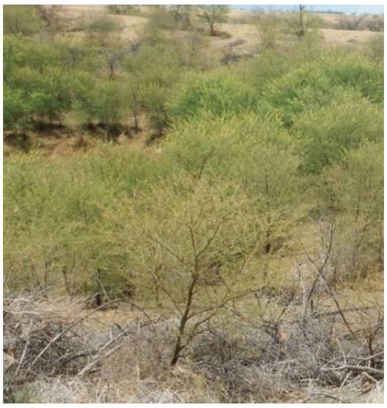



Mount Isa To Townsville Economic Development Zone (MITEZ)

North West Queensland Biomass Project Scoping Study Report

January 2020

Executive Summary

Mount Isa to Townsville Economic Development Zone (MITEZ) commissioned GHD to investigate the opportunity to establish a biomass production facility in North West Queensland based on potential synergies regarding control of prickly acacia in the region and establishment of irrigated Leucaena-based farming systems.

These investigations leverage findings from earlier biofuels cropping trials at Cloncurry and recent initiatives by Meat and Livestock Australia (MLA) and the University of Queensland regarding development of sterile Leucaena varieties.

Prickly acacia is a thorny shrub to small tree, native to South Africa and to India. In Australia it is widespread in Queensland and also found in the Northern Territory, New South Wales and South Australia. It interferes with livestock movement by reducing pasture area and preventing access to water, which in turn leads to negative economic impacts. It is a restricted invasive plant under the Biosecurity Act 2014. A range of methods have been deployed to control the spread of Prickly acacia, and while some have had impact, the problem remains widespread.

If prickly acacia infestations are not actively combatted, they will continue to spread, with the potential to infest large portions of the northern parts of Australia, rendering large tracts of land worthless for grazing and/or impossible to negotiate. This project could potentially form part of a long-term program to clear land of prickly acacia while producing biomass pellets for export as fuel and partially “sponsoring” the harvesting of prickly acacia.

Leucaena is a small fast-growing mimosoid tree, native to southern Mexico and Central America. It is used for stock forage, wood furniture, pulp/paper production, fuelwood, biomass for power generation and food. It has a woody stem yield under repeated cutting and its chemical composition is ideal for heat generation on combustion. While Leucaena can also be considered a weed, current research is being conducted to develop sterile plants suitable for cultivation, and current varieties and management practices largely constrain historical weediness factors.

This proposed project concept includes removal and processing of prickly acacia in the first instance and replace previously infested cleared areas (with access to irrigation water) with a sterile Leucaena cropping system to facilitate the manufacture of both wood fuel pellets for export and high protein, low methane cattle feed pellets.

While there is currently a high export demand for wood pellets, demand is expected to grow in Europe, Korea, Japan and Canada due to legislation during the next decade.

To investigate, at a high level, the technical and commercial potential of this project, methods of planting irrigation, harvesting, drying and pelletising needed to be analysed. This report explored each of these processes, recommending preferred process parameters, and assessed costs and investment returns via high level financial modelling. Only woody Leucaena was considered for the wood pelleting heat and mass balance work following evaluation of both materials properties and determining that they are similar enough to produce heat and mass balances that would closely resemble each other. In addition, the wood pellets would be similar in quality (heating value and ash content), and therefore pricing for both wood pellet materials is expected to be the same. Published information was used to characterise both woody Leucaena and prickly acacia for the heat and mass balances. Initial modelling assumed that Leucaena would be planted in double rows at 6 m centres, with 5 ML/ha irrigation, application of fertiliser, harvesting on an 18 month rotation, planting of inter-row crops and protection from wallabies and kangaroos (at least during crop establishment). Woody material would be processed and pelletised for biomass fuel, and leafy material would be processed into animal

feed pellets. Modelling indicated that the project would benefit from further system optimisation, and a number of alternate scenarios and sensitivities were tested.

Accessing part of the 200 GL of water allocation already released by the State Government, GHD proposes that mosaic style irrigation be utilised to support plantation biomass and inter-row cropping development. This project concept uses off-stream storage captured during wet-season stream flows for later irrigation purposes. Storage locations would need to be assessed on an individual basis. In preparing this report it has been assumed that the project is advanced on a mosaic irrigation basis which is considered appropriate for the Flinders River catchment and assumed irrigation water being sourced by water-harvesting would be directed to multiple off-stream storages of 5,750 ML to meet the irrigation needs of five storage modules i.e. the farm model has been based on the irrigation development of 4,600 ha.

This project would lead to various regional job opportunities; labour would be required for harvesting and transport of the raw material and pellets. In addition, specialised labour would be needed to operate and maintain the pelleting plants and co-generation facility, making the project an excellent opportunity for upskilling some of the regional labour force. It is estimated that approximately 28 full time employees would be required to operate the pelleting plants, while more would be employed indirectly, with up to an estimated 250 potential regional employment positions created.

In addition, while large portions of the co-generation and pelleting facilities would be modularised and therefore built elsewhere and shipped to site, there would still be some site construction and integration work to complete, which would employ a number of local employees.

Harvesting and hauling prickly acacia would be relatively labour-intensive as it is wide-spread and relatively sparse, and several small harvesting or contracting “groups” could be employed to clear land of prickly acacia.

Preliminary findings and recommendations

The initial capital and establishment investment costs were estimated to be $86.1 million and the total investment required over a 25 year period was calculated to be $117.9 million.

The total operating costs are estimated to be $21.9 million AU$/annum for years harvesting sterile Leucaena, and $24.4 million AU$/annum, for years harvesting prickly acacia.

Financial model results show that using these figures, without altering costs, the project would have a 30 year IRR of 6.46% and negative net present value of approximately -$27 million. Several sensitivities have been conducted which impact NPV.

The operating cost has a larger influence on the economic indicators than the capex and establishment costs, and it is recommended that further work be done to identify opportunities to reduce operating costs, particularly in the initial period to improve the economic indicators for the project.

Operating, capex, and establishment costs need to be decreased or offset to yield a positive NPV.

Based on current assumptions, importing electricity from the grid rather than generating electricity at the co-generation site, along with steam for process heating, could lead to improved economic indicators.

Changing the crop split from more area for Leucaena growth and less area for rotational crops to more area for rotational crops and less area for sterile Leucaena leads to a slight weakening of NPV, indicating that maximising sterile Leucaena output provides more efficient return on capital invested.

Inclusion of shipping costs and adjusting the wood pellet price from FOB Townsville to a landed price in Japan does not negatively impact project economics.. Further work is recommended to further quantify shipping costs and landed wood pellet pricing.

Producing wood chip rather than wood pellets leads to a reduced capital and operating cost to process the woody sterile Leucaena material, however lower returns associated with reduced revenue resulted in this not being considered a viable scenario.

Although wood chip could be subjected to ambient drying only; and this would decrease capital spent on a wood chip facility, the price for the product decreases and the transport cost per unit product increases (due to additional moisture in the product).

The timeframe for the commercial development of sterile Leucaena is likely to be in the order of 10 to 12 years.

To improve overall project viability and address key areas of risk, the following recommendations are made.

Recommendations for further agronomic studies include:

- Vegetatively propagate 1-3 best performing sterile Leucaena lines
- Plant large trial plots of Leucaena in the MITEZ area for performance evaluation and demonstration
- Research various inter-row cropping species such as brassica carinata, mungbeans and Rhodes grass
- Explore opportunities to develop/refine potential harvesting equipment.

Recommendations for approvals include:

It is recommended that a desktop-based environmental scoping and approvals review is undertaken for preferred sites.

General recommendations

The study was primarily focused on identifying potential constraints and fatal flaws that may impact the project. The study identified a number of areas that would require further investigation to progress the concept to preliminary feasibility evaluation and any subsequent detailed feasibility study.

Recommendations for further investigation include:

- MITEZ liaise with DAF, the University of Queensland, MLA and the Department of State Development, Manufacturing, Infrastructure and Planning with regard to:
  - Advancing the development and trialling of sterile Leucaena and Carinata lines in the region
  - Understanding the likely costs and timeframes for commercial propagation of sterile Leucaena and Carinata varieties
- MITEZ assist with and facilitate the identification of a potential demonstration site for a traditional Leucaena plantation.
- MITEZ work with regional NRM groups to identify opportunities to leverage investment in mechanical controls of prickly acacia to consolidate for wood chipping opportunities to increase initial project viability with the further benefit of potential to assist funding prickly acacia control measures.

- MITEZ engage with DSDMIP to investigate funding support options for further, more detailed investigation of the technical and commercial feasibility of progressing this biomass industry development opportunity, and potential to secure investment support in the form of establishment grants.
- More detailed mapping of prickly acacia distribution using more precise remote sensing or aerial photo interpretation etc.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.3 and the assumptions and qualifications contained throughout the Report.

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Abbreviations

APVMA	Australian Pesticide and Veterinary Medicines Authority
ARENA	Australian Renewable Energy Agency
CAGR	Compound annual growth rate
CEFC	Clean Energy Finance Corporation
CNH	Case New Holland
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCQ	Desert Channels Queensland
DM	Dry matter
DNRME	Department of Natural Resources, Mines and Energy
DSDMIP	Department of State Development, Manufacturing, Infrastructure and Planning
GBO	General biosecurity obligation
GCM	Gross combination mass
GIS	Geographical information system
GRDC	Grains Research and Development Corporation
GVP	Gross value of production
ha	Hectare
HP	Horsepower
IRR	Internal rate of return
km	Kilometres
km2	Square kilometres
kW, MW	Kilowatt, megawatt
L	Litre
LHV	Lower Heating Value
MEB	Mass Energy Balance
MITEZ	Mount Isa to Townsville Economic Development Zone
ML, ML/a	Megalitre, Megalitres per annum
MLA	Meat and Livestock Australia
m, mm	Metre, Millimetre
Mtpa	Metric tonnes per annum
NCR	New Century Resources
NHVR	National Heavy Vehicle Regulator
NPV	Net present value
NRM	Natural resource management
rpm	Revolutions per minute
SRWC	Short rotation woody crop
TIC	Total installed cost
tpa, tph	Tonnes per annum, tonnes per hour
UAV	Unmanned aerial vehicles
UQ	University of Queensland
wb	Wet basis, used to express the basis for proximate, ultimate analyses
WONS	Weed of national significance

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1. Introduction

1.1 Background

The North West Queensland Biomass Project leverages investigations associated with earlier biofuels cropping trials in Cloncurry and recent initiatives by Meat and Livestock Australia (MLA) and the University of Queensland (UQ) in the development of sterile Leucaena varieties. Leucaena was one of the biomass cropping candidates included in the Cloncurry biofuels irrigated crop trials, and is grown by a number of graziers in Central Queensland and the MITEZ region (non-irrigated forage planting north of Charters Towers).

Plantation biomass can take some time to reach continuous production. However, biomass harvested via clearing of existing prickly acacia weed infestation in an identified biomass plantation zone could potentially offset the lead-time for initial supply of new plantation biomass. It was envisaged that a biomass processing centre developed near plantation/s in the North West region may make commercial sense, with local energy recovery from processing by-products such as bark and trimmings, and production of biomass fuel pellets for export via Townsville or Karumba.

However, to assess overall scheme potential, a number of aspects required investigation. Limited quantitative data is currently available on the extent and density of existing prickly acacia weed infestation in North West Queensland. The Australian Renewable Energy Mapping Infrastructure (AREMI) biomass database for Queensland[1] has been recently updated, however prickly acacia mapping is not included.

GHD was commissioned by Mount Isa to Townsville Economic Development Zone (MITEZ) to undertake a staged investigation that further develops the biomass production concept, and addresses the short-term information needs of potential investors to advance this concept.

1.2 Purpose of the report

The purpose of this report is to document findings from high level investigations into potential for developing a biofuels industry in North West Queensland centred on removal of prickly acacia weed in selected areas and establishing sterile Leucaena plantations to generate biomass for production of wood pellets. Investigations included:

- Stage 1 – GIS Analysis by overlaying a range of data sets including:
  - Prickly acacia distribution
  - Rail and major road corridors
  - Major water courses (of interest)
  - National electricity grid transmission lines
  - Soil types (Flinders catchment)
- Stage 2A – Carry out a Mass Energy Balance (MEB) – pellet production for:
  - Prickly acacia (acacia nilotica)
  - Leucaena

[1] Queensland Government, Department of State Development, Manufacturing, Infrastructure and Planning – Queensland biomass mapping and data: https://www.statedevelopment.qld.gov.au/industry-development/queensland-biomass-mapping-and-data.html accessed 14 August 2019

- Stage 2B – Reviewing of established harvesting options (prickly acacia and sterile Leucaena), including coppice rotation, field-based processing (stripping and chipping) and wet biomass transport.
- Stage 2C – High level cropping system assessment:
  - Leucaena yields and irrigation requirement
  - Plantation configuration
  - Water supply and irrigation development
- Stage 3A – Concept level assessment of pellet production including:
  - Receiving and storage
  - Milling and drying
  - Biomass fuel pellets
  - Feed pellets
  - Product storage and load-out
- Stage 3B – Concept level assessment of cogeneration option
- Stage 3C – Indicative development costing, including:
  - Land lease/purchase
  - Prickly acacia harvesting and clearing
  - Irrigation and farm development
  - Sterile Leucaena propagation for plantation establishment
  - Plantation development and management
  - Production facilities for pellets
  - Co-generation facility
  - Transport and shipping options
  - High level financial model
- Stage 4 – Capture deliverables from earlier stages in a consolidated report including:
  - Identification of data gaps
  - Aggregation of initial findings
  - Identifying funding support options
  - Risks and opportunities
  - Regulatory approval considerations
  - Preliminary findings and recommendations for further work

1.3 Scope and limitations

This report: has been prepared by GHD for Mount Isa To Townsville Economic Development Zone (MITEZ) and may only be used and relied on by Mount Isa To Townsville Economic Development Zone (MITEZ) for the purpose agreed between GHD and the Mount Isa To Townsville Economic Development Zone (MITEZ) as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Mount Isa To Townsville Economic Development Zone (MITEZ) arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by the Department of Agriculture and Fisheries, University of Queensland and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared the preliminary cost estimate/prices set out in various sections throughout this report using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD based on similar relevant projects etc.

The Cost Estimate has been prepared for the purpose of developing a ‘high level’ assessment of potential project viability and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the project can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the preliminary planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

1.4 Assumptions

The investigations in this study aim to fill key knowledge gaps for potential investors in developing the concept of biomass production from North West Queensland utilising sterile Leucaena and Prickly acacia. In completing the study, a number of assumptions have been made in relation to the scope of works, which have been summarised below:

- This study is based upon information freely available in the public domain or information provided by the Department of Agriculture and Fisheries, University of Queensland, CSIRO and other private sources which has not been independently verified by GHD.
- Economically viable propagation techniques for sterile Leucaena (unable to self-propagate) can be developed to support commercial biomass plantation establishment consistent with potential scale up timeframe requirements.
- Any necessary regulatory approvals required for prickly acacia removal, handling, transport, processing and pelletising can be obtained from relevant authorities in the timeframes necessary to enable commercial exploitation in support of Leucaena plantation establishment (Refer also to Section 3.5).

- Port access for export of biomass fuel pellet production can be secured cost effectively and within timeframes necessary to enable commercial project development.
- The project economics are heavily dependent on the price expected for sale of wood pellets. All costs and quantity figures used in developing the mass energy balance and financial model are reasonable estimates based on current prices and available information.
- Where reference is made to Leucaena in this report in a cropping context, it is envisaged that the cropping system would utilise a sterile variety, unless otherwise stated.

Detailed additional assumptions are provided throughout the report.

2. Broader project objectives

This project set out to investigate potential for development of a biofuels industry in North West Queensland involving establishing biomass plantations for wood fuel pellets and stockfeed. The longer term objectives of the North West Queensland Biomass Project include:

- Rehabilitation of rangelands lost to noxious weed (prickly acacia – Acacia nilotica)
- Staged industry development through a mosaic irrigation approach resulting in increased economic benefit from land and water resources in the region (increased productivity and capacity)
- Production and export of renewable biomass fuel pellets
- Plantation biomass industry development scale of up to and potentially in excess of 10,000 hectares.

The staged development would incorporate clearing and potentially harvesting prickly acacia (Acacia nilotica) infestation as a source of biomass supporting initial biomass fuel pellet production. Whether the cost of this weed clearing may be offset by future investment returns on renewable biomass processing and sale/export of products was considered in the study.

Selection of Leucaena for biomass plantation establishment considered the potential for harvesting/utilisation of green Leucaena tops as a high protein, low methane stock feed that supports national greenhouse gas reduction targets. Commercial considerations for pelletising the green Leucaena tops were also explored.

The project may have potential to increase renewable power generation in the region, as well as generate an economic return from the Queensland Government's release of water allocation in the Flinders River catchment. The study investigated, at a high level, the technical and commercial feasibility of using biomass processing residues to provide energy via cogeneration for the processing facility required for biomass fuel pellet production, with excess power exported to the electricity grid.

Woody Leucaena from established plantation harvesting (e.g. coppicing) would be processed into wood pellets for export as a carbon neutral biomass fuel, for which there is currently growing international demand. Alternatively the wood pellets could be used onshore as part of Queensland/Australia's moves to cleaner, more sustainable energy sources.

Key local and regional benefits would include:

- Community capacity building
- Strengthening regional communities and related services
- Leucaena production increasing grazing resilience to the impacts of drought
- Increased resilience, carrying capacity and turn-off rates from grazing operations in the region
- Increased exports with corresponding increase in rail and port utilization
- Increased regional jobs and services
- Opportunity to increase flood resilience by the incorporation of cattle 'loafing' areas in the potential development of off-stream storages to support mosaic style irrigation developments
- Broadening of the regional economic base

- Establishment of a renewable energy hub contributing to renewable energy and greenhouse gas reduction targets.

3. Prickly acacia

In its native range there are nine subspecies of prickly acacia (Acacia nilotica) distributed in an arc from northern South Africa to the north and east across to eastern India. In Australia, prickly acacia was well established in Queensland in the Bowen and Rockhampton districts by 1926, and was being actively promoted as a source of shade and forage for sheep while noted as a problem in cattle country. The plant was not declared noxious under the Rural Land Protection Act until 9 March 1957. It is now a weed of national significance. Nomination as a weed of national significance (WONS) recognises a species as a priority current and future weed threat to Australia, requiring coordinated and strategic management along with shared stakeholder investment to develop and implement best practice means to prevent, eradicate, contain, and/or minimise its impacts in different parts of the country. All WONS have individual national strategic management plans; the scope of which include establishing strategic, coordinated control programs and research to develop new control tools.

The prickly acacia is a thorny shrub to small tree (see Figure 3-1) and encourages erosion, threatens biodiversity, and reduces cattle grazing productivity. Prickly acacia is currently a restricted invasive plant under the Biosecurity Act 2014.

Figure 3-1 Prickly acacia[2]

In terms of direct economic impacts, prickly acacia decreases pasture grasses and out-competes for water. It also forms dense thorny thickets that interfere with cattle mustering, stock movement and access to water. In addition, its thorns damage tyres on farm vehicles.

[2] *Prickly acacia, Vachellia nilotica subsp. Indica (Benth) Kyal and Boatwr*, Department of Agriculture and Fisheries, Biosecurity Queensland, Queensland Government, 2016.

3.1 Extent

Prickly acacia is present in much of Queensland, in isolated pockets of the Northern Territory, New South Wales, and at one location in South Australia. It also has a wide tolerance for rainfall variance and has been found in areas receiving less than 230 mm per year and in areas receiving more than 1500 mm per year[3].

In Queensland, prickly acacia is already widespread (refer Appendix A) and has the potential to grow in most areas of the state.

In 2003, prickly acacia covered an estimated 6 to 7 million ha of Queensland; by 2013 it was estimated to infest more than 22 million ha of potential grazing land. The original outbreak was recorded around Winton, Richmond, Cloncurry and Hughenden, with lighter infestations around Longreach, Bowen and Rockhampton.

The infestation has spread to other states and outbreaks have also been recorded in the Northern Territory, Western Australia and the north-eastern parts of South Australia.

Earlier mapping of concentrated areas and property clusters are shown in Appendix A. Other related maps showing the proximity of areas of infestation to key infrastructure (rail, road and power) and potential irrigation water sources (e.g. Flinders and Cloncurry Rivers and Julia Creek) are also shown in Appendix A. However it is acknowledged that available mapping has been based on inputs by local experts as distinct from more precise remote sensing or aerial photo interpretation etc. Further work is needed to accurately map and identify areas that may present opportunity for economically viable harvesting.

It is widespread on several million hectares of Mitchell Grass plains and occurs from Barcaldine to Hughenden, west to Longreach, Winton and Julia Creek. It is also found along the coast, in particular, Home Hill, Bowen, and Rockhampton. Prickly acacia is often found growing on clay-rich soils, but may also grow on sandy loam soils under higher rainfall conditions.

Landlocked drainage channels, such as the Diamantina River, may carry water into regions that have extremely low, long-term average rainfall. With little topographic relief, this water can take a long period to drain or evaporate, providing enough moisture for germination and subsequent seedling establishment of a perennial plant. The plants might then persist until another such flooding event stimulates seed production and germination. This would allow populations to persist in locations such as Hungerford in southern Queensland[4]. More recently, there is evidence of prickly acacia establishing itself in this catchment.

Two prickly acacia mapping projects were undertaken between 2013-2016 by Desert Channels Queensland as part of the Queensland Regional Natural Resource Management Investment Programme. The Programme's final report[5] states:

> *The project has relied strongly on innovative weed survey techniques built on the foundation provided by landscape scale foliar mapping targeting prickly acacia. This mapping, a collaboration between DCQ and DISITI provided, for the first time, a regional view of this weed. This new regional view supported anecdotal information by landholders that the extent of this weed was much larger than the 6 million hectares reported by Government. Updated Government mapping released in 2016 matches the estimates provide by the foliar mapping with the infestation area now estimated in excess of 23 million hectares.*

[3] *Climate change and the potential distribution of an invasive alien plant: Acacia nilotica ssp. Indica in Australia*, D. Kriticos etc. al, Journal of Applied Ecology, British Ecological Society, February 2003
[4] Climate change and the potential distribution of an invasive alien plant: Acacia nilotica ssp. Indica in Australia, D. Kriticos et al, Journal of Applied Ecology, British Ecological Society, February 2003
[5] Attachment 3 Final Report Desert Channels Queensland, Queensland Regional Natural Resource Management Investment Program 2013-14 to 2017-18, Desert Channels Queensland

However, the area at risk of invasion by prickly acacia under current climate conditions greatly exceeds the current distribution, with ‘suitable’ to ‘highly suitable’ habitat covering more than one-third of Australia. Climate change as-predicted will most probably increase the area at risk of invasion, most noticeably in New South Wales and the moderately productive coastal zones of Western Australia. The large potential for further invasion under both current and future climates justifies concerns that this plant is a weed of national significance[6].

3.2 Impacts

If permitted to spread to their full potential, most weed species can impact extensive areas of land, affecting multiple local, state and territory jurisdictions, often multiple agricultural industries and a variety of significant environmental assets. For example, prickly acacia poses a serious threat to 20 to 30 million hectares of grazing land in Queensland, the Northern Territory and Western Australia.

Prickly acacia rapidly grows to 4 to 5 m tall and can grow up to 10 m tall. The trees branch out and link up, making passage through the thorny trees difficult. The trees kill all other vegetation growing around it, rendering large tracts of land worthless for grazing.

The plants infests waterways and dams, preventing stock access to vital water resources.

3.3 Propagation

Although capable of regenerating from cut stumps, prickly acacia only reproduces by seed. A healthy, medium-sized tree in a well-watered environment can produce as many as 160,000 to 200,000 seeds per year. The seeds can remain viable for 7 to 10 years, and possibly much longer.Seeds are spread primarily by livestock through ingesting mature pods (long-distance movement is possible by livestock transport). Long distance spread in Australia is mainly attributed to consumption of seeds by cattle, which readily eat the nutritious, ripe seed pods. At least 40% of the seeds consumed in this way are viable after being excreted, which is normally up to six days after consumption. Manure assists germination by providing extra moisture and nutrients. Cattle spread viable seeds more effectively than either goats or sheep, which tend to chew the seeds.

Minor spread may occur by mud on vehicles and water movement. The recent major flood across the North West Region may exacerbate areas of infestation and potentially re-infect areas where it had previously been controlled or eradicated in Queensland. This observation appears to be supported by other research sponsored by the National Heritage Trust and the Department of Natural Resources, Mines and Energy which noted that:

> *The spread of prickly acacia has been dominated by episodic mass establishment events, which require a succession of above average wet season rainfalls. Given that soil seed reserves and cattle stocking are now constants over many areas infested with prickly acacia, a further succession of rainfall events such as those in the 1950’s and 1970’s would result in both geographic expansion and increased density of infestations[7].*

However, anecdotal advice suggests that the most recent major flood may not have resulted in the mass germination and spread of this weed due to low numbers of seed pods (and degraded seed pods) due to the pre-existing drought conditions[8].

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[6] Ibid

[7] Prickly acacia, National Case Studies Manual Approaches to the management of prickly acacia (Acacia nilotica subsp. indica) in Australia, NHT, DNRME, CSIRO, NSW Agriculture, Dept of Agriculture of Western Australia, May 2004, P9

[8] Personal comment, DAF 22 July 2019

A published report[9] provided the information on the distribution of prickly acacia shown in the first two columns of Table 3-1.

Table 3-1 Estimate of available tonnages of prickly acacia

Infestation Level	Area ha (million)	Trees per ha	Average Spacing (m)	Trees (million)	Tonnage per ha
Low (<20 trees/ha)	5	10	32	50	5.1
Medium (20-120 trees/ha)	1.2	80	11	96	40.7
High (>120 trees/ha)	0.5	180	8	90	91.5
Total	**6.7**			**236**	

An investigation by Pioneer Corporation[10] stated the available prickly acacia resource was "over 100 million tonnes". The basis of this number was not stated and the veracity is not able to be confirmed by GHD due to an absence of available field survey data. However, using this as a basis, it can be estimated that the average tree weighs approximately 0.5t, assuming:

- The claim that over 100 million tonnes is correct
- 120 million tonnes is a reasonable estimate
- The average number of trees/ha in each zone is as shown in the third column of the table above.

Column 5 of the table also indicates that approximately 40% of the prickly acacia is located on only 7% of the land, and 80% is located on only 30% of the land. The areas with high infestation rates may therefore contain around 45 million tonnes of prickly acacia biomass.

3.4 Control measures

A range of methods have been deployed in efforts to control the spread of prickly acacia including:

- Mechanical controls
- Herbicide controls
- Physical controls
- Biological controls.

Landholders, Councils, State agencies and regional Natural Resource Management groups (such as Desert Channels Queensland) have been adopting a range of the above measures. However, to date it is likely that gains in some areas are being offset by setbacks in others.

Land use can influence the likelihood of prickly acacia invasion, which can take five years to mature, and any disturbance that destroys juveniles every five years or less would prevent widespread recruitment. The effectiveness of fires in preventing recruitment will depend upon their frequency and intensity. Tillage-based agriculture should prevent prickly acacia invasion[11].

3.4.1 Biological controls

Prickly Acacia has been recognised as a target for biological control through a cross-jurisdictional government process, and a biological control program has been operating since

[9] Prickly acacia (Acacia nilotica) in Queensland, Pest Status Review Series - Land Protection Branch, Edited by A.P. Mackey, Queensland Government Department of Natural Resources and Mines, June 1996, P9
[10] Converting prickly acacia from Pest to Sustainable Fuel, Government Brief, Pioneer Corporation Pty Ltd
[11] Climate change and the potential distribution of an invasive alien plant: Acacia nilotica ssp. Indica in Australia, D. Kriticos etc. al, Journal of Applied Ecology, British Ecological Society, February 2003

1980. Some native insect species that attack native acacias will also attack actively growing prickly acacia.

A total of six insects have been introduced as biological control agents against prickly acacia, with two establishing and providing some benefit. The beetle Bruchidius sahlbergi established successfully and is now widespread. Seed predation is generally low but may reach up to 80% where mature pods are available. The leaf-feeding caterpillar Chiasmia assimilis is not abundant in western Queensland but is exerting pressure on prickly acacia in coastal locations. Researchers continue to look for new biological control agents overseas, with India the current focus[12].

One of these insects - the root eating Cicada Cicadema oldfieldi - is thought to be one of the causes of the prickly acacia dieback observed occasionally during drought conditions. A biological control program has been operating since 1980. Of 260 insect species known to attack Prickly Acacia, 17 are likely to only feed on prickly acacia and are therefore potentially suitable for introduction to Australia.

3.4.1.1 Native insect attack and dieback

Prickly acacia is attacked by native insects associated with Australian native acacias and other native plants. Native insects can weaken prickly acacia and contribute to the death of plants when other stresses are involved. Generally, leaf-feeding, sap-sucking, root, pod and seed feeding insects attack actively growing prickly acacia. Bark and wood-feeding insects (including borers and twig-girdlers) prefer stressed and dying plants.

Dieback of areas of prickly acacia has occurred occasionally throughout western Queensland infestations. Causal factors remain unclear but may involve soil-based pathogens, water stress during dry seasons and drought, high salt concentrations in soils, root predation by cicada nymphs, and attack by other insects and diseases on stressed plants[13].

The CSIRO, UQ and others are continuing to investigate the causes of dieback and other control opportunities. However a common factor with dieback appears to be drought and other factors that stress the plant.

Anecdotal advice suggests that the dieback is not expected to ‘jump’ species to Leucaena in a well-managed plantation arrangement where significant plant stress is avoided.

3.4.2 Herbicide controls

Chemical control is most effective after the wet season when soil moisture is still high, and may be effected by basal bark spray (suitable for stems up to 100 mm in diameter), cut-stump technique or foliar (overall) spraying, which is especially effective on seedlings and young plants up to 2 m tall as a follow-up to other forms of control. Soil-applied herbicides placed as close to the trunk as possible can also be highly effective, especially when applied before rainfall (i.e. October-November for central Queensland).

A range of herbicide treatments are available for the control of Prickly Acacia, however UQ (and its commercial development entity – BioHerbicides Australia) have been advancing significant innovations in the control of woody weeds with injectable chemical capsules. This approach can be used to control invasives such as prickly acacia and mesquite among others, and could clean up ‘escaped’ Leucaena as well. The company is currently only selling a bioherbicide for Parkinsonia control. However other chemical products are currently undergoing registration with

[12] https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/health-pests-weeds-diseases/weeds-diseases/invasive-plants/restricted/prickly-acacia
[13] Ibid

registration for glyphosate capsules nearing completion. There is potential to link UQ initiatives in this area with its sterile Leucaena project as part of an integrated plan to provide a containment safety net if required. It could also be used to manage unwanted competitors in a more targeted way[14].

Of the two projects undertaken by Desert Channels Queensland as part of Queensland Regional Natural Resource Management Investment Programme (2013 – 2016), one was a Prickly acacia Control Program in the Northern Lake Eyre Basin. A number of innovative ground and aerial applications of herbicides to control prickly acacia were pioneered. The Programme's final report states[15].

> *The most spectacular of these, a purpose-specific agricultural unmanned aerial vehicle (UAV) applies chemical to high density weed sites at a rate of 1 hectare every 8 minutes, an operating cost of less than $16/ha and with an application accuracy of +/-1 m. The main chemical applied, tebuthiuron, provides multi-year control of prickly acacia, allowing rehabilitation of these sites.*

3.4.3 Potential for mechanical control or harvesting

Research has indicated that the timing of any mechanical control (or potential harvesting) is critical to mitigate the potential spread of this weed. It was found that to achieve the best kills, control work should be done during the mid to late dry season (July to October), before the seed pods are dropped. Prickly acacia pods at this time contain seeds that are immature with little risk of spread. The plants are also suffering from moisture stress and there is less chance of their surviving any significant root damage[16.].

Large areas with a scattered to medium density of trees with trunk diameters less than 150 mm can be grubbed, cutting the root to at least 300 mm below the soil surface to prevent regeneration. Pushing and stick-raking of prickly Acacia are suited to large areas of medium-density infestation.

Chaining, or double-chain pulling, is especially useful for larger trees (greater than 40 mm trunk diameter) in established very dense stands of prickly acacia. Chaining is best suited to the second year of drought or before the first seed pod drop following drought. All forms of mechanical control require follow-up to check for regrowth. Thompson (1992) reported that while A. nilotica is technically suitable for wood-chipping using modern techniques, analysis concluded that it was uneconomical to harvest the plant commercially at the time[17]. A copy of this report was unable to be sourced, however it is noted that technologies and potential mechanical treatments have evolved further since.

3.4.4 Ongoing Government actions

The State and Commonwealth Governments have committed considerable efforts towards managing prickly acacia over an extended period. In March 2019, in a joint media release, both Governments committed $5 M each to assist with control of this weed over a five year period

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[14] Personal comment, Prof. Victor Galea , BioHerbicides Australia, UQ (1/8/2019)
[15] Attachment 3 Final Report Desert Channels Queensland Queensland Regional Natural Resource Management Investment Program 2013-14 to 2017-18, Desert Channels Queensland
[16] Prickly acacia, National Case Studies Manual Approaches to the management of prickly acacia (Acacia nilotica subsp. indica) in Australia, NHT, DNRME, CSIRO, NSW Agriculture, Dept of Agriculture of Western Australia, May 2004, Pp 17, 18
[17] Reported in - prickly acacia Infestation on the Mitchell Grasslands: Pasture Condition, Economic Effects, Prediction of Mass Establishment and Alternate Animal Production, Final Report: National Soil Conservation Program. Richmond Landcare Group, Richmond Australia

(through to 2023-24). The timing of the State's funding commitment is unclear[18]. The Commonwealth Government has since reaffirmed its commitment to providing its contribution[19].

3.5 Legal requirements

Prickly acacia is a restricted invasive plant under the *Biosecurity Act 2014*. It must not be given away, sold, or released into the environment without a permit. The Act requires everyone to take all reasonable and practical steps to minimise the risks associated with invasive plants and animals under their control, known as a general biosecurity obligation (GBO). At a local level, each local government must have a biosecurity plan that covers invasive plants and animals in its area and notes that everyone needs to take an active role in managing biosecurity risks under their control[20].

Any company wishing to commercially harvest prickly acacia would need to apply for a restricted matter permit for this purpose, if their activities breach the restrictions placed on prickly acacia. Biosecurity Queensland have previously issued permits for the commercial harvest of prickly acacia with conditions to mitigate potential for harvesting, transport and stockpiling of harvested material to spread prickly acacia seeds to new areas. As such it could be expected that Biosecurity Queensland would need specific details as to the process, localities, types of bins on trucks, routes and handling processes to properly assess the risks involved and how these would be mitigated/addressed. Proponents may also need to consider whether other entities in their supply chain may also require permits for their activities.

