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Analysis of bagasse and trash utilisation options

by

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Executive Summary

The range of potential value adding processes for bagasse and trash currently being considered by the industry is diverse. There is, therefore, an urgent need for a preliminary evaluation of the relative merits of these processes, products and markets in order to provide appropriate commercial and research direction.

This project is aimed at providing the industry with a first order analysis of the relative technical and financial merits of a wide range of value adding options for bagasse and trash and is the result of a direct call from SRDC for a study in this area.

An Industry Consultative Group comprising representatives from both the milling and growing sectors of the industry was formed in the early stages to provide feedback and input at salient stages of the project. The project has been carried out in four stages:

Stage 1.
A wide-ranging review and collation of data on end products from and processes for value adding to bagasse and trash has been carried out. A total of 44 primary processes have been identified as potential value adding options for bagasse. A range of yield and final product revenue data have been established for these options.

Stage 2.
From the processes and technologies identified in stage 1 a preliminary short-list was established of processes deemed attractive in terms of revenue generation, cost of production, technical development and market prospects. Ranking was achieved by determining factors that would enable each product to be represented within a RISK versus GROSS REWARD matrix. Six products and associated processes were shortlisted from low RISK/ low GROSS REWARD (near-term opportunity) and medium RISK/ high GROSS REWARD (longer development horizon) regions of the matrix (Table 1).

Table 1 Shortlisted value adding options

Low RISK/ low GROSS REWARD
1. High pressure/ condensing steam power generation
2. Harvesting of cane tops for cattle feed
3. Furfural as a commodity chemical
4. Ethanol production from hydrolysis and fermentation
Medium RISK/ high GROSS REWARD
5. Diesel via hydrothermal liquefaction
6. Biorefinery production of lignin and pulp

Stage 3
Capital and operating costs were collected and used to carry out a more detailed financial (discounted cash flow) analysis of the six short-listed value adding options. The options

were evaluated for a range of bagasse and trash supply scenarios. The main findings from the analysis carried out as part of this stage were:

- Large scale production of commodities using the technology options selected from the low RISK/ low GROSS REWARD category is not viable for small mills (300 tch). This is true even for the most favourable feedstock scenario.
- For larger mills (600 tch) importing surplus bagasse there is a marginal business case for a stand-alone, year-round, power generation project.
- The results of the analysis of furfural and ethanol production from bagasse are similar to those for power generation in terms of financial returns. There is scope for improved profitability via judicious choice of technology and factory integration strategies.
- Trash is not a viable feedstock for any of the low RISK/ low GROSS REWARD options investigated.
- A viable business case exists for limited production of cattle feed from the harvesting of cane tops. Transport costs would limit such a venture to within 200 kms between farm and market. In addition given the quantities produced by a single mill region (typically 100,000 to 200,000 tonnes of cane tops) the total estimated market for this product (300,000 to 400,000 tonnes) would be rapidly saturated.
- For both the production of biodiesel via hydrothermal liquefaction and biorefinery production of lignin and pulp (medium RISK/ high GROSS REWARD options), the predicted range of Internal Rate of Return (13% to 35%) was commensurate with that required to progress a project with moderate levels of associated technical or financial risk.
- Medium RISK/ high GROSS REWARD options greatly extend diversification opportunities within the industry to those smaller (300 tch) or geographically more isolated factories previously excluded on the grounds of diminished economies of scale.
- Trash (at $20 per tonne) improves the financial viability of all medium RISK/ high GROSS REWARD options investigated.

As part of the process of selection and evaluation, reports have been prepared summarising the processes, technology status and product markets associated with these shortlisted value adding options.

Stage 4

The findings from stages 1 to 3 were presented and feedback sought at an industry workshop. Industry feedback has been collated and included in the final report.

The primary outputs from this project include: an interim report delivered to the Industry Consultative Group summarising the results of stages 1 and 2 of the project, the development of a financial analyses of the most viable options for value adding to bagasse and the dissemination and reporting of findings from the study at the stage 4 industry workshop.

It is anticipated that the outputs from this study will assist the industry in a number of areas including:

- Deriving additional revenue from bagasse and trash.
- Decision making at the early stages of product diversification.
- Increased awareness of the benefits and risks associated with value adding to bagasse and trash.
- Improved understanding of financial and technical barriers associated with bagasse and trash utilisation.
- Deriving environmental and social benefits from the initiation of a large scale renewable products industry.

Analysis of bagasse and trash utilisation options

1 Background

By exporting 80-85% of its raw sugar product the Australian industry is exceptionally exposed to the vagaries of the world market. Other producers either have large domestic demands accompanied by price protection, with or without some access to protected, high priced European Union or United States domestic markets (Hildebrand, 2002). This exposure was felt by the industry during the recent near-collapse in world sugar prices and exacerbated by a series of poor seasons and a strengthening Australian dollar.

There has long been substantial interest within the industry in product diversification (e.g. Allen et al., 1997) as a means of reducing commercial exposure although until recently such ventures have been viewed as economically marginal. This situation is now rapidly changing as Australia, like much of the industrialised world, is confronted with major issues regarding the security of oil supplies and the impact of anthropogenic carbon dioxide production on global warming. It is against this background that the industry is starting to focus on becoming a supplier of renewable energy products such as ethanol and electricity (Keating et al., 2002; Sutherland, 2002) and other bio-commodities.

More specifically the industry is looking at cane fibre for the production of these bio-commodities as this is complementary to the core process of sugar production. Although the combustion of bagasse provides the energy for processing cane to raw sugar, it is available in quantities well in excess of minimum requirements. In addition the use of cane harvest residues is seen as a resource that would benefit from similar value adding processes. The utilisation of some or all harvest residues would potentially increase the economies of scale and underpin overall industry viability by providing a new revenue stream back to growers. However, this must be balanced against the agronomic benefit of harvest residues left on the field.

The range of potential value adding processes for bagasse currently being considered by the industry is diverse. Therefore, there is an urgent need for a preliminary evaluation of the relative merits of these processes, products and markets in order to provide appropriate commercial and research direction. This project is aimed at providing the industry with a first order analysis of the relative technical and financial merits of a wide range of value adding options for bagasse and trash.

This project is the result of a direct call from SRDC for a negotiated study in the area of bagasse and trash utilisation.

2 Objectives

The primary objectives are to:

- Undertake a desktop review of published and unpublished information on the projected capital and operating costs to establish various industries to utilise bagasse and some trash as a feedstock. A range of value-added products will be assessed including (but not limited to) cattle-finishing stock feed, electricity generation, pulp and paper, ethanol, bio-oils and other chemical compounds including polymers and lignin, and biodegradable packaging materials;

- Identify the risks associated with each bagasse and trash utilisation option, including marketing risks;

- Estimate the likely revenue associated with each bagasse utilisation option;

- Involve appropriate representatives of CSR, Bundaberg, Mackay, NSWSMC, Tully and Proserpine Sugar milling companies, and CANEGROWERS as a consultative group in each of the above activities to ensure relevance to the Australian sugar industry.

3 Methodology

3.1 Overview

The project was carried out in four stages, viz.:

1. A wide-ranging review and collation of data on end products from and processes for value adding to bagasse and trash.

2. A preliminary short-listing of processes deemed attractive in terms of revenue generation, cost of production, technical development and market prospects.

3. The collection of capital and operating costs and the use of this data to carry out a more detailed analysis of the relative profitability of the short-listed value adding options.

   As part of the process of selection and evaluation, reports have been prepared summarising the processes, technology status and product markets associated with these shortlisted and related value adding options.

4. The presentation of findings from stages 1 to 3 at an industry workshop, collation of industry feedback and reporting of project outcomes.

Communication of the results of the study to and feedback from the industry was at two main points in the project. Initially at stage 2 when the results of a short-listing of bagasse utilisation options was communicated to an Industry Consultative Group and at the end of the project (stage 4) when the results of the study are presented at a participative industry workshop.

3.2 Review and collation of data on end products from and processes for value adding to bagasse and trash.

A total of 79 primary processes have been identified as potential value adding options for bagasse. A range (maximum, mean and minimum) yield and final product revenue data have been established for 44 of these options. Revenue data has been adjusted as necessary to 2006 dollars using the Consumer Price Index. In addition data of a more qualitative nature has been collated on the developmental status of the newer technologies and associated final product markets. This data and information on the associated sources have been put into an EXCEL database.

Linked to this database is a model which for a given set of harvest and process conditions establishes bagasse and trash availability so that yields and revenues from each value adding option can be expressed on a per tonne of cane basis. Another function of this feedstock availability model is to provide biomass composition data (moisture, brix, pol, ash and organic fibre) allowing dry ash free (d.a.f.) yield calculations to be carried out for any arbitrary mixture of bagasse and trash. This biomass availability model was also used in the more detailed cost benefit analysis carried out later on the shortlisted options.

Details of the biomass availability model and the database output sheets showing the complete set of raw and derived data are given in appendix A.

3.3 Short-listing of processes deemed attractive in terms of revenue generation, cost of production, technical development and market prospects.

Given the large number of processes being evaluated at this stage, full cost benefit analyses on all of these options was not considered practicable. The approach adopted was to develop a RISK v GROSS REWARD matrix to assist in the decision making process. The definitions of RISK and GROSS REWARD used in this study are given in appendix B.

In ascribing values to some components of the RISK and GROSS REWARD factors it is inevitable that qualitative judgements have to be made. This is particularly true of any assessment of emerging technologies and markets. In making these qualitative judgements the strategy adopted in the current study was to:

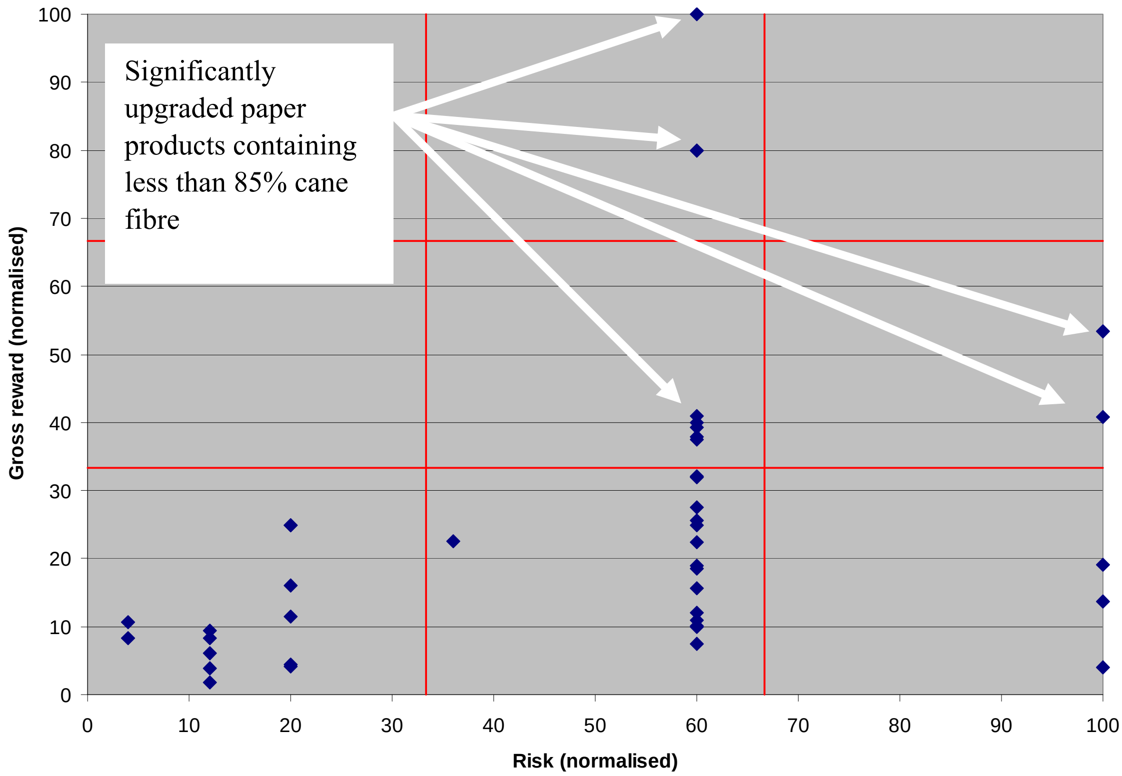
- Restrict the levels of RISK and GROSS REWARD to just three levels (High, Medium and Low). It was considered that any attempts to discern greater resolution could not be justified in many cases.

- Use known technologies such as co-generation as benchmarks for the qualitative components of RISK and GROSS REWARD.
- Assign the task of making qualitative assessments to project team members considered 'closest' to the relevant field.
- Give the Industry Consultative Group an opportunity to review these qualitative assessments.

The initial quantitative results of the RISK v GROSS REWARD analysis are shown in Figure 3.1. This analysis assumes that harvest residues (trash and tops) are being recovered from the field. This is necessary in order to capture those products and processes (such as cane tops for cattle feed) which use only trash or tops rather than bagasse as a feedstock. The additional biomass contributed by the harvest residues does not affect the ranking of the processes that use bagasse only as a feedstock.

One of the immediately noticeable features of Figure 3.1 is the clustering of points with similar RISK values. This is due to the small number of levels (i.e. HIGH, MEDIUM and LOW) attributed to components of the risk calculation and is a reflection of the uncertainty in subjective evaluation. The same clustering does not occur in the GROSS REWARD values as this term contains a component related to product yield and revenues.

Figure 3.1 Initial RISK v GROSS REWARD analysis



Another feature of Figure 3.1 is the high indicated GROSS REWARD values for upgraded paper products. It was considered that the high capital cost, quality issues and the fact that much of the final value of the product can be attributed to the addition of non-cane derived softwood fibres are not adequately reflected in the GROSS REWARD values. A decision was taken therefore to remove upgraded paper products from the analysis. Market ready chemi-mechanical and chemical pulps were retained in the analysis.

The result of removing these high value paper products is shown in Figure 3.2. The full set of processes and corresponding values represented in Figure 3.2 are given in appendix C.

