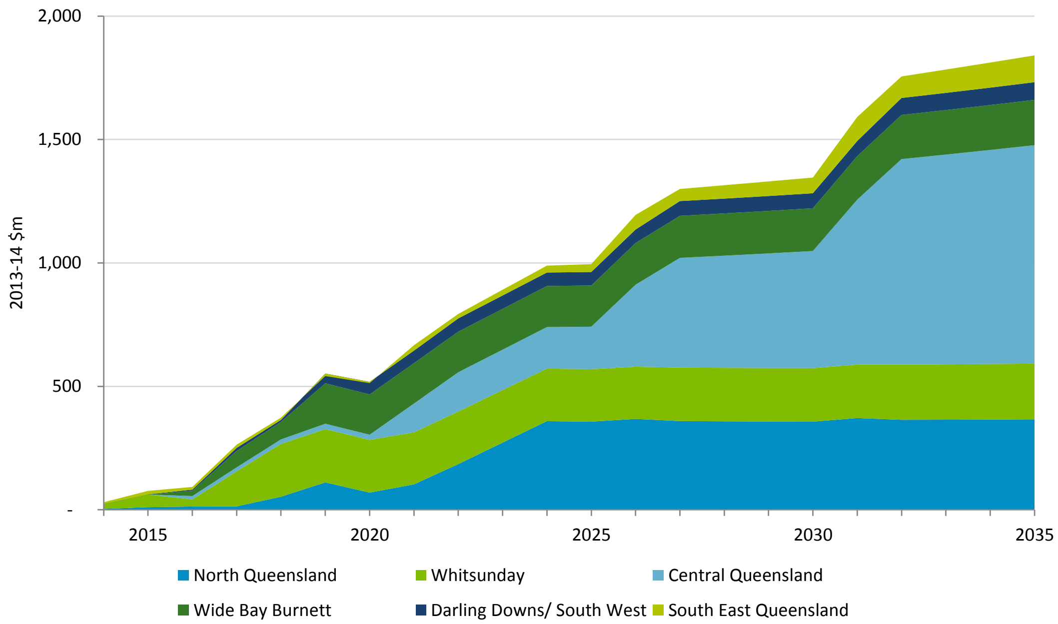
In this analysis, project establishment and operations are modelled out to 2035-36. In reality, projects would very likely operate beyond 2035-36, with ongoing economic impacts.

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



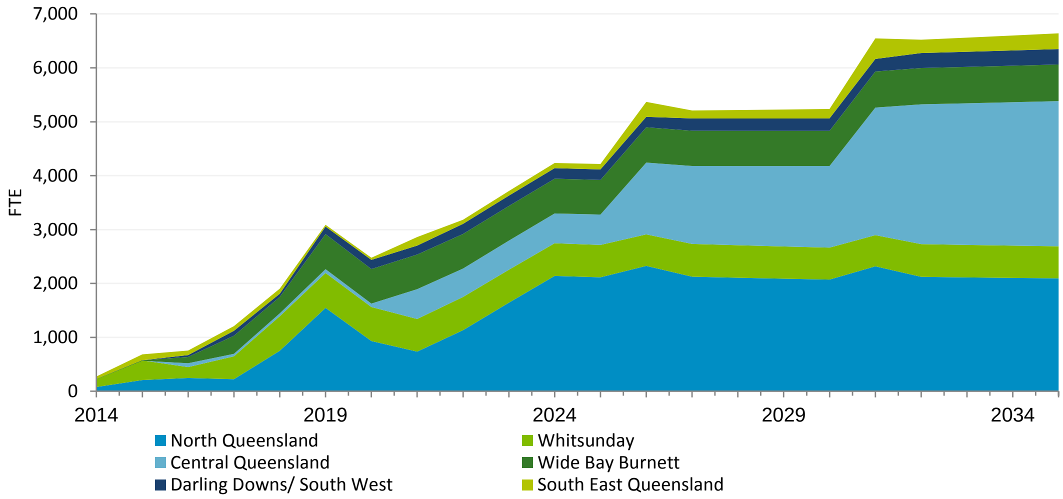
Employment

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.

References

"5,219 thousand US barrels/day http://www.indexmundi.com/energy.aspx?product=jet-fuel."