[18] Palaszczuk reneges on $5m prickly acacia funding, Queensland Country Life (18/6/2019) https://www.queenslandcountrylife.com.au/story/6220162/5-million-cop-out-palaszczuk-reneges-on-prickly-acacia-control/
[19] North Queensland getting back to business, Media Release, Prime Minister of Australia, 8 August 2019, https://www.pm.gov.au/media/north-queensland-getting-back-business accessed 19 August 2019
[20] Prickly acacia, Vachellia nilotica subsp. Indica (Benth) Kyal and Boatwr, Department of Agriculture and Fisheries, Biosecurity Queensland, Queensland Government, 2016.

4. Leucaena

Leucaena leucocephala is a small fast-growing mimosoid tree native to southern Mexico and northern Central America and is now naturalised throughout the tropics. It has a very fast growth rate with young trees able to reach a height of more than 6 metres in two to three years. The stems are from 6 mm to 400 mm in diameter and up to 10 metres tall[21].

During the 1970's and 1980's, it was promoted as a "miracle tree" for its multiple uses (stock forage, wood furniture, pulp/paper production, fuelwood, biomass for power generation and food). It has also been described as a "conflict tree" because it is used for forage production but spreads like a weed in some places. It is a legume (efficient at fixing nitrogen at a rate of in the order of 500 kg/ha/year) and has been promoted in several countries of Southeast Asia, most importantly as a source of quality animal feed, but also for residual use for firewood or charcoal production. Large plantations in Thailand as a plantation biomass crop are now establishing for the purpose of exporting wood pellets as renewable biomass fuel.

Leucaena has also been promoted as a fast-growing legume in Australia as a valuable feed option for drought-affected graziers in northern Australia (due to drought resilience associated with its deep root system). Pastures of this tropical forage tree are the most productive, profitable and sustainable pastures available to graziers in northern Australia. Graziers are adopting this pasture system with over 200,000 ha established at present[22].

In addition, Leucaena is very effective at reducing methane emissions from cattle when introduced as part of their food ration, and in sequestering carbon[23].

As noted above (with respect to Thailand), Leucaena has also been used for biomass production because of its reported yield of foliage which corresponds to a dried mass of 2,000–20,000 kg/ha/year, and that of wood 30–40 m^3/ha/year, with up to twice those amounts in favourable climates. It has a high woody stem yield under repeated cutting and has a suitable chemical composition for excellent heat generation on combustion[24]. In India it is being promoted for both fodder and energy[25].

Leucaena performs best in tropical climates (hot, wet summers and mild winters – average annual rainfall above 600 mm) and effectively stops growing when the average day temperature falls below 15°C. Leucaena will grow in a wide range of soils but is most productive in fertile (high phosphorus and alkaline pH), deep (>1 m), well-drained soils (tolerant to waterlogging). Leucaena performs best in soils with phosphorus above 20 mg/kg, sulphur above 5 mg/kg and good levels of trace elements, particularly potassium and zinc. It is susceptible to frost and so is more productive in frost-free areas[26].

Soils should have good structure and low risk of crusting. Soils high in magnesium or sodium may require gypsum to ameliorate this problem. Soils pH, should be above 5.5, and if required, lime should be applied to lift pH to 6 or above.

[21] Agnote, Leucaena – An extremely valuable browse shrub legume for cattle in the Top End, Northern Territory Government
[22] Conserving Leucaena ssp. Germplasm collection, Final Report, Dr. C. Lambrides, University of Queensland, April 2017, P4
[23] Prof. Neal Menzies, University of Queensland, Leucaena Conference University of Queensland 29/10/2018
[24] Dual use of Leucaena for bioenergy and animal feed in Thailand, S. Tudsri et al, Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand, 2018, P194
[25] How One Tree Could be the Answer to India's Fodder, Fuel Needs, A. Rajvanshi, The Better India, February 2019
[26] MLA at https://www.mla.com.au/news-and-events/industry-news/top-tips-for-planting-Leucaena/#

Future research should consider these climatic and soil factors to map the likely zones across North West Queensland that Leucaena will be most adapted too, and concentrate trial plantings in these regions.

Leucaena was included in trial plantings at the Cloncurry biofuels project site in the summer of 2017/18 to evaluate its adaptation and suitability to the soils and climate of the region. Those parameters did not seem to be limiting, however, early weed control, and intense selective pressure from resident wallabies, yielded no pertinent data, except that it should suit the soils and climate of the North West, if agronomic practices are adopted.

A number of research projects have also been undertaken with regard to control of Leucaena[27] which would tend to suggest that transitioning from a traditional Leucaena plantation to sterile plantations over time may present a viable near term opportunity for project development.

4.1 Varieties

Leucaena has been widely adopted in northern Australia and other tropical countries in the past 20 years, and has been the subject of considerable research.

In Australia four established commercial cultivars are available, all of which are susceptible to psyllid attack:

1. Peru is shrubby with good basal branching. Peru has been superseded by newer varieties.
2. Cunningham is more productive than Peru, however is a prolific seeder and is susceptible to psyllids.
3. Tarramba is taller, more tree like, produces less seed and has greater early seeding and cold vigour. It is susceptible to psyllid attack but grows sooner after psyllid damage.
4. Wondergraze is the latest release which has similar early seedling vigour and psyllid tolerance, but is bushier than Tarramba[28].

Very recently, a new psyllid resistant variety called “Redlands” has been released, and is showing very promising results, especially in higher rainfall regions where psyllid attack is likely [29].In addition to the above, UQ in partnership with Meat and Livestock Australia and the Australian Government, collected seeds from 87 species of Leucaena and planted at an orchard at Redlands for future seed collection opportunities and breeding programs. The trees have been thinned and coppiced to facilitate greater accessibility for those working the orchard. This orchard is now providing a core resource for the development of sterile Leucaena by providing diploid and tetraploid taxa that can be inter-crossed to make sterile triploids[30].

It is anticipated that release of a sterile Leucaena will address community and grazier concerns in the North West expressed during biofuels cropping trials at Cloncurry.

4.2 Cropping systems

In Australia Leucaena is typically cropped in a hedgerow silvopastoral system with almost all grown under dryland conditions and unfertilised. Plant establishment typically involves:

- Planting in double rows at 6 to 10 metre centres

[27] E.g. Evaluating a Novel Stem Applied Herbicide Capsule Methodology for Control of Leucaena and Peruvian Apple, L. Bradburn, UQ, 2019 and Preliminary screening for compatibility and efficacy of stem-injected chemical and biological herbicides to manage weedy Leucaena leucocephala, O. Cooray, UQ, October 2018
[28] MLA at https://www.mla.com.au/news-and-events/industry-news/top-tips-for-planting-Leucaena/#
[29] https://www.mla.com.au/news-and-events/industry-news/psyllid-resistant-redlands-Leucaena-set-for-commercial-launch/
[30] Conserving Leucaena ssp. Germplasm collection, Final Report, Dr. C. Lambrides, University of Queensland, April 2017, P2

- Keeping weed free until 1-2 m tall, then planting appropriate grass in the inter-row (Figure 4-1).
- First graze when 2-4 m tall (6-12 months).

Table 4-1 presents the results of five Leucaena cultivars/lines in Thailand grown for both high stem and leaf production to satisfy high biomass yield and the by-product of nutritious animal fodder.

Table 4-1 Cumulative production over seven years

Cultivar	Leaf (t/ha)	Woody stem (t/ha)	Total DM[1] (t/ha)	Heating value[2] (kcal/g DM)	Ash[2]%	Cultivar t.DM/ha.yr
Tarramba	24.1	173.6	213.1	4.7	2.18	25.7
Cunningham	19.2	131.1	169.4	4.6	1.93	25.6
Peru	14.0	90.3	116.7	4.6	2.06	24.7
KU19	27.2	161.1	212.8	4.6	1.72	24.3
KU66	27.8	167.0	215.1	4.6	1.75	24.2

Notes: 1 – Includes branches. 2 – One sampling date

Figure 4-1 Typical Leucaena establishment suited to grazing

Leucaena pastures are expected to last for 30-40 years without the need to replant. Rhodes grass and other locally suited grass species are generally planted in the inter-row.

4.2.1 Irrigation

The irrigation of Leucaena as pasture cropping can increase beef production by three to six times compared with dryland plantings[31].

There is little data on the specific irrigation water use of Leucaena production although there are suggestions that Leucaena in pasture cropping anticipated use in the order of 4 – 6 ML/ha[32].

In general, the ideal rainfall region is within the 600-800 mm annual rainfall band. In the North West Queensland region, this encompasses a reasonably significant area however moving west from Charters Towers (with estimated annual evaporation of 2000 mm), water demand increases to an estimated 2400 mm at Richmond, and 2800 mm at Cloncurry. Therefore, it could be concluded that to achieve reliable and productive Leucaena growth, irrigation would need to be included in a farming system west of Charters Towers. Depending on the location, soils and climate, this suggests supplementary irrigation requirements for Leucaena could be from 4-8 ML/ha per year to achieve optimal production. However irrigation supplies are likely to be a constraining factor. For the purpose of this report an average application of 5 ML/ha has been assumed.

In establishing plantations in drier environments or outside the wet season, drip irrigation can be installed to ensure germination and successful establishment of the newly planted Leucaena. As the crop grows and production increases, drip irrigation would supplement the summer wet season, and extend the growth and productivity of the crop longer into the dry season. This would significantly increase dry matter production and biomass yield.

An alternate irrigation method would be to establish the plantation and use a lateral movement travelling irrigator. With a high set machine, and regular harvesting of the Leucaena, this would contain the crop below the height of the irrigator. This system would be considered appropriate if looking to increase the productivity of the whole field, including the inter-row space and grow annual cash crops or pasture grasses. Further discussion on cropping systems is provided in section 5.3.

4.2.2 Fertiliser

Like all crops, Leucaena may benefit from fertilizer application, depending on the soil type where the plantation is established. Typically potassium (K), phosphorous (P) and sulphur (S) may be required to achieve preferred production levels[33]. However soil testing should guide all fertiliser application decisions. This soil testing activity should consider both the surface and rooting depth regions to ensure any impediments to establishment, and ongoing productivity are addressed. Given Leucaena also prefers neutral to alkaline soil types, and low salt or sodicity, the soil testing will reveal whether other soil is a leguminous and ameliorants may be required such as lime or gypsum. As previously mentioned, Leucaena may fix nitrogen at a rate in the order of 500 kg/ha/year. Therefore, it is unlikely that nitrogen based fertilisers would need to be applied.

A regular topdressing fertiliser program would be incorporated into the cropping system to ensure nutrient removal from harvesting is replaced and available to the crop to have un-impeded productivity. This program would be based on removal rates, and adjusted based on tissue testing to monitor for any emerging nutrient deficiencies.

[31] Production economics and environmental benefits of Leucaena pastures, Tropical Grasslands (2007) Volume 41, Shelton and S. Dalzell, School of Land, Crop and Food Sciences & School of Animal Studies, The University of Queensland, Queensland, Australia, P175
[32] Ibid
[33] Dual use of Leucaena for bioenergy and animal feed in Thailand, S. Tudsri et al, Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand, 2018, P196

4.3 Pests and diseases

The main threat to Leucaena establishment is early grazing by wallabies, kangaroos, pigs or cattle. Controlling this threat is vital for successful establishment. This issue was highlighted by the recent biofuels cropping trials at Cloncurry where the Leucaena was targeted by wallabies and kangaroos.

Soil insects such as termites and hoppers may also be a problem to emerging seedlings.

Another notable pest is the Leucaena psyllid (Heteropsylla cubana), which caused considerable damage in Leucaena world-wide, particularly in humid areas, during the 1980's and 1990's. In the Northern Territory, the effects of this pest are noticeable only during the mid to late wet season and the start of the dry season when the leaves develop, off-colour and marked (spotty appearance). Psyllids are also a key pest during the establishment phase of the crop. The pest is more likely to be an issue in the eastern regions being investigated, therefore psyllid tolerance will be a key task in Leucaena variety selection. The symptoms tend to disappear as the dry season progresses, without causing a great deal of visible damage. Growth retardation may be experienced during this period of infection. The psyllid is visible to the naked eye and can be found, if present, by shaking a frond onto a dark sheet of paper. The psyllids are around 0.5-1 mm long and are cream to whitish in colour[34].

4.4 Coppicing

To optimize production levels and promote coppicing it is suggested that Leucaena should not be harvested more frequently than annually to ensure satisfactory stem yields and stem diameter. At this frequency stem yields should be around 17.3 t DM/ha/yr and leaf yields around 2.3 t DM/ha/yr. The optimal time to harvest Leucaena for biofuel and fodder production would appear to be early in the dry season as stems and leaf dry quickly in the dry conditions, and the leaf can be used to supplement livestock during the period of poor pasture quality. Research in Thailand indicated that harvesting Leucaena frequently (every 9 months) produced low stem yields, which were thin (2.68 cm diameter), but high leaf yields, while delaying harvesting until 36 months increased main stem diameter and woody yields but markedly reduced leaf yields[35]. The results of these Thailand trials are shown in Figure 4-2.

[34] Agnote, Leucaena – An extremely valuable browse shrub legume for cattle in the Top End, Northern Territory Government

[35] Dual use of Leucaena for bioenergy and animal feed in Thailand, S. Tudsri et al, Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand, 2018, P195

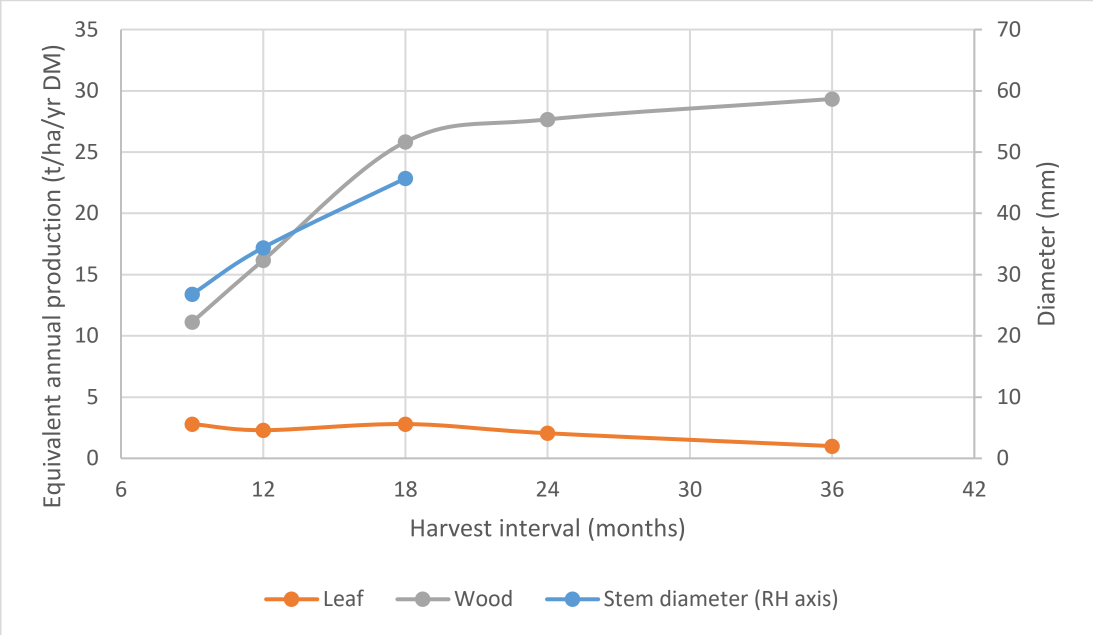

Figure 4-2 Impact of harvest interval on yield and stem diameter

Optimal time for harvesting may be constrained since wood processing mills require a regular supply of material. Timing of harvest may also be managed with regards to facilitating inter-row production of complimentary crops during the dry season to aid machinery movements and increase sunlight to the inter-row crop.

Other considerations include:

- Optimal economic sizing of the processing plant requires high capacity factors, which can only be achieved by operating through most of the year i.e. use of equipment and processing plant.
- Irrigation will mitigate dry season impacts on biomass growth and leaf yield.

4.5 Legal requirements

Leucaena is listed as a weed in New Guinea, Hawaii, western Polynesia and the USA. In Australia, it has naturalised in many areas and on a number of offshore islands. Unless heavily grazed or otherwise controlled, Leucaena can spread rapidly to adjacent areas.

Leucaena is not currently a prohibited or restricted invasive plant under the *Biosecurity Act 2014*. However, by law, everyone has a general biosecurity obligation to take reasonable and practical steps to minimise the risks associated with invasive plants and animals under their control.

Local governments are required to have a biosecurity plan that covers invasive plants and animals in their area. This plan may include actions to be taken on certain species. Some of these actions may be required under local laws[36].

The Leucaena Network have also published a code of conduct, which also details best management practices to ensure that Leucaena seed is not inadvertently spread off site, becoming a weed. This includes activities around plantings in relation to water courses, fencing and inter-row space management[37].

[36] Leucaena, Leucaena leucocephala, Invasive Plant, Dept of Agriculture and Fisheries, Biosecurity Queensland, Queensland Government, 2016
[37] www.Leucaena.net factsheet 8 “code of practice”

4.6 Analysis scenario

GHD considers that the following is the likely base case operating scenario, and has used this as the basis for the high level economic assessment.

- Leucaena will be planted in double rows at 6 metre centres.
- Irrigation will be required at an annual rate of 5 ML/ha.
- An allowance for regular top dressing of potassium and sulphur fertiliser is included.
- Harvesting will be carried out on an 18 month rotation interval throughout the year, except for two months during the wet season when access will typically be impaired.
- Harvest yields will be 24, 3 and 2 t/ha/yr DM for wood, leaf and waste respectively.
- Inter-row crops will be grown.
- Provision for protection from wallabies and kangaroos is included.
- Provisions for legal requirements and compliance with codes of conduct are included.

5. System concept fundamentals

This project concept involves the processing of prickly acacia in the first instance to recover biomass and generate a financial return from manufacturing wood pellets whilst assisting to address a serious woody weed issue. The intention is to replace the previously infested cleared areas (with access to irrigation water) with a Leucaena cropping system to manufacture both wood pellets and cattle feed pellets.

5.1 Wood pellets

Wood pellets are generally made from compacted sawdust, or as is being proposed in this case, wood chips. Pellets are categorized by their heating value, moisture and ash content, and dimensions. They can be used as fuel for power generation, commercial or residential heating, and cooking. Pellets are extremely dense and can be produced with a low moisture content (below 10%) that allows them to be burned with a very high combustion efficiency.

Further, their regular geometry and small size allow automatic feeding with very fine calibration. They can be fed to a burner by auger feeding or by pneumatic conveying and their high density also permits compact storage and transport over long distances. They can be conveniently blown from a tanker to a storage bunker or silo on a customer's premises.

The wood pellet market consists of two primary sectors: industrial wood pellets which are used as a renewable substitute for coal in power plants, and premium pellets used for heating pellet stoves and industrial boilers.

The conversion of large electricity plants to fire renewable biomass instead of coal is a key factor in efforts to achieve renewable energy targets and is driving increasing global demand for wood pellets (see Figure 5-1 below).

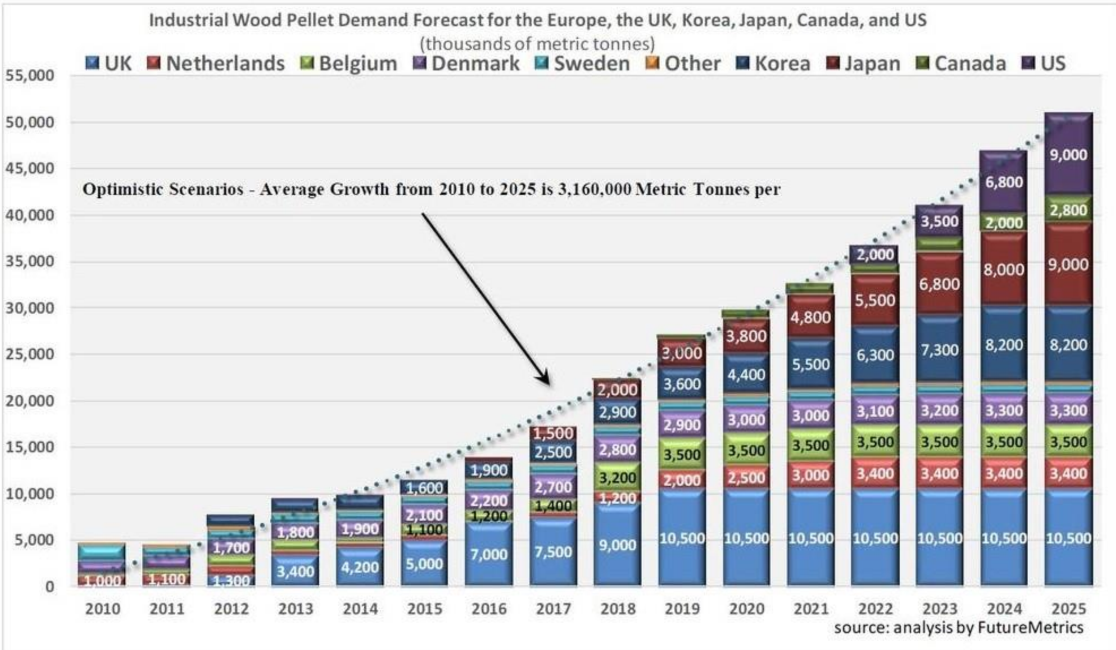

Figure 5-1 Actual and forecast global demand for wood pellets[38]

Future demand in Europe is expected to continue to rise driven by new regulations coming into effect in 2020, whilst major growth is expected in Korea and Japan in the 2020's.

[38] Note: Potential demand from China is not shown

Canada could also become a significant consumer of industrial wood pellets, as shown in Figure 5-1 given the recent announcement of a national carbon pricing system to price carbon at $50 per metric ton by 2030.

5.1.1 Wood pellet market and pricing

At a meeting with Trade and Investment Queensland and Sumitomo Forestry in July 2018, GHD was advised that wood pellets had been achieving only USD$95/t FOB twelve months earlier (July 2017), but were then achieving USD$155 to USD$160/t (spot price 2018). The benchmark rate indicated by Sumitomo at the time was circa USD$140/t FOB at 1.5% escalation, with Sumitomo itself looking to secure long term supply of 1 Mtpa and another 2 Mtpa for their partners iConn Japan.

Australia exported 97,497 tonnes of wood pellets (bone dry) during 2018, according to Forest and Wood Products Australia[39], with the export wood pellet market growing on a year-by-year basis.

Altus Renewables in Maryborough, Queensland can produce up to 125,000 tonnes of wood pellets a year, which are sold into a combination of domestic and export markets. Exported product is shipped to England, Denmark, Korea and Japan via port facilities at Bundaberg. They are also preparing for a project in Mount Gambier in southern Australia with planned capacity of 500,000 tonnes per annum.

Plantation Energy Australia (PEA) operated a facility at Albany, Western Australia with capacity to produce 125,000 tonnes of wood pellets a year from wastes from sustainable wood (Bluegum) plantations. PEA exported wood pellets to Belgium, with Japan and Korea earmarked as potential markets due to the shorter transport distance, however the company experienced operating difficulties and entered Voluntary Administration in late 2018. A deed of company arrangement has since been executed with control reverting to the company directors.

Export value of 3 Mtpa of wood pellets ex-Townsville or Karumba would potentially earn in excess of AUD$500M per annum (at $0.75 exchange rate AUD:USD), assuming that volume could be produced in the North West Queensland region. Global demand for wood pellets is continuing to increase. Notwithstanding this, it is expected there may be future demand onshore as power and other high energy input and emissions intensive industries in Australia seek to transition to cleaner, renewable energy sources.

The cost of wood pellets delivered to the end-user power plant obviously also depends on the cost to produce and the cost of pellet transportation (truck/rail/shipping/handling).

Most industrial wood pellets are produced for a specific buyer e.g. Sumitomo. These offtake agreements typically have negotiated prices that are sustainable for both parties and involve multi-year commitments. That is, prices that are not too high so as to erode the purchaser's margins and not too low to undermine profitable operation by the producer. The contracts typically include price adjustors and terms defining currency risk. The adjustors provide a mechanism for mitigating risk for both the producers and buyers from changes in critical inputs such as wood and shipping costs. Each pellet mill and offtake agreement will typically have unique characteristics and different pricing arrangements. Although most pellets are currently traded through bi-lateral contractual agreements and trading for industrial wood pellets on the spot markets is limited, the spot price informs supply and demand trends and foreign exchange effects.

Figure 5-2 shows historical and forecast Cost Insurance and Freight (CIF) spot prices for wood pellets delivered to Amsterdam, Rotterdam, or Antwerp in US dollars at exchange rates to the Euro calculated for each month in the series to October 2016. The recent fall in spot prices was

[39] https://www.timberbiz.com.au/pellets-are-a-growth-opportunity-for-australia/ , accessed 17/01/2020.

due to excess production capacity in industrial pellet markets and, to some degree, dampened demand for heating pellets due to several warm winters and therefore some heating pellet production available to the industrial sector. It was also a function of a strong US dollar versus the Euro and Pound at the time.

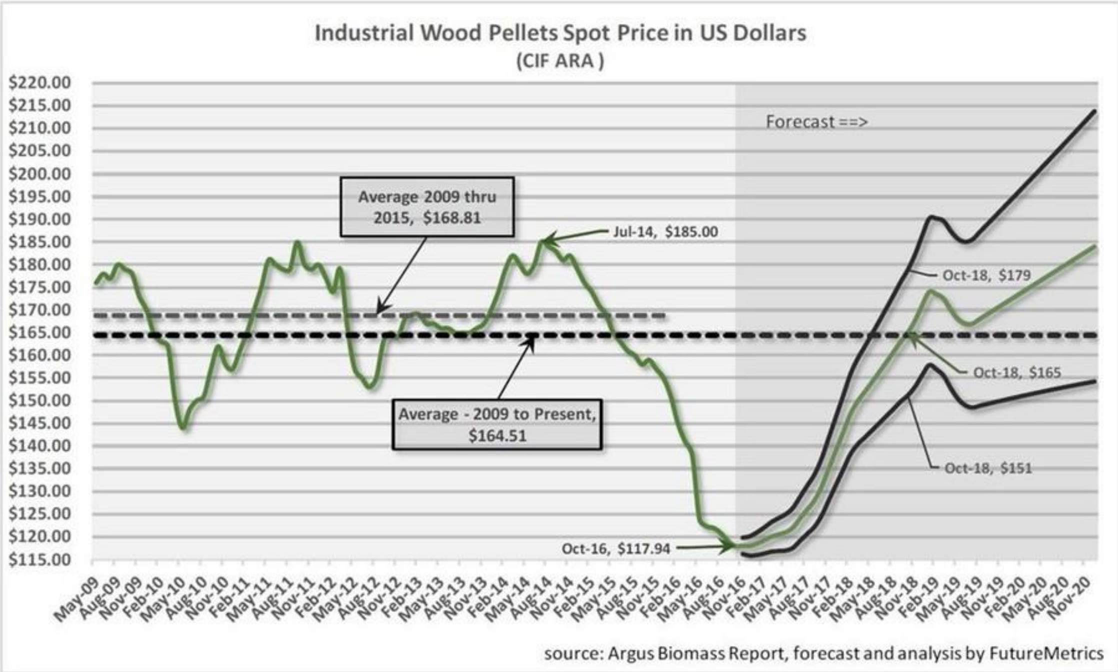

Figure 5-2 Spot price of wood pellets (to Oct 2016)

While there are many assumptions behind forecasts for both demand and spot prices, many often do not eventuate as currency exchange rates also influence prices. Supply could exceed demand or vice versa. However, the forecast increase depicted in Figure 5-2 was in fact quite accurate, as shown by the more recent data presented in Figure 5-3.

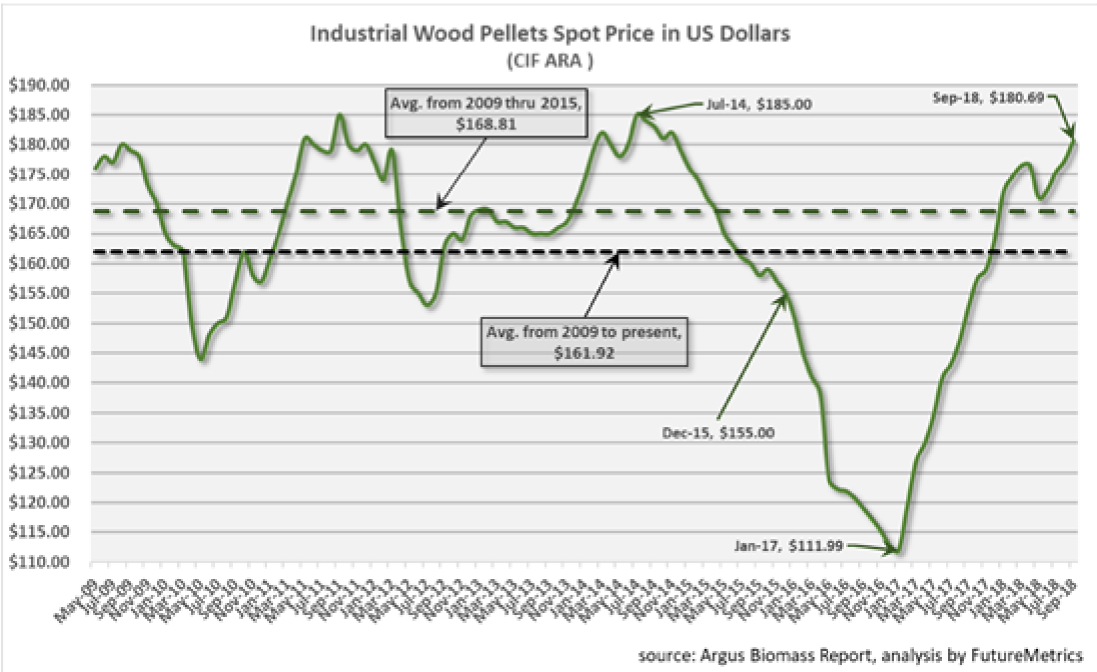

Figure 5-3 Spot price of wood pellets (to Sept 2018)[40]

The spot market matters because if the industrial wood pellet market has aspirations of becoming a true commodity market, spot and forward prices have to support producers and satisfy buyers.

Wood pellets are the main product in this project, and therefore the price of wood pellets drives project economics.

5.2 Cattle feed pellets

In addition to wood pellets production, it is proposed that the non-woody (leafy) material from Leucaena harvesting be diverted to a mill for processing into cattle feed pellets. Additives may be included for specific purposes during this process (e.g. minerals, vitamins etc.). Feed additives are controlled through the Australian Pesticide and Veterinary Medicines Authority (APVMA), with only registered products approved for use by stockfeed manufacturers[41].

Feed pellet production uses steam to condition the meal. The hot conditioned meal is then pressed through a die to form pellets, after which the pellets are cooled rapidly to make them durable. The modern feed mill is a highly automated and computer controlled manufacturing plant.

Manufactured feed products are supplied either in bulk by delivery trucks to larger scale livestock producers, or in bags to smaller scale producers and livestock owners. Throughout the feed manufacturing process, quality assurance steps require the products to be sampled and tested to ensure finished products meet minimum quality standards.

5.2.1 Cattle feed pellet market and pricing

Currently, feed costs constitute 60–70% of livestock production costs in Australia and technologies to improve nutrient and energy uptake can result in significant economic benefits. 11.5–12 million tonnes of animal feed are used in Australia per year (Stock Feed Manufacturers' Council of Australia), over 90% of which is manufactured domestically. While traditional feed grains are currently in short supply, there are significant quantities of agricultural residues (biomass) from crop wastes that contain significant amounts of energy. However, the amount of energy that animals can extract from this material is limited by poor digestibility of the material, which depends on the composition and structure of the fibres. Around 680 million tonnes of animal feed is produced globally each year (GVP of $370 billion, CAGR 3.7%), so a technology that improves nutritional value, and hence the dollar value, of biomass offers significant commercial opportunities.

As previously discussed, this project concept is to utilize the non-woody components of Leucaena cropping and harvesting for the production of stock-feed pellets. This would deliver significant commercial benefit to feed producers and farmers at a regional scale initially, with capacity to expand. Anticipated benefits include:

- Increased drought resilience
- More rapid weight gain/turn-off rate for cattle producers (and increased carrying capacity)
- Reduced carbon footprint from cattle operations (i.e. reduced methane production).

The price of cattle feed pellets varies due to multiple factors, including cost of additives, and ranges between around $250/tonne - $800/tonne. For conservative purposes, it has been

[40] Source: www.pellet.org/about/markets
[41] http://www.sfmca.com.au/info_centre/feed_milling_principles/

assumed that Leucaena pellets wood contain no feed additives and would be sold at an average price of $300/tonne ex-mill.

5.3 Leucaena production system

Considerable research has been undertaken as to preferred row spacing and this typically comes down to relative importance of the end use (i.e. biomass production versus production of leaf for stock feed).

Queensland Department of Agriculture and Fisheries (DAF) staff have developed best management practices to prepare, establish and manage Leucaena plantations in the high rainfall zones of Queensland. This could be adapted to the North West region after considering key impediments. Initially the region will need zoning assessment for appropriate climate and soil conditions. Once suitable areas are identified for plantations, soil tests should be undertaken on potential field areas.

Below are key steps that should be followed to successfully establish Leucaena. The main challenges are effective weed control, water availability, soil health and nutrition, and accurate planting equipment.

Establishment costs are estimated to be in the order of $350 – $450/ha for a bare field.

The Leucaena Network have published a series of valuable factsheets for new growers at www.leucaena.net. A “Code of Practice” has also been developed by the industry to assist with selecting and developing potential plantation areas, and controlling spread[42].

5.3.1 Field preparation

The area to be planted should be deep ripped, at 6-10 metre centres, the area should be cultivated to form a 1 metre wide seed bed “strip” for Leucaena planting. Based on soil test results, any required amendments such as lime, gypsum or fertiliser should be incorporated into the cultivated strip prior to planting.

Any pre-plant weed control, in particular for broad leaf weeds, should be managed with knockdown herbicides, cultivation or a combination of both over time.

5.3.2 Row spacing

The choice of row spacing depends on final use of plantation, machinery and management practices employed. When considering an inter-row fodder or cash crop, the row spacing may be increased to 8-10 metres to suit harvesting equipment. The wider spacing will also reduce establishment costs across the whole area due to the requirement for less cultivation, seed and fertiliser expenses. However, for this project planting is driven by production of biomass, so a narrower spacing will increase production per hectare, but results in a commensurate increase in establishment and production expenses.