One of the objectives of this study is to provide the industry with information on options that cover a range of investment horizons with a focus on the near to mid term. Value adding options selected for further more detailed analysis have therefore included four from the (relatively) low RISK/ low GROSS REWARD and two from the medium RISK/ high GROSS REWARD regions of the graph shown in Figure 3.2. The relative positioning of the six selected value adding options is indicated in Figure 3.2 and a summary of factors considered in their selection are given in Table 3.1

Figure 3.2 RISK v GROSS REWARD analysis (with significantly upgraded paper products removed) showing options chosen for further analysis

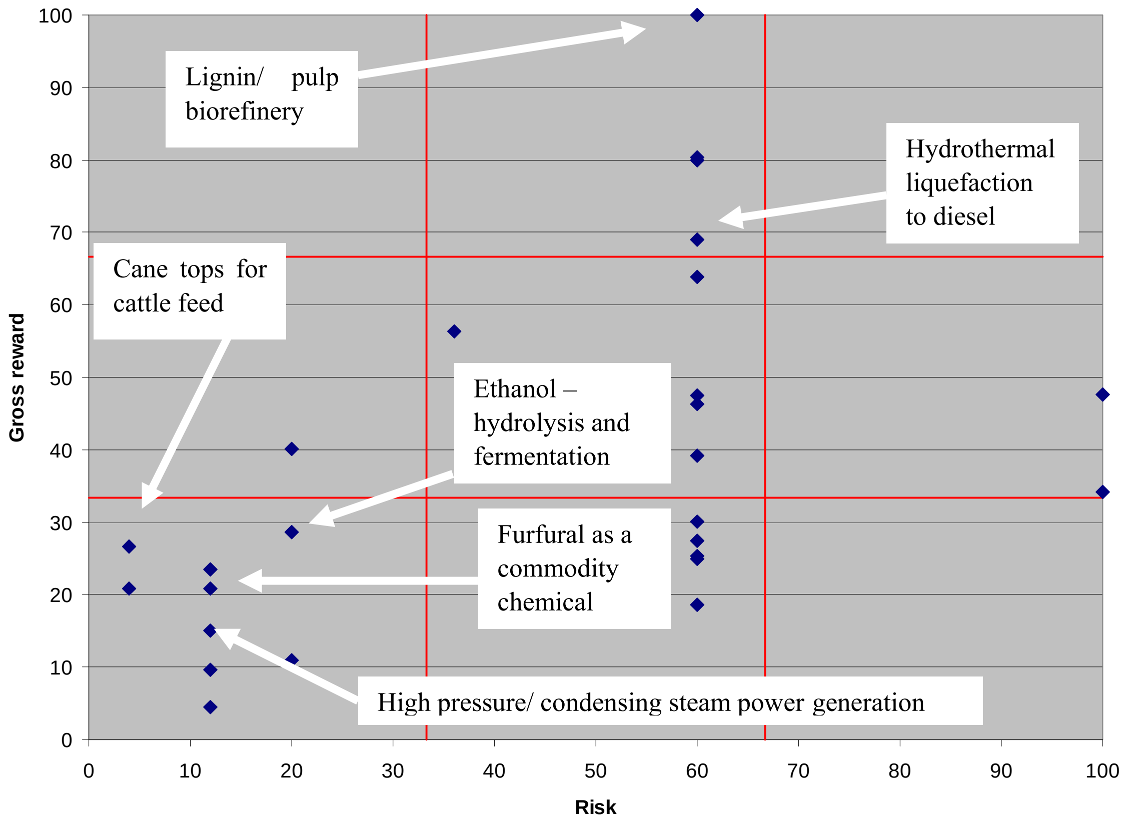


Table 3.1 Value adding processes selected for further analysis

Opt No.	Process	Comments
1	High pressure/ condensing steam power generation	Relatively low reward and risk. A useful benchmark in the study.
2	Cane tops for cattle feed	One of the lowest risk options with reasonable but still relatively low reward.
3	Furfural as a commodity chemical	A technology currently being developed in the Australian industry. Higher reward than cogeneration and relatively low risk (relatively simple process, done in other industries).
4	Ethanol – hydrolysis and fermentation	Moderately low risk and improved returns relative to other low risk options. A technology very much on the horizon in both this and other sugar industries.
5	Hydrothermal liquefaction to diesel	High gross reward and medium risk. A technology rapidly being developed for other industries and well suited to processing a wet feedstock.
6	Lignin/ pulp biorefinery	Highest reward, modest risk, long term prospects. Also currently being considered by the Australian industry.

Capital, labour, operating and maintenance costs have been established for the above six processes and the data used in a discounted cash flow analysis of costs and revenues for a number of factory and cane supply scenarios. This more detailed aspect of the current study is described in section 3.4.

3.4 Definition of scenarios for the further analysis of short-listed value adding options

This section provides a summary description of the value adding scenarios investigated including some of the underpinning quantitative data utilised in the analysis. Extended descriptions of and status reports on the more generic processes, technologies and markets from which these options are derived, are provided in appendix D.

3.4.1 Scenario features common to the analysis of all short-listed value adding options

<u>Feedstock supply</u>
The six options shortlisted in Table 3.1 were each evaluated in the context of ten cane supply scenarios.

Two crop/ factory sizes were evaluated. These were:

- 2,160,000 tonnes of cane with a factory crushing rate of 600 tch; and
- 1,080,000 tonnes of cane with a factory crushing rate of 300 tch

For each factory size the following five feedstock scenarios were investigated:

- Surplus bagasse only. All surplus bagasse is consumed in the crush (3600 hours).
- Surplus bagasse stored and recovered such that the co-located plant can be operated over the year with an availability of 92% (8059 hours).
- Surplus bagasse used and supplemented (doubled) by the transporting and storage of bagasse from other mills. Under this scenario the co-located plant was assumed to operate over the year with an availability of 92%.
- Trash recovered for use with surplus bagasse. All available biomass is utilised in the crushing season.
- Trash recovered for use with surplus bagasse. This biomass is stored and recovered such that the co-located plant can be operated over the year with an availability of 92%.

Bagasse and trash quantities for these ten scenarios are given in Table 3.2. The main storage, handling and other operating costs associated with the biomass feedstock are given in Table 3.3

Table 3.2 Biomass supply scenarios

Scenario	Operation (weeks)	Biomass supply (tonnes)				
		Trash	Imported bagasse	Surplus bagasse	Total biomass	Total storage
300 tch factory						
Crush only	21	0	0	106,780	106,780	0
Extended operation	48	0	0	106,780	106,780	59,082
Extended operation, additional bagasse	48	0	106,780	106,780	213,561	118,164
Crush only, with trash	21	133,333	0	106,780	240,114	0
Extended operation, with trash	48	133,333	0	106,780	240,114	132,856
600 tch factory						
Crush only	21	0	0	213,561	213,561	0
Extended operation	48	0	0	213,561	213,561	118,164
Extended operation, additional bagasse	48	0	213,561	213,561	427,121	236,329
Crush only, with trash	21	266,667	0	213,561	480,227	0
Extended operation, with trash	48	266,667	0	213,561	480,227	265,712

Table 3.3 Feedstock operating costs used in the analyses

Operation	Cost per tonne of feedstock on an as received basis
Factory produced surplus bagasse delivered to stockpile[1]	$5.00
Surplus bagasse delivered to stockpile from nearby factories[1]	$11.00
Agronomic, harvesting, transport and storage costs associated with trash recovery via whole crop harvesting[2]	$20.00
Costs associated with recovering all biomass from storage[1]	$5.00
Opportunity cost of surplus bagasse	$0.00

The changes in cane quality (and therefore extraneous matter recovery) in going from conventional to whole of cane harvesting is that given in appendix A (table A.1).

Factory changes

In all scenarios surplus bagasse was made available assuming the following factory modifications:

- Low pressure process steam flow is reduced from 52 to 45 steam %cane rate
- The factory retires one of its two boilers. The remaining boiler is upgraded such that the thermal efficiency is increased from 56% to 68%. Associated savings in boiler maintenance costs of $350,000 are assumed for both the 300 tch and 600 tch factories (Hodgson and Hocking 2006).
- Mill drives are electrified with the additional power requirement being met by existing turbo alternator capacity[3]
- For the scenarios involving trash recovery it is assumed that a cane separation plant similar to the SRI prototype tested at Condong Mill (Schembri and Hobson 2002) is installed. Annual maintenance costs of 1.5% of capital and a power consumption of 5 kw/ tch are assumed for the cane separation plants[4].

Capital costs associated with the above factory changes are given in Table 3.4.

[1] Hodgson and Hocking (2006)
[2] From a range of SRI (2000 to 2006) and other data including Thorburn et al (2006)
[3] This feature was initially added in anticipation of investigating lower steam %cane flows

Table 3.4 Capital costs associated with factory changes[4]

Item	Capital costs ($000)	
	300 tch factory	600 tch factory
Boiler upgrade	5,968	9,695
Process steam economy measures[5]	1,305	2,121
Mill electrification	4,639	7,536
Removal of redundant gear	15	24
Other factory internal work	965	1,567
Sub-total	12,892	20,943
Cane separator	4,390	7,131
TOTALS	**17,282**	**28,074**

Financial inputs

The financial inputs given in Table 3.5 were applied to the analysis of all value-adding options.

Table 3.5 Financial inputs used in analyses

Item	Value
Discount rate	10.0%
Annual inflation on all operating costs	2.0%
Annual inflation on commodity prices unless otherwise stated	3.0%
Assumed project start date (used in inflation calculations)	01/06/2008
Capital cost scaling factor	1/7
Split in capital expenditure over year 1 and year 2 of project	70% & 30%

3.4.2 Option 1 – High pressure/ condensing steam power generation

The main features of the power generation scenarios are:

- The plant is stand-alone in the sense that it operates independently of the factory. There is no low pressure steam extracted for sugar processing.
- The boiler operates at high steam pressure (64 bar abs) and temperature (520 °C) relative to most current plant. The boiler efficiency on a higher heating value basis is 71%.
- Power generation net of ancillaries is 1.27 MWh per dry ash-free tonne of bagasse (i.e. the mid-range value given in table A.2).
- Revenues (Hodgson and Hocking 2006) are:
  - Time averaged price of export power - $35.5 per MWh.

[4] Costs from SRI records except as indicated

[5] Lavarack et al (2005)

  - Value of Renewable Energy Certificates (RECs) are $30.8 until 2020 and $0 thereafter.
  - Avoided Transmission Use of Service payment - $3.18 per MWh.

Items included in establishing capital and operating costs for the power generation scenarios are listed in Table 3.6. Total costs for these items are given in Table 3.12.

Table 3.6 Capital and operating cost items for power generation analysis

Capital cost items	Operating cost items
New high pressure boiler Turbo-generator set Cooling water system Pre Boiler work Steam pipe work Ash Plant Services Water demineralisation plant Civil work and buildings Electrical and I&C Spares Additional bagasse handling and storage Engineers (EPCM) costs Owner's costs Contingency costs	Fixed operating and maintenance costs Connection and access fees Salaries and on-costs for additional technical staff Salary and on-costs for plant administrator/ accountant Above-allocation water charges incurred out of crush (based on condensing turbine vapour flow) Consumables (water treatment chemicals)

3.4.3 Option 2 - Cane tops for cattle feed

The notional process assumed in the current analysis for harvesting and baling cane tops is based loosely on that currently being proposed by Australian Sweet Forage Pty Ltd (ASF). It should however be emphasised that harvesting logistics and costs for this notional process have been established independently of ASF. The main features of the cane tops collection scenarios are:

- Cane tops are harvested as a separate operation ahead of the conventional cane harvesting operation.
- The yield of cane tops is 10 tonnes/ ha assuming a 100 tonnes/ ha cane crop.
- The number of tops harvesting groups are:
  - Equivalent to the number of conventional cane harvesters (the multiple row cane tops harvester being developed by ASF could reduce this number).
  - Based on a cane harvesting delivery rate of 50 tch, 20 harvest hours per day and one maintenance day out of 14 days harvesting (pers. comm. G. Sandel, Consultant, Harvesting Solutions, April 2006).
- A single haul out and service vehicle are required for each tops harvester. These haul out requirements are less than those for conventional cane harvesting as the tops harvester has integrated in-field storage capacity.

- A mobile sidings-based baling operation is assumed.
- The mobile baler produces 600 kg, plastic wrapped bales.
- The bales are transported by road a distance of 100 kms to a wholesale outlet.
- A baled tops storage facility (shed) is constructed at each wholesale outlet.
- The wholesale value of baled tops is $100 per tonne as received (pers. comm. J. Linton, Director, ASF, January 2006).

Unit capital and operating costs used in the analysis are given in Table 3.7. Total costs for these items are given in Table 3.14.

Table 3.7 Unit costs used in the analysis of cane tops harvesting

Capital cost per group		**Operating costs (per tonne of cane tops unless otherwise stated)**	
Item	**Cost**	**Item**	**Cost**
Harvest and in-field transport:		Harvesting operation (including haul-out):[6]	
Tops harvester	$ 600,000		
Haul out	$ 140,000	*Wages*	$ 1.06
Service vehicle	$ 35,000	*Fuel and Oil*	$ 0.54
Tools	$ 25,000	*Maintenance*	$ 1.23
Vehicle sheds	$ 80,000	Baling operation (including tractor for baler):[7]	
Baling operation:[7]			
Mobile baler	$ 132,000	*Maintenance*	$ 8.71
Tractor for baler	$ 121,000	*Wages*	$ 1.90
Other:		*Fuel*	$ 0.90
Setup (% total capital)	20%	*Twine/ plastic wrap*	$ 3.79
Spares (%t total capital)	10%	Road transport per 100 kms[8]	$ 8.48
		Storage[7]	$ 1.50
		Other:	
		Agronomic cost of trash removal (% total trash costs)	24%
		Royalties on harvester technology (% product revenues)	4%

3.4.4 Option 3 – Furfural as a commodity chemical

The main features of the furfural production scenarios are:

- Yield and production costs based on a comprehensive feasibility study by Rudus and Katkevies (1998). The study is representative of technology currently used around the world in the sugar and other industries. It is acknowledged that the

[6] Inflated by CPI from SRI/ BSES (2000) data on conventional cane harvesting
[7] Inflated by CPI from Ridge and Hobson (2000) and used with permission of BSES (pers. comm. P. Alsop, BSES, March 2006)
[8] Derived from data provided by Zarbs Transport (pers. comm. J. Casey, Zarbs Transport, April 2006)

SupraYield® process currently being developed by Proserpine Co-operative Sugar Milling Association may deliver higher yields at lower costs than are represented in the current study but constraints on commercially sensitive cost data prevented an analysis of this process.

- A furfural yield of 100 kg per tonne of dry ash-free bagasse.
- The analysis includes the capital cost of dedicated steam and power generation utilities. This approach was adopted to insure that the full cost of steam was captured rather than using available cost of factory steam figures. The latter tend either to reflect a simple opportunity cost (based on power generation potential) or the operating costs only of factory boilers (assets which are assumed to have no book value). In practice additional cost economies may be achievable by judicious factory integration although for the above reasons would be beyond the scope of the present study to adequately cost.
- No external fuel is required; residue from the furfural production process provides sufficient fuel for steam and power generation requirements.
- A mid-range price (see table A.2) of $1000 per tonne of furfural is assumed.

Items included in establishing capital and unit operating costs for the furfural production scenarios are listed in Table 3.8. Total costs for these items are given in Table 3.15.