"http://en.european-bioplastics.org/market/market-development/."

(2011) "The Sugar Rush: Dow, Mitsui revive major renewables project in Brazil. www.biofuelsdigest.com/bdigest/2011/07/20/the-sugar-rush-dow-mitsui-revive-major-renewables-project-in-brazil/." Biofuels Digest.

(2014) "Outlook 2014: Looking forward. www.chemweek.com/lab/Outlook-2014-Looking-forward_57898.html." Chem Week

Aden, A. e. a. (2002). Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover. National Renewable Energy Laboratory.

Adnan, H. (2012) "MYBiomass plans Johor plant. www.thestar.com.my/story.aspx/?file=%2f2012%2f6%2f23%2fbusiness%2f11533691"

Air Transport Department, C. U. (2008). Fuel and air transport. A report for the European Commission.

Albertson, P., H.-H. Wong, L. Moghaddam, W. Stolz, M. D. Harrison and I. M. O'Hara (2013). Energy products from sweet sorghum. . Sweet sorghum: Opportunities for a new, renewable fuel and food industry in Australia. RIRDC Publication N. 13/087. RIRDC Project No. PRJ-005254. I. O'Hara, et al,.

Amryis (2014). "http://www.amyris.com/News/338/Amyris-to-Enter-Partnership-to-Supply-Renewable-Jet-Fuel-to-GOL-Airlines.".

Athanassiadou, E., S. Tsiantzi and P. Nakos (2002). Wood adhesives made with pyrolysis oils A.C.M. Wood Chemicals Plc.

Australian Bureau of Statistics (ABS) 2013, National Regional Profile 2007 to 2011 Cat. No. 1379.0.55.001, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1379.0.55.0012007+to+2011.

Bio-XCell. "www.bio-xcell.my/ ".

BioAmber "www.bio-amber.com/bioamber/en/company/manufacturing_facilities."

BiotechCorp. (2012). "Malaysia to develop Asia's Largest Biorefinery complex in ECER. www.biotechcorp.com.my/media/malaysia-to-develop-asias-largest-biorefinery-complex-in-ecer/."

Blanco-Rosete, S. and C. Webb (2008). "Emerging biorefinery markets: global context and prospects for Latin America." Biofuels, Bioprod. Bioref. 2: 331 - 342.

Booth, T. H., R. J. Raison, D. F. Crawford, T. Jovanovic, M. H. O'Connor, N. Raisbeck-Brown, D. A. O'Connell, B. W. Hogg and D. J. Lee (2014). "Biomass for aviation fuel production in the Fitzroy Basin, Queensland: a preliminary assessment of native and plantation forest potential." Australian Forestry 77(1): 1-8.

Brehmer, B. and J. Sanders (2009). "Assessing the current Brazilian sugarcane industry and directing developments for maximum fossil fuel mitigation for the international petrochemical market." Biofuels, Bioprod. Bioref. 3: 347 - 360.

Bridgwater, A. V. (2012). "Review of fast pyrolysis of biomass and product upgrading." Biomass and Bioenergy 38: 68-94.

Bura, R., A. Vajzovic and S. L. Doty (2012). "Novel endophytic yeast Rhodotorula mucilaginosa strain PTD3 I: production of xylitol and ethanol." J Ind Microbiol Biotechnol. 39(7): 1003-1011.

Coca Cola www.coca-colacompany.com/press-center/press-releases/the-coca-cola-company-announces-partnerships-to-develop-commercial-solutions-for-plastic-bottles-made-entirely-from-plants.

Corelli Consulting 2010, Biorefinery Scoping Study: Tropical Biomass, prepared for Departm ent of Innovation, Industry, Science and Research (DIISR), http://www.innovation.gov .au/Industry/Biotechnology/IndustrialBiotechnology/Documents/BiorefineryScopingS tudyTropicalBiomass.pdf.

De Guzman, D. (2012) "Malaysia sets up Asia's largest biorefinery site. www.oleoline.com/index.php/news/malaysia-sets-up-biorefinery-site-to-attract-chemical-firms/." Oleoline.

de Guzman, D. (2013) "Evonik, LanzaTech bio-based chems activities. http://greenchemicalsblog.com/2013/12/20/evonik-lanzatech-bio-based-chems-activities/." Green Chemicals.