5.3.3 Row alignment

Erosion risk during establishment can be reduced by sowing across the gradient. However, consideration should also be given to planting in an east-west orientation to increase light interception for inter-row planted crops.

[42] The Leucaena Network – Fact Sheet 8: Code of Practice, accessed from http://www.leucaena.net/assets/fs8---code-of-practice-vdec2018.pdf on 11 September 2019

5.3.4 Final seed bed

Final bed preparation can be achieved by using a “Rotocult” unit down the seed bed strips, which will deliver a final deep cultivation to 45 cm, prepare a 1 metre wide fine tilth seed bed, and bury any residual organic matter or weed seeds.

5.3.5 Variety selection

In higher rainfall eastern areas of the North West zone, consideration should be given to planting the psyllid resistant Redlands variety. Otherwise, the cheaper Wondergraze variety may suffice in the hotter, drier western regions.

5.3.6 Seed preparation and planting

Seed should be prepared by scouring and then inoculated with rhizobia (nitrogen fixing bacteria) of the appropriate strain, just prior to or at seeding if using an injected slurry. Ideally, seed will be sown into a moist seedbed, or irrigation be available to wet the seed row. Seed should be sown at around 1.5-2.0 kg/ha depending on seed size and germination percentage at a seeding depth of around 20-40 mm. Either a single or dual row planting configuration can be utilised. The use of a press wheel is recommended to ensure good seed to soil contact. A dual row system, with a drip irrigation line placed between the rows has been affirmed as the basis for plantation establishment for this study.

If the soils are prone to crusting, a line of gypsum could be spread directly over the plant row, to assist with seedling emergence.

5.3.7 Planting time

This is primarily determined by moist soil temperatures, and must be a minimum of 18° and rising for optimal results. Therefore, planting will generally occur mid-late spring. An underlying objective would be to have the crop emerged and established prior to heavy intensive summer rainfall events, which could hinder plant emergence. To assist with germination, establishment and growth, night time minimum temperatures should exceed 15°.

5.3.8 Irrigation

Irrigation is likely to be required to assist with plantation establishment and to achieve optimal biomass growth in areas receiving below 700 mm annually, and due to the high evaporation rates in North Western Queensland, irrigation requirements may be higher in areas considered suitable for plantation establishment further west. Moisture availability at planting and throughout establishment is very important due to the costs associated with this phase, and so irrigation will act as insurance against loss of investment.

Drip irrigation will be the most efficient at delivering the right amount of water to the seeds as they establish, and will be appropriate where a grassed inter-row area is to be established and managed around available rainfall only. If a more diverse cropping system is to be employed, such as growing inter-row cash crops over winter, flood or overhead irrigation systems would need to be incorporated into the system.

5.3.9 Weed control

Post sowing and prior to emergence of the crop, the seedbed area should be sprayed with Imazethapyr at 70-140 g/ha. If any weeds have emerged, or emerge prior to the Leucaena, these can be sprayed with a knockdown herbicide such as Paraquat or Glyphosate.

In-crop control of grass weeds can be achieved with selective herbicides such as Haloxyfop, and broadleaf weeds can be managed with Bentazone (Basagran). Any other weed control required would need to be done with directional knockdown sprays that do not contact the Leucaena, or employment of mechanical agricultural practices like cultivation, slashing or mowing.

5.3.10 Insect control

If psyllids are likely to be an issue, this will influence the variety of Leucaena selected. In areas where termites may be present, or grasshoppers are a threat, active control will be necessary if chewing symptoms are observed during establishment. Termite activity in some young plants had been observed during Leucaena establishment and growth trials in the Gascoyne, northern Pilbara and Kimberley regions of Western Australia, which was controlled by up to two applications of termiticide. Follow up treatments post-establishment have not been necessary[43].

5.3.11 Other pests

Fencing and other control methods need to be considered to reduce pressure from wallabies, kangaroos and pigs.

5.3.12 Stock introduction

If stock grazing is proposed, this is usually introduced after the Leucaena has reached two (2) metres in height.

5.3.13 Ongoing nutrition

Harvest removal and loss of nutrients needs to be considered on an ongoing basis. Key nutrients include calcium, phosphorus, potassium, sulphur and zinc. An individual fertiliser program would be recommended for each field depending on soil and plant nutrient tests, and product removal rates. Nitrogen addition is not required as Leucaena is a legume, and when seed has been appropriately inoculated prior to planting with nitrogen fixing rhizobium bacteria, biological nitrogen fixation satisfies ongoing nitrogen demands.

5.4 Harvesting and transport

In Short Rotation Woody Crop (SRWC) plantations in Europe and North America, crop harvesting is typically the largest single cost factor (~1/3 of the final delivered cost); harvesting, handling, and transportation combined account for 45-60% of the delivered costs[44]. A similar figure is provided in the Irish Best Practice Guidelines for Short Rotation Willow coppicing[45]. Although these figures are based on willow and poplar species, they are also likely to provide a useful guide for Leucaena.

Since 2008, significant research into equipment and procedures has been conducted to reduce harvest costs and increase product quality. However, the preferred solution is often bespoke and governed by particular circumstances, such as harvest area, plant characteristics, planting density, climate, harvest period, local economics, etc. The optimal solution for small scale willow coppice harvesting for fuel in Belgium, or eucalypt coppicing for pulping in Brazil, may not be the optimal solution in Australia. However, learnings from this research and trials can be used to evaluate options in Australia.

Australia does have a strong large scale agricultural systems development history, which includes expertise in harvesting systems. Although there is only a little experience with SRWC

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[43] Pers comment, Clinton Revell, DPIRD WA, 16 October 2019.
[44] Buchholz, T., and T. A. Volk. 2011. Improving the Profitability of Willow Crops—Identifying Opportunities with a Crop Budget Model. BioEnergy Res. 4(2):85–95.
[45] B. Caslin et al, Irish Best Practice Guidelines for Short Rotation Willow coppicing, September 2010

harvesting, Australia has world class experience in sugarcane harvesting and cane harvesting machine design, which can be applied to harvesting of Leucaena.

The following sections describe the requirements for Leucaena harvesting, different procedures and their advantages and disadvantages, harvesting equipment options, and harvesting costs.

5.4.1 Leucaena harvesting requirements

Harvesting requirements are dictated by the plant characteristics and further processing requirements.

Plant characteristics

To enable Leucaena to be coppiced for 20 years or more, it is important to minimise stump mortality. A mortality rate of 1% and a harvest interval of 1.5 years would reduce the number of productive plants by 13% over 20 years. If the mortality rate was 2%, over a quarter of the initial crop would have died after 20 years.

For Leucaena, stump mortality due to coppicing can best be controlled by minimised stump damage and cutting at a controlled level above the ground[46]. Stump damage can be reduced by using equipment that produces a clean cut with a shearing or sawing action rather than grinding. Damage can also be reduced by minimising splintering, which can occur when the stems are pushed excessively sidewards before cutting. Some plants, such as Willow, seem to be tolerant to splitting damage[47], whereas others like Mallee seem to be sensitive to stump damage[48].

Coppicing too low may affect the plant's ability to form new stems, and can allow soil to cover the newly cut surface.

Coppiced plants regrow multiple stems which can develop to an average diameter of around 50 mm after 18 months. Harvesters should have the capacity to cut a number of large stems to accommodate more vigorous individual plants and any increases to the harvest interval.

Yields are expected to be 80 wet tonnes per hectare, if harvested at 18 month intervals. Stems are expected to grow to more than 4 m tall in that time.

Additional work will be needed to quantify the hardness of the stems, the energy required to cut the stems and the influence on mortality rate of different harvesting methods.

Product requirements

A key feature of Leucaena is that all of the plant can potentially be utilised for either animal feed, wood fuel product or energy generation at the processing plant. The harvester can therefore cut the whole plant for subsequent separation of the products, or be designed to separate the products in the field. The advantage of the latter approach is that leaf for animal feed could be left in the field if it becomes uneconomic to process in the future.

It is preferable that harvested stems do not contact the ground, to avoid soil contaminating the product and increases in wear and tear on processing equipment.

The moisture content of the harvested material is also important. If the chipped woody biomass is to be sold as fuel it should have a moisture content less than 30%, for the following key reasons;

[46] Short Rotation Eucalypt Plantations for Energy in Brazil, IEA Bioenergy Task 43, 2011
[47] Development and Deployment of a Short Rotation Woody Crops Harvesting System Based on a Case New Holland Forage Harvester and SRC Woody Crop Header, State University of New York College of Environmental Science and Forestry, 2014
[48]

- They are heavier and can be more expensive to transport.
- They have a lower fuel value on a tonnage basis.
- They are harder to burn and make boilers 2-5% less efficient.
- Biological degradation can cause losses of up to 20% of dry matter over a storage period of 7 months.

Drying chipped wood is more problematic than drying stems because the air circulation in storage piles is worse and stems can conduct moisture to the cut surface which is generally located at the exterior of the pile. Damp conditions and poor circulation at the centre of chip piles encourage bacterial activity which produces elevated temperatures further accelerating the biological activity. Reductions in dry matter content can be higher than reduction in moisture content. Piled stems tend to lose moisture with little loss of dry matter.

Woodchips can be actively dried relatively quickly to avoid the loss of dry matter. However, the hot and dry climatic conditions in the area being considered are likely to offer potential to minimise these costs.

Leucaena is an evergreen plant, which means that it will always be harvested with leaf material. A potential issue with cut and chip harvesting of Leucaena is how well the leaf and wood material can be separated.

A sugar cane harvester removes the leafy tops before the cane is cut and chopped into billets approximately 100mm long. Dead and loose leaf material is separated by a blower within the harvester and discharged onto the ground as cane trash. The blower speed can be adjusted to balance the amount of leaf removed from the billets and the billets ejected with the trash. The differences between Leucaena and sugar cane harvesting that could affect the separation are:

- Sugar cane leaf is stringy.
- Leucaena will be chipped into smaller pieces, which will increase the amount of maceration of the Leucaena leaf
- If good separation cannot be achieved in the field, the wet leaf and wood chips will be piled together in the collection trailers and transport trucks for several hours potentially causing the leaves to sweat and become even harder to separate.

Willow and poplar are the most common SRWCs and both are deciduous. The difference in the harvest product can be seen the following two figures. Figure 5-4 shows the woody chips produced when willow is harvested during the dormant seasons. These chips meet ISO standards for size distribution and ash content.

Figure 5-4 Harvesting of coppiced willow without leaf

Figure 5-5 shows the resulting green product when willow is coppiced during the growing season. This was from a first coppicing where there is a higher leaf to wood ratio than for subsequent coppicing. However, it does illustrate the impact of the leaf on the harvested product. An example of growing season harvesting of poplar coppicing can also be seen in the following video at [www.youtube.com/watch?v=uLnSE1BiELA.](www.youtube.com/watch?v=uLnSE1BiELA).

Figure 5-5 Coppiced willow with leaf harvested during the growing season

Separation of leaf from wood was identified as an issue[49] in the oil mallee project at Narrogin, Western Australia [50]. In this case the leaf was wanted to be separated from the wood to be processed to extract oil. Initial trials of air classification produced limited separation effectiveness. It is understood that further investigation was discontinued due to other priorities.

The potential risks for the plant are:

- Too much leafy material in the wood may affect the classification and hence value of fuel pellets or chips.
- Too much wood in the leaf may impact the value of the feed product.
- Revenue will be reduced if a separation process creates a leaf stream, and wood stream and low value "in between" stream that consists of wet leaves and small wood particles

5.4.2 Harvesting operation options

Pathways

The two pathways generally considered for SRWC harvesting and collection operations are:

- Cutting and chipping in the field, then pneumatic or mechanical transfer into tractor pulled collection bins which transfer the material to a truck/train loading point, then transportation to the processing plant.
- Cutting stems in the field, then discharging into a collection trailer to transport to a bundle aggregation point, loaded onto truck/train for transportation to the processing plant. The bundles are generally stored for 4-8 weeks at one point to enable the stems to dry to 30% moisture before they are chipped. The leaf material is generally discarded in this process.

The two pathways are illustrated in Figure 5-6 and the options at the stages of cutting, collection and transportation to the plant are set out in Table 5-1 below.

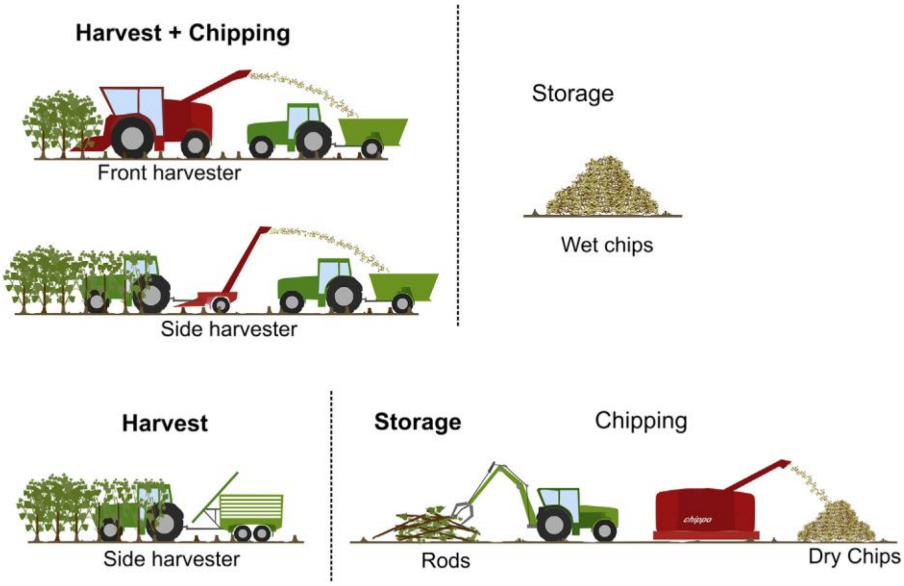

Figure 5-6 Harvesting and chipping pathways[51]

[49] Discussion with Glen Conway, Sept 2019.

[50] Integrated Biomass-Derived Power Generation in the Lachlan Shire, John Larkin and Bernard McMullen, RIRDC Publication No. 14/052, June 2014

[51] Comparative analysis of harvesting machines on an operational high-density short rotation woody crop (SRWC) culture: One-process versus two-process harvest operation, G. Berhongaray, O. El Kasmioui, R. Ceulemans, University of Antwerp, 2013

Table 5-1 Harvesting options

Cutting	On-site Collection	Transport
Chip Output Single stream or dual streams (usually product and trash)	Number of products collected Collection equipment and capacity Distance to drop off point or points.	Loading method Truck and trailer capacity Trailer logistics (drop off or stay with prime mover) Discharge method (tipping or walking floor)
Stem Output Discharged to trailer Discharged to ground	As above plus Stems collected from ground or on trailer Stem storage for drying then chipping required or not	Stem transport or chip transport

Chip quality is generally better when the wood is chipped before drying because there is less splintering and breakage. The chipping power requirement is also less.

Cutting

Recent studies and trials have indicated that the cut and chip option using a modified forager harvester is the lowest cost option for large plantations. Stem harvesting and later chipping is approximately $8-$10/t more expensive, but is often preferred if dried wood chips are to be sold for fuel due to their higher heating value and a market preference for drier chips.

The harvest and chip option has been used as the basis for this study due to the lower cost, the suitability of wet chips for subsequent pelletising and the potential of the climatic conditions to minimise chip drying costs if required.

Collection

There are a variety of options for receiving the material from the harvester, moving material from the field to a landing/despatch location and then loading it into a truck for road transport. Options of collection vehicles considered in an American report on trials to reduce SWRC harvest costs[52] are summarised in Table 5-2 and pictured in Figure 5-7.

[52] Development and Deployment of a Short Rotation Woody Crops Harvesting System Based on a Case New Holland Forage Harvester and SRC Woody Crop Header, State University of New York College of Environmental Science and Forestry, Oct 3, 2014

Table 5-2 Summary of collection vehicles considered in American trials.

	Equipment				
	Small-Medium Dump Wagons/Carts	Self-Propelled Wagons	Cane Wagons	10-Wheeled Trucks	18-Wheeled Trucks
Capacity (Mg_{wet})	4-8	4-5	10-12	12-14	12-22
Operating Cost	Low	Medium	Medium	Medium	High
Local Availability	High	Low	Very Low	Medium	High
Able to Load Semi-Truck at Field Edge	No	No	Yes	No	N/A
Maneuverability	Fair-Excellent	Excellent	Excellent	Fair-Good	Poor
Cycle Time	Good	Poor	Excellent	Good	Poor
Operability on Soft Ground	Excellent	Excellent	Good	Poor	Impossible
Estimated Range to Unloading	< 1-3 km	< 1-3 km	<1-5 km	< 50 km	> 2 km
Durability in SRWC, Especially Related to Tire Punctures	Variable	Good	Excellent	Fair	Poor
Primary Limitations	(1) Capacity (2) Wheel Spacing	(1) Capacity (2) Cycle Time	(1) High Center of Gravity	(1) Tire damage (2) Sensitive to Field Layout and Headlands	(1) Turning radius (2) Effective Capacity
Example	Richardton 960	Oxbo Pixall Big Jack (harvesting head removed)	Broussard 4408	Mack DM 690S Mack CH613	

Figure 5-7 Pictures of collection vehicles considered in American trials.

Options for loading trucks at the delivery point include:

- Direct discharge from collection trailers to transport trucks
- Discharge to a temporary pile and loading with a front end loader
- Discharge to a temporary pile and loading with a blower fed by front end loader.

The options for transport trucks to deliver the material to the processing plant include:

- Truck and trailer configuration for transport and minimising discharge turnaround time
- Whether the truck drops off empty trailers and picks up full ones, or stays connected to the trailers and waits for them to be filled.

The best matched and co-ordinated system has the potential to significantly increase productivity and therefore reduce costs. Time and motion studies of harvesting trials using a cut and chip system have shown that the effective harvest capacity of can be as low one third of the capacity of the harvester. This was due to a range of delays including:

- Harvester and collection vehicle caused delays,
- Headland turns and delays
- Landing area and short term storage delays

Good field layout and logistic design can minimise delays, improve equipment utilisation. Although each handling process adds costs for equipment, labour and fuel, this may be offset by productivity improvements. An evaluation of the two different methods shown in Figure 5-8 for coppicing of 400,000 tpa (DM) of willow and delivery to a central plant showed a reduction in cost of 35% from $52 to $35 USD(2014)/t (DM).

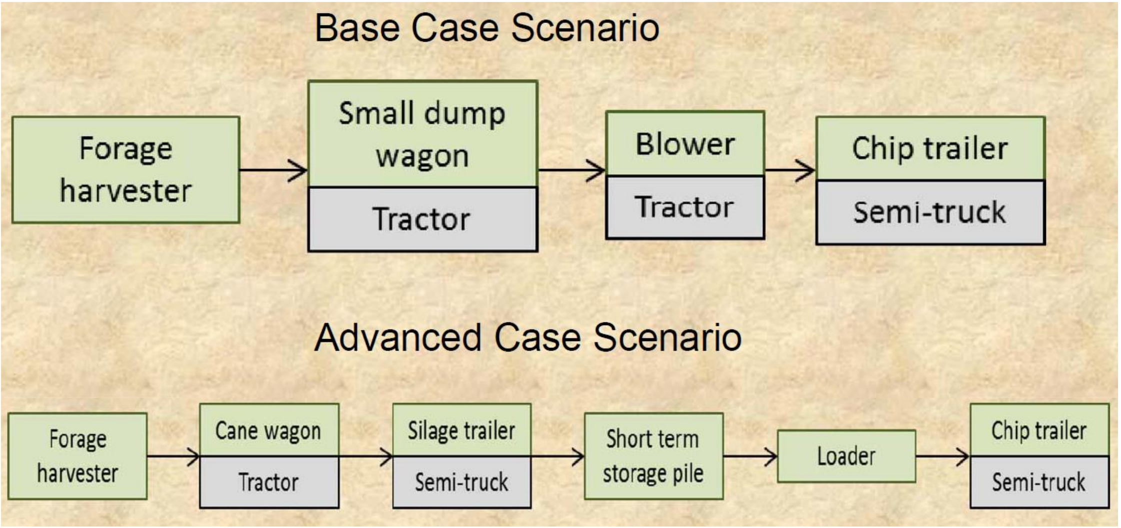

Figure 5-8 Alternative scenarios for SRWC harvesting study

For this study it has been assumed that the forage harvester will load into tractor pulled wagons that have a capacity of 15t of chipped material. This may be a single large wagon or two smaller 7-8t wagons. These will discharge to a storage pile at a landing area. Double road trains will be loaded by a front end loader and will travel to a processing plant on well maintained sealed roads.

A recent Leucaena workshop at UQ[53] flagged the potential to increase the productivity of existing large areas of Leucaena where it has become too ‘lanky’ for cattle to graze effectively. As a consequence GHD has provided The Leucaena Network with contact details for Canetech Pty Ltd to further explore harvester development and potential opportunities.

5.4.3 Processing plant location

A further consideration is whether the processing plant should be located at the plantation site, or at a site with better transport connection, utilities and access to labour resources.

The relative advantages of the two options are set out below.

[53] An environmentally friendly option for forage, fuel and fibre production in Northern Australia, 26 September, 2019

Processing plant on plantation	Centralised processing plant
Minimises transport distance of wet chips Reduces one cycle of loading and unloading wet chips Better land availability	Higher potential to connect to a grid power supply Closer to main transport routes Potential to become a large facility serving multiple plantations Potential to share existing facilities Easier to accommodate workers

The processing plant has been assumed to be an average of 50 km from the landing areas.

5.4.4 Forager chipping harvesters

There are a number of forager harvesters that have been developed for SRWC. Two Australian prototypes and one commercially available international option are described in the following sections.

Case New Holland Forage Harvester

There are a number of European designed cut and chip harvesters that have been adapted for SRWC. Ny Vraa from Denmark manufactures a unit, JF-Z200 HydroE, that operates from the side of a 250 h.p. tractor. However the most studied over the past ten years is one commercially available from Case New Holland (CNH). This unit is based on the CNH FR-9000 forage harvester range with their 130_FB biomass coppicing head attachment. The FR 9000 Forage Harvester range are rated between 395 and 768 h.p.

Figure 5-9 Case New Holland forage harvesters including with coppice head.

The coppicing head attachment has kits for both willow and poplar harvesting. It is likely a kit could be developed for Leucaena. The CNH product description for the header states:

> *This header transforms the FR Forage Harvester into a single pass, cut-and-chip harvesting system for short-rotation woody crops. The resulting woody biomass is used for the production of biofuels and traditional wood and fiber products. Large, quarter-inch-thick, high speed, carbide-tipped saw blades cut cleanly and quickly through tree trunks. Next, two slow-turning vertical gathering towers feed the severed trunks into the horizontal rolls that, in turn, feed the trunks butt-end first into the massive cutterhead. In addition to working faster than other harvesting methods, the 130FB also leaves clean stubble for maximum regrowth*

The CNH unit is designed for large scale SRWC sites and has been the subject of a number of trials and studies in both Europe and North America. For example, the US Department of Energy funded an evaluation of the harvester by State University of New York at Greenwood Resources' tree farm at Boardman in Oregon, USA. The Boardman tree farm is a 23,500 acre poplar farm that produces timber logs, pulp logs and biomass. For biomass production, poplar trees are planted in rows at 1100-2200 per acre and are harvested at 2-3 year intervals.[54]Video of the harvester in operation can be seen on www.youtube.com/watch?v=uLnSE1BiELA.

The forager does not have a blower mechanism to separate the leaf from the wood, so all material would be discharged into the same wagon for later separation at the pellet plant.

Adapted sugarcane harvester[55]

A sugarcane harvester was adapted to harvest Leucaena in 2009 by Canetec Pty Ltd, a manufacturer of sugarcane harvesters and harvesting equipment based in Bundaberg, Queensland.

The 2009 prototype was a single build and no further machines of this type have been produced. The harvester is shown in the following three figures.

Figure 5-10 Canetec Leucaena Harvester (2009 Build)

[54] Boardman Tree Farm, FRA Fall Meeting Presentation, September 2012
[55] Source: Canetec Pty Ltd (August 2018)

Figure 5-11 Main drum 2009 Leucaena Harvester build

Figure 5-12 2009 Model Canetec Leucaena Harvester in operation

Canetec has advised that the design would need to be updated to support a new machine build and specific plantation characteristics and harvesting conditions would need to be considered.

The simplest pathway is expected to be adapting a current AX5000 / YT6000 Sugarcane Harvester to a Leucaena Harvester.

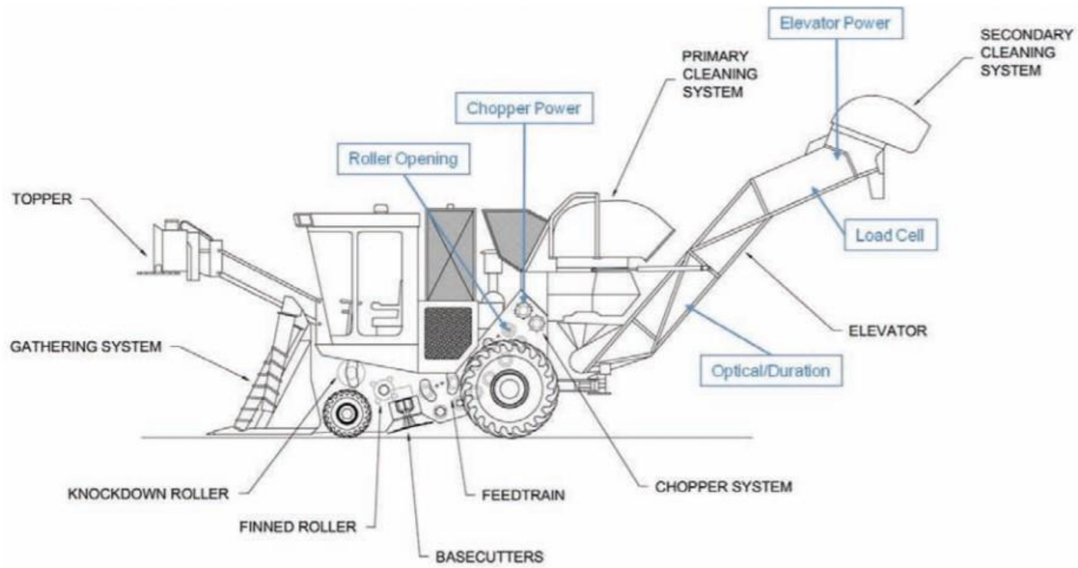

Figure 5-8 Typical sugarcane harvester

Canetec advise that their preferred harvesting approach for Leucaena involves:

- Straight rows with accompanying haul-out or tractor with bin for collection
- Target speed 3-4 km/hr when harvesting
- Drive over plant, stems bent over by push bar
- Stem base cut out by saw blades
- Stems processed up rollers to shredder
- Shredded into 10-40 mm pieces
- Offloaded by thrower and spout.

Other key elements proposed in a modified harvester include:

- 200 mm set height above ground for basecutter (adjustable – multi-bolt in tilting basecutter style)
- Sawblades in place of basecutter
- Shortened roller train (design for four roller chassis)
- Separation of light leafy matter for cattle fodder, heavier woody matter for export as biofuel.

This aspect would be further explored in a development phase, however the most efficient approach is considered (at this stage) to be by sorting after shredding and collection.

Figure 5-13 Canetec Leucaena Harvester – Basic Mock-up Render

5.4.5 Bionic-Beaver woody biomass harvester

Biosystems Engineering Pty Ltd has developed a harvester suitable for either single stem or multi stem SRWC plantations. It was given the trade name Bionic-Beaver. The unit was developed with funding support from ARENA. Rather than continue the development in Australia, an agreement was established with Caterpillar to market the unit in Brazil. Soon however, Caterpillar withdrew from the timber market and development has since stalled. Biosystems Engineering are currently considering a new application for funding to continue the development[56].

A key feature of the Bionic-Beaver is that the stems are held vertically while they are cut. This avoids splitting of stems from being pushed forward before cutting. This was identified during the Oil Mallee project in Narrogin, as a requirement to minimise mortality loss of coppiced Mallee. The stems are then elevated while being held vertical and then lowered into a chipper. An advantage of this approach is that the harvested plant does not come into contact with the ground and pick up any dirt. This in turn provides a clean product and reduces the wear rate on the chipper and associated power increase and deterioration of chip quality when operating with blunt knives. Chipped material is discharged through an elevated nozzle and can be directed to a collection trailer.

The unit is designed to coppiced material as well as single stem tress up to 150 mm diameter and up to 12 m tall.

A chain flail could be added to remove the leaf material which could be collected separately[57].

[56] Private conversation with Richard Sulman, August 2019.
[57] Ibid

Figure 5-14 shows a four wheel articulated unit, however the next iteration was proposed to be based on a larger 500 HP tracked unit. The tracks would reduce soil compaction and enable the harvester to operate in wetter conditions.

Figure 5-14 Bionic Beaver prototype harvesting larger single stem trees

5.5 Harvesting prickly acacia

5.5.1 Harvesting requirements

Given the government funding commitment to control prickly acacia there would appear to be the opportunity to consolidate 'pulled areas' of prickly acacia and harvest it for produce fuel

Harvesting of prickly acacia can be done either to:

- Clear the Leucaena plantation site, or
- To source a supply of wood for the pellet plant while the Leucaena crop is getting established, or
- Supply additional wood to enable an addition to, or expansion of, the pellet plant.

To clear any prickly acacia on the plantation site, the whole tree including the stump will need to be removed. For off-site harvesting, the stump can remain in the ground, however it should preferably also be killed to prevent the plant regrowing from the stump.

The following options were considered for clearing of prickly acacia. These were considered because they are based on either using a harvester similar to that proposed for Leucaena, or employing chain clearing which is stated to be the lowest cost method, particularly for areas of high infestation.

Table 5-3 Selected options for clearing prickly acacia

	On the plantation site	Away from the plantation site
Recovering the wood	1) Cut and chip using harvester. Haul to landing area, load onto trucks and transport to pellet plant. Separately stick bar the area to remove the stumps, pile up and burn. 2) Chain clear the area. Collect the fallen trees and feed into a diesel powered chipper. Manually trim unwanted bits (soil covered stumps, right angle branch connections that may jam the chipper). Haul chips to landing area, load onto trucks and transport to pellet plant. Pile up and burn residuals. 3) Chain clear the area. Collect the fallen trees and feed into a diesel powered mulcher. Haul mulch to landing area, load onto trucks and transport to pellet plant. Pile up and burn any residuals.	4) Cut and chip using harvester. Haul to landing area, load onto trucks and transport to pellet plant. Apply poison to stumps. 5) As for 2) but without piling up and burning residuals. 6) As for 3) but without piling up and burning residuals. Chain clear the area. Collect the fallen trees and feed into a diesel powered mulcher. Haul mulch to landing area, load onto trucks and transport to pellet plant. Pi
Not recovering the wood	Chain clear the area, pile up and burn.	Spray herbicide onto trees using drones.

Three features of prickly acacia that are not favourable to harvesting are:

- The irregular plant locations as shown in Figure 5-15, especially compared to the managed design of a plantation. This makes movement of a harvester less efficient and of collection vehicles even more so. Instead of collection wagons, Canetech has proposed that one cubic metre bags filled by the harvester and left for later collection may be more suitable. However this will also be more expensive than plantation harvesting.
- The propensity for tyre damage to haul-out equipment. Tracked vehicles of vehicles fitted with forestry grade tyres will be required.
- The unprepared travel paths for all vehicles and distances to well maintained roads.

Figure 5-15 Example of the random location of prickly acacia.

5.5.2 Harvest Equipment

The three cut and chip harvesters proposed for Leucaena are all likely to be suitable for prickly acacia. Canetec have suggested some modifications to the Leucaena harvester to enable it to cut the thicker stumps. These are included in Appendix B. CNH may be able to produce a prickly acacia kit to better adapt the header the new application just as they produced a poplar kit.

Another harvester was trialled by the Queensland government as part of the War on Woody Weeds programme. This was called the Marshall Tree Saw and is shown in Figure 5-16.

Figure 5-16 Marshall Tree Saw

The Marshall Tree Saw is an American-built mechanical device that is attached to a bobcat or loader for woody weed treatment. Although it is called a saw, it uses a shearing action, powered by two hydraulic rams, which cut through the stem of the plant. The device is also equipped with a sprayer which may be used to immediately treat the cut surface of the plant with a herbicide and diesel mixture.

Field trials in 2017 show cut rates of 300-400 trees/hour as shown in Figure 5-17 below[58]. This corresponds to a tree every 8-12 seconds, which appears very quick when including time for moving and cutting. Cost were reported to be between $40 and $400/ha. This corresponds to 60-80 cents per tree.

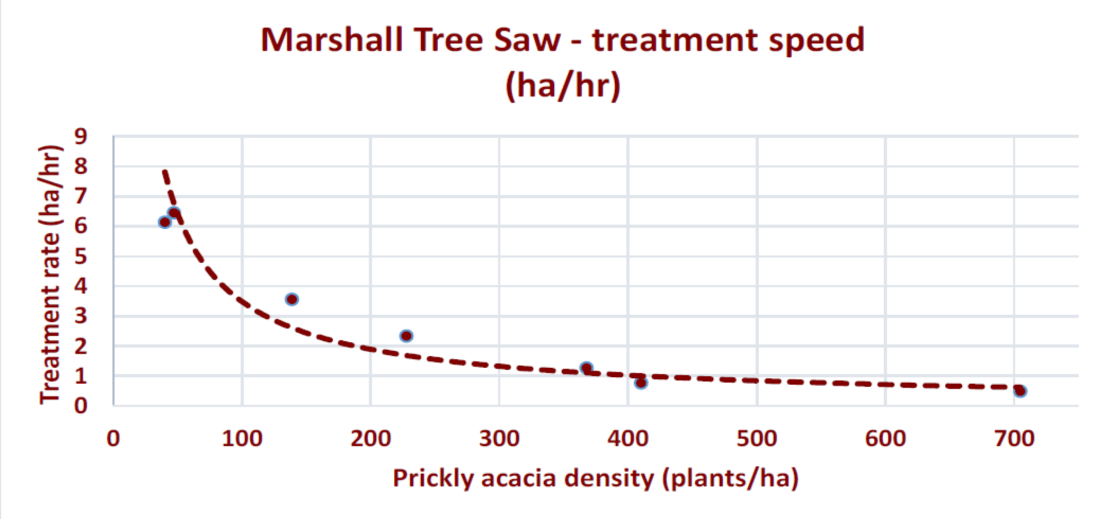

Figure 5-17 Marshall Tree Saw trial results on prickly acacia from 2017.

5.6 Harvesting and logistics costs

5.6.1 Leucaena

Harvesting and haul out.