Table 3.8 Capital and operating cost items for furfural production analysis

Capital items costed in analysis	Operating items and unit costs (per tonne of furfural unless otherwise stated)	
	Item	**Unit cost**
Feedstock and product handling equipment	Chemicals	$ 60.5
Digester	Power	$ 5.4
Distillation plant	Water	$ 84.2
Boiler	Effluent	$ 17.8
Flue gas scrubber	Maintenance (%capex)	3.00 %
Water treatment	Labour (%capex)	0.65 %
Furfural storage facility	Royalty on furfural technology (% product revenue)	4.00 %
Transport		
Computing and control equipment		
Mounting equipment		
Engineering (EPCM)		
Construction		
Start-up and working capital		
Commissioning		

3.4.5 Option 4 – Ethanol from the hydrolysis of bagasse and fermentation

The main features of the ethanol production from bagasse scenarios are as follows:

- A dilute acid hydrolysis technology was selected for analysis. The dilute rather than concentrated acid technology is considered to have greater long term potential as it allows for the recovery of lignin for upgrading to a high value product (not considered in this analysis) rather than simply a fuel source for the ethanol production process.
- Detailed capital and operating costs for this technology have been extracted from a US Department of Energy feasibility study (Aden et al., 2002) in which corn stover was assumed as a feedstock.
- For reasons discussed in 3.4.4 stand-alone utilities (steam and power plants) are costed in the analysis. All of the lignin and some of the cellulose and hemicellulose from the feedstock will remain unconverted through the hydrolysis process. The majority of wastewater from the process is concentrated to syrup high in soluble solids. Anaerobic digestion of the remaining wastewater produces a biogas high in methane. Aerobic digestion produces a small amount of waste biomass (sludge). Burning these by-product streams to generate steam and electricity allows the plant to be self sufficient in energy and reduces solid waste disposal costs.
- An ethanol yield of 334 litres per tonne of dry ash-free bagasse was assumed. This is equivalent on a dry ash free basis to the yield from corn stover used by Aden et al. (2002).
- Ethanol revenues were calculated based on:
    - Energy equivalence with petrol.
    - A (conservative) long term trade weighted oil price of US$ 50 per barrel.
    - An excise (Australian Government, 2004) on ethanol of $0 per litre up to 2011 (price claimed for ethanol = $0.59/L) ramping up in five equal stages to $0.125 per litre excise in 2015 (price claimed for ethanol = $0.46/L).

Items included in establishing capital and unit operating costs for the ethanol production scenarios are listed in Table 3.9. Total costs for the capital items are given in Table 3.16.

Table 3.9 Capital and operating cost items for the ethanol production analysis

Capital items costed in analysis	Operating items and unit costs (per litre of ethanol unless otherwise stated)	
	Item	Unit cost
Feed Handling Pre-treatment Neutralization/ conditioning Saccharification/ fermentation Distillation and Solids Recovery Wastewater Treatment Storage Boiler/Turbogenerator Other utilities Civil and buildings Engineering (EPCM) costs (25% plant capex)	Fixed operating and maintenance costs including labour (% Capex) CSL Cellulase Other raw materials Waste disposal Additional imported electricity Royalty on technology (% product revenues)	3.80% $ 0.011 $ 0.041 $ 0.022 $ 0.012 $ 0.026 4.00 %

Owners costs (10% plant capex) Contingency (3% plant capex)		

3.4.6 Option 5 - Hydrothermal liquefaction to diesel

The main features of the biodiesel production from bagasse scenarios are as follows:

- Costs and yields of intermediate biocrude oil are based on feasibility studies carried out on HTU® technology by technology licence holders, Biofuel B.V. (Goudriaan et al., 2000 and pers. comm. Naber, J., Engineer, Biofuel B.V., 2004 to 2006).
- Biocrude yield is 455 tonnes per tonne of dry ash-free bagasse.
- Hydrogen for upgrading biocrude to diesel is costed at $1,520 per tonne of hydrogen. This cost is based on results of a previous SRI study of an existing hydrogen from natural gas production facility in Queensland and includes amortised capital costs. This hydrogen cost assumes natural gas can be sourced at $3 per GJ.
- Biodiesel revenues were calculated based on:
    - Energy equivalence with conventional diesel.
    - A long term trade weighted oil price of US$ 50 per barrel.
    - An excise (Australian Government, 2004) on biodiesel of $0 per litre up to 2011 (price claimed for biodiesel = $0.90/L) ramping up in five equal stages to $0.19 per litre excise in 2015 (price claimed for biodiesel = $0.71/L).

Items included in establishing capital and unit operating costs for the biodiesel production scenarios are listed in Table 3.10. Total costs for the capital items are given in Table 3.17.

Table 3.10 Capital and operating cost items for analysis of biodiesel production via hydrothermal liquefaction

Capital items costed in analysis	Operating items and unit costs (per tonne of biocrude unless otherwise stated)	
	Item	**Unit cost**
Total biocrude plant capital costs (including 15% contingency) - no further details available	Maintenance and overheads (% capex)	6.00%
	Labour	$ 39.61
	Electricity	$ 10.93
	External fuel (natural gas)	$ 5.46
	Amortised cost of hydrogen for upgrading biocrude to diesel ($/tonne of H_2)	$ 1,520
	Royalty on HTU technology (% product revenue)	4.0%

3.4.7 Option 6 –Lignin and pulp from a biorefinery plant

Costs and yields used in the current analysis have been based on a previous SRI study carried out by Dr G Bullock (currently Queensland University of Technology) to investigate a business case for biorefinery technology in the Australian sugar industry. The estimated uncertainty associated with these costs is ± 30%. The main features of the biorefinery scenarios investigated in the current analysis are as follows:

- Primary products are sulphur free lignin and a chemical grade market pulp
- A lignin yield of 0.19 tonnes per tonne of dry ash free bagasse and 0.095 tonnes per tonne of dry ash free trash. The latter reflects the lower lignin levels found in cane leaf relative to that in stalk.
- A lignin value of $1000 per tonne. This is consistent with a native lignin product and is lower than the lignin values given in table A.2. The latter are based on derivatised lignin which has a market value equivalent to butylacrylate. The capital and operating data developed by Bullock (2006) does not include upgrading the lignin to a butylacrylate substitute.
- A pulp yield of 0.54 tonnes per tonne of dry ash free bagasse or trash
- A pulp value of $270 per tonne. This figure corresponds to the lower end of the price range given in table A.2 for chemical market pulps but is consistent with pulp quality estimates based on bench scale tests carried out at SRI.

Items included in establishing capital and unit operating costs for the biorefinery scenarios are listed in Table 3.11. Total costs for the capital items are given in Table 3.18.

Table 3.11 Capital and operating cost items for analysis of lignin and pulp via biorefinery technology

Capital items costed in analysis	Operating items and unit costs (per tonne of dry ash-free feedstock unless otherwise stated)	
	Item	**Unit cost**
Bagasse fractionation Lignin recovery Brown liquor evaporators Liquid feed boiler Anaerobic digesters Caustic recycle Pulp refining, drying and packing Engineering (EPCM)	Labour - assume constant over current range of plant size Consumables and utilities Maintenance (% capex) Royalty (% product revenues)	 $ 39.07 $ 67.76 3.0 % 4.0 %

3.5 Results of the further analysis of short-listed value adding options

Total capital and annual operating costs have been established and used in a discounted cash flow analysis to determine net present values (NPV) and internal rates of return (IRR) for each of the value adding options under the feedstock scenarios described in section 3.4. Section 3.5 contains a summary of the results of these analyses.

3.5.1 Option 1 – High pressure/ condensing steam power generation

Table 3.12 shows the capacities, costs and revenues for stand-alone co-generation plants operating under the range of fuels supply conditions given in Table 3.2.

Table 3.12 Capacities costs and revenues for power generation scenarios

Scenario	Total capacity (MW)	Costs ($ 000) Capital	Costs ($ 000) Annual operating	Revenue in year 3 ($ 000)
300 tch factory				
Crush only	17	59,361	1,274	4,316
Extended operation	8	41,182	1,728	4,316
Extended operation, additional bagasse	15	56,918	3,157	8,632
Crush only, with trash	34	91,737	4,743	8,605
Extended operation, with trash	15	62,270	5,915	8,605
600 tch factory				
Crush only	34	96,433	1,788	8,632
Extended operation	15	66,901	2,800	8,632
Extended operation, additional bagasse	31	92,463	5,570	17,265
Crush only, with trash	68	149,027	8,545	17,210
Extended operation, with trash	30	101,159	11,055	17,210

The corresponding values for NPV are shown graphically in Figure 3.3.

The results in Figure 3.3 agree broadly with current industry experience including the analysis by Hodgson and Hocking (2006). Apart from the well documented issue of high capital costs, one of the principal reasons for the poor financial performances of power generation projects is the removal of Renewable Energy Certificate revenues in 2020. The fuel scenarios where surplus bagasse is supplemented by imported bagasse have been re-run for the 600 tch and 300 tch factories with the assumption that REC revenues continue for the full life of the project. The results shown in Table 3.13 indicate a significant improvement in returns for these projects to the extent that the smaller scale operation (300 tch factory) starts to become marginally viable. Under these marginally viable conditions other factors (such as the need to replace existing factory steam generation plant) could potentially make power generation a more attractive proposition for the sugar industry.

Figure 3.3 Financial results (NPV) for power generation scenarios

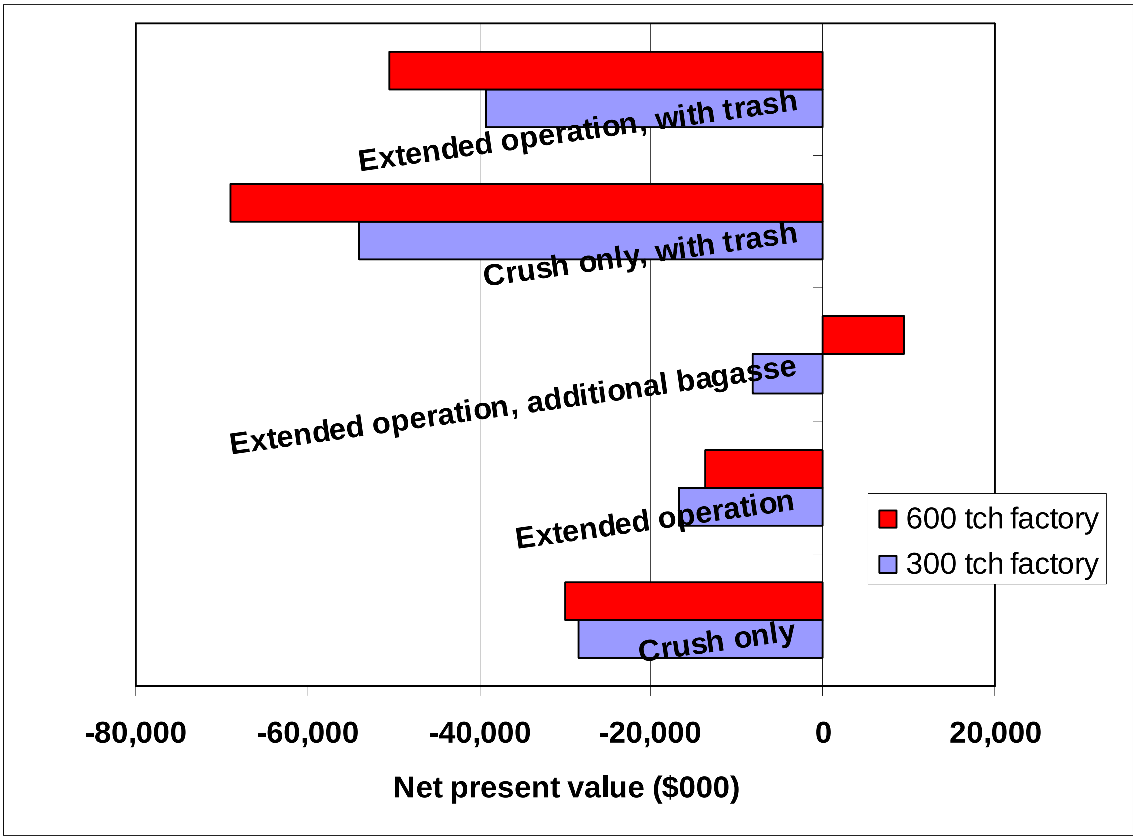


Table 3.13 Comparison of NPVs with and without continuing REC revenues

Scenario	Operation (weeks)	Total capacity (MW)	RECs stops at 2020		Continuing RECs	
			IRR (%)	NPV ($ 000)	IRR (%)	NPV ($ 000)
600 tch factory	48	31	11.6%	9,428	13.9%	28,246
300 tch factory	48	15	7.5%	-8,209	10.3%	1,200

Summarising the case for power generation:

- Power generation from high pressure steam plant although not common in the Australian industry can be considered a mature technology with relatively low technical risk.
- Product (electricity) revenues are generally too low to cover high costs.
- There is a marginal business case that can be made for large factories importing bagasse and operating all year.
- An extension of RECs (even without changing the Mandated Renewable Energy Target) would significantly assist the viability of power generation.
- Trash is not a financially viable fuel.

3.5.2 Option 2 - Cane tops for cattle feed

Table 3.14 shows the total predicted quantities, costs and revenues for tops harvesting operations in the smaller and larger mill regions.

Table 3.14 Harvested quantities, costs and revenues for the recovery of cane tops

Factory	Tops harvested (tonnes)	Regional costs ($ 000)		Revenue in year 3 ($ 000)
		Capital	Operating	
300 tch	108,000	12,764	9,293	11,458
600 tch	216,000	25,529	18,586	22,915

The profitability of tops harvesting will be strongly dependant on the price paid to the grower for access to their crop for the purposes of harvesting tops. Figure 3.4 shows the effects on the access price paid to the grower on the NPV and IRR of a cane tops for cattle feed business.

Some points of interest on Figure 3.4 are where the price paid for access to harvest tops is:

- $0 per tonne (IRR = 34%). This effectively corresponds to the scenario where the grower owns the tops harvesting business.
- $15 per tonne (IRR = 21%). This is the price recently offered to growers for access to their tops by Australian Sweet Forage Pty Ltd (Linton 2006)
- $25 per tonne (IRR = 10%). This is the point at which such a business would break even (i.e. the NPV = $0).

Another key issue affecting profitability is physical proximity of the cane growing area to cattle feed markets. Figure 3.5 shows the effect of transport distances (between harvesting operation and wholesale outlet) on NPV and IRR. This figure shows clearly that returns drop rapidly with increased haulage distances such that the business becomes unprofitable at distances just greater than 200 km.