De Jong, E., A. Higson, P. Walsh and M. Wellisch (2012). Value added products from biorefineries. . IEA Bioenergy.

Denver Post 2011, USDA revises plan to boost biofuel investment, http://www.denverpost. com/business/ci_17876981.

Domínguez, J., J. Salgado, N. Rodríguez and C. Cortés (2012). Biotechnological Production of Xylitol from Agro-Industrial Wastes. Food Additive Y. El-Samragy.

Dow (2007a) "Dow and Crystalsev Announce Plans to Make Polyethylene from Sugar Cane in Brazil."

Dow (2007b) "Dow and Crystalsev's sweet deal" All Business.

DSM. "www.dsm.com/corporate/about/business-entities/dsm-biobased-productsandservices.html."

Efe, C., L. A. M. van der Wielen and A. J. J. Straathof (2013). "Techno-economic analysis of succinic acid production using adsorption from fermentation medium." Biomass and Bioenergy 56: 479-492.

Erickson, B., J. Nelson and P. Winters (2012). "Perspective on opportunities in industrial biotechnology in renewable chemicals." Biotechnol. J. 7: 176–185.

EuropaBio (2011). Biorefinery feasibility study.

European Biofuels Technology Platform. "www.biofuelstp.eu."

European Phenolic Resins Association. "http://www.epra.eu."

Evonik. (2014). "http://corporate.evonik.com/en/media/archive/Pages/news-details.aspx?newsid=28008 ".

Feedipedia – Animal Feed Resources Information System. "http://www.feedipedia.org/node/72."

Galletti, A., C. Antonetti, V. De Luise, D. Licursi and N. o Di Nasso (2012). "Levulinic acid production from waste biomass." BioResources 7(2): 1824-1835.

Gevo Inc (2012) "Gevo Signs Malaysian Collaboration to Produce Cellulosic Isobutanol for SE Asia. http://ir.gevo.com/phoenix.zhtml?c=238618&p=irol-newsArticle&ID=1706669&highlight=."

Girio, F. (2012). Deconstruction of the hemicellulose fraction from lignocellulosic materials into simple sugars D-Xylitol: Fermentative Production, Application and Commercialization. S. Silvério da Silva and A. Kumar Chandel, Springer.

Hayes, D., S. Fitzpatrick, M. Hayes and J. Ross (2008). The Biofine Process – Production of Levulinic Acid, Furfural, and Formic Acid from Lignocellulosic Feedstocks. . Biorefineries-Industrial Processes and Products: Status Quo and Future Directions. . B. Kamm.

Hayward, J., O'Connell, D., Raison, R., Warden, A., O'Connor, M., Murphy, H., Booth, T., Braid, A., Crawford, D., Herr, A., Jaovanovic, T., Poole, M., Prestwidge, D., Raisbeck-Brown, N., Rye, L. (2013). "The economics of producing sustainable aviation fuel: a regional case study in Queensland, Australia." *[pre-press copy provided by authors]*.

International Feed Industry Federation (2013). Annual Report 2012-13. .

International Renewable Energy Agency (2013). Production of Bio-ethylene: Technology Brief 113. iea-etsap.org/web/Supply.asp. IEA-ETSAP.

Kircher, M. (2010). Trends in technology applications. OECD Workshop on "Outlook on Industrial Biotechnology". Vienna.

Ko, B. S., J. Kim and J. H. Kim (2006). "Production of Xylitol from d-Xylose by a Xylitol Dehydrogenase Gene-Disrupted Mutant of Candida tropicalis." Appl Environ Microbiol. 72(6): 4207-4213.

Lane, J. (2013) "zuChem, Godavari to commercialize xylitol bioprocess. www.biofuelsdigest.com/bdigest/2013/02/19/zuchem-godavari-to-commercialize-xylitol-bioprocess/." Biofuels Digest.

Lane, J. (2014) "Capacity for Bio-Based Materials and Chemicals Nearly Doubles to 13.2M Tons in 2017. www.biofuelsdigest.com/bdigest/2014/02/19/capacity-for-bio-based-materials-and-chemicals-nearly-doubles-to-13-2m-tons-in-2017/." Biofuels Digest.