The estimated costs associated with harvesting using the modified Canetec sugar harvester and the CNH forage harvester are shown in Table 5-4. The harvester nominal rates have been reduced by at least 15% to allow for delays. The CNH harvester's effective rate has been reduced to the maximum value recommended in the EcoWillow 2 spreadsheet[59].

Estimated costs for a haul out unit consisting of a 150 h.p. tractor and a 15t wagon are also shown. Operating hours are based on harvesting 50 hours/week for 10 months each year.

Table 5-4 Harvest equipment cost estimates

	Canetec Harvester	CNH Harvester	Haul out unit
Nominal capacity	20 tph	>100 tph	15 t
Effective capacity	17 tph	70tph	
Capital cost	$450,000	$800,000	$275,000
Operating hours/yr	2150	2150	2150
Engine capacity hp	225	685	150
Average engine load	70%	70%	40%
Fuel consumption L/h	41	126	16

[58] Factsheet - Marshall Tree Saw - a mechanical control option for prickly acacia, Southern Gulf NRM and the Department of Agriculture and Fisheries through the Queensland Government funded War on Western Weeds initiative, 2017
[59] https://farm-energy.extension.org/ecowillow-2-0-an-updated-tool-for-financial-analysis-of-willow-biomass/ accessed 9 September 2019

	Canetec Harvester	CNH Harvester	Haul out unit
Life yrs	7	8	12
Labour Costs $/hr	$50.00	$50.00	$40.00
Annual Maintenance (% of capex)	7%	7%	5%
Annual Cost			
Maintenance	$31,500	$56,000	$13,750
Diesel @$1/L	$89,158	$271,436	$33,965
Labour	$107,500	$107,500	$86,000

The quantities of harvesters and associated haul out units are shown in Table 5-5. These quantities are based on a monthly harvest of 28,700 t wet.

Table 5-5 Harvesting equipment quantities and basis.

	Canetec	CNH
Harvester	**7.0**	**2.0**
Tractors	**28**	**18**
Wagons	**30**	**20**
Wood harvest rate (tph wet)	17	70
Leaf harvest rate (tph wet)	1.7	7
Wood Wagon capacity	15	15
Wood Wagons filled/hr	1.1	4.7
Cycle time (2 km one way)	0.4	0.4
Wood Tractors per harvester	2	7
Leaf Wagon capacity	15	15
Leaf Wagons filled/hr	0.1	0.5
Cycle time	0.4	0.4
Leaf Tractors per harvester	2	2

A number of cross checks have been conducted on the above estimates.

- GHD was advised that a typical contract rate for harvesting sugarcane including haul-out is around $10/wet tonne. Sugarcane has a moisture content of around 68%. If the cane figure is adjusted to reflect the lower water content of Leucaena and the likely reduction in production rate due to the hardness of the wood, the equivalent cost for Leucaena is around $14/wet tonne. The table figures correspond to a cost of approximately $20/wet tonne for the Canetec harvester and two haul out units.
- The EcoWillow 2.0 spreadsheet model[60], developed by State University of New York was used to calculate a cost of $16/wet tonne. The model is specifically designed for calculating costs for short rotation willow cropping. The harvesting section is based on the trial performance and costs for the CNH forager.

All figures are with the expected accuracy of the assessment.

[60] ibid

Transport

Costs for transporting the chips to a separate process facility are comprised of loading, travel and unloading costs. The EcoWillow 2.0 model has been used to estimate a cost of $4/wet tonne for loading and unloading of a double road train with a capacity of 50 wet tonnes of chips. Travel costs of approximately $0.12/tonne/km are considered reasonable for this type of vehicle on open roads. A travel distance of 50 km would therefore add an additional $6/wet tonne or $12/dry tonne.

5.6.2 Prickly acacia

The information on the quantity, distribution, number and size of trees is quite uncertain and needs further information to better develop a business case for harvesting. GHD has extrapolated a number of other estimated costs and items of information in order to develop a potential cost for harvesting prickly acacia. All figures are based on wet wood density of 90 t/ha, which was derived from extrapolation of information in Table 3-1.

Table 5-6 Estimated costs for removing prickly acacia on plantation site.

	Recovering wood using harvester	Burning wood	Basis
Chain clear ($/ha)		$50	Based on 2010 reported figure of $40/ha. Increased to $50/ha.
Chain clear ($/t)		$0.6	Conversion assumes 90 t/ha
Pile and burn ($/t)		$3.3	Estimate.
Harvest and haul out ($/t)	$40		Assume double Leucaena harvest cost due to irregular stump location
Transport and loader ($/km/t)	0.16		Higher than Leucaena due to rougher ground and slower speeds.
Distance (km)	50		Assumed same as plantation for ease of comparison
Transport cost ($/t)	$8		
Total cost to process plant ($/t)	**$48**		
Stump removal	$7		$600/ha. Half of cost from WillowCal. More stumps in WillowCal
Total ($/t wet)	**$55**	**$4**	

Table 5-7 Estimated costs for removing prickly acacia from off- plantation site.

	Recovering wood using harvester	Recovering wood using chain clearing	Basis
Chain clear ($/ha)		$50	Based on 2010 reported figure of $40/ha. Increased to $50/ha.
Chain clear ($/t)		$0.6	Conversion assumes 90 t/ha
Collect and bundle		$5	Assume 3 hr /ha @ cost of 150/hr
Trim		$8	Assume 6 min/tree @ labour rate of $40/h

	Recovering wood using harvester	Recovering wood using chain clearing	Basis
Chip		$15	Assume $5/t dm times 3. (From chipping paper and Irish BP plus allowance for people and plant.
Haul out		$19	1.7 times Leucaena due to 50% lower rate
Transport and loading ($/t/km)		$0.2	
Distance (km)		50	
Transport cost ($/t)		$10	
Total cost to process plant ($/t)	**$48**	**$58**	**$48 from table above.**

The final report of Desert Channels Queensland[61] indicated a cost of $0.2 to kill each tree using a remote controlled small helicopter. This suggests that any subsidy from the state government for eradicating some prickly acacia is likely to be low.

[61] Attachment 3 Final Report Desert Channels Queensland, Queensland Regional Natural Resource Management Investment Program 2013-14 to 2017-18, Desert Channels Queensland

6. Production and processing fundamentals

6.1 Feedstock

The project will initially utilise existing prickly acacia as feedstock to the wood pellet plant. Sterile Leucaena varieties would then be planted on the cleared land. When the Leucaena can be harvested, this would become the feedstock to the wood pellet plant and a cattle feed pelleting plant.

Some feedstock parameters have a greater effect on pellet characteristics and durability than others. The lignin content is possibly the most important parameter with regards to pellet durability, followed by moisture content, as these two factors directly interact to affect the temperature at which lignin softens.

The characteristics of the harvested material are in Table 6-1. Different characteristics are important depending on the end use of the material, and are recorded as such.

Table 6-1 Feedstock characteristics

Component	Units	Leafy Leucaena	Woody Leucaena[62]	Prickly acacia
Moisture	% mass	50.0	50.0	40.0
Fixed carbon	% mass		12.5	13.4
Volatiles	% mass		37.0	46.2
Ash	% mass		0.5	0.4
LHV	MJ/kg		19.2	18.9
Crude protein	% mass	25.0[63]		

The crude protein content in the leafy material drops as the growing period extends; however, even after 36 months the crude protein content is still high enough to meet the minimum requirement for ruminant animals (8-12% mass). Therefore the decrease in crude protein content in the leafy matter does not impede a longer growth period.

6.1.1 Proximate analysis for prickly acacia

Research of available literature during the study found reliable reference information on the composition of prickly acacia (Acacia Nilotica), for example in an article by Kumar et al[64], where the “acacia” referred to is Acacia Nilotica. Given the available information, and the early stage of this study, the published information was deemed appropriately reliable for this study work. This circumvented the need to obtain field samples and transport of these to a laboratory for analysis, thereby avoiding the need to obtain licences, permits and agreements through Biosecurity Queensland, the Department of Agriculture and Fisheries and any other relevant local, state and federal agency or authority with reference to the regulations surrounding weeds of national significance.

[62] Rengsirikul, K. et. al. (2011). Potential forage and biomass production of newly introduced varieties of Leucaena (Leucaena leucocephala (Lam.) de Wit.) in Thailand. Japanese Society of Grassland Science, Grassland Science, 57, 94-100.
[63] Tudsri, S. et. al. (2019). Dual use of Leucaena for bioenergy and animal feed in Thailand. Keynote paper presented at the International Leucaena Conference, 1-3 November 2018, Brisbane, Qld.
[64] Kumar, M. et.al. (1992). Effects of carbonisation conditions on the yield and chemical composition of Acacia and Eucalyptus wood chars. Biomass and Bioenergy, Vol 3, No 6, pp 411-417.

Acacia Nilotica is referred to as “babul”, “kikar” or “keselto” in the local vernacular, depending on where it is located. Ultimately, values from the ECN Phyllis classification database (a comprehensive database for biomass sources) for kikar (Acacia Nilotica) were used for the proximate analysis (see attached in Appendix C), and adjusted for an assumed free moisture content at harvest. These were cross-checked against the published values from literature, and also against hardwoods published in the Phyllis classification database.

6.1.2 Differences between woody Leucaena and prickly acacia

The wood pellet mass and energy balance will only be calculated for woody Leucaena, as Leucaena and prickly acacia has properties that are quite similar from a compositional and heating value perspective, and there is not enough granularity at this early stage of the project between the two to justify separate balances.

The justification is as follows:

- Following ambient drying, the moisture content is assumed to drop to 30% mass on both the leafy and woody Leucaena material. As a result, the drying energy required will be similar for both types of wood. This assumption would have to be confirmed from ambient drying tests in future, however it would have been time-consuming to confirm (requiring several weeks to establish drying curves). Therefore, adopting a conservative assumption during this study was considered appropriate and suitably representative.
- Both materials are hardwoods; therefore expected to be similar in density and requiring similar power consumption for grinding.
- Since grinding and drying consume the largest portion of energy required for a wood pelleting facility, it is expected that the overall energy consumption to process both materials would be similar.
- The ash content of the two materials is very similar (0.7% mass for prickly acacia versus 1.0% mass for Leucaena on a dry basis).
- The energy content of the two materials is very similar (LHV of prickly acacia is 98% that of Leucaena).
- Typically, wood pellet pricing would be determined based on moisture content, ash content and possibly heating value. For example, a framework has been suggested for wood pellets for the Japanese market, classifying wood pellets as per Table 6-2. From this table, both Leucaena and Acacia wood pellets would be classified as Class 1, and therefore a similar price could be expected for both.

Table 6-2 Japanese guidelines for wood pellets

Item	Standards			
	Class 1	Class 2	Class 3	Class 4
Raw materials	Tree trunks Whole trees Untreated mill timber offcuts (no chemical treatment)	Class 1 raw materials + shrubs Treetops/branches Timber offcuts from forests	Class 2 raw materials + untreated recycled wood (no chemical treatment)	Class 3 raw materials + Bark Chemically treated mill timber offcuts and recycled wood
Chip dimensions	P8[65], P16, P25, P32			
Moisture	M25[66] or M35	Choose from M25, M35 or M55		
Ash	Up to 1.0%	Up to 1.5%	≤3.0% or ≤8.0%	

Similarly, for Europe, EN 14961-1 is used to classify wood pellets. While the classification is more narrow (for example, both pellets with ash content of less than 0.7 mass% and pellets with ash content of less than 1.0 mass% exists within the classification), the produced pellets could still be considered very similar.

6.2 Process description – wood pellet production

Biomass pelletising consists of multiple steps including material pre-treatment (milling and drying), pelletising mill and post treatment. The quality of the pellets varies depending on the raw material properties and the manufacturing process. Although the inorganic and organic components of the raw material cannot be modified, some variables can be controlled to optimise the production efficiency and enhance the quality of the finished product.

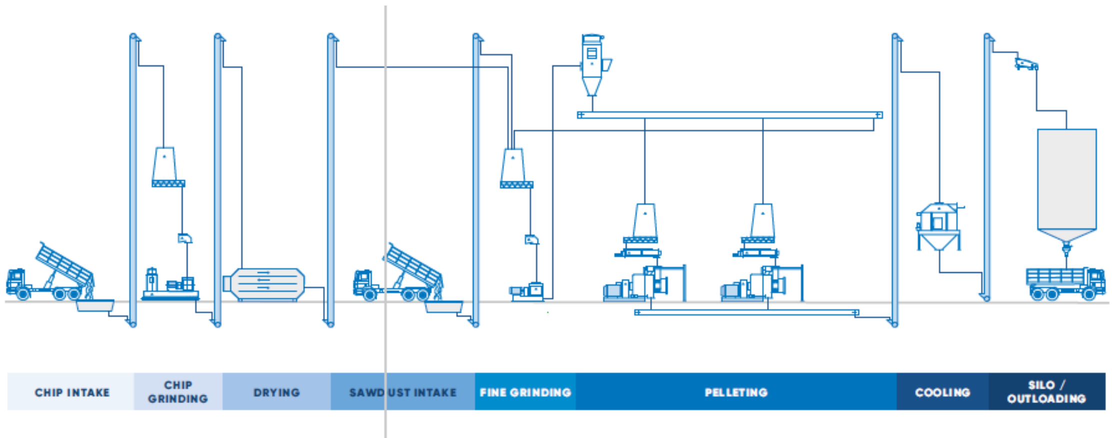

Figure 6-1 Wood pelleting plant representation from Andritz

6.2.1 Receiving and storage

Storage of raw biomass is a critical component in a viable biofuels supply chain. An effective feedstock storage system is required to keep impurities out of the biomass and provide protection from rain and moisture. Increased moisture content could lead to the drying process

[65] Where for example P8 is equivalent to having the longest part of the principal section (80% or more of the weight) be no more than 8mm.
[66] Where for example M25 = Water weight/(Wood weight + water weight) x 100%

becoming unviable. Biomass storage should be managed to minimise dry matter loss and control the self-heating characteristics of stored biomass.

There are different ways in which biomass intended as feed to pelletising can be stored. Wood chips are typically stored in on-ground (above grade) storage, or in below-ground storage bunkers. The following storage systems are common for woodchip storage:

- Linear storage, which is normally closed or covered to minimise the effects of additional moisture on the biomass during storage. A shuttle belt conveyor stacks the linear pile and moves back and forth above the pile to distribute the biomass evenly. The material is reclaimed via screw reclaimers under the pile.
- Round storage, which is a closed or covered silo with a screw reclaimer or other discharge under the silo to discharge the biomass to the centre of the silo. The silo can be steel or concrete with or without a lining. This type of storage equalises the biomass moisture very well. Screw reclaimers can be cantilevered or supported at both ends, depending on the diameter of the silo and the biomass material.

If the woody Leucaena or prickly acacia is delivered to site as logs (that is, not chipped off-site), these will be laid down and stored in stacks in such a way that adequate air flow is achieved. Ideally the logs should be stored in a covered area to achieve some drying of the wood prior to processing.

The finished pellets can be stored in hoppers or silos.

6.2.2 Biomass size reduction

The raw material must be reduced to a uniform size that is adequate for pelletising. The milled material going into the pellet mill has to be smaller than the pellet mill die holes to prevent the holes blocking.

It is generally assumed that small particles with a large surface area will increase density and result in stronger pellets. In addition, a narrow particle size distribution facilitates even moisture distribution during the drying stage. When the particle size distribution is too wide, small particles may become overly dried in the process and make self-bonding more difficult later in the pelletising stage. However, a mixture of particle sizes is considered beneficial, because this increases the durability of the pellets.

Chippers and shredders are used for raw materials with large diameters, while a hammer mill is more appropriate for wood chips or herbaceous raw materials. Often chippers and shredders are used as a first step prior to hammer mills. Typically, chippers and shredders will be utilised prior to drying, while hammer mills are used after drying, as wet biomass is difficult to process through a hammer mill.

The hammer mill should be equipped with a venting hatch to the outside of the building it is housed in to prevent dust explosions in the mill building. The hammer mill will not necessarily have the same capacity as the pellet presses, so there should be an intermediate store of hammer milled material. This material is very fine and dry, so precautions against dust explosions should be taken.

6.2.3 Drying prior to pelletising

Freshly harvested wood has a moisture content of more than 50% mass, dropping to around 30% mass after storage. The moisture content of biomass should be between 10 and 20% mass to assure high quality pellets. If the pellets are too wet, it leads to low combustion temperatures, low energy efficiency and high emissions of unburnt hydrocarbons and particulates. If moisture content exceeds 20% mass (on a dry basis), bacterial growth occur, causing material degradation and self-heating.

The dryer selection influences the particle size that can be accommodated in the dryer, medium utilised for drying, dryer temperature and residence time.

There are various types of wood dryers:

Rotary drum drying

- Rotary drum dryers are a common dryer type for larger woody biomass material such as wood chip. The dryer consists of a cylindrical shell, inclined at a small degree to the horizontal and rotating at 1 to 10 rpm. Flue gas or hot gas is directly supplied to the drum which is rotated mechanically by an electric motor. These units operate at around 200ºC and can evaporate up to 25 tph of water.

Rotary drum dryers can be either directly heated or indirectly heated.

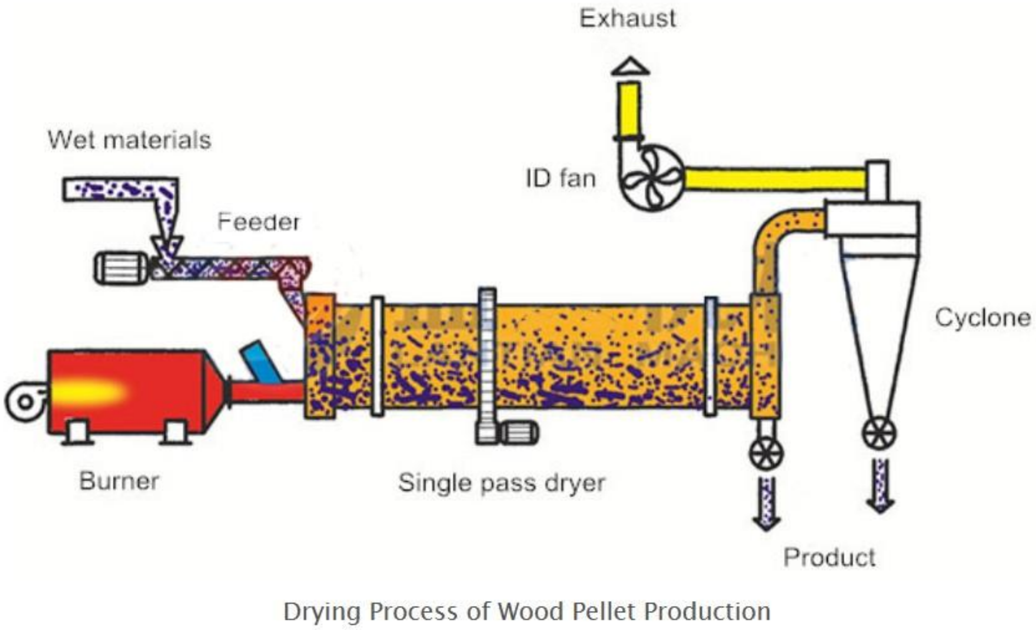

Figure 6-2 Rotary drum dryer

Rotary dryers typically have low maintenance costs. Their robust and simple construction combines flexibility with reliability, so that these units can operate under arduous conditions; handling a wide range of materials and less sensitive to particle size than other dryer types.

Disadvantages include difficulty controlling the outlet moisture content and large footprint.

Fluidised bed drying

- Fluidised bed drying, where preheated gas is passed into a product layer under controlled velocity to fluidise the solids; the main advantage being a short residence time due to good heat and mass transfer and high thermal efficiency.

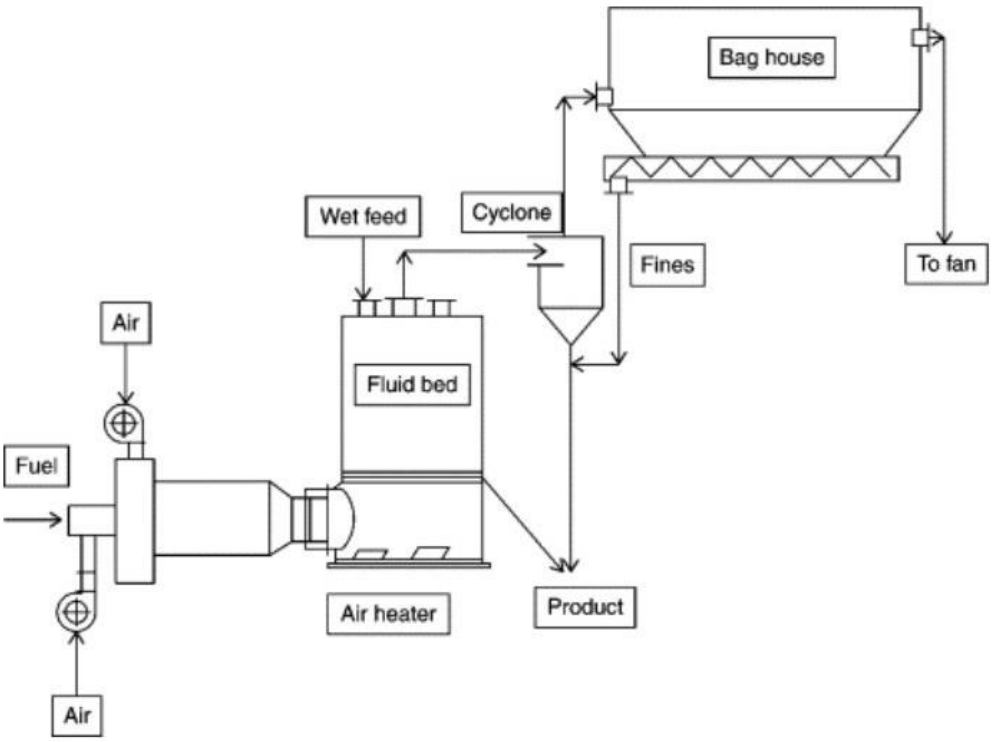

Figure 6-3 Fluidised bed dryer

Flash drying

- Flash drying consists of a stream of very hot air at high flow velocity passing through a tube through which fine biomass particles are pneumatically conveyed. The air entrains the particles and exposes them to the drying medium. The typical residence time for particles is 3-5 s in the tube.

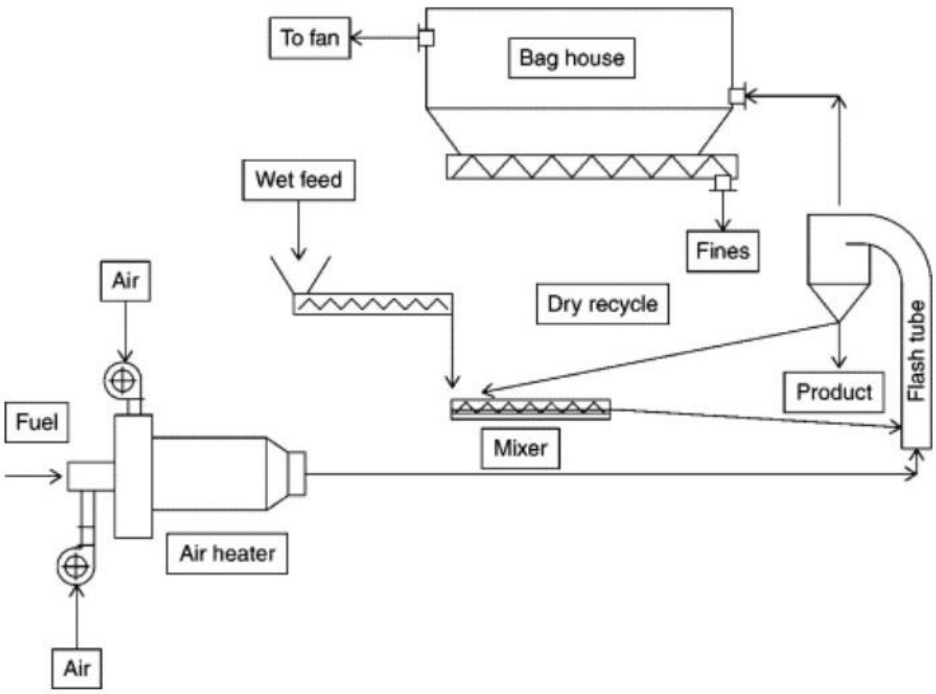

Figure 6-4 Flash tube dryer

These units require small biomass particle sizes to suspend and transport the biomass by the fluid stream alone, and as a result they can be used for biomass that is easy to grind when still wet. They are more compact than rotary dryers, but have higher installation costs. They also have higher blower power costs in addition to heat requirements for drying.

Belt drying

- A belt dryer consists of a biomass layer supported on a perforated belt which can either be stationary or moving. Hot air is passed through the bed. The particles are not fluidised and thus the air flow rate is restricted. The bed depth is typically 0.4-0.6 m, and drying time would be between 5 and 10 h (depending on particle size) at a temperature of 40-70ºC.

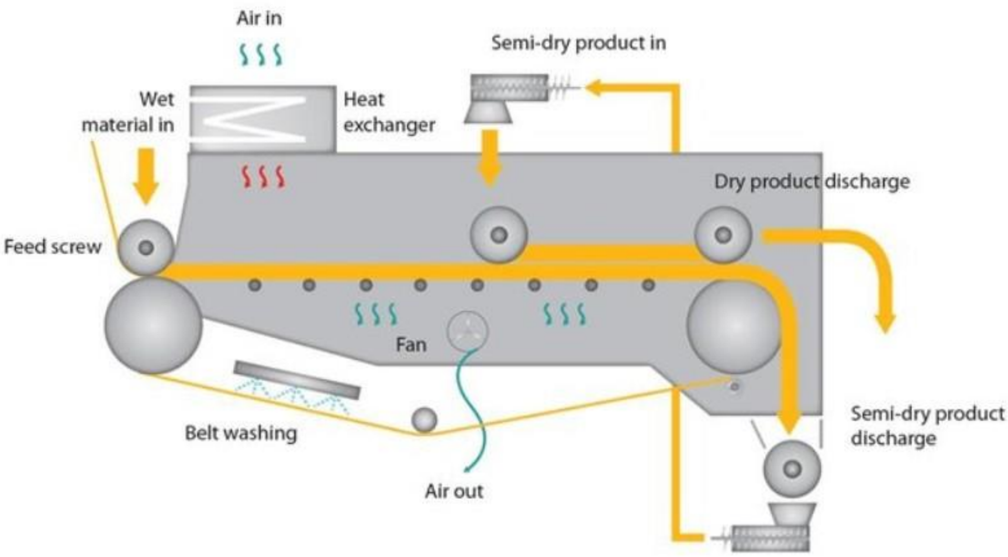

Figure 6-5 Belt dryer

Belt dryers are very versatile and can handle a wide range of materials. They are frequently used in low temperature operations to save energy, reduce air emissions and minimise fire hazards.

Table 6-3 Typical range of design parameters and performance data for various dryers[67]

Parameter	Units	Rotary drum	Flash dryer	Belt dryer
Evaporation rate	tph	3-23	4.8-17	0.5-40
Drying temp.	ºC	200-600	150-280	30-200
Capacity	tph	3-45	4.4-16	
Pressure drop	kPa	2.5-3.7	7.5	0.5
Typical PSD	mm	19-50	0.5 (can handle up to 50 mm)	
Thermal requirement	GJ/t-evaporation	3.0-4.0	2.7-2.8	1.26-2.5

Different media is utilised for drying, including steam, hot air and flue gas. Superheated steam dryers have some advantages compared with air dryers, because no oxidation or combustion reactions are possible. Steam dryers have higher drying rates than air or gas dryers and do not pose any process risk such as fire or explosions, while allowing toxic or valuable liquids to be separated in condensers.

[67] Li, H., et.al. Evaluation of a biomass drying process using waste heat from process industries: A case study. https://research.ncl.ac.uk/pro-tem/components/pdfs/EPSRC_Thermal_Management_Sheffield_Journal_paper_2_Biomass_Drying_Jan_2011.pdf , accessed 7/08/2019

Dryers with longer residence times cause greater losses of volatile organic compounds during drying. For example, sawdust dried in steam driers at 240ºC for 150 s lost 48-71% of their terpene content, whereas 80-83% of the terpene content was lost in a rotary drier at a temperature of 60-82ºC and a retention time of 110 h. In addition, biomass with a higher initial moisture content lose a higher percentage of VOC's as it generally take longer to dry. Significant loss of volatiles result in a decrease in heating value of the pellets and therefore the product value.

It is important to choose the right dryer, as it may constitute one of the largest capital expenditures in a pellet production plant and can be a significant production cost.

Evaporation rate, biomass properties (such as size), operating temperature and availability of heat sources all play a role in selecting the dryer type.

Increasing drying temperature will decrease drying time and increase throughput but not necessarily decrease drying cost. This is due to higher energy use and higher cost of capital such as loading/unloading, and heat generation, although the dryer itself would be smaller.

The most common and generally cheapest method to generate heat for drying is burning a portion of pellets or chips or other material used as pellet feedstock. To reduce energy requirement for drying (from biomass or a fossil fuel), solar drying may be considered, or ambient heap drying could be conducted prior to drying in a dryer.

Fire safety and emissions issues should also be considered. Biomass generally has an auto-ignition temperature of 260-280ºC. In most cases, air drying poses a potentially high fire risk, because of the high amount of oxygen in the air supply. Flue gas dryers can operate at higher temperatures than air dryers, as the flue gases contain lower amounts of oxygen. Superheated steam drying has the lowest fire risk because very little oxygen is present.

6.2.4 Mixing and conditioning

The milled, dried biomass may require mixing to get a more consistent blend to feed the pellet mill when raw material presents significant changes in moisture content, binding properties or material density.

Additives may be used as binding agents, to improve pellet durability and quality reduce dust formation, improve pelleting efficiency and reduce energy costs. A maximum of 2% mass is generally permitted in woody pellets. The most common additives are water and binders like vegetable oil.

Generally, the aim is to produce pellets of high enough strength without adding a binder, which adds to the complexity (additional mixing) and operating cost of the process.

6.2.5 Pelletising

Pellet mills utilise pressure to force the raw materials through holes in the dies. The mill consist of two main elements; the die with the holes that act as the mould and the rollers that force the raw materials to go through the holes of the die.

The temperature increases during pelletising due to pressure and friction. This allows the lignin in the biomass to soften and the fibre to be reshaped into pellet form. The moisture content is also further reduced during pelletising due to temperature rise.

Pellet mills can be classified as (1) flat die pellet mills, using a flat die with slots or (2) round die pellet mills, with radial slots throughout the die. Each of these have advantages and disadvantages (see Table 6-4).

Table 6-4 Advantages and disadvantages of flat and round pellet mills[68]

	Flat die	Round die
Advantages	Relatively easy to clean Quick access to the chamber Compact design Visibility of pellets produced Wider tolerance for problematic feedstock	Lower cost of roller and die consumables Extra friction resulting in more heat and better pellet quality
Disadvantages	Uneven roller and die wear (increased maintenance and impact on pellet quality) Slipping action of the rollers	Extra friction resulting in higher energy consumption Large size and weight Difficult access to rollers and dies Manual roller adjustment High cost No visibility of the pellet process

The most common diameters for biomass pellets are 6 mm and 8 mm, with pellets generally being 6-25 mm in diameter and 3-50 mm in length.

For larger applications such as this one, round die pellet mills would be used.

6.2.6 Product cooling

Due to applied pressure and friction in the pellet mill, biomass pellets leave the pellet mill at temperatures of up to 95ºC. The pellets have to be cooled; allowing the lignin to solidify and strengthen the pellets prior to storage and preventing self-heating during storage which could result in self-ignition.

The pellets are cooled to 5 to 10ºC above room temperature. Passing a stream of air through the pellets cools the pellets while further reducing moisture content. Pellets are air-dried in vertical, horizontal or continuous flow coolers.

The diameter of wood pellets and holding time in the cooler determine the size of cooler required.

Once the pellets are cool, they pass over a vibrating screen to remove fine material. This material can be returned to the pelletising process or utilised as part of the fuel to supply heat for drying.

6.2.7 Product storage and load out

Wood pellets must remain dry and the storage must allow for proper pellet flow. Bulk storage options storing wood pellets include silos, bag silos (for smaller volumes), domes, flat storage, bunkers and bins.

The bulk density of the material varies with biomass utilised and moisture content of the pellets, but a bulk density of 600 – 700 m^3/t can be used to determine the storage volume required.

Other important characteristics for product storage and load out are set out in Table 6-5.

[68] Maraver, A.-G. and Carpio, M. (2015). Biomass Pelletisation. WIT Press

Table 6-5 Physical Properties of Wood Pellets (General)[69]

Property	Units	Value
Pellet diameter	mm	6, 8, 12
Particle density	kg/m^3	1200-1900
Bulk density	kg/m^3	500-600
Lower heating value	GJ/t	16-18
Moisture content	%mass	8-12
Internal friction angle		33-43
Effective internal friction angle		39-45
Angle of repose		37-41
Wall friction angle		9-35
Breakage		Easy to break, brittle

Common problems with wood pellet storage are dust emissions and explosions, degradation in storage, self-heating and ignition.

Dust formation and dust explosions can be prevented through gentle handling of the pellets and "soft" chutes and/or dust extraction and containment. In general, conveying distances and speeds should be kept to a minimum, and transfer points and large drops should be avoided.

Maintaining low temperatures (below 50ºC) during storage is essential, as biomass degradation, with associated release of CO, CO_2, CH_4, aldehydes and other volatile organic compounds or VOC's, are accelerated by elevated temperature. This is managed by aeration during storage. Pellet aeration prevents biological heating in damp pellets, circulates off-gases and removes odours created by off-gases. Pellet aeration also helps to prevent moisture migration and headspace water condensation in humid climates.

Reclaiming pellets from storage should follow the "first-in, first-out" principle. Wood pellets are generally transferred by belt conveyor via hoppers into trucks, which are weighed on leaving the process plant.

6.3 Process description – wood chip export

If the wood is to be sold as wood chips rather than pellets, it will undergo chipping and screening followed by drying.

The received logs are placed in a storage area where they undergo passive air drying. The log stacking area should be roofed or the logs covered.

For Leucaena, de-barking may not be required.

Prior to being routed to the chipper, the wood passes a metal detector and stone traps to remove contaminants that could damage the chipper. There are several chipper models, such as vertical feeding, horizontal feeding and drum chippers. Each produces different quality woodchips. Chip quality is determined by chipping geometry and cutting speed, with chip length being directly proportional to chip thickness. The knives that are utilised in the chipper are usually replaced between each shift.

Chip screening removes particles of undesired size and provides homogeneous quality.