Figure 3.4 Effects of price paid (to growers) for access to harvest tops

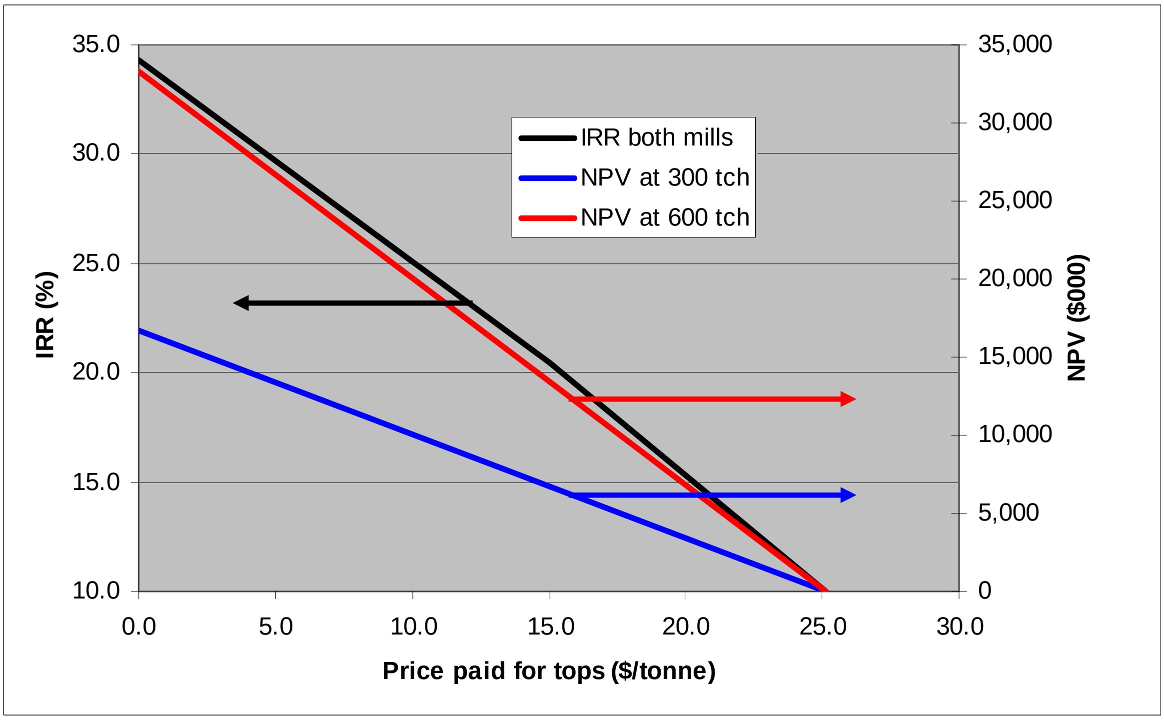
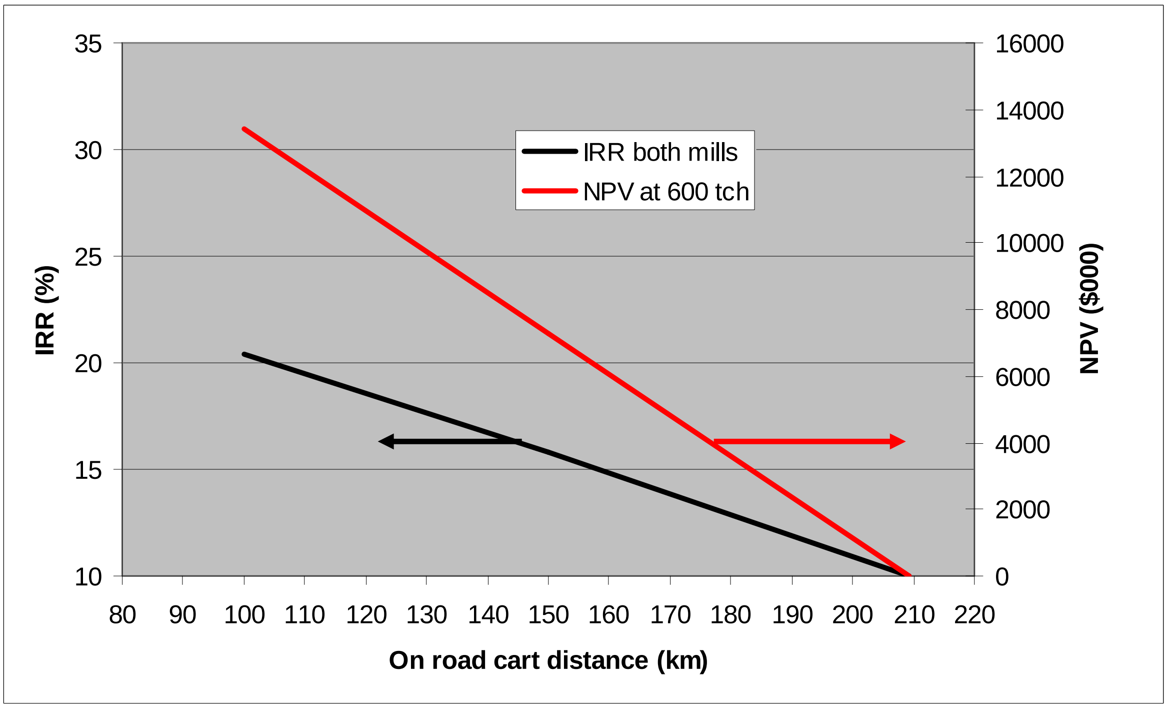


Figure 3.5 Effects on profitability of proximity to cattle feed markets



In summary, for the option of cane tops harvesting and baling for cattle feed:

- The analysis indicates that for low capital input (relative to other options) good rates of return are achieved.
- In terms of production (see Table 3.14) each of the two mill areas satisfies a significant percentage of the total estimated Australian market. The latter is estimated[9] at between 300,000 and 400,000 tonnes. This market size will put significant downward pressure on the $100 per tonne assumed in the analysis.
- Only those cane growing areas within close proximity (i.e. under 200 km) to the cattle feed markets will benefit from this option.

3.5.3 Option 3 – Furfural as a commodity chemical

Table 3.15 shows the capacities, costs and revenues for furfural plants operating under the range of fuels supply conditions given in Table 3.2.

Table 3.15 Capacities costs and revenues for furfural production scenarios

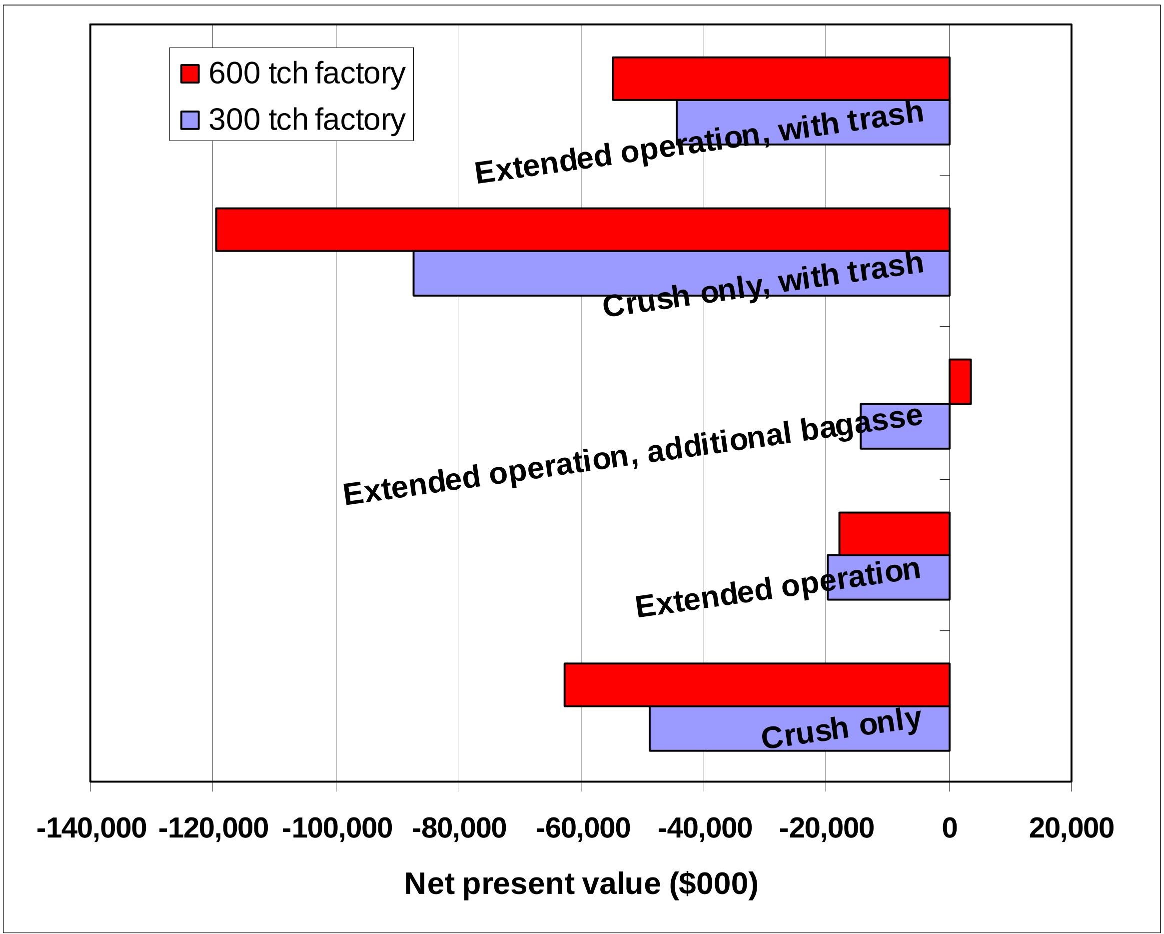
Scenario	Annual furfural production (tonnes)	Costs ($ 000)		Revenue in year 3 ($ 000)
		Capital	Annual operating	
300 tch factory				
Crush only	4,994	63,500	4,713	5,298
Extended operation	4,994	41,681	3,686	5,298
Extended operation, additional bagasse	9,988	59,660	6,931	10,596
Crush only, with trash	9,956	99,313	10,922	10,563
Extended operation, with trash	9,956	63,946	9,662	10,563
600 tch factory				
Crush only	9,988	103,156	7,971	10,596
Extended operation	9,988	67,711	6,545	10,596
Extended operation, additional bagasse	19,976	96,918	12,517	21,192
Crush only, with trash	19,913	161,335	19,461	21,125
Extended operation, with trash	19,913	103,881	17,958	21,125

A feature of the scenarios shown in Table 3.15 is that despite the greater biomass storage and handling costs associated with extending the plant operation beyond the end of the crush, the total indicated operating costs are lower than those for the crush only operation. This feature is a result of operating component costs such as maintenance being a fixed percentage of plant capacity. This may result in an overstatement of the operating costs of the plants sized to utilise all available feedstock in the crush (relative to the smaller plants which operate over an extended period of the year). The approach was however retained in the analysis on the grounds that greater maintenance costs would be incurred when feedstock is processed at a greater rate (crush only operation) relative to that which would be incurred by processing the same amount of feedstock at a lower rate (extended operation).

[9] Pers. comm. J. Linton, Australian Sweet Forage, December 2005

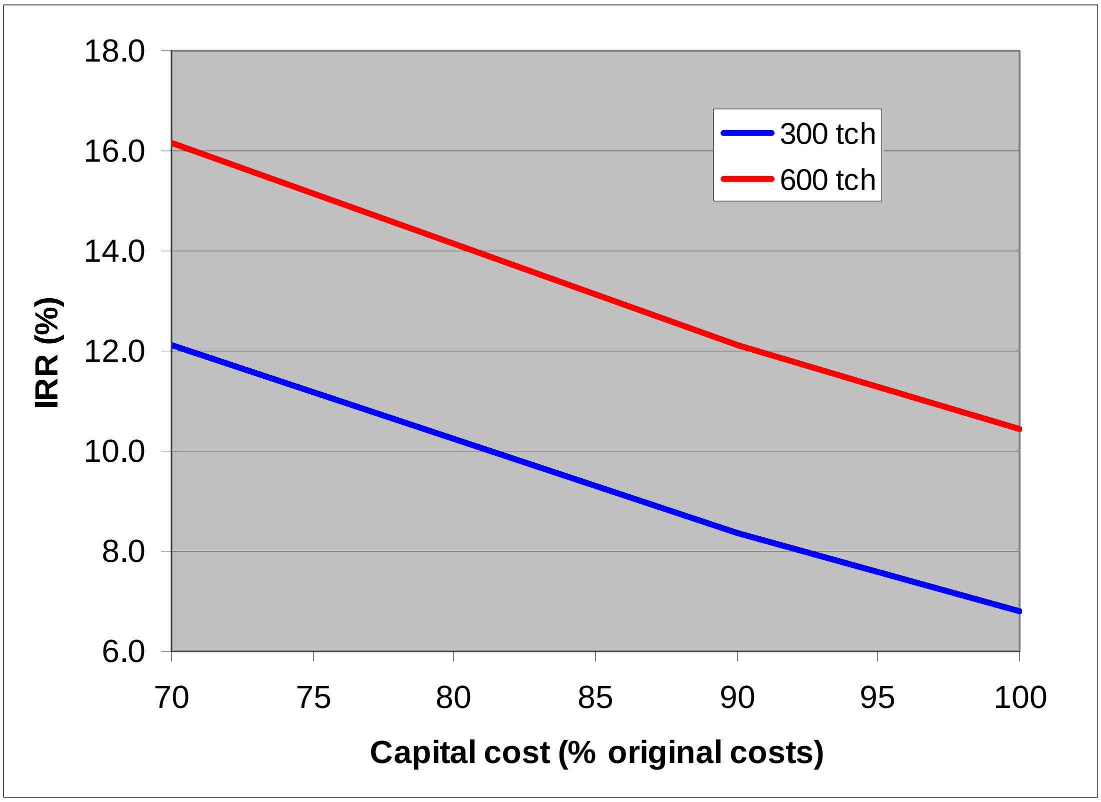
Values for NPV corresponding to the above costs and revenues (Table 3.15) associated with the furfural production scenarios investigated are shown graphically in Figure 3.6.

Figure 3.6 Financial results (NPV) for furfural production scenarios



An issue raised earlier in this report (section 3.4.4) was that technologies such as the SupraYield® process (for which cost data could not be found in the public domain) were currently being developed that would result in reduced capital costs (and increased yield) relative to that reported by Rudus and Katkevies (1998) and used in the current study. To investigate the sensitivity of furfural production to the type of savings that might be achieved by alternative technologies such as SupraYield® the capital cost used in the current analyses were incrementally reduced. This sensitivity analysis was carried out for the most favourable scenarios indicated in Figure 3.6 (extended operation, additional bagasse). The predicted effects of reduced costs on these scenarios are shown in Figure 3.7 for the small (300 tch factory) and large (600 tch factory) scale operations.