Lee, P. C., W. G. Lee, S. Kwon, S. Y. Lee and H. N. Chang (1999). "Succinic acid production by Anaerobiospirillum succiniciproducens: effects of the H2/CO2 supply and glucose concentration" Enzyme Microb Technol. 24: 549-554.

Lerro, C. (2012) "Biobased Jobs, Grown and Made in America. www.biotech-now.org/environmental-industrial/2012/02/biobased-jobs-grown-and-made-in-america#." BIOtech.

Liu, G., B. Yan and G. Chen (2013). "Technical review on jet fuel production." Renewable and Sustainable Energy Reviews. 25: 59-70.

Lux Research (2013) "Newsletter 13th November".

Malaysian Investment Development Authority (2012). "Malaysia: Investment Performance 2012. www.mida.gov.my/env3/uploads/PerformanceReport/2012/MIPR2012_ENG.pdf."

McKinlay, J. B., C. Vieille and J. G. Zeikus (2007). "Prospects for a bio-based succinate industry" Applied Microbiology and Biotechnology 76(4): 727-740.

Moser, B. (2013) "Dow and Mitsui postpone sugarcane polymer plant. www.plasticsnews.com/article/20130110/NEWS/301109988/dow-and-mitsui-postpone-sugarcane-polymer-plant#." Plastics News

Myriant Corp "www.myriant.com/media/press-releases/myriant-produces-at-commercial-scale-thyssenkrupp-uhde-readies-to-provide-guaranty.cfm."

Nova Institute (2013). Market study on Bio-based polymers: Capacities, Production and Applications: Status quo and trends towards 2020.

O'Hara, I. M. (2013). Techno-economic assessment of sweet sorghum opportunities in Australia. Sweet sorghum: Opportunities for a new, renewable fuel and food industry in Australia. RIRDC Publication N. 13/087. RIRDC Project No. PRJ-005254. I. O'Hara, et al,.

Organisation for Economic Co-operation and Development (2012). Green growth and the future of aviation. Paper prepared for the 27th Round Table on Sustainable Development to be held at OECD Headquarters 23-24 January 2012.

Patel, A., K. Koen Meesters, H. den Uil, E. de Jong, K. Blok and M. Patel (2012). "Sustainability assessment of novel chemical processes at early stage: application to biobased processes." Energy Environ. Sci. 5: 8430-8445.

Patel, M., Crank M, Dornburg V, Hermann B, Roes L, Hüsing B, Overbeek L, T. F and R. E (2006). Medium and Long-Term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources: The Potential of While Biotechnology (The BREW Project). Utrecht University.

Patel, R. N., S. Bandyopadhyay and A. Ganesh (2005). Selective Extraction of Phenols from Sugarcane Bagasse Pyrolysis Oil. 10th European Meeting on Supercritical Fluids. International Society for the Advancement of Supercritical Fluids. Colmar, France.

PlasticsEurope (2011). Plastics - the Facts 2011: An analysis of European plastics production, demand and recovery for 2010.

Proactive Investors Australia 2012, Leaf Energy closer to patent grant for bio-ethanol production process, http://www.proactiveinvestors.com.au/companies/news/35973/leaf-energy-closer-to-patent-grant-for-bio-ethanol-production-process--35973.html.

Rao Ravella, S., J. Gallagher, S. Fish and R. Shetty Prakasham (2012). Overview on Commercial Production of Xylitol, Economic Analysis and Market Trends. D-Xylitol: Fermentative Production, Application and Commercialization. S. Silvério da Silva and A. Kumar Chandel, Springer.

Ravenscroft, M. (2013) "Industrial biotechnology: Chemical building blocks from renewable resources." IHS Chemical Week.

Rhodes, C. (2014) "Peak oil is not a myth. www.rsc.org/chemistryworld/2014/02/peak-oil-not-myth-fracking." Chemistry World.

Saidak, T. (2012) "Malaysia MYBiomass looking to build industrial biorefinery plant. www.biofuelsdigest.com/biobased/2012/06/26/malaysia-mybiomass-looking-to-build-industrial-biorefinery-plant/." Biofuels Digest.