Wet wood chip is typically stacked on a drying floor, utilising hot air to dry the woodchips, with the process typically taking between two and three days. Wood chips may have a moisture

[69] Dafnomilis, I. et.al. (2018). Evaluation of wood pellet handling in import terminals. Biomass and Bioenergy 117, pp 10-23

content of up to 50% mass (depending on storage time prior to processing). Biomass-sourced heat is utilised to dry the wood chips. A typical final moisture content is around 25% mass.

The wood chips can then be routed to storage and load-out. Open storage is used for big volumes of up to 200,000 m³ or more, whereas silo storage is used for up to 26,000 m³.

A suggested framework of quality standards for fuel wood chips is shown in Table 6-6.

Table 6-6 Quality standards for fuel wood chips[70]

Parameter	Class 1	Class 2	Class 3	Class 4
Raw materials	Tree trunks, whole trees, untreated mill timber offcuts	Class 1 raw materials + Shrubs, treetop/branches, timber offcuts from forests	Class 2 raw materials + Untreated recycled wood	Class 3 raw materials + Bark, chemically treated mill timber offcuts and recycled wood
Chip dimensions	P8, P16, P25 or P32			
Moisture	M25, M35	M25, M35, M45 or M55		
Ash	Up to 1% mass	Up to 1.5% mass	Up to 3% mass or up to 8% mass	

Where “P8” is equivalent to the longest part of 80% or more of the mass of chips being no longer than 8 mm and M25 is equivalent to a moisture content of 25% or less, then this project could produce Class 1 or 2 woodchips.

6.4 Process description – animal feed pellets

6.4.1 Receiving and storage

For the leafy material to be pelletised into animal feed the material must be stored in a way that avoids degradation. Containers used must be kept clean, with traces of detergents and disinfectants minimised.

It is assumed the material will be kept in a well-ventilated, roofed area to allow some air drying prior to processing.

6.4.2 Balance of plant

Animal feed pelleting proceeds in a similar manner to wood pellet production (see section 6.2).

A rotary drum dryer would be utilised to dry material. The leafy material has to be around 5 to 10 cm in length to be processed through the dryer.

Animal feed may consist of various components other than the biomass material and in such a case a mixer is required to condition the feed prior to routing it to the pellet mill. In this conditioning chamber, controlled amounts of steam are added to improve pellet quality. Steam conditioning lubricates the feed for faster production through the pellet mill, assists in extending die life, assists in reducing energy costs and gelatinises starch for nutritional value.

It is assumed the material will be kept in a well-ventilated, roofed area to allow some air drying prior to processing.

[70] https://www.asiabiomass.jp/english/topics/1409_01.html , accessed 21/08/2019

6.5 Mass and energy balance – pelletising

6.5.1 Assumptions

The following assumptions are specific to the mass and energy balance:

- Total assumed cropping and harvest area is 3,600 ha. Harvesting is staggered so that a specific block is harvested every 18 months to maximise woody Leucaena growth.
- Yields are assumed to be the following as shown in Table 6-7.

Table 6-7 Crop yields

Material classification	Units	Value
Woody material yield	dry t/ha/18 months growing period	36.4
Leafy material yield	dry t/ha/18 months growing period	4.2
Discard material yield	dry t/ha/18 months growing period	3.1
Total dry material yield	dry t/ha/18 months growing period	43.7
Moisture on harvested material	% mass	50
Total wet material yield	wet t/ha/18 months growing period	87.4

- Material is harvested to allow for a 4 week ambient drying period, followed by a maximum of 3 months to process the harvested material. The material is managed in this way as stored wood deteriorates after four months. No degradation or loss of volatiles during storage is assumed at this time.
- No binders are utilised to improve pellet integrity.
- At present, no additional processing losses are taken into account; that is, excluding discard material, it is assumed all dry matter fed to a pelleting line is processed to a final pellet product. Realistically, 10-15% mass of the feed to the pellet plants could become additional waste material (typically this would be utilised as fuel for the facility).
- The free moisture profile of the material is assumed to be as shown in Table 6-8:

Table 6-8 Moisture content on material

Parameter	Woody material (% mass)	Leafy material (% mass)
Moisture on harvested material	50	50
Moisture following ambient drying	30	30
Moisture on material following drying in plant	20	16
Moisture on final pellets*	15	12

*The final moisture on pellets is lower than for material after drying due to heating during pelletising and moisture evaporation during cooling after pelletising.

- Maximum on-line availability is 80% or 7008 operating hours/annum; this is mainly due to the high maintenance schedule required for pelleting mills. The wood pellet mill equipment runs 7 days a week, 24 hour a day. It is assumed that the animal pellet mill equipment runs 5 days a week, 24 hour a day, with 2 days maintenance and cleaning at the end of the week. The wood pellet mill equipment is on-line for 7008 operating hours/annum. The animal feed pellet mill equipment is on-line for 5,040 operating hours/annum.
- Typical wood pellet mill capacity is 3.5 to 5 t/h feed; maximum capacity for the animal feed pellet mill is 10 t/h feed. Both of these are on a wet basis.
- Maximum rotary dryer capacity for biomass has an approximate throughput of 10 t/h.
- Energy consumption in the facility consists of the following as shown in Table 6-9:

Table 6-9 Energy consumption

Parameter	Units	Wood pelleting	Animal feed pelleting
Power consumption	kWh/t pellets produced (dry basis)	142	47
Energy required for biomass drying	MJ/t water evaporated	3500	3500
Steam to pellet mill	MJ/t pellets (dry basis)	--	13

- Where most of the power consumed in each of the lines is consumed in the pellet mills and grinding, and the energy required for biomass drying includes burner efficiency and energy losses from the dryer.
- It is assumed that wood chip is utilised to provide process energy for drying and other uses; and where applicable similar wood chip would be combusted in a boiler to generate power. The wood chip is assumed to have a 30% mass moisture content and lower energy value of 12.2 MJ/kg (assuming 30% mass moisture). Where wood chip is combusted in a boiler for power, an overall efficiency of 25% is assumed (converting wood chip heating value to power output on a higher heating value basis), or 30% starting from a lower heating value basis.

  Since power generation is addressed in detail in section 6.6, the only purpose for calculating the amount of wood chip for power generation in this section is to determine the running harvest cost as an operating cost so that the levelised cost to produce wood pellets or animal feed pellets may be better understood without the full power generation workup.

6.5.2 Plant capacity determination

Each of the processing lines are sized so that it can be fully utilised for the on-line period that is expected per annum.

For the wood pellets processing facility:

- Woody biomass yield = 36 t/ha/18 months, for 3,600 ha, or 86,667 t/annum (dry matter).
- Maximum on-line availability for the woody pellet facility = 7,008 h/annum.
- Thus optimised facility capacity = 86,667/7008 = 12.4 t/h (dry matter)
- Optimised design facility capacity = 13.75 t/h (dry matter), assuming a 10% design margin.
- This relates to a design feed rate of ***20 t/h*** (wet basis), and ***15.6 t/h*** pellet production (12% mass moisture on pellets assumed), or ***109,430 t/annum***.

For the animal feed pellets processing facility:

- Leafy biomass yield = 4.2 t/ha/18 months, for 3,600 ha, or 10,000 t/annum (dry matter).
- Maximum on-line availability for the animal pellet facility = 5040 h/annum.
- Thus optimised facility capacity = 10,000/5040 = 1.98 t/h (dry matter).
- Optimised design facility capacity = 2.2 t/h (dry matter), assuming a 10% design margin.
- This relates to a design feed rate of ***3.1 t/h*** (wet basis), and ***2.6 t/h*** pellet production (15% mass moisture on pellets assumed), or ***13,070 t/annum***.

6.5.3 Leucaena harvesting

The total mass of material that is harvested on an annual basis is ***207,867 t/annum***, assuming a total cultivated area of 5,000 ha, and a moisture content on freshly harvested material of 50% mass.

Once the material is dried under ambient conditions, the moisture content for both the leafy and woody material decreases to 30% mass. This is the assumed entry moisture for feed to both pelleting plants. It is also assumed that the waste material has a similar moisture content, and a lower heating value of 12.2 MJ/kg. This is what is utilised to determine the mass of wood chip or waste material required to provide energy for the process.

6.5.4 Mass and energy balance results – wood pellet plant

The mass and energy balance results for the wood pellet plant are shown in Table 6-10. These numbers are all presented on an operating capacity basis. The waste material is assumed to be included with the woody material feed and routed to fuel once separated from the woody material for pelleting.

Table 6-10 Mass and energy balance results – wood pellet plant

Parameter	Units	Annual basis	Units	Hourly basis
Wet harvested woody material	t/annum	173,333		
Wet harvested waste material	t/annum	14,533		
Processing plant – wood pellets				
Processing time on-line	h/annum	7,008		
Ambient dried material to plant (30% moisture)	t/annum	134,190	kg/h	19,148
Material to drying	t/annum	126,776	kg/h	18,090
Material from drying	t/annum	105,646	kg/h	15,075
No of dryers required		3		3
Material to pellet mills	t/annum	105,646	kg/h	15,075
No of pellet mills required		4		4

Parameter	Units	Annual basis	Units	Hourly basis
Wood pellets to storage	t/annum	98,485	kg/h	14,390
Energy demand				
Energy required for drying	GJ/annum	73,952	MJ/h	10,553
Wood chips for drying	t/annum	6,062	kg/h	865
Power consumption	MWh/annum	14,320	kWh/h	2,043

The waste material component that is generated is large enough to supply all of the dryer energy required. Considering power generation from combustion of wood chips, the waste material component can supply approximately 37% of the total energy demand for the plant.

6.5.5 Mass and energy balance results – animal feed pellet plant

The mass and energy balance results for the wood pellet plant are shown in Table 6-11. These numbers are all presented on an operating capacity basis. The waste material is assumed to be included with the woody material feed and routed to fuel once separated from the woody material for pelleting.

Table 6-11 Mass and energy balance results – animal feed pellet plant

Parameter	Units	Annual basis	Units	Hourly basis
Wet harvested leafy material	t/annum	20,000		
Processing plant – animal feed pellets				
Processing time on-line	h/annum	5,040		
Ambient dried material to plant (30% moisture)	t/annum	14,286	kg/h	2,834
Material to drying	t/annum	14,286	kg/h	2,834
Material from drying	t/annum	12,500	kg/h	2,480
No of dryers required		1		1
Material to pellet mills	t/annum	12,500	kg/h	2,480
No of pellet mills required*		2		2
Animal feed pellets to storage	t/annum	11,765	kg/h	2,334
Energy demand				
Energy required for drying	GJ/annum	6,250	MJ/h	1,240
Wood chips for drying	t/annum	1,162	kg/h	231

Parameter	Units	Annual basis	Units	Hourly basis
Power consumption	MWh/annum	551	kWh/h	109

*For availability purposes, two pellet mills are installed.

6.5.6 Mass and energy balance results – woodchip export only

Woodchip is exported as M35 material (assuming 30% mass moisture on the wood after ambient drying, or as M25 material (assuming 20% mass moisture on the wood after ambient drying and additional drying to 20% mass moisture). For the second case, rotary drum dryers are utilised.

- The following assumptions were utilised to work up the woodchip cases, starting from the information gathered for a wood pelleting plant: Case A – no additional drying allowed, only ambient drying prior to chipping. Final residual moisture content is 30% mass. Case B – additional drying assumed. Final residual moisture content is 20% mass. While some additional drying may occur during the cooling step following drying, this is not currently taken into account.
- To keep the comparison simple, the woodchip facility is assumed to have the same capacity and on-line availability as the wood pelleting plant. However, given the large volumes in which woodchip is typically exported (50,000 t), the cultivated area and volume of product produced may have to be revisited at some point.
- For power consumption, it is assumed that Case A will consume 35% of the power required for wood pelleting per dry t, and 55% for Case B (increased power consumption due to dryers being in use).
- Where dryers are utilised (Case B), the energy requirements are as for the wood pelleting plant.

Results for the woodchip production cases are presented in Table 6-12.

Table 6-12 Mass and energy balance results – wood chip plant

Parameter	Units	Annual basis		Units	Hourly basis	
Wet harvested woody material	t/annum	173,333				
Wet harvested waste material	t/annum	14,533				
Processing plant – wood chip						
Processing time on-line	h/annum	7,008				
Ambient dried material to plant (30% moisture)	t/annum	134,190		kg/h	19,148	
		Case A	Case B		Case A	Case B
Material to drying	t/annum	--	126,776	kg/h	--	18,090
Material from drying	t/annum	--	110,929	kg/h	--	15,829
No of dryers required		--	3		--	3

Parameter	Units	Annual basis		Units	Hourly basis	
Wood pellets to storage	t/annum	126,776	110,929	kg/h	18,090	15,829
Energy demand						
Energy required for drying	GJ/annum	--	55,464	MJ/h	--	7,914
Wood chips for drying	t/annum	--	4,546	kg/h	--	649
Power consumption	MWh/annum	4,411	6,931	kWh/h	629	989

6.5.7 Capital cost build-up for wood pellet and animal feed pellet plants

The capital cost estimates for the wood pelleting facility and animal feed pellet plant have been built up from budget quotations from technology vendors and scaled to suit the plant capacity. Quotes for rotary dryers for biomass drying have been obtained separately. The quotes obtained are all ex-works.

Cost for the wood pellet facility:

- The budget quote for a ~100,000 tpa wood pellet facility is EUR 3.2 M. This excludes any drying equipment. The basis for the quote is ex-works. Converting this to AU$ using an exchange rate of EUR 0.62 to an AU$, the ex-works budget quote for a wood pelleting plant is AU$ 5.1 M.
- The budget quote for a 10 tph biomass dryer (rotary drum) is AU$ 1.0 M. Three of these dryers are required to process the wood chips fed to the plant on an hourly basis, at a total ex-works cost of AU$3.0 M.
- It is assumed that for the wood pelleting plant and the dryers as much as possible of the equipment will be modularised and shipped, including conveyors. These modules will have to be small enough to be transportable by road, and coupled on site. However, this modular approach saves a lot of on-site work and thus cost.
- To convert the capital cost into a Total Installed Cost (TIC), site works, instrumentation (not included in the ex-works pricing), piling and concrete, buildings, equipment rental and commissioning costs have to be factored, as well as freight cost. It is suggested that a conservative factor of 2 be applied to the ex-works estimate as an allowance for these costs.
- The TIC of the wood pellet plant is summarised in Table 6-13.

Table 6-13 Total installed cost for the wood pellet plant

Parameter	Units	Value
Ex-works budget quote wood pellet plant	AU$ M	5.12
Ex-works budget quote rotary drum dryers	AU$ M	3.00
Factor to allow for shipping, buildings, siteworks etc		2.00
TIC	AU$ M	16.24

The animal feed pellet facility cost is build up in a similar manner to the wood pellet facility:

- The budget quote for a 3-4 tph pellet production facility is US$ 225,910, or AU$ 301,213 at an assumed exchange rate of 0.75. This is an ex-works budget quote and excludes any drying.
- The budget quote for a 3.3 tph biomass dryer (rotary drum) is AU$ 795,779 M.
- As the plant is produced as containerised units, a smaller factor may be utilised to convert the ex-works cost to a TIC cost. It is suggested that a factor of 1.8 be utilised to cover site works, freight and connection.
- The TIC of the animal feed plant is summarised in Table 6-14.

Table 6-14 Total installed cost for the animal feed pellet plant

Parameter	Units	Value
Ex-works budget quote wood pellet plant	AU$	301,213
Ex-works budget quote rotary drum dryers	AU$	795,779
Factor to allow for shipping, buildings, site works etc		1.8
TIC	AU$	1,974,586

6.6 Concept level assessment of co-generation options

A nominal 3,600 ha plantation with the Leucaena yields nominated in section 4.6 has been used to derive the amount of heat and power required for the animal feed and pelletising plant. The operating schedule and associated monthly requirements are shown in Table 6-15.

Table 6-15 Production and energy requirements.

	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
Growing season				Yes	Yes	Yes	Yes	Yes	Yes				
Wet season							Yes	Yes					
Harvest (wet tpa).	26,358	26,358	26,358	26,358	26,358	26,358			26,358	26,358	26,358	26,358	263,584
Feed production. (tpa @ 40% moisture)	2,411	2,411	2,411	2,411	2,411	2,411			2,411	2,411	2,411	2,411	24,108
Pellet production. (tpa @15% moisture)	11,392	11,392	11,392	11,392	11,392	11,392		11,392	11,392	11,392	11,392	11,392	125,312
Feed production process power (MW)	0.6	0.6	0.6	0.6	0.6	0.6			0.6	0.6	0.6	0.6	
Pellet production process power (MW)	1.9	1.9	1.9	1.9	1.9	1.9		1.9	1.9	1.9	1.9	1.9	
Total Power (MW)	2.5	2.5	2.5	2.5	2.5	2.5		1.9	2.5	2.5	2.5	2.5	
Pellet production process heat (MW)	2.9	2.9	2.9	2.9	2.9	2.9		2.9	2.9	2.9	2.9	2.9	

Table 6-15 shows that an average power supply of around 2.5 MW will be required when both the feed and pellet processing plants are operating. A 3.2 MW power supply is potentially required to cover periods of peak demand and motor starting. The table also shows that an average heat supply of 2.9 MW will be required for the pellet production process. A 4 MW supply is potentially required to cover peak demand periods.

The energy requirements can be satisfied in three ways.

- An on-site wood fired cogeneration plant to produce both power and heat
- An on-site wood fired boiler providing heat only. Electricity purchased from the grid.
- An on-site wood fired boiler providing heat only. Electricity generated by diesel generators.

A fourth possibility is a low pressure boiler with an Organic Rankine Cycle generator. However the ratio of power to heat does not favour this option so it has not been assessed.

There are also a range of hybrid systems combining solar power and heat with diesel power which may be the optimal solution. However there is insufficient information at this stage to develop these scenarios. The three nominated scenarios are expected to cover the book-ends of the options.

An estimate of capital and operating costs for each option is provided in Table 6-16.

Table 6-16 Comparison of options for heat and power

Item	HP Boiler and turbine	MP Boiler and grid	MP Boiler and diesel
Capital Cost			
High pressure boiler and pass out turbine	22,500,000		
Low pressure boiler only		6,000,000	6,000,000
Grid connection		3,000,000	
Diesel generator sets	800,000	800,000	4,000,000
Total capex	**23,300,000**	**9,800,000**	**10,000,000**
Capital annuity	**2,736,809**	**1,151,104**	**1,174,596**
Operating Costs			
Maintenance ($/y)	908,000	218,000	980,000
Operation ($/y)	100,000	60,000	60,000
Annual O&M ($/y)	**1,008,000**	**278,000**	**1,040,000**
Fuel			
Biomass amount (tph dry)	3.2	0.7	0.7
Biomass amount (tpa dry)	24,556	5,627	5,627
Biomass cost ($/t dry)	60	20	20
Biomass hourly cost ($/yr)	191.8	14.7	14.7
Biomass annual cost ($/yr)	1,473,347	112,532	112,532
Diesel amount (L/h)			756
Diesel cost ($/L)			1
Diesel hourly cost ($/h)			756
Diesel annual cost ($/yr)	5,000	5,000	5,808,403
Electricity amount (MW)		2.5	2.5
Electricity cost ($/MWh)		200	200
Electricity hourly cost ($/h)		500	500
Electricity annual cost ($/yr)		3,840,000	-

Item	HP Boiler and turbine	MP Boiler and grid	MP Boiler and diesel
Total O&M and Fuel cost ($/yr)	**1,478,347**	**3,957,532**	**5,920,936**
Total Annualised cost ($/yr)	**4,215,157**	**5,108,637**	**7,095,532**

The cost of biomass for fuel is based on 6,000 tpa of (dry) waste biomass being available as fuel. A nominal value of $20/t has been allocated for some screening and storage. Additional biomass is valued at the harvesting and collection cost.

The diesel price assumes the project qualifies for the diesel fuel rebate.

HP Boiler and Turbine

This option comprises

- A high pressure boiler producing superheated steam (around 19 MW at 40 bar and 400C) that is suitable for producing power
- A 3.3 MW pass-out turbine which discharges some low pressure steam for thermal use.
- An air cooled condenser
- A 1 MW diesel generator emergency set, but operation is expected to be minimal.

MP Boiler and Grid supply

This option comprises:

- All power to be supplied from the grid (assuming it is available). An allowance of $3M is included to cover grid connection and system upgrades.
- A 4.0 MW medium pressure saturated steam boiler producing steam around 12 bar
- A 1 MW diesel generator emergency set, but operation is expected to be minimal.

MP Boiler and Diesel Generators

This option is an alternative in case the grid supply is unavailable. It comprises:

- A MP boiler as above
- Around 5 MW of diesel generation capacity, including a redundant set and an emergency set.

The results indicate that a high pressure cogeneration option will provide energy at the lowest annualised cost, but at the highest capital cost. Another benefit of this approach is that energy costs will be independent of external electricity and diesel pricing.

6.7 Indicative development

6.7.1 Land lease/purchase

It is hoped that existing landholders would be major participants in the advancement of this project concept. However, in the event that a major new entrant/investor was attracted to the project they could expect to incur costs associated with securing access to land for production purposes. Indicative costs would be in the order of:

- $620 – $870/ha for land with access to water
- $370/ha for dryland areas

- $33,000/1,000 ha/annum[71] as a leasing alternative to land purchase.

6.7.2 Prickly acacia harvesting and clearing

As previously noted, it is anticipated that the State and Commonwealth government will commit $10 M to the control of prickly acacia over the next five years and this is likely to involve a number of mechanical controls. This may present an opportunity with regard to consolidating a source of prickly acacia for chipping/processing as opposed to the alternative of windrowing and burning. Government advice with regard to mechanical controls include:

- Grubbing – Ideal for large areas of scattered to medium-density infestations. Wheeled tractors are usually used with a scoop or grubbing attachment. This method requires a tractor of around 80hp. Trees greater than 15 cm in diameter can be difficult to grub out. Grubbing is best undertaken May- September or before pod drop.
- Blade ploughing – Front-mounted blade ploughs (e.g. Ellrott blade plough) are effective and efficient for medium-density infestations. Timing of this method should be restricted to May-September to lessen establishment of seedling regrowth or during drought conditions.
- Pushing – Pushing with dozers or loaders is useful for large areas of medium-density infestation. Timing of this method should be restricted to May-September to lessen establishment of seedling regrowth or during drought conditions. Massive seedling emergence may occur in areas around permanent waters and drainage lines.
- Stickraking – Use a stickrake with cutter bars attached to bottom of tines. Timing should be restricted to May-September or during drought conditions.
- Double chain pulling – Adopted by those with high densities of prickly acacia. It is effective against established stands but not plants below 40 mm in basal diameter[72].

6.7.3 Irrigation and farm development

In advancing this project concept, it could be expected that broad-acre farm development occur in areas of heavy prickly acacia infestation and access to irrigation supplies.

Indicative farm development aspects and costs are outlined below.

Mosaic irrigation development

CSIRO[73] and GHD[74] have previously identified the potential benefits of mosaic style irrigation developments. This is particularly relevant in the Flinders catchment where the State Government has released in the order of 200 GL of water allocation (since 2012) and any subsequent development of a large on-stream water storage would present significant challenges in meeting downstream environmental flow objectives and water allocation security objectives of the recently released water allocations as stipulated under the Gulf Water Plan. To date very little of the 200 GL has been developed to drive economic activity.

In 2017 GHD developed a conceptual water harvesting configuration as part of its investigation into opportunities for mosaic irrigation development across North Queensland. This conceptual configuration is outlined below noting that costs have not been escalated to 2019 figures.

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[71] Personal comment, Stock and Station Agent, Richmond (31/7/2019)
[72] https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/health-pests-weeds-diseases/weeds-diseases/invasive-plants/restricted/prickly-acacia
[73] CSIRO (2013b) Irrigation costs and benefits. A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia
[74] DSD NQ Mosaic Irrigation Investigation: Opportunities to Promote Sustainable Mosaic Irrigation Development Across North Queensland, Department of State Development/GHD, 2017

This off-stream storage concept is based around harvesting wet-season floodwaters for later use to irrigate in the order of 1,000 ha (depending on crop type e.g. Leucaena and inter-row rotation – reflecting irrigation demand) of land as a shared scheme or standalone farming unit. The irrigation of this area of land would make a significant difference to a farming operation and would likely influence surrounding farms over time. For the purpose of this concept it is assumed that an off-stream storage consists of a fully-enclosed ring-tank located on largely flat topography adjacent to a watercourse (e.g. Flinders or Cloncurry River, Julia Creek etc.) which is the supply source.

In order to maximise storage, it is usual practice to site an off-stream storage over favourable topography, such as a depression or gully. It may also be advantageous to augment the watercourse flood harvesting operation by incorporating a temporary storage or sump to take advantage of any overland flows that may occur. Such features and opportunities will reduce the volume of earthworks required per unit of storage; however, they are quite site-specific and were not considered for this model storage development.

This model storage was used to establish an indicative cost based on the capacity to irrigate the above mentioned area. It was assumed that reliable annual yield and water-harvesting opportunity of at least 30 days per year is available from the watercourse to supply the model storage. It is further assumed that a modular pump-station would be employed to take advantage of lower stream-flows in order to maximise the volume of water harvested annually. An assumed maximum diversion rate of 200 megalitres per day, (approx. 2.3 cumecs), is considered the practicable upper range for a diesel-powered modular pump-station (although electric units would be more cost effective where power is readily available). It must be highlighted that water harvesting opportunity will change vastly from catchment to catchment and also within a catchment. As such the information provided in this section is offered as a guide only to assist in considering the scale of potential development options.

Ring-tank Dimensions and earthworks quantity

A circular ring-tank is the most efficient in terms of volume stored per unit area. A circular configuration also optimizes earthworks volume and minimizes evaporation losses. Numerous configurations are available of course, but it is considered that an embankment to a maximum height of 5 metres, surrounding an area of 120 ha would be the most cost-effective in storing the required 5,750 ML (allowing 25% losses and noting that losses could be significantly higher). It is envisaged that approximately 425 000 cubic metres of earthworks would be required to construct the embankment; assuming a crest width of 5 metres, 3:1 batters and a 5 per cent settlement allowance.

Although not considered in estimating quantities, and given the huge loss of cattle in the recent flood, it would seem advantageous to broaden the crest of potential ring-tanks to provide elevated cattle ‘loafing’/refuge areas to assist with mitigating losses during severe flood events.

Water-harvesting equipment

It has been assumed that the water-harvesting pump-unit would operate for approximately 35 days per year at an average extraction rate of 165 ML per day to fill the ring-tank.

It seems reasonable to assume that the ring-tank and pump-unit would be suitably arranged to minimize the length of rising-main required to deliver water to the storage. It is expected however that in order to achieve a relative degree of flood-protection, the ring-tank would be located on elevated land within 200 metres of the pump-site. A single rising-main of at least 800 mm diameter, or preferably dual 600 mm pipelines, would be required to deliver a maximum flow-rate of about 200 ML per day.

Power requirement would be around 750 kW to deliver 200 ML per day against an estimated maximum head of 20 metres. A modular pump unit comprising two 660 mm, axial-flow pumps may perform this duty. Two-stage pump-units would be required to achieve the total head requirement. These pumps would be arranged on the bank (in a flood free zone) of the watercourse in a fixed, inclined installation.

Estimate of cost – water-harvesting plant

The table below presents indicative costing for the off-stream storage and water-harvesting scheme as discussed above based on a landholder-driven style of development.

Table 6-17 Preliminary cost estimate – off stream storage and water harvesting

Item	Description	Estimated Cost
Earthworks:- Embankment	425 000 m^3 compacted fill @ $5.50	$2,340,000
Ancillary Works	Mobilization & de-mobilization, site clearing, works area preparation.	$ 60,000
Inlet/Outlet Pipework & Valves	2 x R.C. through-pipe, 600mm dia., anti-seep baffles & dissipater. Inlet/outlet control valves.	$ 50,000
Flood-harvest Pump Unit	2 x 660 mm axial-flow pump w/- 375 kW diesel engines, protective equipment, inclined mounting w/- suction & delivery fittings.	$ 130,000
Delivery Pipeline	2 x HDPE pipe, 660 mm dia.	$ 48,000
Inlet Pipework	200 m @ $ 120/metre installed	$ 35,000
Investigation & Design	2 x R.C. through-pipe, 660 mm dia., anti-seep baffles & dissipater.	$ 30,000
TOTAL		**$2,693,000**

To pump water to storage for irrigation and to establish off-stream storage requires an estimated AU$2.7M per modelled system (Table 6-17) to support 1,000 ha. Irrigation of 4,600 ha would require approximately five similar modules, however it could be expected that efficiencies or around 20% could be achieved through sharing earth embankments etc. As such, the total cost for this element would be in the order of AU$10.8M. The costs shown in the above table are indicative only, for the purposes of this concept level model and equate to approximately $626/ML of effective yield (assuming net yield of around 17,250 ML/annum). Actual costs are likely to vary considerably depending upon actual site conditions. It is also highlighted that this cost makes no provision for the on-farm distribution and application of irrigation water or ongoing operations (e.g. pumping cost) and maintenance costs.

Land clearing

It is estimated that the cost of initial land preparation to be in the order of $1,300 per hectare based on the costs shown in Table 6-18 below and a fuel price of $1.05 cents per litre (inclusive of fuel excise rebate and exempt of GST).

Table 6-18 Initial land preparation costs

Land Preparation	Unit	Rate/ha	Fuel use/hr	Progress/hr (ha/hr)
Chain and rake scrub (1)	Per ha	$535	80	5
Cutter bar (2)	Per ha	$215	40	2
Survey in 50 m swaths	Per ha	$16	NA	NA
Laser levelling (3)	Per ha	$270	30	3
Cross rip, rip and bed form	Per ha	$75	40	2

Land Preparation	Unit	Rate/ha	Fuel use/hr	Progress/hr (ha/hr)
(1) This will be much cheaper on clay soil plains where there is little timber and on heavily timbered areas of prickly acacia where costs may be offset by government funding commitments for its control (as discussed in Section 6.7.2).				
(2) Range \$160 – \$270/ha – average price used of \$215/ha				
(3) Shifting 100 m^3 soil/hr				

It is estimated that initial on-farm irrigation establishment to average in the order of \$3,500 per hectare based on 30 per cent of the area under surface irrigation (at \$1,500 per hectare), 65 per cent under low pressure overhead spray (at \$4,000 per hectare) and 5 per cent under trickle irrigation (at \$9,000 per hectare).

6.7.4 Sterile Leucaena propagation for plantation establishment

The commercial propagation of sterile Leucaena has not been explored at this stage e.g. clonal propagation or tissue culture (onshore or offshore). By way of example an indicative cost of 90 cents/plant for clonal propagation has been obtained although anecdotal advice suggests that clonal propagation of salt bush in Western Australia is being achieved at much lower rates. However the University of Queensland (UQ) is currently advancing research in this area noting that the strategies undertaken by UQ to develop sterile Leucaena have largely been successful to date. Sterile plants will have been identified and placed into multiple strategies for multiplication. In the first instance vegetative propagation by applying rooting hormones has been successful. Sterile Leucaena can also be developed by making triploid hybrids produced from crosses between diploid and tetraploid varieties.

UQ has a number of plants believed to be sterile triploids growing in the field. It should be noted however, that there is currently a severe funding shortfall to complete this research. As such this area remains a significant area of commercial risk with regard to large scale plantation ramp-up of sterile Leucaena production[75] [76].

6.7.5 Plantation development and management

There is the opportunity to establish a range of crops within a Leucaena farming system. As mentioned previously, grasses are typically utilised in the inter-row within a grazing environment; however a range of other potential cropping options also exist that could enhance farm cash-flow and improve soil health and structure through crop rotation. Some of these are discussed below, including preferred cropping options identified as part of the recent study undertaken by Coriolis[77].

In addition, chick peas have been successfully grown in the Richmond area recently utilising soil moisture from recent flooding. Yield and overall crop performance has been impressive.

A proposed integrated cropping system would include the rotation of the following crops in the inter-row space of a well-managed Leucaena plantation (i.e. Leucaena is not directly fed to cattle), as set out in Table 6-19 below.

[75] Personal comment A/Prof. Chris Lambrides, UQ (15/8/2019)
[76] Further reference material may be sourced at Sterile Leucaena becomes a reality?, Keynote paper, Tropical Grasslands-Forrajes Tropicales (2019) Vol. 7(2):74-79, H. McMillan et al
[77] Identifying diversification opportunities in North West Queensland, Coriolis, December 2018

Table 6-19 Integrated cropping system – rotations

Season	Crop	Use	Plant	Harvest	Irrigation
Winter	Carinata	Oilseed	April	Sept/Oct	2-3 ML/ha
Spring	Mungbean	Legume	August	November	2-3 ML/ha
Summer	Rhodes Grass	Hay	November	March	1-2 ML/ha
Annual	Leucaena	Biomass	October	Dec / March	4-6 ML/ha

Brassica Carinata

The current global jet fuel consumption is 300 billion litres annually and expected to grow to 500 billion litres annually by 2030. The aviation industry has committed to a carbon neutral future targeting a 50% reduction on 2010 levels of CO^2 by 2050. While biofuels are currently mandated in 62 countries around the world, and demand for renewable diesel and jet fuels is the most rapidly growing segment of the renewable fuels industry, the 'biojet' component currently has approximately 100 million litres of unmet demand.

Biojet fuels produced from Carinata (Brassica Carinata) oil have already been used successfully in both engineering test flights and commercial flights, including the world's first 100% biojet fuelled flight. Today many commercial flights are powered by a proportion of biojet fuels. With 40% erucic acid content, Carinata offers manufacturers more efficient conversion into biojet fuel with reduced amounts of secondary products compared to other industrial oilseeds and bio-waste streams.

Commercial Carinata operations are established on three other continents and the University of Queensland (UQ) has worked with the Canadian company Agrisoma to develop Brassica Carinata for Australia (see Figure 6-6). The aim of this project is to develop varieties of Brassica Carinata that are more specifically adapted to Australian conditions to enable commercial quantities of biojet fuels to be produced here. This project focuses on genetic selection, adoption and scale-up within Australia.

Figure 6-6 Brassica Carinata cropping trials[78]

Trials Conducted to-date

- Trials in 2014 and 2016 showed that Carinata had potential compared to canola but the Canadian material flowered too late to be effective in Australia except in good spring conditions.
- In 2017 UQ tested 1900 rows at Bordertown (SA) and Gatton (Qld) to evaluate agronomic performance and selected for early flowering and reduced height to identify lines that could be further evaluated for yield and quality. Several of these lines had oil content similar to the best canola checks.
- In 2018 UQ established 20 trials throughout Australia to compare their best selections, several lines that have been previously selected in other countries and Australian canola controls to begin the process of developing elite varieties.
- Savannah Ag Consulting conducted one of these trials at the DAF research facility at Walkamin on the Atherton Tablelands. The highest yielding varieties achieved yields in excess of 3 tonnes per hectare.