Figure 3.7 The effects of reduced capital costs on the viability of furfural production



This sensitivity analysis indicates that if, as a result of improved technology, capital costs could be reduced to 80% of those used in the current analysis then the smaller scale (300 tch factory) operation starts to become viable (IRR of 10%). In reality an IRR of 10% for a relatively novel technology would not provide a compelling business case for furfural production at this scale. With the same level of capital cost saving (80%) the larger scale (600 tch factory) operation starts to produce a level of profitability (an IRR of 14%) commensurate with a financially viable operation.

Summarising the case for furfural production:

- For the technology evaluated the capital and operating costs as well as revenues are very similar to those for power generation.
- A marginally viable business case is indicated for a large mill producing and importing surplus bagasse as feedstock for the furfural process.
- A sensitivity analysis indicates that moderate capital cost reductions such as those which might be achieved by utilising more advanced furfural processes (such as SupraYield®) would result in a sound business case for furfural production at large factories and a borderline case for small factories where in both cases supplementary bagasse is available from nearby mills.

3.5.4 *Option 4 – Ethanol from bagasse hydrolysis and fermentation*

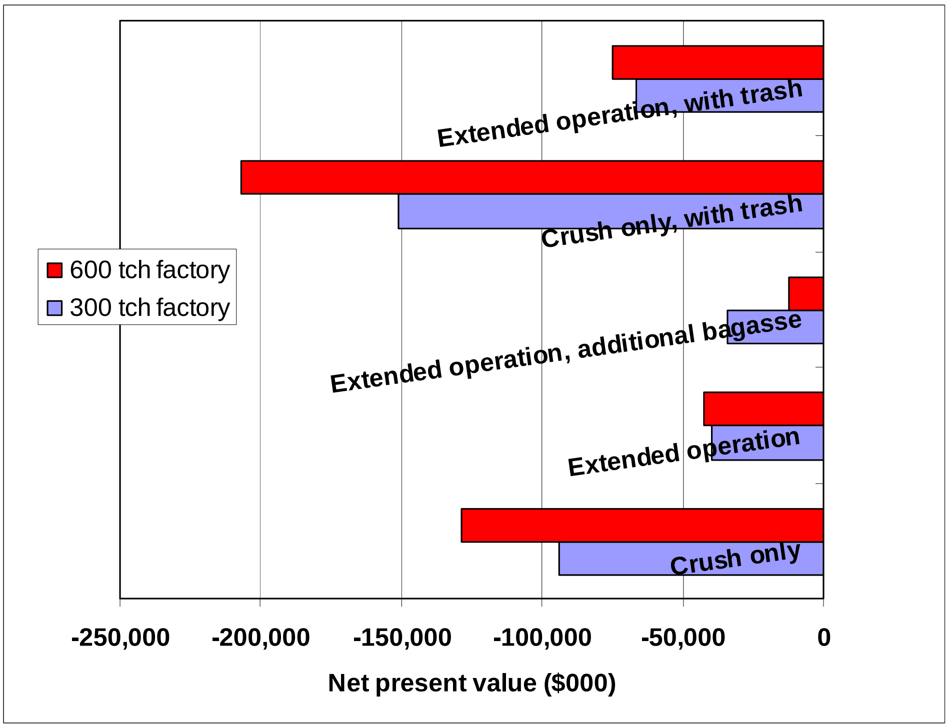
Table 3.16 shows the capacities, costs and revenues for bagasse to ethanol plants operating under the range of fuels supply conditions given in Table 3.2.

Table 3.16 Capacities costs and revenues for ethanol production from bagasse scenarios

Scenario	Annual ethanol production (ML)	Costs ($ 000) Capital	Annual operating	Revenue in year 3 ($ 000)
300 tch factory				
Crush only	15	104,475	8,855	9,696
Extended operation	15	67,102	6,584	9,696
Extended operation, additional bagasse	31	97,897	11,728	19,392
Crush only, with trash	31	164,356	17,855	19,331
Extended operation, with trash	31	103,778	14,577	19,331
600 tch factory				
Crush only	31	169,720	15,029	19,392
Extended operation	31	109,008	11,580	19,392
Extended operation, additional bagasse	61	159,034	20,965	38,784
Crush only, with trash	61	266,997	31,378	38,662
Extended operation, with trash	61	168,588	26,597	38,662

Values for NPV corresponding to the above costs and revenues (Table 3.16) associated with the ethanol production scenarios investigated are shown graphically in Figure 3.8.

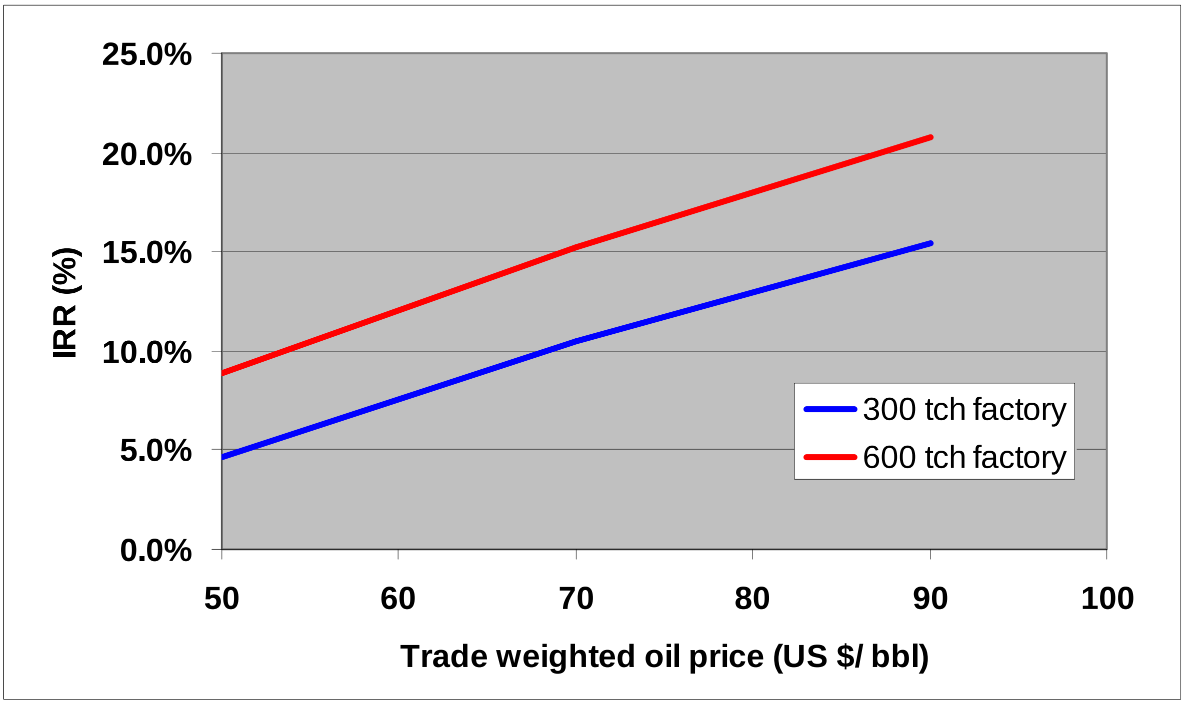
Figure 3.8 Financial results (NPV) for ethanol production scenarios



A critical (and volatile) factor in the profitability of any ethanol project is going to be the price of ethanol which in turn is a function of world oil price. The predicted profitability of bagasse to ethanol projects have been investigated as a function of trade weighted oil price. This has been carried out for the small (300 tch) and large (600 tch) factories where in each case supplementary bagasse is imported and the plant operated with an utilisation of 92%.

The resulting predicted sensitivity of the analysis to oil price (Figure 3.9) indicates that at US$ 70 per barrel the smaller scale (300 tch factory) operation is profitable but not an attractive proposition given the technical uncertainty associated with this relatively unproven technology. At US$ 70 per barrel the larger scale (600 tch factory) operation starts to produce a level of profitability (an IRR of 15%) commensurate with a financially viable operation.

Figure 3.9 Effects of oil price on ethanol production from bagasse



In summary for the bagasse to ethanol technology:

- Both capital and operating costs are high relative to other low RISK/ low GROSS REWARD options
- None of the scenarios are profitable below a trade weighted oil price of US $55/ bbl
- At current actual (US$ 70/ bbl) rather than currently predicted long term (US$ 50/ bbl) oil prices a sound business case can be made for the co-location of an ethanol plant at a 600 tch factory with access to supplementary bagasse from neighbouring mills.
- The viability of ethanol production from bagasse may improve further with:

- Revenues from sale of surplus power and RECs by upgrading the currently assumed steam and power plant to improve the efficiency of steam and power production.
- Factory integration to utilise factory steam and power.
- Co-location of an ethanol from molasses fermentation operation to increase the economies of scale of distillation plant.

3.5.5 Option 5 – Biodiesel from hydrothermal liquefaction of bagasse

Table 3.17 shows the capacities, costs and revenues for bagasse to biodiesel plants operating under the range of fuel supply conditions given in Table 3.2.

Table 3.17 Capacities costs and revenues for biodiesel production from the hydrothermal liquefaction of bagasse

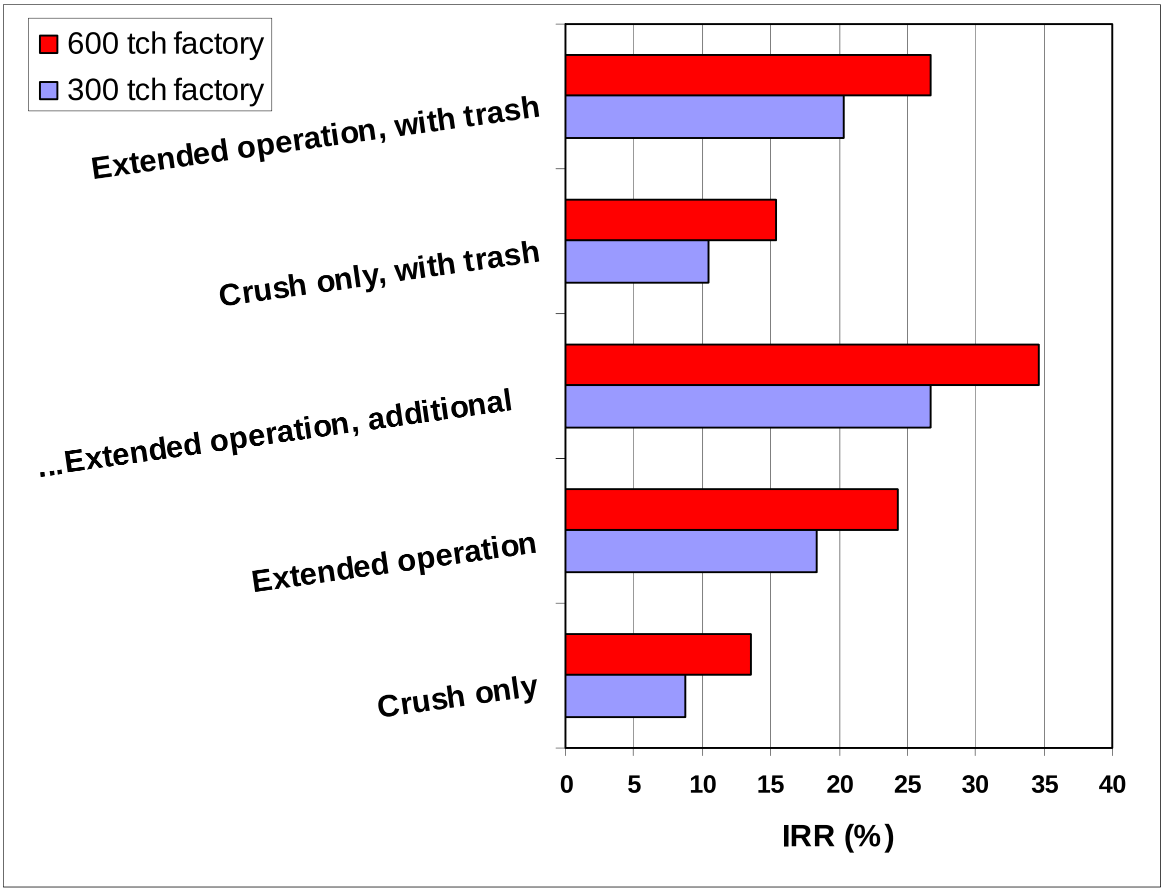
Scenario	Annual biodiesel production (ML)	Costs ($ 000)		Revenue in year 3 ($ 000)
		Capital	Annual operating	
300 tch factory				
Crush only	21	63,482	7,817	14,025
Extended operation	21	41,671	6,279	14,025
Extended operation, additional bagasse	42	59,644	11,864	28,049
Crush only, with trash	42	99,285	16,669	27,961
Extended operation, with trash	42	63,930	14,580	27,961
600 tch factory				
Crush only	42	103,128	13,734	28,049
Extended operation	42	67,695	11,477	28,049
Extended operation, additional bagasse	84	96,891	21,972	56,099
Crush only, with trash	84	161,288	30,233	55,922
Extended operation, with trash	84	103,855	27,384	55,922

Values for IRR corresponding to the above costs and revenues (Table 3.17) associated with the biodiesel production scenarios investigated are shown graphically in Figure 3.10.

The capital costs shown in Table 3.17 do not include those associated with the production of hydrogen for upgrading the biocrude oil to diesel. For reasons outlined in section 3.4.6 the latter have been amortised across the cost of hydrogen and included as an operating cost. Hence the low capital relative to operating costs indicated in Table 3.17.

Although the capital cost data used in the analysis is based on a detailed study (Goudriaan et al., 2000), there is little detail provided in terms of a breakdown of included costs. Given this lack of detail and uncertainty associated with upgrading costs other than those due to hydrogen production, a sensitivity analysis has been carried out on capital costs for hydrothermal liquefaction technology. The effects on NPV of incrementally increasing the capital costs (expressed as a percentage of the costs associated with the extended operation, additional bagasse scenarios given in Table 3.17) are shown in Figure 3.11.

Figure 3.10 Financial results (IRR) for biodiesel production scenarios



A further sensitivity analysis has been carried out on the effects of trade weighted oil price on the profitability of biodiesel production. The results of this sensitivity analysis are shown in Figure 3.12.