Shen, L., J. Haufe and M. K. Patel (2009). Product overview and market projection of emerging bio-based plastics. PRO-BIP 2009. European Polysaccharide Network of Excellence and European Bioplastics.

Song, H. and S. Y. Lee (2006). "Production of succinic acid by bacterial fermentation." Enzyme and Microbial Technology 39: 352–361.

Tetra Pak (2013) "Tetra Pak and Braskem to sign supply agreement on bio-based plastic for carton packaging in Brazil. www.tetrapak.com/about-tetra-pak/press-room/news/bio-based-plastic-brazil."

ThyssenKrupp (2013) "ThyssenKrupp investing in industrial biotechnology. www.thyssenkrupp.com/en/presse/art_detail.html&eid=TKBase_1373445409469_62472790."

United Nations Environment Programme (2012). Global Chemicals Outlook.

US Congress (2013). H.R.3084 - Qualifying Renewable Chemical Production Tax Credit Act of 2013. 113th Congress (2013-2014). http://beta.congress.gov/bill/113th-congress/house-bill/3084.

US Dept of Agriculture (2010). 7 CFR Part 1450. Biomass Crop Assistance Program.

US Dept of Agriculture (2012). Agriculture Secretary Vilsack Announces Support for a New Bio-Based Chemical Production Facility in Louisiana. Release No. 0202.12. Office of Communications (202) 720-4623.

van den Berg, L., H. Kay and K. Sichone (2010). Pyrolysis: Market and Technical Assessment. U. o. W. WaikatoLink Limited.

Voegele, E. (2013) "USDA accepting applications for Biorefinery Assistance Program. http://biomassmagazine.com/articles/9571/usda-accepting-applications-for-biorefinery-assistance-program." Biomass.

Watson, E. (2012) "JBF to build giant bio-glycol plant in Brzil to hlep Coca-Cola meet Plant Bottle 2020 target. www.foodnavigator-usa.com/Markets/JBF-to-build-giant-bio-glycol-plant-in-Brazil-to-help-Coca-Cola-meet-PlantBottle-2020-target." Food Navigator USA.

Werpy, T. and G. Petersen (2004). Top value added chemicals from biomass - Results of screening for potential candidates from sugars and synthesis gas, National Renewable Energy Laboratory.

World Economic Forum (2010). The Future of Industrial Biorefineries. http://www3.weforum.org/docs/WEF_FutureIndustrialBiorefineries_Report_2010.pdf.

Zhang, Y. H. (2008). "Reviving the carbohydrate economy via multi-product lignocellulose biorefineries." J Ind Microbiol Biotechnol. 35: 367–375.

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.

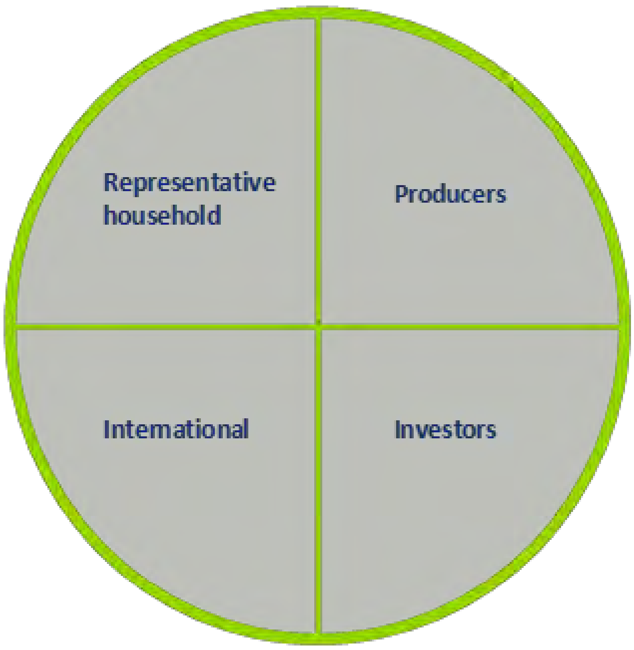
Appendix E: CGE modelling

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.

Limitation of our work

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