At present herbicides that can be used on conventional canola can't be used on Carinata and there are no lines with specific herbicide tolerance such as Clearfield or triazine tolerance. Herbicide tolerance is currently being incorporated to enable Carinata to be grown more widely[79]. The plant itself, however, is very competitive and so with the correct paddock selection and good crop management practices, the risk of production losses due to weeds can be minimised.

Production costs for Carinata would be in the order of $800/ha, including planting, inputs water and harvest. Estimated farm gate returns would be $650/tonne. Working on a targeted yield of

[78] Source – University of Queensland
[79] Personal comment, Dr. Anthony van Herwaarden, UQ

2.5t/ha for irrigated Carinata, an average gross margin would be in the order of $825/ha with a 5 month production cycle.

Mungbean

Mungbeans (Vigna radiata) are a short season, high value grain legume, that was identified in the recent Coriolis report as being a rotational option suited to the North West mineral province of Queensland. They can be grown as either a spring or late summer crop, and with a production cycle of just 90 days, present a unique opportunity in a tight cropping cycle. Australian mungbeans are a high value commodity into the sub-continent market place with growing demand. New and upcoming varieties of mungbeans are high yielding with a well adopted production system giving grower confidence to their viability.

The supply chain for mungbeans is also well established with a grading and packing facility operation in the Burdekin region meaning freight and logistics would work out of the region. Mungbeans have already been a successful crop choice in the region, and with similar machinery requirements to that of the Carinata, plant and machinery would be well utilised across the crops.

Processing grade (mid-level quality) mungbeans would currently fetch $1,050/tonne on farm, with irrigated yields able to be achieved in excess of 2.25 tonnes per hectare. With production costs around that $1000/ha, mungbeans could achieve a gross margin return of an estimated $1,350/ha in just 3 months from planting to harvest.

Mungbeans would be planted (direct drilled) into the Carinata stubble once it had been harvested, allowing for quick turn-around of the country, optimising its utilisation.

Rhodes grass for hay

Similar to a recent cropping system identified and being used in Brazil, a fodder crop could then be planted into the legume stubble left from the mungbean harvest, and grown for hay production and to maintain ground cover for erosion control over the summer wet season.

A long season Rhodes grass variety or something similar and adapted to the region could be planted and grown over the summer months, and cut for Hay when the monsoon has ceased, clearing the ground ready to return to your winter crop. Irrigation demand would be low, but useful to ensure timely planting if early storms were lacking and soil moisture was low.

The fodder production would support and drought proof local grazing operations, and ensure feed supply was ample for the upcoming winter months. With a local market likely and therefore, a freight advantage to traditional suppliers, prices would remain strong. An estimated gross margin of $1,100/ha would be achieved from 6t/ha being baled at $300/tonne with estimated production costs of $700/ha.

Planting and spraying equipment would be the same as that utilised in the other inter-row crops deployed, however, specialty hay cutting and bailing equipment would be required for harvest.

Other options

Not covered in detail here, but other crops to consider that have been trialled as part of the initial Cloncurry work, highlighted in the recent Coriolis report, or new crops being researched in a broader oilseed project that may include biofuel options are:

- Sesame – summer crop option with heat and dry tolerance with high value markets and large growing demand. Following the release and evaluation of the Coriolis report, State Development is considering some research frameworks in this space.
- Safflower – a flexible winter through spring oilseed with new varieties opening up high value industrial markets.

- Camelina – a short season spring oilseed crop, with broad market segment demand with no footprint in Australia currently, but research is underway.

Management of Leucaena plantation

For the above integrated farming system to work, careful planning and management of the Leucaena crop would be required. The key considerations would be:

- Ensuring the row spacing is wide enough to manage both the Leucaena and the inter row crops, considering machinery widths and not creating competition for resources (light, water, nutrients) between the complimentary crops. A width of 10 metres would appear to be a good balance.
- If feasible, plant the Leucaena rows east west, to maximise light penetration for the inter row companion crop.
- Irrigation planning and availability will be crucial. If the height of the Leucaena can be managed, a lateral move irrigator that can straddle all crops, provides a method that can cover the whole area, and be moved out of the way for harvest or other field operations. It also provides scale efficiency to match crop area to the potential output of the machine to maximise return on investment of the infrastructure. Other options or combinations would include drip and flood systems. An irrigation consultant should be engaged to ensure the optimum system is deployed for each situation. This will vary across scenarios due to a number of constraints or factors such as topography, area and water availability.
- Initially it is hypothesised that a biennial harvest of the Leucaena is undertaken. Following the wet season and the field is accessible (for machinery) harvest should commence to capture the bulk growth achieved over the summer months and before conditions cool and growth slows. This will open up the inter-row space, and reduce light competition for the winter and spring crops to be grown from April onwards. A second harvest would be required after the harvest of the mungbeans and prior to the planting of the summer grass crop, to again capture the early Leucaena growth that has occurred with the rising day temperatures, and again increase light intensity for the emerging grass crop so it can be well established prior to the wet season and main growth period of the Leucaena.

If achievable, this integrated system would provide some key benefits:

- Cash flow created immediately from inter row crops whilst Leucaena is establishing
- Land and water utilisation is optimised and can be scaled to suit available resources
- Spreads risk across a number of markets and commodities
- Diversifies the operation and creates stable employment opportunities for employees throughout the year
- Leads to local commercial value adding opportunities and potential security of key inputs such as biofuels.

Protects and enhances the local grazing industry through fodder and complimentary feed sources.

6.7.6 Production facilities for pellets

Equipment specifics - delivery

The pellet plant equipment is typically delivered in modules. Depending on the capacity and weight of equipment, some equipment may be grouped together in a module (e.g. two pellet mills). Equipment that would be modularised includes dryers, screens, grinding equipment (hammer mills), pellet mills and coolers.

Most of the equipment may be delivered in modules small enough to be transportable by road if required.

At site, concrete and piling are required for the modules, as well as various buildings (for example, dryers are typically roofed, and buildings for on-site spares, etc.). The modules will be connected and commissioned at site. The capacities required for the project are not outside technology vendor experience; therefore GHD is confident that the equipment can be delivered without long design times.

Some equipment may have relatively long procurement lead times; and these items include the hammer mills, dryers and pellet mills. A lead time of around 18 months is typically expected.

Processing plant development

An indicative processing plant development and spend timeline is shown in Figure 6-7. Initial investment in the wood pellet mill plant, co-generation facility and animal feed pellet plant is made in Y0, Q1. This triggers design and construction of the wood pellet plant for completion in Y2, Q1, following a design period of 9 months and a total construction period of 24 months (site and yard work).

Prickly acacia clearing commences in Y2, Q1 to allow for ambient drying and initial processing for processing from Y2, Q2. Prickly acacia is processed until Y4, Q4.

Land preparation and irrigation systems establishment takes place from Y2, Q4 until the end of Y3, Q1. Following this, Leucaena is planted in Y3, Q2, for first harvesting 18 months later in Y4, Q4. First processing of Leucaena commences in Y5, Q1.

Following the design of the animal feed pellet plant at the start of the project along with the other units (in order to define the footprint and utilities required for the animal feed pellet plant), this unit is constructed in Y4 for start-up at the beginning of Y5, when the first Leucaena is processed through the wood pellet and animal feed pellet plants.

Once Leucaena processing commences, the plants are assumed to be operational for 25 years (thus the project runs for 30 years in total).

The wood pellet plant and the animal feed pellet plant is constructed at the same site. This way, utilities and support systems can be shared by both plants; as well as for example on-site spares storage, site security, laboratory facilities and operator and maintenance staff.

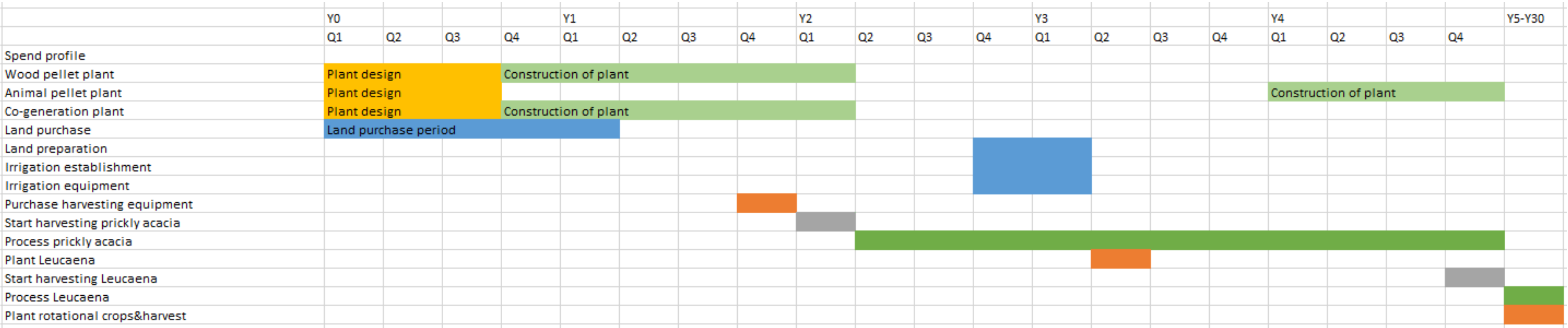

Figure 6-7 Pellet plant development – indicative timeline

6.7.7 Co-generation facility

Further work is required to determine the optimal configuration and balance of cogeneration and grid-supplied energy, and development expenditure timing to optimise investment returns. A number of scenarios have been investigated at high level, and although a high pressure cogeneration option would provide energy at the lowest annualised cost, the capital investment required is significant. Although a key benefit of this approach is that energy costs will be independent of external electricity and diesel pricing, the proposed Copper String development may make lower cost grid-supplied energy available on a long-term contract basis, and that would also influence investment decision-making around cogeneration options.

6.7.8 Transport and shipping options

Transport from harvesting location to process plant would be via high productivity road transport vehicles. Although the location of the processing plant will have a large influence on the most efficient logistics combination, it is expected that transport to either Karumba or Townsville would be the two sea freight export options available.

Karumba Port considerations

The Port of Karumba is located at the mouth of the Norman River in the south-east corner of the Gulf of Carpentaria. The port provides for general cargo, fuel, fisheries products and the export of live cattle. Far North Queensland Ports Corporation Limited, trading as Ports North, is a Queensland Government Corporation responsible for development and management of certain far north Queensland ports, including Karumba.

According to Ports North, base metal company New Century Resources (NCR) has committed to re-establish transhipment operations through the Port of Karumba. NCR projects annual export volumes of 300,000 – 400,000 tonnes over an estimated mine life of 6.5 years, and has also negotiated with Ports North to maintain the channel depth over the life-time of the project.

Port procedures and information for shipping for Karumba Port indicate that movement of vessels greater than 50 metres in length is restricted to tides having an hourly change of 30 centimetres or less, and maximum vessel length allowed is 100 metres[80]. There are restrictions on vessel movements associated with tidal flow, and it is understood that the Karumba Channel is subject to extensive shoaling and siltation caused by extreme weather. The maintained depth of 3.4 metres cannot be guaranteed during the NW Monsoon season. Therefore, it is likely that export via Karumba would be highly constrained and the preferred export option would be Townsville.

Townsville Port considerations

Significantly larger vessels are permitted to use the Townsville port than those accommodated at Karumba. The maximum size of a ship for the port are 238 metres overall length, 32 metres beam and 13.1 metres maximum draft. Design depth of the channel is 11.7 metres however this may reduce between scheduled dredging. Deep draft vessels will be tidal restricted[81].

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[80] Queensland Department of Transport and Main Roads, Port Procedures and Information for Shipping - Port of Karumba https://www.msq.qld.gov.au/Shipping/Port-procedures/Port-procedures-karumba accessed 1 Aug 2019
[81] Queensland Department of Transport and Main Roads, Port Procedures and Information for Shipping - Port of Townsville https://www.msq.qld.gov.au/Shipping/Port-procedures/Port-procedures-townsville accessed 15 Aug 2019

Access to the port of Townsville from the study region has the option of access to established road or rail infrastructure, and there may be scope to secure an industrial site for locating the biomass processing facility at or near a rail siding in, for example, Richmond.

Road transport

According to the National Heavy Vehicle Regulator (NHVR) Route Planner, road access along the Flinders Highway between Mount Isa and Townsville port is approved for Class 2 high productivity vehicles including Type 2 road trains with an overall length of up to 53.5 metres and a gross combination mass (GCM) of 115.5 tonnes[82].

Rail transport

The rail line between Mount Isa and Townsville connects mineral resource operations and agricultural centres through the region. The line was extensively damaged by monsoonal flooding in February 2019, and closed for several months, returning to full service in May following repairs.

The closure also enabled critical maintenance works to be completed, removing previous speed and load restrictions that had existed on the line for some time.

There has been a reduction in rail utilisation in recent years with lower cost road transport alternatives being offered, and the long term contractual commitments required to secure lower cost rail transport have deterred some former users from opting for rail.

According to local Member of Parliament Robbie Katter, “The problem at the moment is the price and that's why there's over a million tonnes now on the road that used to be on rail”[83].

Notwithstanding the above issues, given the large quantities of product this project may generate, over several decades, rail transport may emerge as a potentially viable option in the longer term.

6.8 High level financial model

6.8.1 General assumptions

- Exchange rate for the AU$ to the US$ is 1:0.75.
- Exchange rate for the AU$ to the Euro is 1:0.62.
- CPI is assumed to be 2.5%.
- A discount rate of 10% is used.
- A total of 4,600 ha is assumed to be occupied for the project as crop space. Of this, 3,600 ha is utilised for Leucaena, while the additional 1,000 ha in between Leucaena is utilised for supplemental crop growth (Rhodes Grass, mung bean and carinata).
- In all cases, the pelleting and co-generation facilities are run for 27 years, 25 of which is with Leucaena. Supplement crops will be planted from year 3 until year 27, that is, the supplement crops will be planted and harvested from the first year Leucaena is harvested.

[82] National Heavy Vehicle Regulator (NHVR) Route Planner https://www.nhvr.gov.au/road-access/route-planner, accessed 16 August 2019
[83] Mount Isa to Townsville rail line set to reopen after north-west flood, North Queensland Register, 26 April 2019, https://www.northqueenslandregister.com.au/story/6092000/isa-townsville-rail-to-reopen/ accessed 21 August 2019

6.8.2 Capital and establishment cost assumptions

- Land purchase cost is AU$620-870/ha for land with access to water. For the financial model an average cost of AU$745/ha is utilised. Total land purchase cost for 4,600 ha is AU$3.45 M.
- A harvester is required at a cost of AU$800,000 to purchase (CNH Harvester), and 2 harvesters are required. In addition, AU$300,000 is required to purchase a haul-out tractor and bins, and 16 of these are required. Total harvesting equipment cost is therefore AU$6.40 M. It is assumed that the same equipment could be utilised for prickly acacia with some modifications.

  Harvesters have to be replaced every 8 years (25% of the total initial cost) and the haul-out tractors and bins every 12 years (75% of the total initial cost).

  Costs have also been determined for utilising smaller harvesters; the initial investment cost for the smaller harvesters and associated haul-out tractors and bins is estimated at AU$ 11.55 M. This may be the more conservative assumption and could therefore be tested in the economic model if required.
- Initial land preparation is estimated at AU$1,300/ha, thus for 4,600 ha, the cost is AU$5.94 M.
- Irrigation establishment cost is AU$3,500/ha, and thus AU$16.0 M for 4,600 ha.
- To pump water to storage for irrigation and to establish off-stream storage requires an estimated AU$2.70 M per modelled system to support 1,000 ha. Irrigation of 4,600 ha would require approximately five similar modules however it could be expected that 20% efficiencies could be achieved through sharing earth embankments etc. As such the total cost for this element would be in the order of AU$10.8 M.
- The wood pelleting plant cost is estimated at AU$ 17.0 M (TIC).
- The animal feed pellet plant cost is estimated at AU$ 2.0 M (TIC).
- The co-generation facility cost is estimated at AU$ 23.0 M (HP boiler and turbine option, see section 6.6). This assumes that power and heat is generated on site using biomass as fuel, and no grid connection is required.

Table 6-20 Summarised capital and establishment investment costs

Item	Cost (AU$ M)
Land purchase cost	3.45
Harvesting equipment	29.64
Land preparation cost	5.94
Irrigation establishment cost	16.00
Irrigation pumping and storage capital	10.80
Wood pellet plant	16.24
Animal feed pellet plant	1.97
HP boiler and turbine for power and heat generation	23.30
Leucaena establishment cost	5.73
Total capital investment cost	**113.07**

Sterile Leucaena establishment costs

- Leucaena establishment costs are assumed to be AU$400/ha. It is assumed that 3,600 ha will be planted with Leucaena, and that it has to be replaced every 20 years. Leucaena establishment and replacement cost is assumed to be AU$2.0 M.
- No mortality with harvesting of Leucaena has been assumed at present. In reality, a percentage of Leucaena plants will be lost with each harvest and would have to be replaced.

The indicative capital and establishment cost breakdown is presented in Figure 6-8. From this, the two largest contributors are the co-generation plant and irrigation establishment (including infrastructure), with 60% of the total cost being attributed to these two items. The wood pelleting plant is the next largest contributor at 20% of the total spend.

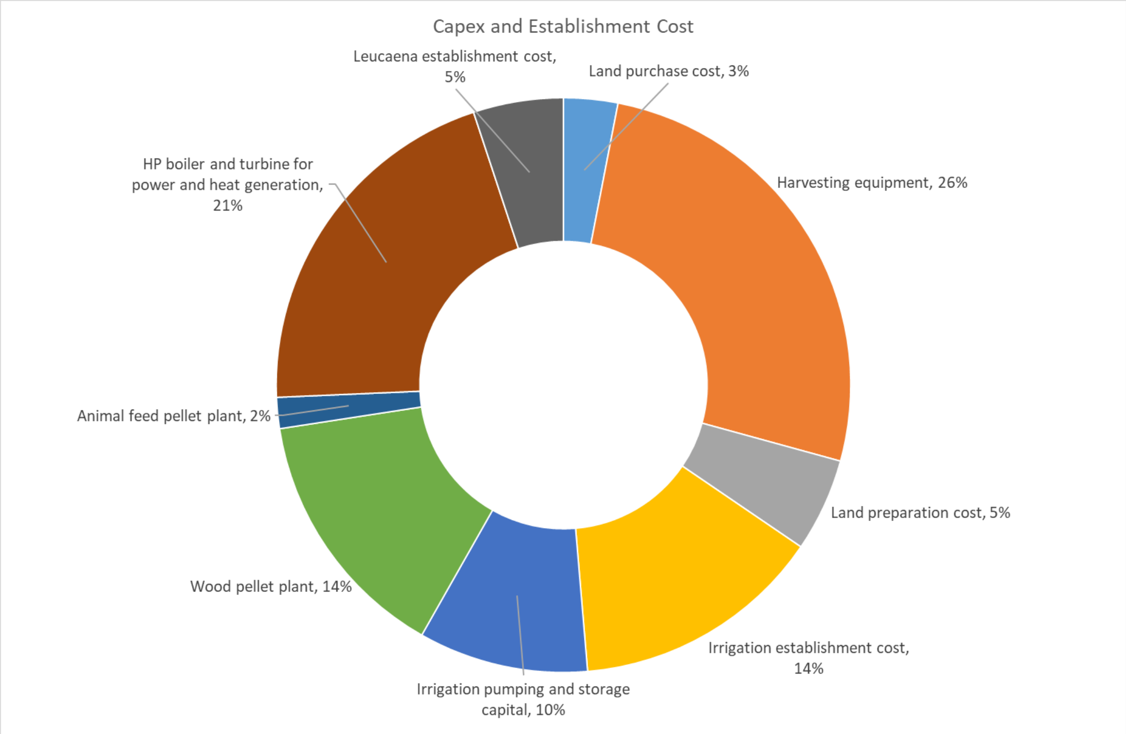

Figure 6-8 Capital and establishment cost breakdown

The spend profile for capital and establishment costs is summarised in Table 6-21.

Table 6-21 Summarised spend profile for capital and establishment costs

Spend profile summary	Y0	Y1	Y2	Y3	Y4	Y8	Y12	Y13	Y16	Y22	Y24
Wood pellet plant	25%	50%	25%								
Animal pellet plant	25%				75%						
Co-generation plant	25%	50%	25%								
Land purchase	50%	25%	25%								
Land preparation			100%								
Irrigation establishment			100%								
Irrigation equipment			100%								
Purchase harvesting equipment		100%				25%*	75%**		25%*		100%***
Plant Leucaena				100%						100%	

*Replace harvesters; ** Replace haul-out tractors and bins; *** Replace harvesters and haul-out tractors and bins.

The spend profile was developed using the following assumptions:

- In Year 0, the project commences with a 25% payment for design work of the wood pellet plant, co-generation facility and the animal feed pellet plant.
- As all three types of plant are relatively well defined, nine months of design time is allowed before construction of the wood pellet and co-generation facilities commence is Y1, Q4. Two payments of 25% each (thus 50% of the total) cost of the wood pellet and co-generation facilities are made during Y1.
- Construction is completed in Y2, Q1, with the last 25% payment for each of the wood pellet and co-generation facilities assumed.
- Land purchase starts in Y0 and continues through Y1 and Y2, with the bulk of land being purchased in Y0 to secure land for farming crops and construction of the pelleting and co-generation plants.
- Land preparation, irrigation establishment and irrigation equipment are all paid for in Y2, once harvesting and processing of prickly acacia commence. These activities are required in Y2 in preparation of planting Leucaena in Y3.
- Leucaena is planted in Y3 and then replaced every ten years (thus in Y13 and Y23).The plant ceases operation in Y30 (after 25 years with Leucaena as feedstock).

6.8.3 Operating cost assumptions

Rotation crops (supplemental crops) establishment costs

The growing seasons for rotation crops are assumed to be the following:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
			Carinata planting					Carinata harvest			
									Mung-bean plant		Mung-bean harvest
Rhodes grass planting		Rhodes grass harvest									

Figure 6-9 Rotation crop growing seasons

While this rotation schedule may be more aggressive than may be followed, it is a starting point, and may be adjusted to allow for land fallow time.

- For Rhodes Grass, establishment costs are assumed to be AU$700/ha. At the assumed 1,000 ha to be planted, the establishment cost is calculated at AU$ 0.7 M/annum.
- For carinata, establishment costs are assumed to be AU$800/ha. At the assumed 1,000 ha to be planted, the establishment cost is calculated at AU$ 0.8 M/annum.
- For mungbean, establishment costs are assumed to be AU$1,000/ha. At the assumed 1,000 ha to be planted, the establishment cost is calculated at AU$ 1.0 M/annum.

Other cropping/farming costs

- The irrigation pumps require 620kWh/h to pump 165ML/day for 35 days/annum. This translates to 21,656 kWh/annum. The pumps are assumed to be driven by a diesel generator, and assuming an efficiency of 0.4L of diesel/kWh, 8662 L/annum of diesel is required to drive the irrigation pumps. Assuming a cost of AU$1.05/L of diesel, this becomes AU$9,095/annum. This is negligible at present.

- No additional cost is allowed for water purchase.
- No additional cost is allowed for extra weed control or fertiliser chemical addition to crops, however the cost of production figures provided include allowance for typical fertiliser and herbicides etc.
- For harvesting, the following is assumed:
  - Moisture content for fresh biomass harvested is 50% mass (used to determine the mass of biomass harvested).
  - Cost per tonne to harvest Leucaena is AU$ 10.14/t, where AU$4.55/t is utilised to harvest and AU$ 5.59/t to haul the harvested material.
  - Cost per tonne to harvest prickly acacia is estimated at AU$42/t. This is a "best guess" at present and will have to be firmed up as the study progresses to subsequent stages of investigation and trials.
  - Transport from where the material is harvested to the pelleting site is assumed to be 50 km, and the associated cost is AU$6/t.
  - Transport for prickly acacia is assumed to be AU$ 10/t. Again this number will have to be confirmed.
  - For the rotational crops, the same harvesting and transport cost is assumed per tonne as for Leucaena. It may be less expensive to harvest these crops compared to Leucaena.

Pelleting facility operating costs

- 24 FTE's are assumed for the wood pelleting plant, plus an additional 4 FTE's for the animal feed pelleting plant, at an annual cost of AU$100,000/FTE. From literature, this may be higher than what is currently assumed.
- Maintenance cost is AU$13.5/t pellets produced (wet basis) for the wood pellet facility (cost from Andritz including maintenance labour, spares and lubrication) and 4% of the TIC on an annual basis for the animal feed pellet facility.
- A general site cost of AU$500,000/annum is assumed to cover building maintenance, laboratory consumables, etc.
- No insurance is currently taken into account. This is usually around 1-2% of TIC on an annual basis.

Co-generation facility

- O&M cost for the co-generation facility has been estimated at AU$1,008,000/annum.
- Biomass fuel cost has been estimated at AU$1,473,000 /annum.

Table 6-22 Operating cost summary

Parameter	Value (M AU$/annum)
Seedling establishment cost (rotation crops only)	2.50*
Harvest and transport cost	3.53 (for years harvesting Leucaena) 9.00 (for years harvesting prickly acacia)
O&M for pellet facilities	4.21
O&M for co-gen facility	1.01
Biomass fuel for co-gen	1.47
General site costs	0.50

Parameter	Value (M AU$/annum)
Trucking pellets to port	5.91
Port storage and loading costs	2.76
Total operating cost	21.89 (for years harvesting Leucaena) 24.86 (for years harvesting prickly acacia)

*Only for years where Leucaena is also harvested.

During the years where prickly acacia is harvested, the operating cost is almost 14% higher than for the years when Leucaena is processed. This is largely due to the harvest and transport costs associated with prickly acacia, which contributes 36% of the total annual opex during these years.

The operating cost breakdown for years when Leucaena and rotational crops are grown, harvested and processed is shown in Figure 6-10.

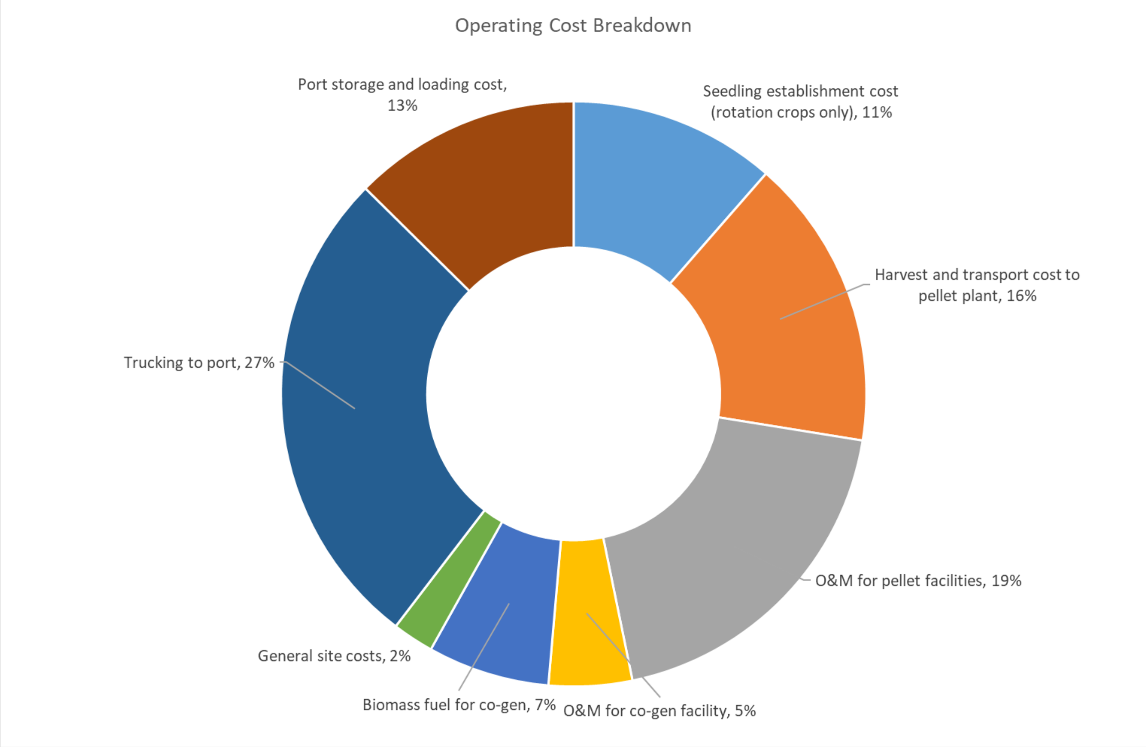

Figure 6-10 Operating cost breakdown (Leucaena years)

Harvest and transport cost (excluding transport of the wood pellets to port) is a significant operating cost at 16%, however transport of wood pellets to port, and storage and ship loading costs are the largest operating cost component at 40% (combined), followed by labour cost for the pellet facilities at 13% and rotational crops establishment at 11%.

6.8.4 Production, product pricing and shipping cost assumptions

Production is assumed to be the following on an annual basis

- Wood pellets – 98,485 t/annum (at 12% mass moisture)
- Animal feed pellets – 11,765 t/annum (at 15% mass moisture)
- As an alternative product to wood pellets, woodchip could be produced – 126,776 t/annum (at 30% mass moisture) or 110,929 t/annum (at 20% mass moisture)
- Carinata production – 2,500 t/annum

- Mungbean production – 2,250 t/annum
- Rhodes grass production – 6,000 t/annum.

Product pricing is assumed to be the following

- For wood pellets, a price of US$165/t is assumed, or AU$220/t FOB. This may be higher or lower and some sensitivities have been tested to assess the effect of wood pellet price on project economics.
- For animal feed pellets, a price of AU$300/t is assumed ex-plant. This price could be considerably higher but is dependent on the specific composition of the pellets, local demand and cost of handling and transport (to be borne by the customer).
- For wood chips, a price of AU$159/t (bone dry) was obtained for hardwood chips. For the Leucaena chips, it is assumed that 80% of this price could be achieved, or AU$127/t (bone dry). Translating this back to the two moisture conditions assumed for woodchip product, the price is AU$89/t (wet) for woodchip assuming no drying beyond ambient drying (30% mass moisture) or AU$102/t (wet) for woodchip with additional drying (20% mass moisture).

Transport cost to port

- The transport cost is assumed to be AU$0.12/t/km, and the port is assumed to be approximately 500 km from site.
- At this stage no shipping costs have been taken into account to deliver the products to an overseas market (modelling assumes wood pellets are sold on an FOB basis, and therefore port storage, handling and ship loading have been accounted for)
- The rotational crops are assumed to have a local market, that is, no additional transport cost has been taken into account for these crops at present.

Port costs (including storage and ship loading)

A Queensland precedent exists for wood pellet export via Bundaberg, with Altus Renewables utilising the raw sugar load-out facilities of Queensland Sugar Limited (QSL) at Bundaberg under long term contract. QSL are based at the Port of Townsville, however looking at the land available at the port, it may be difficult to find land to place a new storage shed for the wood pellets close to QSL's ship loader. Further investigation of port access and storage arrangements would be required as part of a more detailed study, to determine whether any latent storage capacity exists. Another consideration may be assessing potential for exporting via the Port of Lucinda, 100km north of Townsville via the sugar terminal, though this would add around 100km to road transport, with associated additional costs.

The following rates for port handling and ship loading have been assumed in modelling:

- Port intake cost $5/tonne
- Storage costs $3/tonne
- Terminal/ship loading cost $20/tonne

Total port handling and ship loading cost modelled is therefore $28/tonne.

Port considerations and limitations

- Listed prices are subject to securing access to an existing dry bulk ship loader (sugar)
- All prices are subject to commercial negotiations
- Assumes wood pellet storage stockpile/shed has direct access to ship loader intake

- Total costs modelled exclude booking/agent fees that may apply, which have not been ascertained at this stage.

6.8.5 Total Project Spend Breakdown

The total spend for the project has been broken into various categories to determine the largest contributors to project cost.

Operating cost contributor costs have been calculated over the 30 year duration of the project.

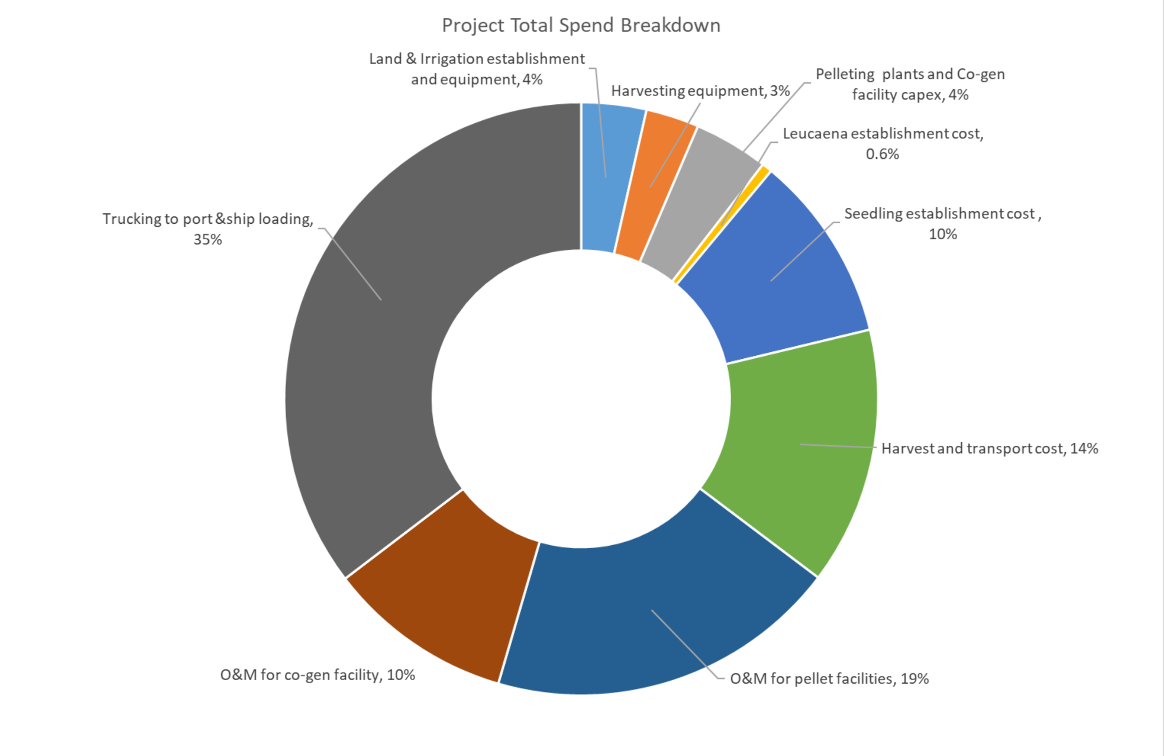

Figure 6-11 Project total spend breakdown

From the above, harvesting and transport of the crops (14%) to the processing site, operating and maintenance costs for the pelleting facilities (19%), as well as transport of the final products to port and ship loading (35%), are the largest contributors to the project cost, at a total of almost 68% of the project cost. Ongoing rotational crop establishment and operating and maintenance costs for the co-generation facility both contribute 10% to the total spend.