Figure 3.11 The effects of increased capital costs on the viability of biodiesel production (extended operation, additional surplus bagasse scenarios)

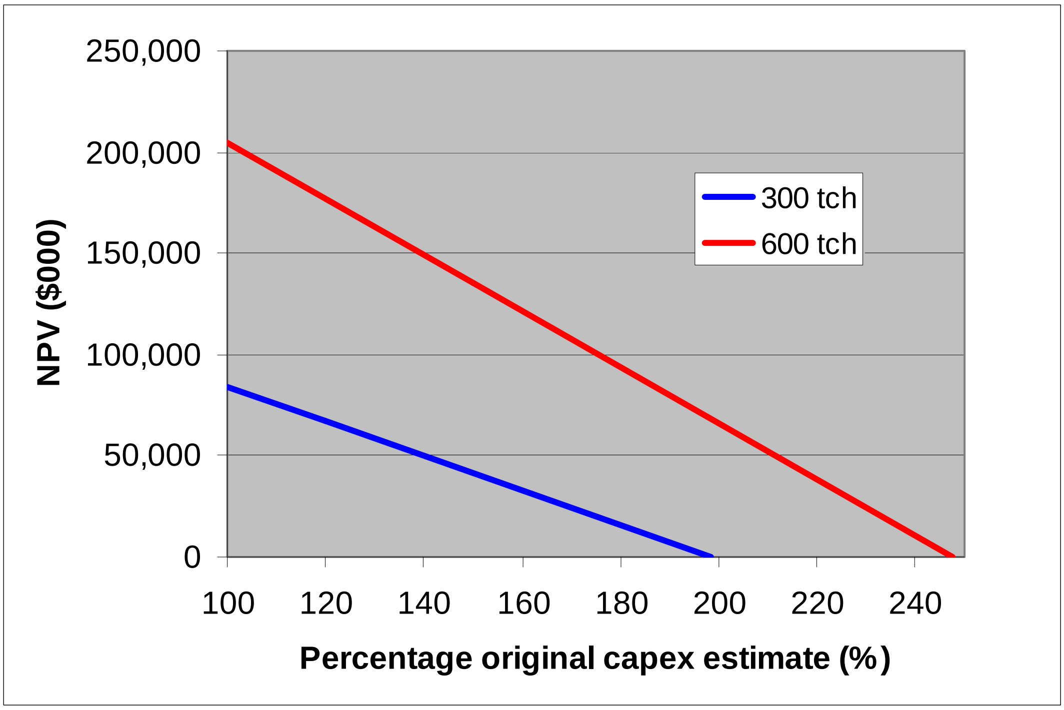
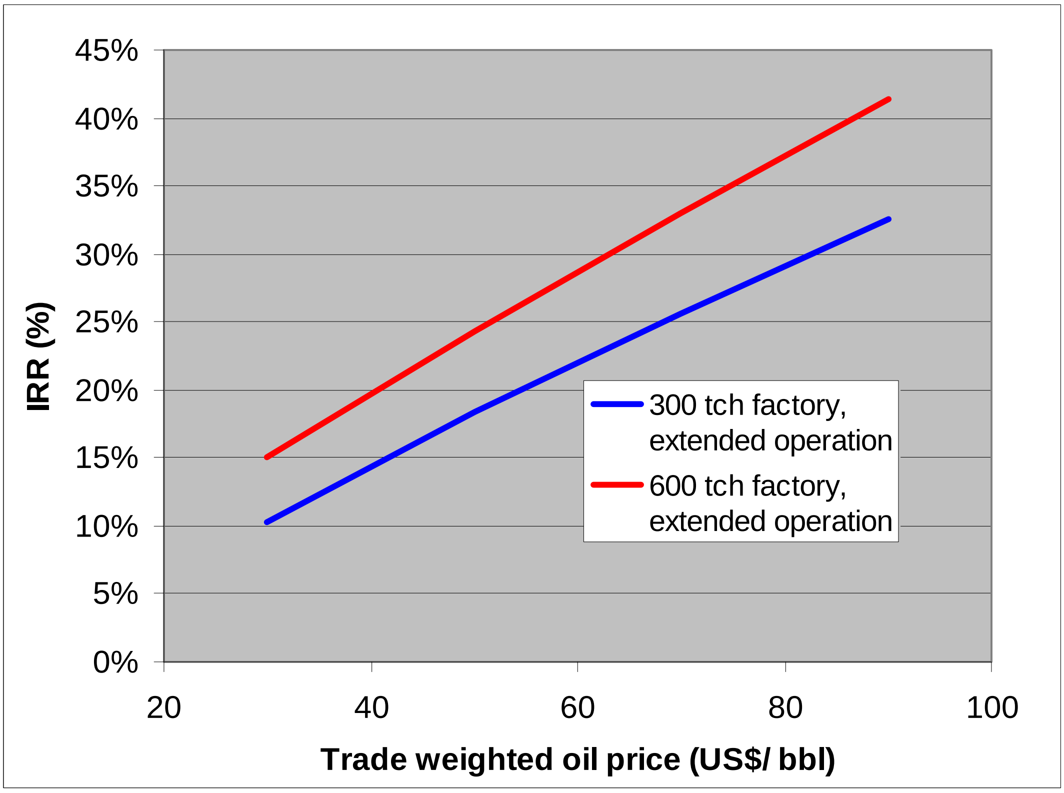


Figure 3.12 Effects of oil price on biodiesel production from bagasse (extended operation without additional surplus bagasse)



Summarising the results for the production of biodiesel via hydrothermal liquefaction of bagasse:

- Despite capital costs equivalent to those for co-generation and operating costs similar to those for ethanol production the yields and revenues from diesel production are sufficiently high to give good net returns on most scenarios
- The above (positive) results have been shown to be robust with respect to cost uncertainty:
  - Extended operation, supplementary feedstock scenarios for both 300 tch and 600 tch are profitable even when the hurdle rate is increased to 20% (Figure 3.10).
  - Alternatively the capital cost can be increased to 200% and 250% respectively (Figure 3.11) of that derived originally from Goudriaan et al., (2000) before all 300 tch and 600 tch extended operation factory scenarios cease to be profitable (based on a 10% hurdle rate).
- Trash (at a cost of $20 per tonne) improves financial returns on all scenarios where previously it reduced financial returns
- Small (300 tch) factory based operations without supplementary fuel exceed a 20% hurdle rate at oil prices greater than US $60/ bbl.

3.5.6 Option 6 – Biorefinery production of lignin and pulp from bagasse

Table 3.18 shows the capacities, costs and revenues for biorefinery plants operating under the range of fuels supply conditions given in Table 3.2.

Table 3.18 Capacities costs and revenues for biorefinery production of lignin and pulp

	Production (tonnes/ year)		Costs ($ 000)		Revenue in year 3 ($ 000)		
Scenario	Lignin	Pulp	Capital	Annual operating	Lignin	Pulp	Total
300 tch factory							
Crush only	7,732	24,854	113,380	7,568	8,203	7,119	15,323
Extended operation	7,732	24,854	70,056	7,582	8,203	7,119	15,323
Extended operation, additional bagasse	15,465	49,709	105,755	12,700	16,407	14,239	30,645
Crush only, with trash	15,416	49,552	180,164	14,992	16,355	14,194	30,549
Extended operation, with trash	15,416	49,552	109,939	15,419	16,355	14,194	30,549
600 tch factory							
Crush only	15,465	49,709	184,186	12,049	16,407	14,239	30,645
Extended operation	15,465	49,709	113,806	12,314	16,407	14,239	30,645
Extended operation, additional bagasse	30,930	99,417	171,799	22,356	32,813	28,477	61,291
Crush only, with trash	30,832	99,104	292,677	26,532	32,710	28,388	61,098
Extended operation, with trash	30,832	99,104	178,597	27,770	32,710	28,388	61,098

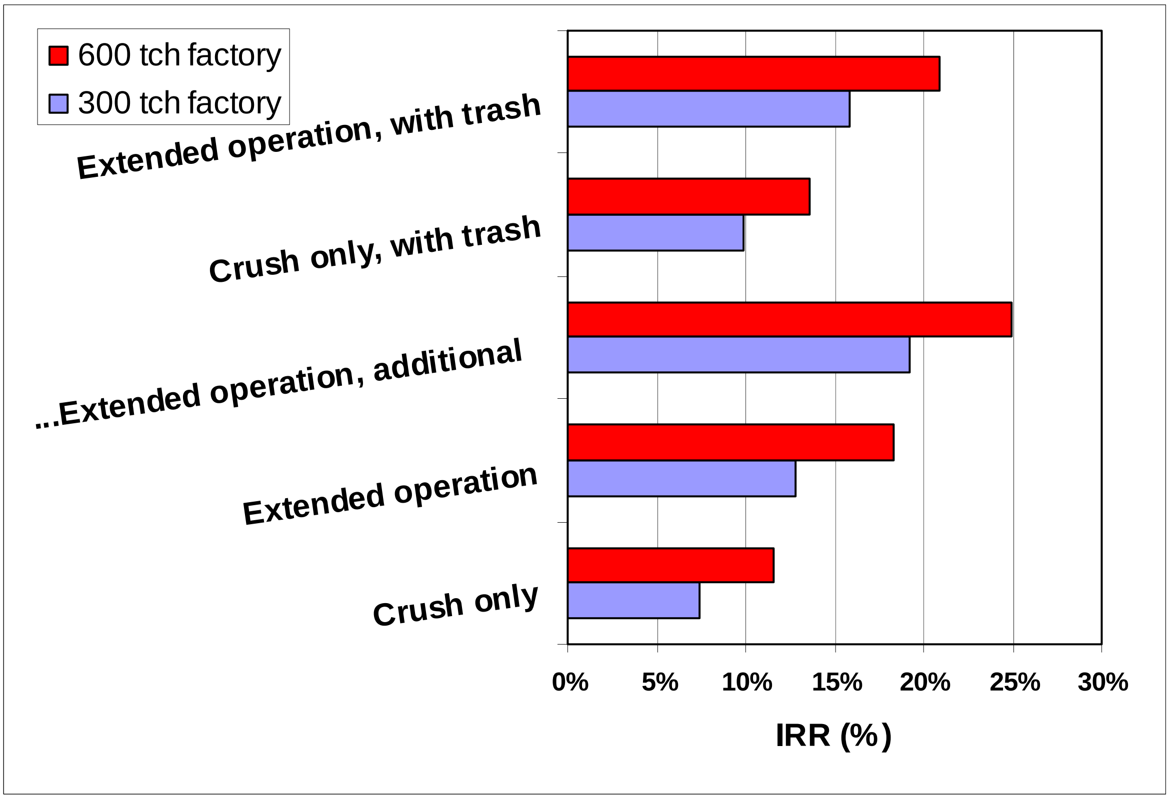
Values of IRR corresponding to the above costs and revenues (Table 3.18) associated with the biorefinery scenarios investigated are shown graphically in Figure 3.13.

Summarising the biorefinery case:

- Outcomes in terms of the financial viability for different feedstock supplies are similar to those presented in section 3.5.5 for biodiesel:

- Analysis of most extended operations with and without supplementary fuel produce IRRs of between 15% and 25%. These results are commensurate with those required to progress a project with moderate levels of associated technical or financial risk
- The use of trash as a supplementary feedstock improves the financial returns on all scenarios

Figure 3.13 Financial results (IRR) for biorefinery production of lignin and pulp



➢ In the current and anticipated continuing climate of high oil prices the further upgrading of native lignin to provide a substitute for butylacrylate would significantly boost biorefinery revenues. For a crude oil price range of between US$30 and US$70 per barrel, a one-to-one substitution for butylacrylate puts a value on derivatised lignin of between $1434 and $2774 per tonne (see table A.2).

3.5.7 Conclusions

<u>For the low RISK/ low GROSS REWARD options:</u>

➢ Large scale production of commodities is not viable for small mills (300 tch) using the technology options selected in this category. This is true even for the most favourable feedstock scenario corresponding to the import of surplus bagasse from nearby factories.

➢ For larger mills (600 tch) importing surplus bagasse there is a marginal business case for a stand-alone, year-round, power generation project. Power generation under all other biomass supply scenarios investigated would require costs to be amortised over other co-processes.

- The results of the analysis of furfural and ethanol production from bagasse are similar to those for power generation in terms of financial returns. The difference with these non-power generation options is that there is potentially scope for improved profitability via judicious choice of technology (particularly in the case of furfural) and factory integration strategies. Investigating improved profitability by these means requires a level of analysis which is beyond the scope of the current study and has to be established on a site-specific basis.
- Trash is not a viable feedstock for any of the low RISK/ low GROSS REWARD options investigated.
- There is some scope for regional production of cattle feed from the harvesting of cane tops. For such a venture the analysis undertaken in this study indicates that:
    - Proximity to feed markets (less than 200 kms) is essential
    - The quantities that can be produced by a single mill region (typically 100,000 to 200,000 tonnes) would satisfy a significant proportion of the total Australian market for this product, which is estimated at between 300,000 to 400,000 tonnes.

<u>For medium RISK/ high GROSS REWARD options:</u>

- The analyses indicated that for both thermochemical biodiesel and biorefinery production of lignin and pulp the range of IRRs (13% to 35%) produced for most extended production scenarios were commensurate with those required to progress a project with moderate levels of associated technical or financial risk (15% to 25%).
- These options greatly extend diversification opportunities within the industry to those smaller (300 tch) or geographically more isolated factories previously excluded on the grounds of diminished economies of scale.
- Trash (at $20 per tonne) improves the financial viability of all medium risk/ high reward options. This provides significant opportunities (subject to the appropriate management of the environmental impact of trash recovery) for the utilisation of a major source of additional fibre.
- By definition this category of options requires significant investment in technical development to the stage where yields (revenues) and costs assumed in the current study are confirmed or known with greater certainty. This said hydrothermal liquefaction technology has already progressed beyond the pilot plant stage with plans by the technology providers to build the first commercial plant by 2011. Also critical processes in biorefinery technology are soon (2006) to be tested in the sugar industry at the pilot scale with other biorefinery components already operating on a commercial basis in other industries.

3.5.8 Industry workshop

As part of this project an industry workshop was held in Mackay to coincide with the ending of the ASSCT conference on Friday May 6 2006. The purpose of the workshop was to present the results of stages 1 to 3 and elicit industry feedback on the project findings. A total of 44 attendees registered for the workshop although the actual number of participants on the exceeded 60. The workshop was structured such that ample opportunity was provided for feedback through professionally facilitated[10] discussion forums. A full report on the workshop is provided in appendix E.

4 Outputs

- An interim report delivered to the Industry Consultative Group outlining the results of a wide-ranging review of options for bagasse and trash utilisation with recommendations on a short-list of options which warrant more detailed analysis.
- The development of analyses of the most viable options.
- A presentation of costs, risks and returns for each option in a miller- and grower-participative workshop.
- A summary of the workshop outcomes and final report.

5 Intellectual Property

- A database of bagasse products, yields and product values.
- Knowledge of the relative ranking of a wide range of bagasse products in terms of their commercial significance (risk and reward) for the Australian sugar industry.
- Knowledge of the net financial benefit to the Australian sugar industry of six processes and technologies shortlisted from the abovementioned ranking process.

Whilst the authors retain copyright ownership it is anticipated that the above mentioned IP will be shared freely with the Australian sugar industry.

Active dissemination of the information beyond the Australian sugar industry by QUT or SRDC will be by mutual agreement.

6 Environmental and Social Impacts

As a desktop study there is little direct environmental risk associated with this project.

In a broader context the project has the potential to have a significant positive environmental and social impact by stimulating the production of renewable commodities and improving the triple bottom line (sustainability) of the Australian sugar industry.

[10] Facilitator - Ted Scott, Human Factor Australia.

7 Expected Outcomes

- Increased revenue derived from a currently low value feedstock that does not compete significantly with the production of raw sugar.

- Long term viability benefits via improved decision making at the early stages of product diversification within the industry.

- Increased industry awareness of benefits and risks associated with value adding to bagasse and trash.

- Increased levels of capital entering the industry via external investors.

- Improved understanding of technical barriers associated with bagasse and trash utilisation and appropriate targeting of industry and government R&D funds to overcome these hurdles.

- Environmental benefits from the initiation of a large scale renewable products industry.

8 Future Research Needs

- Site specific feasibility studies of near-term (low risk/ low reward) options for the implementation of value adding processes for bagasse at large mills or mill groups should be conducted. These studies should focus on the strategy of co-location (particularly of co-generation) and factory integration (utilisation of existing factory plant) as a means of increasing overall profitability. More specifically options within this category identified in this study are:

    - Ethanol production from bagasse and molasses combined with power generation.

    - Combined furfural and power production.

    - Combined activated carbon and power production.

- Technology evaluation and active development of longer term (moderate risk/ high reward) prospects. Candidate technologies identified in this category include:

    - Biodiesel production via hydrothermal liquefaction of bagasse.

    - Combined lignin/ pulp and lignin/ ethanol biorefinery technologies.

    - Ethanol production via Fischer Tropsch processes.

9 Recommendations

In order to increase the viability of the industry at current scales of operation and to utilise trash as a means of significantly increasing the economies of scale it is essential for the industry to identify and actively develop currently emerging technologies where high degrees of value adding are achieved. More specifically this might be achieved by:

- Increased awareness and willingness within the industry to support the development of high value adding technologies with longer term development horizons.
- Investigating the potential for pooling R&D funding and technical resources with other (fibre producing) agricultural industries to share the cost of long term technology development.

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11 References

Aden A., Ruth M., Ibsen K., Jechura J., Neeves K., Sheehan J., Wallace B., Montague L., Slayton A. and Lukas J. (2002). *Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover.* NREL report number NREL/TP-510-32438. Available from: www.energy.ca.gov/pier/renew/biomass/bioch_en/ethanol/pdfs/lignocellulosic.pdf

Australian Government (2004). *Securing Australia's energy future*. Section 4, pp 96. Policy document available on http://www.dpmc.gov.au/energy_future

Allen, C.J., Mackay, M.J., Aylward, J.H. and Campbell, J.A. (1997). *New technologies for sugar milling and by-product modifications*. In: Keating, B.A. and Wilson, J.R.

(Eds.). Intensive sugarcane production: Meeting the challenge beyond 2000. CAB International, Wallingford, pp 267-285.

Goudriaan F., van de Beld B., Boerefijn F.R., Bos G.M.,Naber J.E., van der Wal S. and Zeevalkink J.A. (2000). *Thermal efficiency of the HTU process for biomass liquification.* Tyrol, Austria. Proc. Progress in Thermochemical Biomass Conversion. (ISBN 0-632-0533-2), pp 1312-1325.

Hildebrand, C. (2002). *Independent Assessment of the Sugar Industry*. Report to the Hon. Warren Truss MP, Minister for Agriculture, Fisheries and Forestry (Copy of report obtained courtesy of Sugar Milling Council).

Hodgson, J.J. and Hocking B. (2006). *Viability of sugar mill co-generation projects.* Proc. Aust Soc. of Sugar Cane Tech. Vol. 28: 1 - 11.

Keating, B.A., Antony, G., Brennan, L.E. and Wegener, M.K. (2002). *Can renewable energy contribute to a diversified future for the Australian sugar industry?* Proc. Aust. Soc. Sugar Cane Technol., 24: 26-39.

Lavarack, B.P., Hodgson, J.J. and Broadfoot B. (2005), *Prioritising options to reduce the process steam consumptions of raw sugar mills.* Proc ISSCT Vol 25, 1:134-141

Linton, J. and M. (2006). *Good news for the sugar industry.* Letter circulated to growers on behalf of Australian Sweet Forage Pty Ltd (March)

Ridge, D.R. and Hobson, P.A. (2000). *Analysis of field and factory options for efficient gathering and utilisation of trash from green cane harvesting.* Final project report, SRDC project BS157S.

Rudus, I.A. and Katkevies, J. (1998). *Furfural production in Latvia: a pre-feasibility study.*

Schembri, M.G., Hobson, P.A. and Paddock, R. (2002). *The development of a prototype factory-based trash separation plant,* Proc. Aust. Soc. Sugar Cane Technol. 24: 12 - 18.

Sutherland, R.F. (2002). New *energy options in the Australian sugar industry.* Proc. Aust. Soc. Sugar Cane Technol., 24: 19-23.

Thorburn, P.J. et al (2006). *Value chain analysis of whole crop harvesting to maximise co-generation.* Proc. Aust Soc. of Sugar Cane Tech. Vol. 28: 37 - 48.

Appendix A Biomass model inputs and database output sheets

A.1 Biomass availability

Surplus bagasse and harvest residue models were established at an early stage so that initially the product value could be expressed on a per tonne of cane basis. Table A.1 shows the inputs used in establishing surplus bagasse and harvest residue availability.

Table A.1 Biomass availability model inputs

Input	Value	Units	Source
Cane supply to mill			
Cane supply	600.00	tonnes/h	1
Fibre in cane	14.70	% wet basis	1
Ash in bagasse fibre	4.00	% dry basis	1
Pol in bagasse	2.20	% wet basis	1
Brix in bagasse	3.10	% wet basis	1
Tops in clean cane supply	4.00	%cane	1, 2
Trash in clean cane supply	5.00	%cane	1, 2
Bagasse moisture a.r. (w.b.)	50.00	% bagasse	1
Mud solids in cane	0.60	% cane	
Fibre ratio	0.60		
Factory			
Process steam consumption	45.00	% on cane	1
Factory boiler efficiency on bagasse (HHV basis)	56.49	%	1
Factory HP steam pressure	18.00	bar abs	1
Factory HP steam temperature	260.00	^{0}C	1
Factory boiler feed water temperature	96.00	^{0}C	1
Factory crushing time	3340.00	hours	1
Bagasse consumed during shutdowns and startups (as a percent of total available)	11.00	%	
Whole of crop harvest			
Tops in cane supply with harvest residues	6.00	% cane	1, 2
Fibre in tops	12.00	% tops (wb)	Esimate
Ash in tops	8.00	% dry fibre	1
Pol in tops	1.70	% tops (wb)	1
Brix in tops	7.00	% tops (wb)	1
Trash in cane supply with harvest residues	13.00	% cane	3
Fibre in trash	46.00	% trash (wb)	1
Ash in trash	11.00	% dry fibre	1
Pol in trash	1.00	% trash (wb)	1
Brix in trash	6.00	% trash (wb)	1
Harvest residue recovered	No		
Analysis			
Date of current analysis	15/02/2006		

1 SRI records
2 Bureau of Sugar Experimental Stations (BSES) data
3 CSIRO data

The model used inputs from table A.1 to carry out the following sequence of calculations:

1. The total bagasse production from milled cane with a defined level of extraneous matter (trash, tops and dirt).
2. An estimate of the bagasse requirements of the factory based on steam generation efficiency, process steam demand and bagasse required for start-up at the beginning of the crush and after mid season stoppages.
3. The availability of surplus bagasse from the difference between the outputs from steps 1 and 2.
4. The availability of dry ash free fibre from surplus bagasse based on defined levels of moisture and ash in the bagasse supply.
5. The additional biomass available due to whole of crop harvesting (when required). This included increases in all components of extraneous matter over and above the base levels used to calculate step 1.
6. The availability of dry ash free fibre from the increased levels of harvest residue due to levels of moisture and ash defined for all extraneous matter components.
7. The total available dry ash free fibre from surplus bagasse and trash as the sum of outputs from steps 4 and 6. <u>This figure was then expressed as a fraction of the tonnes of cane harvested prior to any additional recovery of harvest residue</u>.

A.2 Database output sheets

A database has been compiled and contains the following information on value adding options:

- Primary, secondary and co-products are identified
- The corresponding biomass conversion process or technology used is named or a brief description provided.
- Maximum, mean and minimum yield data are provided for each final product together with source references for the data. Yield data available in the literature are often those corresponding to biomass feedstocks with very different levels of ash and moisture compared with bagasse and trash. The data from all sources was therefore reduced to a dry ash free basis before being entered into the database.
- Maximum, mean and minimum wholesale price data (Australian dollars) are provided for each final product together with source references for the data. Also recorded is the date corresponding to this price data. The latter was used to carry out a Consumer Price Index (CPI) adjustment on all price data such that it could be expressed in 2006 dollars.
- Provision was made in the database for additional comments relating to market or technical aspects of the products and processes.
- Using final product yields and CPI adjusted prices together with cane fibre availability (the latter determined as in section A.1) a range of values per tonne of cane was calculated for each product in the database. The minimum value per tonne

of cane was determined as the product of the minimum yield and minimum price. Mean and maximum values were generated in a similar fashion.

The data base output sheets for surplus bagasse only are shown in table A.2 (parts 1 to 4) and in table A.3 (parts 1 to 4) for surplus bagasse and trash.

Table A.2 Database output sheet for surplus bagasse only (part 1 of 4)

Primary product	Upgraded primary product	Co-product	Process	Product yield: On a units per tonne of *dry ash free* fibre basis OR units per tonne of intermediate product — Max	Mean	Min	Units (eg MWh) per tonne	Source of yield data	Product wholesale value (AUD): On an A$ per unit of product basis — Max	Mean	Min	Units (eg $/kg)	Date of price data (eg 1998)	Source of price data	Comments	Additional industry revenue from surplus bagasse only ($/tonne of original cane supply with inflation set by CPI) — Max	Mean	Min
Electricity			Combustion, low pressure steam & condensing turbo-alternator (TA) set	0.610	0.370	0.290	MWh/t	SRI calculations	81	65	60	$/MWh	2005	Hodgson J.J. and Hocking B. Viability of sugar co-generation projects, ASSCT, 2006	Three pricing tranches used to develop minimum, mean and maximum prices corresponding to demand in 2nd ($29/MWh), 4th ($34/MWh) and 1st ($50/MWh) quarters of the year respectively (Queensland). A single REC value of $28/MWh was applied. Avoided TUoS of $3/MWh is applied to all.	1.31	0.64	0.46
Electricity			Combustion, HP steam & condensing TA set	1.350	1.270	1.070	MWh/t	SRI calculations	81	65	60	$/MWh	2005	As above	As above	2.85	2.15	1.67
Electricity			Combined cycle gasification				MWh/t	SRI calculations								5.69	4.30	3.34
Mulch/poultry litter/dunnage			In-field drying (2-3 days) to 15% moisture before winrowing, raking & baling. No post-baling processing	0.080	0.080	0.080	per tonne cane	Pers. comm. Greg Zips (24/3/06), Raylorn Pty Ltd, Rocky Point mill area	220	162	105	$/tonne	2006	Pers. comm. Greg Zips (24/3/06), Raylorn Pty Ltd, Rocky Point mill area	Currently a slowly growing but fairly saturated market. Any inroads into the market made at the expense of other players. Some suppliers add value via further communition in a hammer mill (eg Rocky Point Mulching) or add colour.	A product of tops only not surplus bagasse	A product of tops only not surplus bagasse	A product of tops only not surplus
Animal feed			Recovery of tops for cattle feed	0.100	0.100	0.100	per tonne cane	Pers. comm. 23/12/05 Joe Linton, Australian Sweet Forage. Assumes 10 tonne/ha recovery of	100	100	100	$/tonne	2005	Pers. comm. 23/12/05 Joe Linton, Australian Sweet Forage	Product does not have bagasse component. Also delivered at 60% moisture - assume this was the initial moisture ie 1tonne tops produces 1tonne of feed	A product of tops only not surplus	A product of tops only not surplus bagasse	A product of tops only not
Pulp & paper products	- Newsprint		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		860	860	860	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	No maximum or minimum price range available	14.76	13.99	13.21
Pulp & paper products	- Packaging linerboard		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		817	817	817	$/tonne	2002	AusNewz yearbook 2002	No maximum or minimum price range available	15.39	14.58	13.77
Pulp & paper products	- Corrugating medium		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		450	450	450	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	No maximum or minimum price range available	7.72	7.31	6.91
Pulp & paper products	- Sack papers		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		1172	1172	1172	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	No maximum or minimum price range available	20.11	19.05	17.99
Pulp & paper products	- Packaging materials		Chemimechanical	0.578	0.567	0.544	tonnes/tonne		882	882	882	$/tonne	2002	AusNewz yearbook 2002		14.87	14.57	13.99
Pulp & paper products	- Sack papers		Chemimechanical	0.578	0.567	0.544	tonnes/tonne		817	817	817	$/tonne	2002		Use mechanical linerboard as conservative estimate	13.77	13.50	12.96
Pulp & paper products	- Market chemimechanical pulps (bleached &		Chemimechanical	0.643	0.630	0.605	tonnes/tonne		658	658	658	$/tonne	2005	Personal communication with Robert Eastmont, IndustryEdge, 7/12/05 with 10% reduction for bagasse	Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	11.23	11.01	10.57
Pulp & paper products	- Tissue hardroll (bath & facial)		Alkaline/sulfite processes (inc AQ soda)	0.374	0.320	0.272	tonnes/tonne		1800	1584	1584	$/tonne	2002		AusNewz yearbook 2002. Maximum product price is a consevative estimate.	19.63	14.76	12.56
Pulp & paper products	- Converted tissue products (bath & facial)		Alkaline/sulfite processes (inc AQ soda)	0.299	0.256	0.218	tonnes/tonne		7002	7002	7002	$/tonne	2005		ref John Trewick 13/12/05, 2005 Industry Edge yearbook, $2.10 per box. 1 box measured at 271.32 g of tissue (exc box obviously) = $7780/t	55.64	47.55	40.47

Table A.2 Database output sheet for surplus bagasse only (part 2 of 4)