6.8.6 Base case results

Utilising all the assumptions as noted in sections 6.8.1 through 6.8.5, the base case economics were developed. The IRR (30 yr) for the base case is 6.40% and the NPV AU$ -26,884,432.

The inclusion of harvesting and processing of prickly acacia, rotational crops and animal feed pellet production were subsequently tested to determine if they added value to the project, or detracted from investment returns. The results are shown in Table 6-23.

Table 6-23 Testing "value add" items for the Base Case

Case	Short description	IRR (%)	NPV (AU$)	Adds value?
Base Case		6.40	-26,884,432	
Prickly acacia exclusion	Exclude harvesting and processing of prickly acacia. Defer wood pellet	9.66	-2,383,223	No

Case	Short description	IRR (%)	NPV (AU$)	Adds value?
	and co-generation facilities spend to later in project.			
Rotational crops exclusion	Smaller land area assumed, no rotational crops planting & harvesting.	3.66	-39,948,665	Yes
Animal feed pellet exclusion	Leafy material is left in field, no animal pellet plant included, co-gen plant is smaller	3.73	-39,128,213	Yes

From the above, with the exception of prickly acacia processing inclusion, the “value-add” items improve the project economics. It is therefore recommended that prickly acacia processing not be included in the project as a wood pellet production input, unless there are some incentives associated with removing and processing this material or the land available has to be cleared prior to establishing Leucaena.

Moving forward, the case with no prickly acacia harvesting and processing will be adopted as the Base Case.

6.8.7 Cases modelled

The following cases have been modelled to determine the impact of various potential changes in project parameters on the financials (Table 6-24).

Table 6-24 Cases modelled

Case Description	Changes from Base Case	Objective
Base Case		
Sensitivity 1	Assume that irrigation establishment, pumping and storage will be covered by incentive payment (AU$ 30 M in Y2).	Test the influence of incentive payments (e.g. State Government grants)
Sensitivity 2	Reduce all initial investment costs to 70% or 80% of the base case.	Determine the influence of initial investment cost
Sensitivity 3	An on-site wood fired boiler to provide heat only, as per the MP boiler and grid electricity case (see section 6.6).	Determine whether it is better to co-generate electricity or import from grid. Determine the influence of imported electricity price.
Sensitivity 4	Reduce all operating costs to 70% or 80% of the base case.	Determine the influence of operating cost.
Sensitivity 5	Vary wood pellet selling price from AU$ 200/t to AU$ 320/t.	Determine the influence of product pricing.

Case Description	Changes from Base Case	Objective
Sensitivity 6	Change base case cropping areas (3,600 ha for Leucaena and 1,000 for supplemental crops, rotated through 3 crops per annum) to 2,300 ha for Leucaena and 2,300 ha for supplemental crops. Pellet facilities reduce in capacity and capex.	Determine the influence of crop mixture.
Sensitivity 7	Chip and dry woody product only to produce M25 woodchip for export. Woodchip facility capex is estimated at AU$ 7.31 M. Maintenance cost is AU$ 450,000/annum for the woodchip facility. The woodchip sells for AU$102/t wet woodchip. Woodchip product price is varied.	Determine the influence of final product – wood pellets versus woodchip only.

6.8.1 Results

The summarised results are shown in Table 6-25.

Table 6-25 Financial model results

Case	IRR (%)	NPV (AU$)
Base Case	9.66	-2,383,223
Sensitivity 1 – incentives	9.51	-2,566,576
Sensitivity 2 – reduce capex Capex @ 70% of Base Case Capex @ 80% of Base Case	 13.56 12.03	 19,785,698 12,396,058
Sensitivity 3 – grid electricity Electricity @ AU$100/MWh Electricity @ AU$150/MWh Electricity @ AU$ 200/MWh Electricity @ AU$ 229/MWh	 8.84 8.11 7.33 6.86	 -7,104,576 -11,304,998 -15,505,419 -17,961,192
Sensitivity 4 – reduce opex Opex @ 70% of Base Case Opex @ 80% of Base Case	 13.73 12.47	 29.887,050 19,130,292
Sensitivity 5 – vary wood pellet product price	See Figure 6-12.	See Figure 6-12
Sensitivity 6 – change crop mix ½ : ½	8.84	-7,168,194
Sensitivity 7 – woodchip replaces wood pellet product		

Case	IRR (%)	NPV (AU$)
Woodchip @ AU$102/t wet	N/A	-93,616,715
Woodchip @ AU$184/t wet	5.75	-27,225,300

Product pricing sensitivity

The price received for wood pellets has a significant influence on the project economics. The price has been varied from AU$200 to AU$320/t wood pellets, where the Base Case price is AU$220/t wood pellets. Results are shown in Figure 6-12.

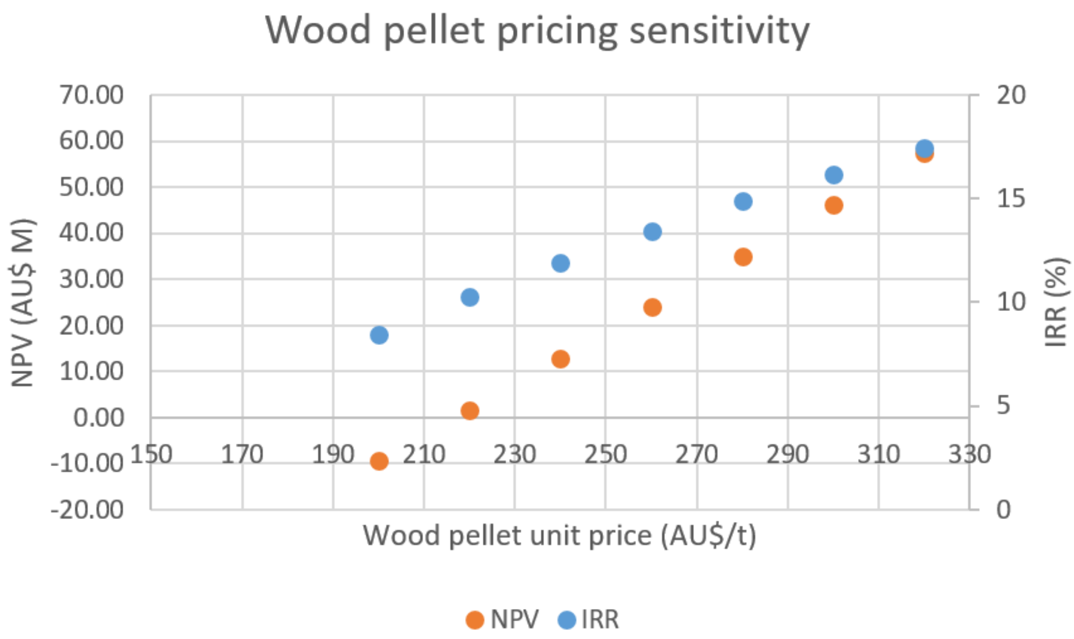

Figure 6-12 Financial indicators for the project with changes in wood pellet pricing

6.8.2 Observations

Utilising all the assumptions as noted in sections 6.8.1 through 6.8.5, the base case economics were developed. The IRR for the base case is 6.40% and the NPV AU$ -26,884,432.

The inclusion of harvesting and processing of prickly acacia, rotational crops and animal feed pellet production were subsequently tested to determine if they added value to the project.

It was determined that with the exception of prickly acacia processing inclusion, the “value-add” items (feed pellets and inter-row cropping) improve the project economics.

The base case was adapted to exclude the harvesting and processing of prickly acacia, with all subsequent cases modelled without. For the modified base case, the economic indicators calculated are 9.66% (IRR) and AU$ -2,383,223 (NPV).

Importing electricity from the grid rather than generating electricity at the co-generation site along with steam for process heating could lead to an improvement of the economic indicators, although this is dependent on the electricity price. The co-generation capital cost and operating cost decrease, noting that a grid connection fee of AU$ 3 M must be paid.

Changing the crop split from more area for Leucaena growth and less area for rotational crops to more area for rotational crops and less area for Leucaena leads to deterioration of economic indicators.

From section 5.1.1, it can be seen that the wood pellet price can vary significantly over time. There appears to be a generally upward trend currently and the price appears to be driven by seasonal demand. The wood pellet price has a significant impact on project economics.

Producing wood chip rather than wood pellets leads to a reduced capital and operating cost to process the woody Leucaena material. Dryers would still be required, so approximately 45% of the base case capital is needed for a wood chipping facility (dryers account for 35% of the equipment cost for the wood pelleting facility). Alternatively, the wood chip could be subjected to ambient drying only; this leads to a considerable decrease in the capital required, but the product value is lower and transport cost per unit product increases (due to additional moisture in the product). Given the distances involved in transport to the port for a lower value product, a viable business case for wood chip instead of wood pellets is considered unlikely.

6.8.3 Exclusions from the financial model

There are some aspects that have not been taken into account as yet for financial modelling:

- Indicative rates based on sugar and grain handling at port facilities have been used in modelling. Equipment has to be specifically designed for the material. Dust emission and explosions, degradation in storage, self-heating and ignition are important criteria when designing a wood pellet port terminal, and can greatly affect associated logistics[84].
- Although ship loading has been accounted for, shipping and handling costs for wood products have not been assessed in detail. Typical items to consider are listed in “Shipping and handling costs for Australia’s wood product exports – Data availability and methodological issues” by ABARES[85].
- At present, no replacement for irrigation equipment (e.g. pumps) or irrigation network piping has been taken into account. These may have a typical lifetime of around 15 years.
- No transport costs have been taken into account for delivering rotation crops to market. It is assumed that the market will be local and the cost should therefore be low. This assumption should be tested following a market study.
- No Leucaena mortality has been included. A percentage of plants will be lost during every harvest and would have to be replaced.

An alternative to land purchase would be long-term leasing. An indicative leasing cost for land in the study area would be AU$33 /ha/annum (this would be an operating cost in this case). This option has not been modelled within the study.

6.8.4 Inclusion of shipping costs to Japan

This study did not consider shipping costs to another country. However, to determine what the potential impact of shipping and port costs would have on the project economics, one of the cases (Sensitivity 1 – inclusion of incentives) was modelled to include port and shipping costs.

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[84] Dafnomilis, I. et. al. (2018). Evaluation of wood pellet handling in import terminals. Biomass and Bioenergy 117, 10-23.

[85] Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (2016). Shipping and handling costs for Australia’s wood product exports – Data availability and methodological issues. https://www.fwpa.com.au/images/Newsletter_Images/Statistics-count/2016/Sept2016/ABARES_2016_Port_Handling_Costs_-_Draft_report_to_FWPA_Final.pdf Accessed 2/09/2019.

The following assumptions were made:

- Port and ancillary costs were determined from a previous GHD study at AU$7.00/t for wood pellets.
- Shipping costs for wood pellets were calculated starting from a formula presented in Renewable and Sustainable Energy Reviews "Wood pellet supply chain costs – A review and cost optimization analysis"[86] and adjusted to Australian dollar cost and shipping from Mackay to Tokyo (6,400km from port to port). The published shipping cost was 1.70 to 2.00 EUR/t-1000 km, or AU$2.75 to 3.23/t-1000 km, so that the shipping cost was calculated at AU$17.60 to 20.70/t. An average of these values was used to develop the case where shipping was included, that is AU$19.00/t.
- Landed wood pellet cost in Tokyo was determined to be US$190/t, or AU$253/t.

The modelling results are shown in Table 6-26.

Table 6-26 Modelling results to show the impact of inclusion of shipping costs

Case	IRR (%)	NPV (AU$)
Sensitivity 1 – incentives, excluding shipping	9.51	-2,566,576
Sensitivity 1 – incentives, including shipping	10.04	215,204

From the results, the inclusion of shipping costs do not have a negative effect on the project economics, due to the higher price expected for wood pellets landed at market. However, project economics are again highly dependent on the expected wood pellet market price.

This work was only completed for bulk shipping of wood pellets; from the information supplied by MITEZ, GHD believes that containerised shipping will not be economically viable and as such it was not considered further.

[86] Visser, L, Hoefnagels, R and Junginger, M. (2020). "Wood pellet supply chain costs – A review and cost optimization analysis". Renewable and Sustainable Energy Reviews 118 (2020) 109506.

7. Key data gaps

7.1 Introduction

A number of data gaps have been identified during this study, and further work is needed to understand commercial and timing implications of closing those gaps.

7.2 Cropping systems

7.2.1 Sterile Leucaena

At this stage there is enough data to suggest that Leucaena based pasture systems could be viable if supported with irrigation (and potential capital grant) to maintain production levels. However, to date there appears limited support for traditional Leucaena varieties to be mass planted in plantation type formats due to concerns with regard to its environmental weed potential. This would be resolved with the commercial production and distribution of a sterile or seedless variety. This is currently the focus of a research project being led by the UQ with the support of Meat and Livestock Australia (MLA). It is understood that a number of seedless varieties have been successfully propagated, but their production qualities and ability to be commercially propagated (at a price that is commercially attractive for large plantings) has not been assessed and would be the subject of further research and cropping trials.

Notwithstanding this, opportunity exists for research funding contributions to be matched on a dollar for dollar basis by MLA Donor Company and government for this project.

Suggested research program[87]

2019/20

- Vegetatively propagate 1-3 best performing sterile Leucaena lines

2020/21

- Plant large trial plots of Leucaena in the MITEZ area for performance evaluation

2021/22

- Contract growing of 10 ha of 2 best performing sterile Leucaena lines for demonstration/production

This research program could be developed in association with UQ and MLA. However as an interim step it may be beneficial to plant a large area of a traditional Leucaena variety in a location where it can be appropriately managed to control/contain its production, and replace as sterile varieties become commercially available. If this trial area is managed under the industry code of practice, many of the current concerns regarding weed potential would be mitigated. Research should also focus on method, timing and regularity of harvesting green (leafy) material, and in so doing, remove viable seeds from the system, thus reducing or eliminating the risk of weed seed spread.

Whilst this potential research project would need to be further developed in association with UQ it could be expected to require a budget in the order of \$150,000/yr[88] over a three year program.

The scale and locations for any research trials in the MITEZ region would need to factor in availability of land, water, irrigation infrastructure, required machinery and implements, plus suitable personnel to manage trials.

[87] Personal comment, Assoc. Prof. Christopher Lambrides, UQ
[88] Ibid and subject to opportunities for further collaboration between parties and trials.

With regard to the biofuels cropping trials completed at Cloncurry, Tony Matchett from Savannah Ag was able to plant trials utilising DAF equipment. A spray rig and tractor was made available however watering, pesticide sprays and potential harvest all need to be carried out appropriately and on time. In expanding cropping trials sourcing appropriate skills and resources would be critical.

Similarly, as planting ramps up to a commercial scale will necessitate appropriate machinery/ equipment and dedicated resources with the appropriate skills.

7.2.2 Brassica Carinata (Carinata)

To data there has been limited research undertaken on potentially suitable Brassica Carinata varieties that would be suitable for Australian conditions. In the winter 2018 cropping trials conducted at Cloncurry, the Carinata variety trialled was observed to have grown very well, and if harvested would have been mature four months following planting. Trials in 2018 at Walkamin in Far North Queensland had 26 Carinata varieties, and were evaluated for yield (both grain and oil), height, lodging and pod shatter resistance. This type of work is assisting with the selection of lead cultivars for further assessment. UQ has suggested the following program to advance the knowledge base to support commercial decisions with regard to the opportunity to establish on a broad-acre basis.

Suggested research program[89]

2019

- Plant a yield trial of promising Carinata lines at UQ Gatton campus for selection of best performing lines
- There is a Carinata variety trial currently underway at the DAF Walkamin Research facility, to replicate 2018 performance, and select for the best available lines.

2020

- Plant 3 irrigated Carinata yield trials in the MITEZ area for evaluation of advanced breeding lines
- Contract growing of 10 ha of 2 best performing Carinata lines for biodiesel demonstration/production

2021

- Demonstration of Carinata-based biodiesel for ground vehicles and stationary electricity generation in mini-grids.

Whilst this potential research project would need to be further developed in association with UQ, it could be expected to require a budget in the order of $150,000/yr[90] over a three year program although there is likely economies of scale by combining/co-ordinating research cropping trials.

7.2.3 Mungbean

Whilst confident in the suitability of mungbean in North West Queensland and the agronomic best management practices to achieve this, it will be important to ensure that the right variety adapted to the region is identified. This could vary across the whole region.

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[89] Personal comment, Dr. Anthony van Herwaarden, UQ
[90] Ibid and subject to opportunities for further collaboration between parties and trials.

Suggested research program

2019

- Plant an initial mungbean variety trial at Walkamin looking at several green mungbean varieties alongside the new Black mungbean variety recently released.

2020

- Plant 3 irrigated mungbean yield trials in the MITEZ area for evaluation of a selection of varieties from the 2019 trial and upcoming breeding lines.
- Contract growing of 10 ha of 2 best performing varieties for demonstration/production and supply chain evaluation.

Whilst this potential research project would need to be further developed in association with UQ, DAF Queensland and GRDC, it could be expected to require a budget in the order of $5,000 for the 2019 program, $50,000 for the 2020 program. This would be planted directly following the harvest of the Carinata trials so that the system can be tested and any constraints be identified that may need managing.

7.2.4 Rhodes Grass (hay)

Rhodes Grass adaption and farming practices don't require much research, and validation of assumptions will generally involve assessment of the availability of machinery to accurately plant, manage and harvest (cut, rake and bale) any trials planted.

Suggested research program

2020

- Contract growing of 10 ha of two of the best performing varieties for demonstration/ production and supply chain evaluation. This would be planted directly following the harvest of the mungbean trials so that the system can be tested and any constraints be identified that may need managing.

7.3 Transport summary

In general, industry norms have been used to estimate transport costs (at a high level only) for system cost estimating purposes, and further work will be needed to firm up assumptions once details are available on likely location/s of plantations and processing infrastructure. Based on preliminary research conducted to-date, and data on prickly acacia distribution, it would be reasonable to assume that the port of Townsville would be preferred over Karumba for export of biomass pellets to overseas markets.

If production were centred around, say Richmond, the transport distance alone favours Townsville over Karumba. When the port restrictions at Karumba are considered, Townsville presents as a more attractive option for export, however further work is required to assess likely costs and validate assumptions.

8. Approvals

8.1 Introduction

The Project will be subject to environmental and planning requirements stipulated by the Commonwealth, State and local legislation and policy. Approvals and permitting for a biomass project would typically require the following:

- Planning approval – associated with the use or change in use of the land on which the project activity is proposed to be undertaken.
- Environmental assessment and approvals, permits and licenses – associated with identifying the environmental, cultural and social values of the project site and potential impact area, including off-site locations. Predicting project impacts on these values seek to inform environmental approval, permit and licencing triggers, as well as actions necessary to manage, mitigate or offset impacts arising.

In order to inform what approvals the project will require a review of the environmental values on the selected site need to be understood. This will help in determining the environmental constraints, how the project will impact the environment and land values and therefore what approvals will be required. A review of environmental values will include the following elements:

- Land use and tenure
- Soils and topography
- Watercourses and water quality
- Flora
- Fauna
- Noise, lighting, vibration and air quality
- Cultural heritage (including indigenous cultural and existing historical cultural heritage)
- Climate
- Sustainability.

This study will be a desktop-based and will rely on publically and freely available and/or client supplied data.

8.2 Typical approvals for a biomass project

Due to the early development stage of the project, a high level overview of typical approvals for a biomass pelletising project are supplied, these are summarised in Table 8-1. Once a site has been selected and the project capacity and general scope have been developed further, additional work can be completed in this regard.

Table 8-1 Typical approvals for a biomass pelletising project

Legislation / Approval	Jurisdiction	Potential relevance
Environmental Protection and Biodiversity Conservation Act 1999	Commonwealth Department of Environment and Energy	Projects that potentially impact on matters of national environmental significance (MNES) require approval by the Minister. Likely for a greenfield site with high value sensitive areas.

Legislation / Approval	Jurisdiction	Potential relevance
Planning Act 2016	State and Local Council	Material change of use of premises assessable against a local planning scheme.
Environmental Protection Act 1994	State Department of Environment and Science	Environmentally relevant activity (ERA) and environmental authority for example: Chemical/fuel storage Crushing, milling, grinding or screening Bulk material handling (at port) Regulated waste storage and transport.
Environmental Protection (Noise) Policy 2008	State Department of Environment and Science	An environmental authority is required to conduct an ERA and will include conditions to protect the noise environmental values from environmental harm. Noise from other non-ERA commercial or industrial activities, or noise from domestic premises, is typically regulated by the local council.
Environmental Protection (Air) Policy 2008	State Department of Environment and Science	An environmental authority is required to conduct an ERA and will include conditions to protect the air quality. The Environmental Protection (Air) Policy 2008 (EPP (Air)) establishes long-term objectives for sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, particles, lead and a number of air toxics. Decisions regarding conditions of approval will consider these objectives.
Environmental Protection (Water) Policy 2008		The quality of Queensland waters is protected under the Environmental Protection (Water) Policy 2009 (EPP (Water)). The policy provides the framework for developing environmental values (EVs), management foals and water quality objectives for Queensland waters and will need to be assessed.
Water Act 2000	Department of Natural Resources Mining and Energy (DNRME)/ Department of Environment and Science	If water is proposed to be taken or interfered with from an unmapped water course DNRME will need to be contacted. If the proposed works involve interfering with a water course then a development application will be required.

Legislation / Approval	Jurisdiction	Potential relevance
	DNRME	A riverine protection permit may be required if vegetation in any watercourse, lake or spring is to be destroyed for the development of access roads or site infrastructure.
Vegetation Management Act 1999	State Department of Natural Resources and Mines	Operational works for clearing of regulated vegetation (native vegetation). Location specific.
Fisheries Act 1994	State Department of Agriculture and Fisheries	Operational works for damage to or clearing of marine plants. Location specific.
Transport Infrastructure Act 1994	Department of Transport and Main Roads	Road access works permit may be required if the proposed site requires a physical means of entry or exit between land and a road (drive way). Should works require establishing or constructing roads or things associated with roads a road works permit may be required.

These are all applicable in Queensland.

8.2.1 Proposed methodology in advancing the project

It is recommended that an environmental scoping and approvals review is undertaken for preferred sites, once identified. This is typically desktop-based and would include:

Environmental (physical, biophysical, social/land use, cultural) scoping, including:

- Review of ecological databases, including Commonwealth, State and local government
- Review of Government mapping layers, in particular regulated vegetation, essential habitat, protected plants, cultural heritage, homesteads/sensitive receptors, land use and tenure, amongst others.
- Review of similar, recent projects (as available).
- Identify environmental values present
- Prepare a high level likelihood of occurrence (presence/absence) register for listed threatened flora and fauna species.

Regulatory approvals strategy, including:

- Review of Federal, State and local government legislation, regulation and planning schemes to identify relevance.
- Define the required approval pathways including any applicable exemptions under the Planning Act 2016.
- Develop an approvals register
- Identify statutory timeframes for assessment and approval

Typically, during the early stages of project development, external stakeholders would not be engaged, unless the review identified a critical matter requiring clarification. In the same manner, site investigations would occur after some initial project development.

Detailed investigations would be undertaken once a preferred site is determined and concept design is understood to enable the disturbance footprint and impacts to be predicted. Understanding planning and environmental constraints and opportunities during site selection can assist in nominating sites that have reduced requirements or provide early information to inform design that seeks to avoid, mitigate and manage impacts to acceptable threshold levels.

Undertaking targeted field investigations at an early stage of project planning will assist in validating desktop review data and confirm the presence or absence of sensitive environmental areas and places. Similarly, targeted modelling may assist in defining early no-go zones or areas where avoidance of impacts through design is required, for example in relation to air quality.

Early engagement with regulatory agencies can assist in understanding local capacity, expectations and concerns. Legislative triggers can be subjective. Local Council is well placed to provide confirmation of assumptions regarding the proposed regulatory approach, confirm timeframes and expectations.

9. Funding support options

This project concept may be eligible to access a wide range of potential funding support opportunities including:

- Potential grant funding:
  - North Queensland Water Infrastructure Authority
  - ARENA
  - Queensland Department of State Development, Manufacturing, Infrastructure and Planning (DSDMIP) Building our Regions programme
  - Queensland DSDMIP Waste to Biofutures Fund
  - Jobs and Regional Growth Fund
  - Maturing Infrastructure Pipeline

Trade and Investment Queensland provides a "Queensland Government Grants Finder" search assistance function on its website[91]. Further sources of funding support may also include:

- Queensland DSDMIP Investment facilitation
- Clean Energy Finance Corporation (CEFC)
- Private equity
- Loan facilities.

In addition to the above, potential partnering opportunities may exist for businesses seeking to transition away from a heavy reliance on fossil fuels/energy to a cleaner, more sustainable energy source/s.

The Queensland government released a North West Queensland Economic Diversification Strategy[92] on 27 August 2019. The release of the strategy coincided with new funding announcements for energy and agriculture in North West Queensland. Additional funding announced included:

- $1.68 million towards energy supply and transmission projects
- $600,000 investment into catalytic projects including fodder production and ongoing irrigated cropping trials, identification of co-investment opportunities for common user facilities and development of a targeted program for global investment attraction.

The media release also highlighted a recent State government initiative to reduce rail access charges on the Mount Isa Line by $80 million over four years.

It is therefore recommended that MITEZ engage with the Queensland Department of State Development, Manufacturing, Infrastructure and Planning to investigate funding support options for further, more detailed investigation of the technical and commercial feasibility of progressing this biomass industry development opportunity.

[91] https://www.grants.services.qld.gov.au/
[92] Queensland Government media release: *Future looking bright for North West Queensland,* *http://statements.qld.gov.au/Statement/2019/8/27/future-looking-bright-for-north-west-queensland* accessed 28 August 2019.

10. Project risks and opportunities

10.1 Risks

Key project risks identified in this study include:

- Identifying potential project proponents
- Securing access to land
- Securing access to appropriate volume of water allocation
- Securing the appropriate skills/staff to establish trials and roll-out
- Developing sufficient quantities of seed for commercial propagation of sterile Leucaena to support mass plantings. Expert advice suggests that the development of commercial sterile varieties may take up to 10-12 years.[93]
- Developing an effective and efficient harvester/harvesting system within the requisite timeframe
- Optimising Leucaena varieties and farming systems for local climatic conditions in the final selected location/s
- Establishing forward ‘offtake’ agreements for the supply of wood pellets etc.
- Securing funding for development
- Identifying the optimal row spacing and biomass plantation configuration with or without inter-row plantings of cash crops or stock grazing protocols
- Cost effectively managing insect pests and weeds in the plantation
- Achieving and maintaining economically viable plantation yields.

10.2 Opportunities

There are a potential wide range of opportunities that may emerge as this biomass industry development project concept is promoted, For example, the opportunity:

- For the development of a ‘community’ farm that is ideally located and provides the nucleus for the scaling up of production on a mosaic irrigation basis. Involvement with research bodies could consolidate research efforts and showcase broader agricultural innovations e.g. trial sites, farm walk throughs, field days and landholder capacity building.
- To leverage government and community investment in prickly acacia management/eradication to consolidate woody material for chipping, etc. i.e. reduce harvest/logistics costs and assist with development of self-funding management/eradication programs.
- To explore supporting field harvesting and processing trials in the region, such as proposed by Carbon Renewable Energy to harvest and destroy prickly acacia and transform it into an exportable wood pellet product[94]
- For domestic power generators, miners and other heavy industries currently exploring opportunities to shift to cleaner, more sustainable energy sources; potential

[93] Personal comment, Prof. M. Shelton, UQ Leucaena Workshop 26/9/2019
[94] http://www.creaustralia.com/

partners/investors or local offtakers of biomass fuel or energy, may include Yurika Energy (a division of Queensland Energy Group – a state Government owned corporation)[95]

- To develop a Leucaena harvester to cut large areas of existing Leucaena to increase its productivity for cattle grazing. Whilst it is unlikely to be viable for an individual farmer to purchase a harvester for this purpose on a single property, there may be scope for a contractor to offer harvesting services on a contract basis to multiple graziers in the region. If demand exists for biomass in the region (for example, to fuel a biomass energy plant at a minesite), prickly acacia eradication initiatives may also present an opportunity for contract harvesting. Drone surveys would likely be needed to identify areas suitable for harvesting.
- To develop two separate businesses i.e. based on scaled-up Leucaena production/ processing and chipping prickly acacia as part of a broader eradication/control program. This may provide opportunity for areas lacking access to irrigation supplies a more targeted opportunity and facilitate the use of tailored machinery/equipment for both production systems to increase efficiencies and viability.

[95] Pers comm, Troy Philpot, Yurica Energy, 6 September 2019

11. Preliminary findings

The base case project includes a 100,000 tpa wood pelleting plant, an animal feed pelleting plant utilising the leafy portion of material harvested and a co-generation plant to supply electricity and heat to the pelleting facilities. The co-generation plant utilises wood waste and wood chip as fuel. The main feedstock is Leucaena (ideally a sterile variety to address local concerns).

Seasonal crops are assumed to be planted on a rotational basis on the same land, these being Brassica Carinata, mungbean and Rhodes grass (hay). It is acknowledged that there has been considerable recent success with chickpea production in the Richmond area.

Land would be acquired, prepared and irrigation systems established prior to a Leucaena crop being established (ideally a sterile variety). Leucaena would be harvested in blocks every 18 months for optimal growth.

The farmland is assumed to be 50 km from the pellet processing site, and following processing, the wood and animal feed pellets have to be transported 500 km to the closest suitable port.

It was proposed that prickly acacia be harvested and processed for wood pellets during the Leucaena establishment years. However, from financial modelling, the project economics decline when prickly acacia harvesting and processing is included. This is mainly due to the higher transport cost associated with prickly acacia (67% higher than for Leucaena) and higher harvesting cost (~320% of Leucaena harvesting cost on a per ton basis). The prickly acacia does not grow in neat formations like the Leucaena plantation rows and is sparsely distributed in remote areas, leading to higher harvesting and transport costs.

It is recommended that prickly acacia harvesting and processing not be included as part of the project and the wood pellet and co-generation facilities spend delayed, unless there are specific incentives associated with processing prickly acacia, or it has to be cleared from land acquired for the project to grow Leucaena.

The IRR (30 year) for the modified base case is 9.66% and the NPV AU$ -2,383,223.

The project items that have the largest spend proportion are, in decreasing order, trucking of the pellet product to port, with storage and shiploading (35%), general operating and maintenance costs associated with the pellet and co-generation facilities (29% combined), harvest and transport cost to site (14%), and seeding establishment cost for rotational crops (at 10% of the total project spend over the lifetime of the project).

Therefore, finding a site closer to port or reducing transport costs by utilising, for example larger trucks, or rail, could improve the project economics significantly. For example, a 100 km reduction in distance to port theoretically leads to an NPV of AU$ 3.2 M, which is an improvement of AU$ 5.6 M over the base case distance of 500 km.

Reducing harvest costs and locating the farm land closer to the pelleting facility would also lead to more favourable project economics. However, it is unlikely that these could be significantly reduced, and further study work would be required to firm up cost estimates, particularly relating to harvesting costs.

The number of operators has a large impact on project economics. It is suggested that a manning study be conducted as part of further investigation to determine the minimum number of operators required. It is also recommended that plant automation be considered to reduce the number of operators required, although pelleting plants in general, and animal feed pelleting plant specifically, are not suited to full automation.

Maintenance costs associated with pelleting and co-generation facilities are high and are unlikely to offer significant scope for reduction. Pellet mills have high wear components that require frequent replacement. This also leads to relatively low achievable on-line availability, however this inefficiency is generally accounted for in project financial modelling.

The cost/benefit of installing a co-generation facility as part of the project was investigated. Process heat will be required for the drying process and steam (utilised in the pelleting mills), so some form of a co-generation plant is unavoidable. However, reducing this plant to a medium pressure (MP) boiler system only and paying for a connection to the power grid leads to a decrease in capital spend (AU$ 10.5 M), as well as reduced operating and fuel cost for the co-generation facility. At lower electricity prices, the project economics are more favourable for the electricity import cases; for example, at an electricity import price of AU$ 150 / MWh, the IRR is 10.7% and the NPV AU$ 4.2 M.

It is recommended that the project install an MP boiler with the option of later installing co-generation equipment. However, since this exposes the project to market electricity pricing and the uncertainty associated with it, it is recommended that this option and especially the expected electricity price (locked in a contract) be explored in a next phase of the project.

It was determined that growing rotational crops as part of the project improves project economics, and a higher split of land to grow these crops could be considered. There will be a point where the unit costs associated with pellet production increases beyond the benefit of growing additional rotational crops; this could be further investigated in the next phase of the project to determine an ideal crop split.

It is important that the market for the rotational crops be further investigated; at present it is assumed that a local market is available so that transport cost for the product is negligible. The pricing associated with the crops is also important; should the pricing drop to 60% of the base assumed pricing for the various crops, it would no longer make sense to include these crops in the project, as the economic indicators then become worse than for a case where no rotational crops are grown.

Incentives or grant funding assistance realised at the start of the project could lead to improved project financials. Assuming that irrigation establishment, pumping and storage costs would be covered by incentive payments (AU$ 29 M in Y2), the IRR becomes 9.49% and the NPV improves to AU$ -2.8 M.

The inclusion of shipping costs to, for example, Japan was briefly studied and from initial findings does not appear to have a negative impact on the project economics determined to date, mainly as a result of the higher assumed landed wood pellet price in Japan (compared to FOB pricing). Further work is required to confirm shipping costs and landed wood pellet pricing. Only bulk shipping was considered, as container freight was considered to be cost prohibitive.

Producing wood chip rather than wood pellets is not favourable, despite the reduced capital cost associated with the wood processing plant and co-gen facility. Since these costs have a small impact on overall project spend (4% of total spend is attributed to equipment capital), reducing these costs do not have a large influence on project financials, while the price available for wood chip is considerably lower than for wood pellets.

An integrated Leucaena plantation with inter-row space cropping rotation provides a sustainable farming system that maximises asset and resource utilisation whilst ensuring sustainable profitability, given the right alignment of capital and operating costs, and product revenues.

This project would be a showcase for the potential for North Queensland agriculture and would provide a way to engage with investors looking to diversify their footprint in the region.

The project has potential to deliver improved environmental outcomes for the region with support for management of prickly acacia, reducing methane emissions associated with cattle production and enhanced soil fertility whilst increasing the value and productivity of North West Queensland land and water resources beyond existing mining or grazing systems.

12. Recommendations for further work

Although the findings of this study are generally favourable, the underlying objective of the study was to investigate, at a high level, the technical and commercial potential of developing an irrigated biomass fuels industry in North West Queensland. The study relies on numerous assumptions that require further work to validate.

The study was primarily focussed on identifying potential constraints and fatal flaws in the system concept, as well as key underlying investment considerations. The study identified a number of areas that would require further investigation to progress the concept to preliminary feasibility evaluation and any subsequent definitive feasibility study.

Existing available mapping is not sufficiently detailed to inform optimal site selection to enable targeted prickly acacia eradication as a first step towards irrigated sterile leucaena plantation establishment. Further mapping work is therefore recommended.

Key recommendations from this study are as follows:

- MITEZ liaise with DAF, the University of Queensland, MLA and the Department of State Development, Manufacturing, Infrastructure and Planning with regard to:
  - Advancing the development and trialling of sterile Leucaena and Carinata lines in the region
  - Understanding the likely costs and timeframes for commercial propagation of sterile Leucaena and Carinata varieties
  - Monitor progress towards commercial development of sterile Leucaena
- MITEZ assist with and facilitate the identification of a potential demonstration site for a traditional Leucaena plantation.
- MITEZ work with regional NRM groups to identify opportunities to leverage investment in mechanical controls of prickly acacia to consolidate for wood chipping opportunities to improve initial project viability with the further benefit of potential to enhance prickly acacia control measures.
- MITEZ engage with DSDMIP to investigate funding support options for further, more detailed investigation of the technical and commercial feasibility of progressing this biomass industry development opportunity.
- MITEZ support initiatives to undertake more detailed mapping of prickly acacia distribution, using more precise remote sensing or aerial photo interpretation etc.

A follow up study integrated with a field trial program would further develop the concept, identify key funding requirements, validate key assumptions and inform system design refinement, in turn informing project investment requirements.

Appendices

Appendix A – Mapping

Map A-1 – Potential Project Area Locality

Map A-2 – Prickly Acacia Distribution in Central West and North West Queensland 2013-14

Map A-3 – Prickly Acacia Distribution 1999

Map A-4 – Potential Project Area - Soil Classification

Map A-5 – High/Widespread Prickly Acacia Distribution (1999 – 2013-14)

Map A-6 – Potential Project Area - Slope

Population Places
Major Watercourse (of interest)
Rail
Major Roads
North West Qld Pipeline
National Electricity Transmission Lines
Ergon Network
33 kV
66 kV
132 kV
220 kV
MITEZ Region Boundary

Paper Size ISO A3
0 25 50 75 100
Kilometres
Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

Mount Isa To Townsville Economic Development Zone
North West Queensland Biomass

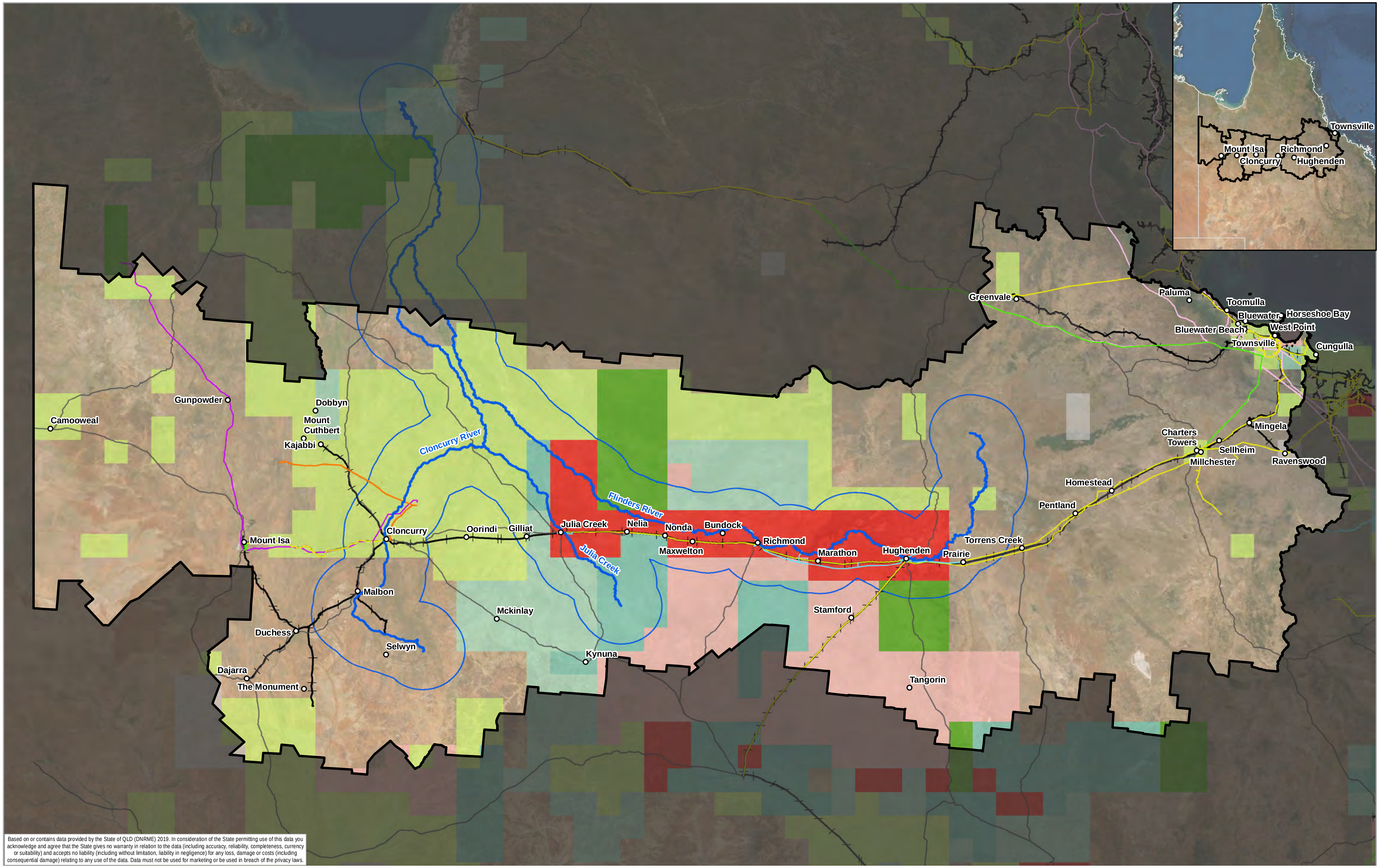
Project No. 12510680
Revision No. 0
Date 23/10/2019

Potential Project Area Locality

A-1

G:\41\12510680\GIS\Maps\MXD\41_12510680_001_Locality_Rev0.mxd
Print date: 24 Oct 2019 - 10:49

Data source: ABS: LGA Boundaries (2016), State and Territory Boundary (2016); DNRME: Rail, (2016), Roads (2019), Place Names (2019); Ergon Energy: Ergon Electrical Network (2019); Sun Water: North West Qld Pipeline (2016); GHD: MITEZ Region Boundary (2019) Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
Created by: knoble



Population Places
Major Watercourse (of interest)
Rail
Major Roads
North West Qld Pipeline

National Electricity Transmission Lines
Ergon Network
33 kV
66 kV
132 kV

220 kV
MITEZ Region Boundary
Major Watercourse 30km Indicator

Prickly Acacia Distribution 2013-2014 (DAFF)
Abundant, Widspread
Abundant, Localised
Common, Widespread
Common, Localised
Occasional, Widespread
Occasional, Localised
Unknown

Paper Size ISO A3
0 25 50 75 100
Kilometres
Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

Mount Isa To Townsville Economic Development Zone
North West Queensland Biomass

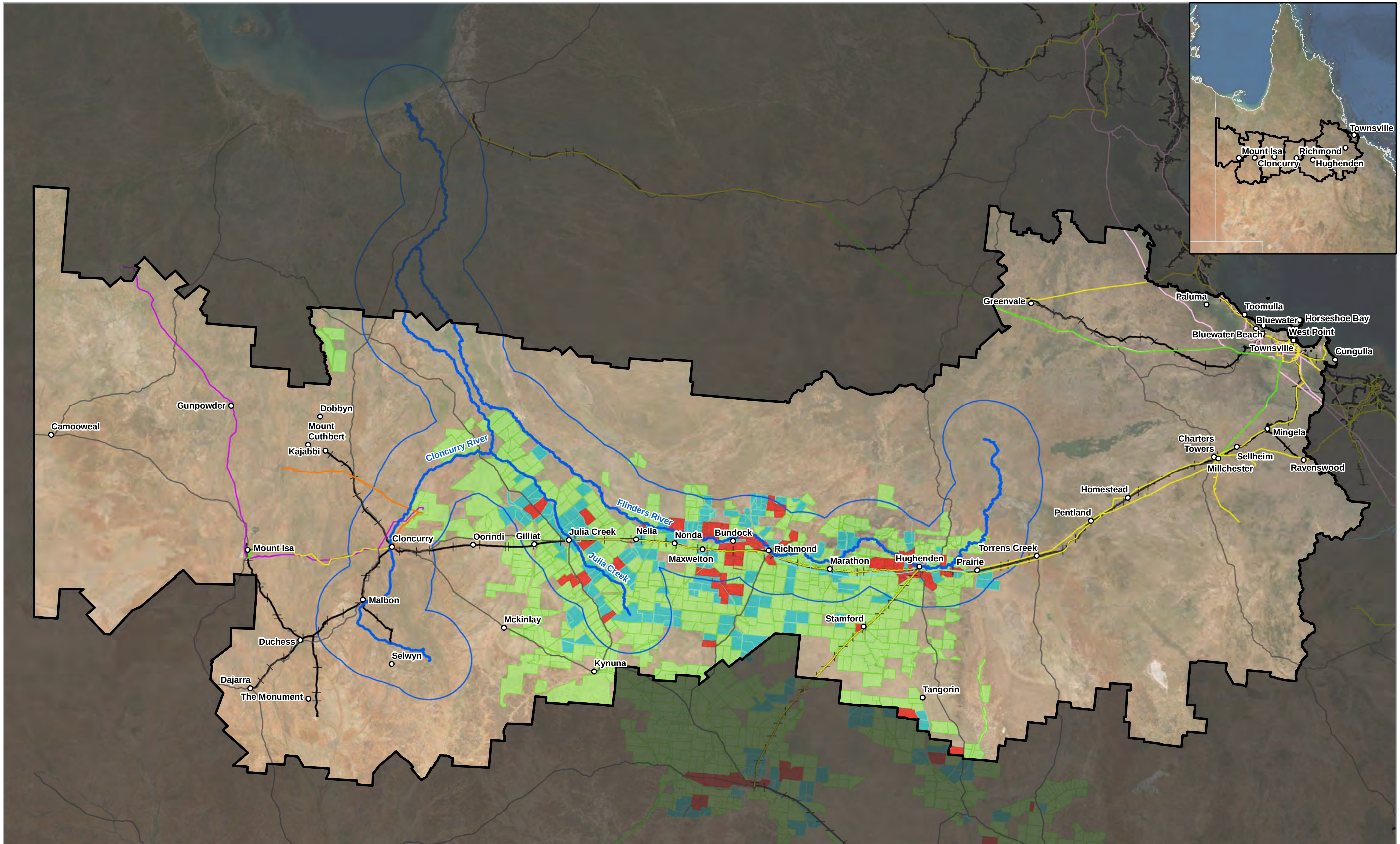
Project No. 12510680
Revision No. 0
Date 23/10/2019

Prickly Acacia Distribution 2013 - 2014

A-2

G:\41\12510680\GIS\Maps\MXD\41_12510680_002_PricklyAcacia_2013-14_Rev0.mxd
Print date: 24 Oct 2019 - 10:49

Data source: ABS: LGA Boundaries (2016), State and Territory Boundary (2016); DNRME: Rail, (2016), Roads (2019), Place Names (2019); DAFF: Prickly Acacia Distribution (2013-14); Ergon Energy: Ergon Electrical Network (2019); Sun Water: North West Qld Pipeline (2016); GHD: 30km Major Watercourse Indicator (2019), MITEZ Region Boundary (2019) Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: knoble



Based on or contains data provided by the State of QLD (DNRME) 2019. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for marketing or be used in breach of the privacy laws.

Population Places
Major Watercourse (of interest)
Rail
Major Roads
North West Qld Pipeline

National Electricity Transmission Lines
Ergon Network
33 kV
66 kV
132 kV

220 kV
MITEZ Region Boundary
Major Watercouse 30km Indicator
Prickly Acacia Distribution 1999 (DAFF)
High (>120 trees/ha)
Medium (20 -120 trees/ha)
Low (<20 trees/ha)

Paper Size ISO A3
0 25 50 75 100
Kilometres
Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

Mount Isa To Townsville Economic Development Zone
North West Queensland Biomass

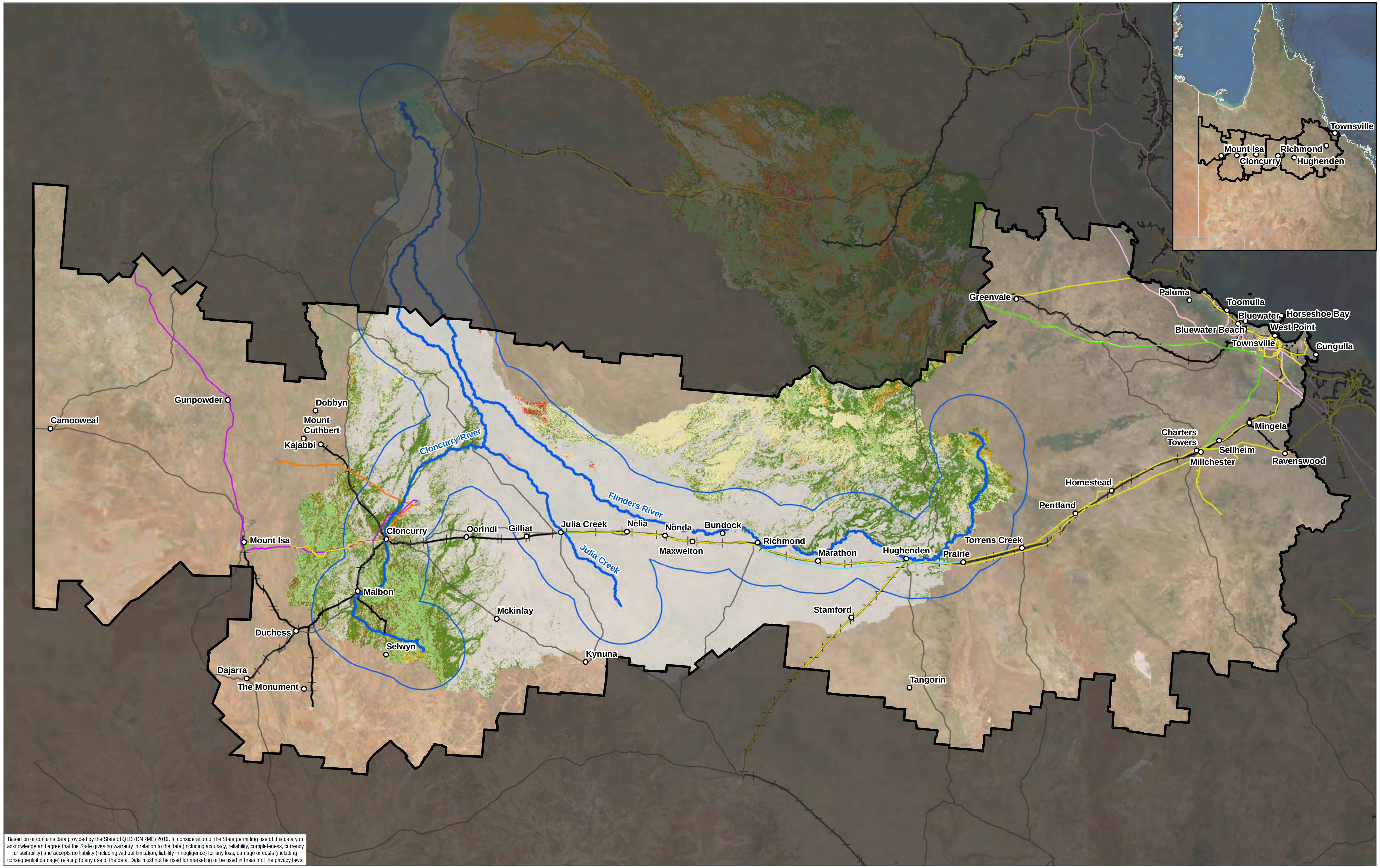
Project No. 12510680
Revision No. 0
Date 23/10/2019

Prickly Acacia Distribution 1999

A-3

G:\41\12510680\GIS\Maps\MXD\41_12510680_003_PricklyAcacia_1999_Rev0.mxd
Print date: 24 Oct 2019 - 11:45

Data source: ABS: LGA Boundaries (2016), State and Territory Boundary (2016); DNRME: Rail, (2016), Roads (2019), Place Names (2019); DAFF: Prickly Acacia Distribution (1999); Ergon Energy: Ergon Electrical Network (2019); Sun Water: North West Qld Pipeline (2016); GHD: 30km Major Watercourse Indicator (2019), MITEZ Region Boundary (2019) Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: knoble



Population Places
Major Watercourse (of interest)
Rail
Major Roads
North West Qld Pipeline
National Electricity Transmission Lines

Ergon Network

33 kV
66 kV
132 kV
220 kV
MITEZ Region Boundary
Major Watercouse 30km Indicator

Soil Types (Flinders Catchment)

Sand or loam over friable or earthy clay
Friable non-cracking clay or clay loam soils
Seasonally wet soils requiring drainage or special management
Red, yellow or grey loam or earth soils
Deep sandy soils
Shallow sandy/stony soils
Sand or loam over sodic/interactable clay
Cracking clay soils

Paper Size ISO A3

0 25 50 75 100

Kilometres

Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

GHD

Mount Isa To Townsville Economic Development Zone
North West Queensland Biomass

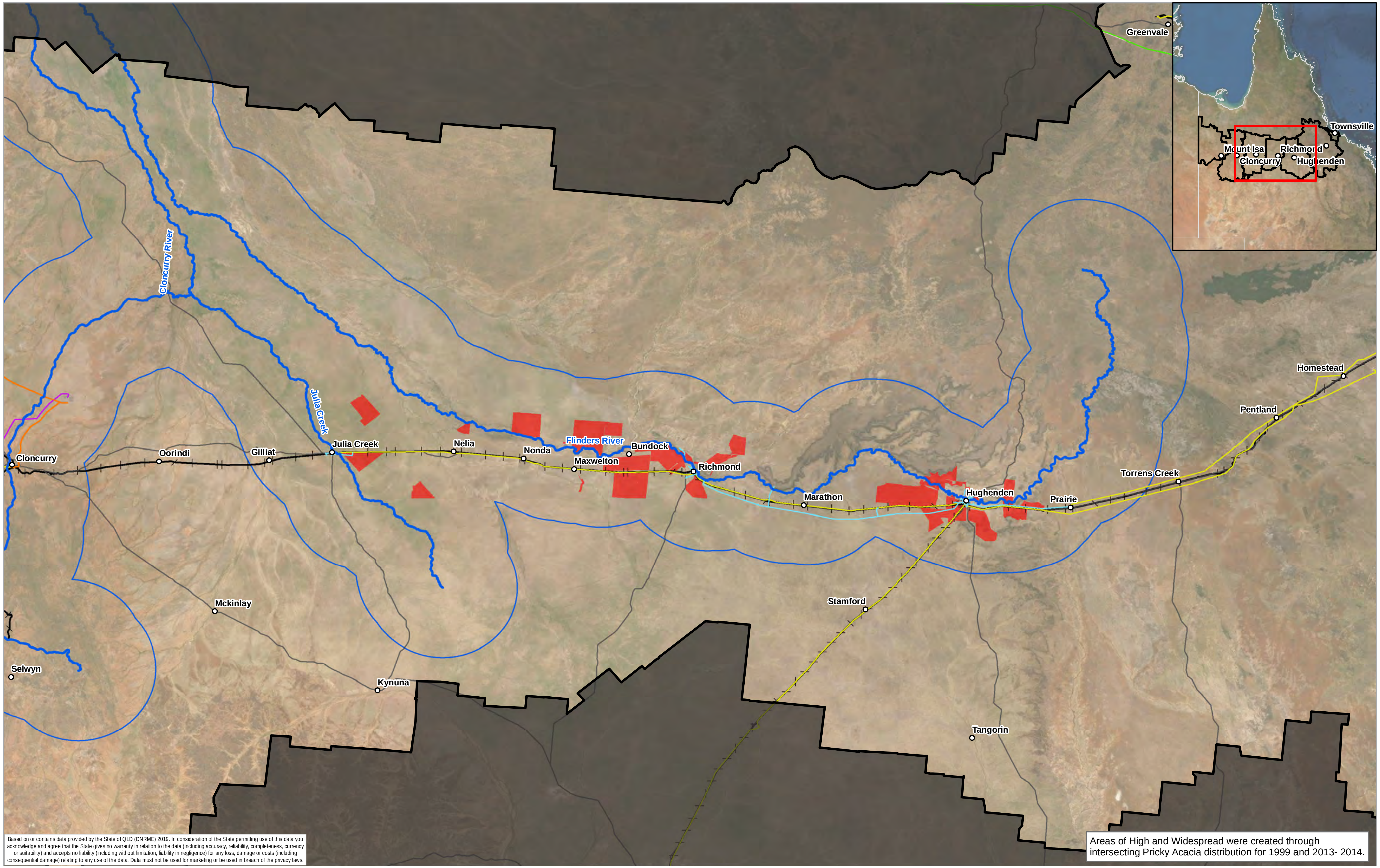
Project No. 12510680
Revision No. 0
Date 23/10/2019

Potential Project Area
- Soil Classification

A-4

G:\41\12510680\GIS\Maps\MXD\41_12510680_004_Locality_Soil_Rev0.mxd
Print date: 24 Oct 2019 - 11:09

Data source: ABS: LGA Boundaries (2016), State and Territory Boundary (2016); DNRME: Rail (2016), Roads (2019), Place Names (2019); CSIRO: Soil Types (2016), Ergon Energy: Ergon Electrical Network (2019); Sun Water: North West Qld Pipeline (2016); GHD: 30km Major Watercourse Indicator (2019), MITEZ Region Boundary (2019) Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: knoble



Areas of High and Widespread were created through intersecting Pricky Acacia distribution for 1999 and 2013- 2014.

Population Places
Major Watercourse (of interest)
Rail
Major Roads
North West Qld Pipeline
National Electricity Transmission Lines
Ergon Network
33 kV
66 kV
132 kV
220 kV
MITEZ Region Boundary
Major Watercouse 30km Indicator
High/Widespread Prickly Acacia Disturbuiton 1999 and 2013-2014

Paper Size ISO A3
0 10 20 30 40
Kilometres
Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

Mount Isa To Townsville Economic Development Zone
North West Queensland Biomass

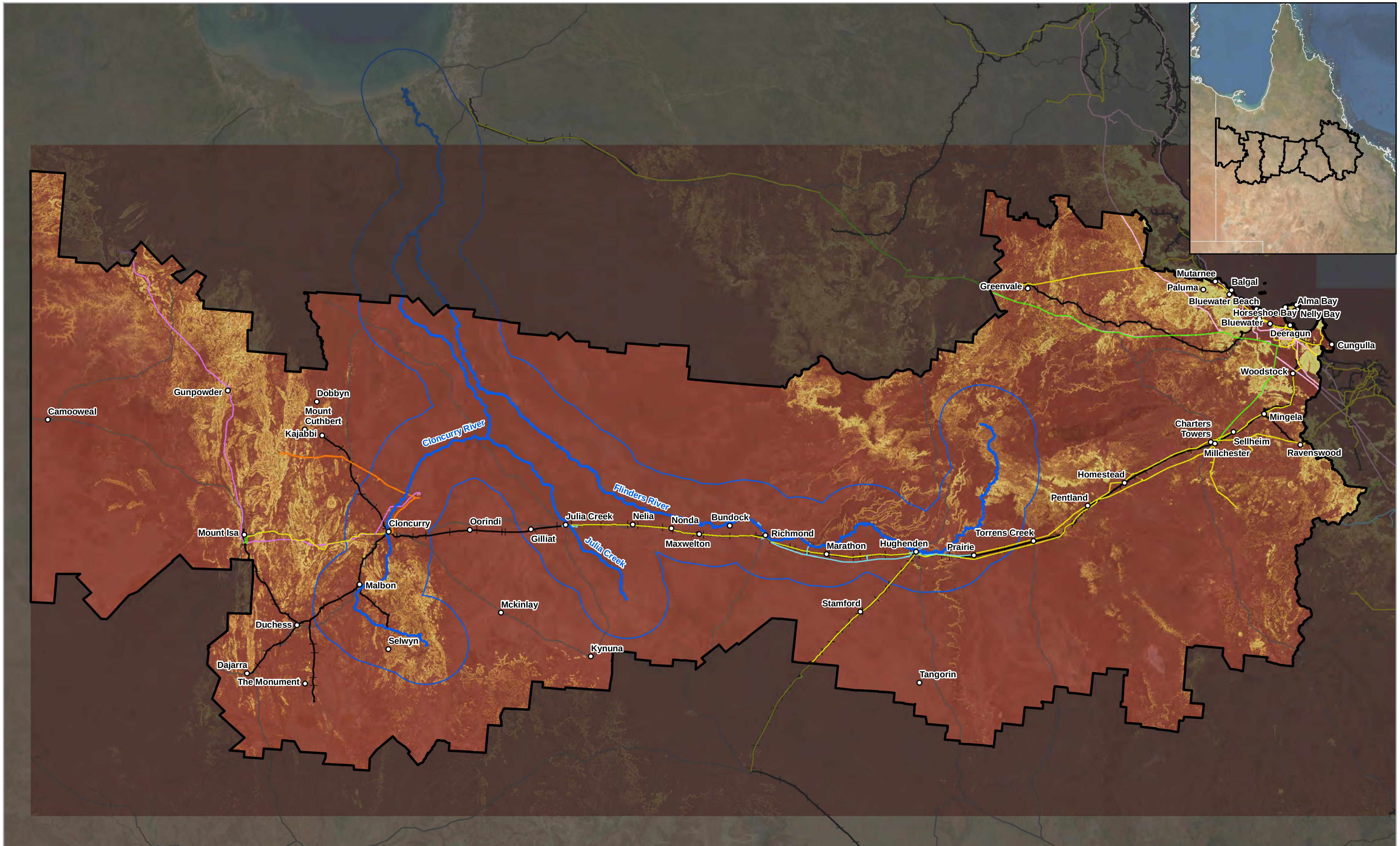
High/Widespread Prickly Acacia Distribution (1999 - 2013-2014)

Project No. 12510680
Revision No. 0
Date 23/10/2019

A-5

G:\41\12510680\GIS\Maps\MXD\41_12510680_005_High_PricklyAcacia_Rev0.mxd
Print date: 24 Oct 2019 - 11:26

Data source: ABS: LGA Boundaries (2016), State and Territory Boundary (2016); DNRME: Rail, (2016), Roads (2019), Place Names (2019); DAFF: High/Widespread Prickly Acacia Distribution (1999 - 2013-14); Ergon Energy: Ergon Electrical Network (2019); Sun Water: North West Qld Pipeline (2016); GHD: 30km Major Watercourse Indicator (2019), MITEZ Region Boundary (2019) Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: knoble



- Population Places
- Major Watercourse (of interest)
- Rail
- Major Roads
- North West Qld Pipeline
- National Electricity Transmission Lines

Ergon Network

- 33 kV
- 66 kV
- 132 kV
- 220 kV
- MITEZ Region Boundary
- Major Watercouse 30km Indicator

Slope %

- 0 - 3
- 3.1 - 7
- 7.1 - 15
- 16 - 20
- 21 - 30
- 31 - 60

Paper Size ISO A3

0 25 50 75 100

Kilometres

Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

Mount Isa To Townsville Economic Development Zone
North West Queensland Biomass

Project No. 12510680
Revision No. 0
Date 23/10/2019

Potential Project Area - Slope

A-6

G:\41\12510680\GIS\Maps\MXD\41_12510680_006_Slope_Rev0.mxd
Print date: 24 Oct 2019 - 11:40

Data source: ABS: LGA Boundaries (2016), State and Territory Boundary (2016); DNRME: Rail, (2016), Roads (2019), Place Names (2019), % Slope from DEM (2015); Ergon Energy: Ergon Electrical Network (2019); Sun Water: North West Qld Pipeline (2016);GHD: 30km Major Watercourse Indicator (2019), MITEZ Region Boundary (2019) Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: knoble

Appendix B – Options for Modifying the Canetec Leucaena Harvester for prickly acacia

The following information was provided by Canetec Pty Ltd, in support of this study.

Prickly acacia reclamation methodology

Operating in rough fields, where the weed is prevalent.

Two Modes of operation are envisaged, as described below.

Where trees are small enough, process as per Leucaena:

a. Run over tree with harvester

b. Base cut out by saw blades

c. Processed up rollers to shredder

d. Shredded into wood chips

e. Offloaded by thrower and spout to transport[96]

f. Using spray tank mounted on machine and controlled from cabin, spray stump with herbicide to ensure tree does not regrow.

Where trees are too large to be processed as normal, mulch on site using forward mounted mulcher:

a. Use mulcher to cut into tree near base

b. Mulch tree at ground level once felled, with mulch spread along ground (not gathered for processing)

c. Using spray tank mounted on machine and controlled from cabin, spray stump to ensure tree does not regrow.

Figure B-1 Typical prickly acacia distribution and terrain

A front mounted CIMAF-type[97] planer mulcher may be suitable for field chipping of prickly acacia, assuming a suitable drip catching arrangement can be incorporated with the mulcher.

---

[96] Potential for bag integrated into machine to collect shredded material for processing if economical, rough terrain may hinder transport vehicles access

[97] http://deniscimaf.com/en/product

Potential power breakdown:

- 75 HP for Shredder Drum and Thrower
- 10 HP for Front Augers and Knockdown Roller
- 65 HP for Traction
- 75 HP for front Mulcher for prickly acacia Destruction.

Figure B-2 Commercial mulching attachment (75HP range) – trees to 250 mm diameter

Basic Proposal LF6000 Leucaena Harvester

Modified AX5000 / YT6000 Sugarcane Harvester for Leucaena harvesting

Key features

- YT6000 Bag Frame 6 Roller Variant as base machine
- Single auger front end
- No side trim knives
- No topper – push bar variant
- Full track – 225 HP as base machine Tier 4 emissions engine (Tier 3 option available).

Modifications needed

- Drum style shredder for processing
- Forage Harvester style spout mechanism and thrower
- APKD walkdown feed roller – modified
- 600 L spray tank in place of bag.

Figure B-3 Example of commercial mulching attachment

Prickly acacia eradication add on kit

- Add on 600 L Spray tank to spray cut plants to prevent regrowth
- Machine potentially includes bag or bin type for easier transport of cut plants for processing
- Add on front mounted shredder / mulcher for eradication of larger prickly acacia plants
- Using a rotary drum as an eradication device, thicker trees that could be normally processed could be mulched on site.

Mounting this on the topper / Little Joe location could allow easier processing of prickly acacia.

Figure B-4 Canetec Leucaena Harvester and prickly acacia eradicator mock-up render

Benefits of a joint Leucaena harvester – prickly acacia eradicator

- Year-round employment possibility for operators
- Allows for land where prickly acacia is prevalent to be converted to Leucaena production
- Possibility for bin attachment for gathering shredded material for export as wood pellets
- Two machine functions in a single machine.

Potential future options

With additional funding beyond basic R&D support, Canetec advise they could produce a machine specially designed to harvest Leucaena and eradicate Prickly acacia.

Key additional features would include:

- 4WD wheeled or Quad Track Option- Easier transport and manoeuvrability
- Central Pivoting for higher manoeuvrability and stability on steep banks
- Higher engine horsepower and more powerful shredder
- Integrated Storage to allow operation along riverbanks and on rough terrain.

Appendix C – Extract from ECN Phyllis2 database for prickly acacia (acacia wood)

Phyllis2

wood, kikar (acacia) (#1460)

Permanent link: https://phyllis.nl/Biomass/View/1460

General properties

ID-number	#1460
Material	wood, kikar (acacia)
Classification	ECN Phyllis classification > untreated wood > other hard wood
	NTA 8003 classification > [100] hout > [110] vers hout > [120] loofhout > [125] hard loofhout
Submitter organisation	ECN (Netherlands)
Submission date	1999-06-18
Remarks	devolatilisation occurs between 270 and 680°C, maximum rate at 340°C
Literature	P. D. Grover: Thermochemical characteristics of biomass residues for gasification, Indian Institute of Technology, Delhi, India (1989).

Fuel Properties

Property	Unit	Value			Method	Remarks
		ar	dry	daf		
Proximate Analysis						
Ash content	wt%		0.60			
Volatile matter	wt%		77.00	77.46		
Fixed carbon	wt%		22.40	22.54	Calculated	
Ultimate Analysis						
Carbon	wt%		45.89	46.17	Measured	
Hydrogen	wt%		6.08	6.12	Measured	
Oxygen	wt%		47.43	47.72	Calculated	
Total (with halides)	wt%		100.00	100.00	Calculated	
Calorific Values						
Net calorific value (LHV)	MJ/kg		18.92	19.04		
Gross calorific value (HHV)	MJ/kg		20.25	20.37		
HHVMilne	MJ/kg		17.99	18.09	Calculated	

Physical Properties

Property	Unit	Value	Method	Remarks
Ash melting behaviour				
American standard method, measured in oxidizing conditions				
IDT (initial deformation temperature)	°C	1 320		
FT (fluid temperature)	°C	1 390		

Contact

Thousands of biomass items are available at the Phyllis2 database of biomass and waste: phyllis.nl

Do you have questions regarding biomass properties or application of biomass feedstock? Please contact us at Secretariaat-BEE@tno.nl!

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	M Smith R Coertzen P Wootton T Matchett	M Gravett	M Gravett*	J Skene	J Skene*	12/09/2019
0	M Smith R Coertzen P Wootton T Matchett	M Gravett	M Gravett*	J Skene	J Skene*	25/10/2019
1	R Coertzen P Wootton T Matchett	M Gravett	Martin Gravett 2020.01.20 10:29:05 +08'00'	M.Smith		20/01/2020

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