				Product yield					Product wholesale value (AUD)							Additional industry revenue from surplus bagasse only ($/tonne of original cane supply with inflation set by CPI)		
				On a units per tonne of dry ash free fibre basis OR					On an A$ per unit of product basis									
Primary product	Upgraded primary product	Co-product	Process	Max	Mean	Min	Units (eg MWh) per tonne	Source of yield data	Max	Mean	Min	Units (eg $/kg)	Date of price data (eg 1998)	Source of price data	Comments	Max	Mean	Min
Pulp & paper products	- Paper towelling hardroll		Alkaline/sulfite processes (inc AQ	0.374	0.320	0.272	tonnes/tonne		1584	1584	1584	$/tonne	2002	SRI estimates (TJR)	Awaiting firm numbers from industry	17.27	14.76	12.56
Pulp & paper products	- Converted paper towelling product		Alkaline/sulfite processes (inc AQ soda)	0.299	0.320	0.218	tonnes/tonne		7002	7002	7002	$/tonne	2005	SRI estimates (TJR)	Representative of maximum Source data waiting firm numbers from industry	55.64	59.44	40.47
Pulp & paper products	- Fluff pulp		Alkaline/sulfite processes (inc AQ soda)	0.374	0.320	0.272	tonnes/tonne		838	838	838	$/tonne	2005	Personal communication with Robert Eastmont	Price for Aspen BCTMP delivered to asia. Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	8.32	7.11	6.05
Pulp & paper products	- Market pulp (bleached)		Alkaline/sulfite processes (inc AQ	0.416	0.355	0.302	tonnes/tonne		718	718	718	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	7.93	6.77	5.77
Pulp & paper products	- White office papers		Alkaline/sulfite processes (inc AQ soda)	0.320	0.299	0.218	tonnes/tonne		1683	1683	1683	$/tonne	2005	2005 (Nov) IndustryEdge newsletter		14.29	13.37	9.73
Pulp & paper products	- Specialty papers (e.g. wax, cleansers)		Alkaline/sulfite processes (inc AQ soda)	0.320	0.299	0.218	tonnes/tonne		4590	4590	4590	$/tonne	2002	AusNewz yearbook 2002	Price is for thermal papers	42.78	40.05	29.12
Insulating products (inc. household insulation)			Depithing + mechanical pulping and air drying	0.643	0.630	0.605	tonnes/tonne	Britton P., The E. and Close D (2005). Proc ASSCT, 27,462:471	800	800	800	$/tonne	2005	Pers. comm between P. Britton (JCU) and T. Rainey		13.65	13.38	12.84
Dissolving pulp (rayon)				0.245	0.245	0.245	tonnes/tonne		1064	1064	1064	$/tonne	2000	Personal communications with John Trewick	Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	8.13	8.13	8.13
Furfural C5H4O2 (commodity chemical)	-	-	IFT; (Rosenlew not in market)	0.109	0.109	0.109	tonnes/tonne	Watson, L.J. (2005) Personal communication.	1286	1000	714	$/tonne	2004	Watson, L.J. (2004) Personal communication.	Price is gate price (fob). IFT design has low effluent & high yields	3.81	2.97	2.12
Furfural	Furfural alcohol C5H6O2	-	Catalytic hydrogenation	0.939	0.939	0.939	t furfural	Zeitsch, K.J. (2000). The chemistry and technology of furfural and its many by-products. Vol. 13. Sugar Series. Elsevier, Amsterdam.	1420	1000	790	$/tonne	2006	Price estimate	65% of furfural used for furf. Alc.	3.77	2.65	2.09
Furfural	-	Acetic acid CH3COOH	TOPO extn or other techol.	0.045	0.023	0.000	t daf bagasse	Zeitsch; Lavarack	1786	1030	730	$/tonne	2004	Lavarack, B.P., Rainey, T.J., Bullock, G.E. and Falzon, K.L. (2004). Technical and economic feasibility of the Ecopulp process for Australian sugar cane bagasse. Confidential report to DSDI. SRI Job No. 3168.	Food grade.Technology dependent: uneconomic for low conc.	6.01	3.61	2.12
Furfural	-	Diacetyl (CH3CO)2	Rosenlew reactor with air	0.014	0.014	0.014	t furfural	Zeitsch	20000	20000	20000	$/tonne	2000	Zeitsch USD 14/kg	By-product from air oxid in Roselew reactor	4.76	3.91	3.06
Furfural	-	2,3 pentandione CH3COCOCH2CH3	Rosenlew reactor with air	0.002	0.002	0.002	t furfural	Zeitsch	430000	430000	430000	$/tonne	2000	Zeitsch USD 300/kg	By-product from air oxid in Roselew reactor	6.43	5.58	4.74
Furfural	-	Acetoin CH3COCHOHCH3	Catalytic hydrogenation	0.972	0.972	0.972	t diacetyl	Zeitsch	20000	20000	20000	$/tonne	2000	Zeitsch >USD 14/kg	Derivative of diacetyl, forms two different dimers	12.30	11.45	10.60

Table A.2 Database output sheet for surplus bagasse only (part 3 of 4)

				Product yield					Product wholesale value (AUD)							Additional industry ($/tonne of original cane supply with inflation set by CPI)		
				On a units per tonne of dry ash free fibre basis OR units per tonne of intermediate product					On an A$ per unit of product basis				Date of price data (eg 1998)					
Primary product	**Upgraded primary product**	**Co-product**	**Process**	**Max**	**Mean**	**Min**	**Units (eg MWh) per tonne**	**Source of yield data**	**Max**	**Mean**	**Min**	**Units (eg $/kg)**		**Source of price data**	**Comments**	**Max**	**Mean**	**Min**
Biorefinery type 1			**Ethanol and lignin are co-products**															
Lignin (as a platform chemical)	- Native lignin only			0.190	0.190	0.190	tonnes/tonne	SRI confidential report. Yield is automatically adjusted such that lignin component of cane trash is assumed to be 50% of that due to bagasse	2774	2104	1434	$/tonne	2005	SRI confidential report	Based on a 1 to 1 substitution of butylacrylate at oil prices of $30, $40 and $70 US/bbl	13.98	10.60	7.23
	- Vanillin			0.048	0.048	0.048	tonnes/tonne	SRI confidential report.	350000	181000	12000	$/tonne	2005		Small market - 12,000 tonnes globally	0.00	0.00	0.00
	- Barrier coatings, films resins, adhesives, paint ingredients, floculants			0.190	0.190	0.190	tonnes/tonne	SRI confidential report.	1800	1450	1100	$/tonne	2005	ICIS LOR		0.00	0.00	0.00
		- Toluene, ethylene, phenol, benzene	Pyrolysis in reducing artmosphere	0.004	0.003	0.002	tonnes/tonne	SRI confidential report.	858	1221	1584	$/tonne	2005	ICIS LOR	Low yield, waste remediation	0.00	0.00	0.00
- Pharmaceuticals															Development horizon too long term to determine commercial yields and revenues			
		Ethanol	Based on NREL dilute acid prehydrolysis and enzymatic hydrolysis process	334.000	334.000	334.000	L/tonne	Aden A,Ruth M, Ibsen K, Jechura J, Neeves K, Sheehan J, Wallace B, Montague L, Slayton A and Lukas J (2002). Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover. NREL	0.59	0.47	0.36	$/L	2006	Based on LHV of ethanol (21.1 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document	Maximum, mean and minimum prices are determined assuming trade weighted crude oil prices of USD 30, 50 and 70 per barrel resepectively. The Federal Government's long term discount on fuel excise of 50% contributes to these values.	5.13	4.09	3.13
Total biorefinery 1																19.11	14.69	10.35
Biorefinery type 2																		
		Drylap pulp (bleached & unbleached)	Ecopulp	0.540	0.540	0.540	tonnes/tonne	SRI confidential report	718	494	270	$/tonne	2006	Upper price in range is based on the production of a high quality (chemical) bleached pulp. Work at SRI indicated that significant further R&D is required to achieve this quality. The lower price value is that estimated for the quality of pulp produced during bench scale tests at SRI		10.09	6.94	3.79
Lignin (as a platform chemical)	- Native lignin only			0.190	0.190	0.190	tonnes/tonne	SRI confidential report. Yield is automatically adjusted such that lignin component of	2774	2104	1434	$/tonne	2005	SRI confidential report		13.98	10.60	7.23
Lignin	- Vanillin			0.048	0.048	0.048	tonnes/tonne	SRI confidential report.	350000	181000	12000	$/tonne	2005	0.00	Small market - 12,000 tonnes globally	0.00	0.00	0.00
	- Barrier coatings, films resins, adhesives, paint			0.190	0.190	0.190	tonnes/tonne	SRI confidential report.	1800	1450	1100	$/tonne	2005	ICIS LOR		0.00	0.00	0.00
		- Toluene, ethylene, phenol, benzene	Pyrolysis in reducing artmosphere	0.004	0.003	0.002	tonnes/tonne	SRI confidential report.	858	1221	1584	$/tonne	2005	ICIS LOR	Low yield, waste remediation	0.00	0.00	0.00
Total biorefinery 2																24.07	17.55	11.02

Table A.2 Database output sheet for surplus bagasse only (part 4 of 4)

				Product yield					Product wholesale value (AUD)							*Additional industry ($/tonne of original cane supply with inflation set by CPI)*		
				On a units per tonne of dry ash free fibre basis OR units per tonne of intermediate product					*On an A$ per unit of product basis*				*Date of price data (eg 1998)*					
Primary product	***Upgraded primary product***	***Co-product***	***Process***	***Max***	***Mean***	***Min***	***Units (eg MWh)***	***Source of yield data***	***Max***	***Mean***	***Min***	***Units (eg $/kg)***		***Source of price data***	***Comments***	***Max***	***Mean***	***Min***
Bio-crude	- Upgrading to hydrocarbon fuels or extenders eg biodiesel		Hydrothermal liquefaction (HTU, CWT) then hydrodeoxygenation over zeolite catalysts, Fe oxydation, CO	521.000	455.500	390.000	L/tonne	Goudriaan F., van de Beld B., Boerefijn F.R., Bos G.M.,Naber J.E., van der Wal S. and Zeevalkink J.A. (2000) Thermal efficiency of the HTU process for biomass liquification. Tyrol, Austria. Proc. Progress in Thermochemical Biomass Conversion. (ISBN 0-632-0533-2), pp 1312-1325	1.06	0.83	0.61	$/L	2006	Based on LHV of diesel relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document	Two calculations are carried out to determine Maximum and minimum yield of diesel equivalent per tonne of fibre. The first is based on a simple efficiency of energy conversion (75% - Goudriaan, 2000) and assumes that the biocrude can be further upgraded with minimal loss in original energy content to produce a fuel additive equivalent to diesel (the minimum value). The second calculation uses the results of more detailed SRI models which assume that the biocrude is upgraded using H_2. This gives an apparently higher yield due to the added energy content in the H_2.	14.37	9.84	6.19
	- Fertiliser		Residual ash from liquefaction process															
Ethanol only			Based on NREL dilute acid prehydrolysis and enzymatic hydrolysis process	334.000	334.000	334.000	L/tonne	Aden A,Ruth M, Ibsen K, Jechura J, Neeves K, Sheehan J, Wallace B, Montague L, Slayton A and Lukas J (2002). Lignocellulosic biomass to ethanol	0.59	0.47	0.36	$/L	2006	Based on LHV of ethanol (21.1 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document	Maximum, mean and minimum prices are determined assuming trade weighted crude oil prices of USD 30, 50 and 70 per barrel resepectively. The Federal Government's long term discount on fuel excise of 50% contributes to these values.	5.13	4.09	3.13
Methanol			Fischer Tropsh	550.000	550.000	550.000	L/tonne	van Thuijl E, Roos C.J. and Beurskens L.W.M. (2003). An Overview of biofule technologies, markets and policies in Europe	0.50	0.40	0.31	$/L	2006	Based on LHV of methanol (15.65 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document		7.16	5.73	4.44
Ethanol			Pearsons Technology	745.000	745.000	745.000	L/tonne	Vantine B. (2004) Untitled presentation made at New Mexico Green Fuels symposium, May 13	0.59	0.47	0.36	$/L	2006	Based on LHV of ethanol (21.1 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document		11.44	9.11	6.98
Hydrocarbons			Fischer Tropsh diesel using Co/Al_2O_3 catalysts	140.000	165.000	190.000	L/tonne	Kuester J.L. (1984). Diesel fuel from biomass. Paper presented at Energy from Biomass and Wastes VIII Symposium, Lake Buena Vista, Florida, January 30 – February 3.	1.06	0.83	0.61	$/L	2006	Based on LHV of diesel relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document		3.86	3.56	3.02

Table A.3 Database output sheet for surplus bagasse and trash (part 1 of 4)

				Product yield					Product wholesale value (AUD)							Additional industry revenue from surplus bagasse and trash ($/tonne of original cane supply with inflation set by CPI)		
				On a units per tonne of dry ash free fibre basis OR units per tonne of intermediate product					On an A$ per unit of product basis				Date of price data (eg 1998)					
Primary product	Upgraded primary product	Co-product	Process	Max	Mean	Min	Units (eg MWh) per tonne	Source of yield data	Max	Mean	Min	Units (eg $/kg)		Source of price data	Comments	Max	Mean	Min
Electricity			Combustion, low pressure steam & condensing turbo-alternator (TA) set	0.610	0.370	0.290	MWh/t	SRI calculations	81	65	60	$/MWh	2005	Hodgson J.J. and Hocking B. Viability of sugar co-generation projects, ASSCT, 2006	Three pricing tranches used to develop minimum, mean and maximum prices corresponding to demand in 2nd ($29/MWh), 4th ($34/MWh) and 1st ($50/MWh) quarters of the year respectively (Queensland). A single REC value of $28/MWh was applied. Avoided TUoS of $3/MWh is applied to all.	3.45	1.68	1.21
Electricity			Combustion, HP steam & condensing TA set	1.350	1.270	1.070	MWh/t	SRI calculations	81	65	60	$/MWh	2005	As above	As above	7.48	5.64	4.39
Electricity			Combined cycle gasification				MWh/t	SRI calculations								14.95	11.29	8.78
Mulch/poultry litter/dunnage			In-field drying (2-3 days) to 15% moisture before winrowing, raking & baling. No post-baling processing	0.080	0.080	0.080	per tonne cane	Pers. comm. Greg Zips (24/3/06), Raylorn Pty Ltd, Rocky Point mill area	220	162	105	$/tonne	2006	Pers. comm. Greg Zips (24/3/06), Raylorn Pty Ltd, Rocky Point mill area	Currently a slowly growing but fairly saturated market. Any inroads into the market made at the expense of other players. Some suppliers add value via further communition in a hammer mill (eg Rocky Point Mulching) or add colour.	17.60	12.98	8.36
Animal feed			Recovery of tops for cattle feed	0.100	0.100	0.100	per tonne cane	Pers. comm. 23/12/05 Joe Linton, Australian Sweet Forage. Assumes 10 tonne/ha recovery of	100	100	100	$/tonne	2005	Pers. comm. 23/12/05 Joe Linton, Australian Sweet Forage	Product does not have bagasse component. Also delivered at 60% moisture - assume this was the initial moisture ie 1tonne tops produces 1tonne of feed	10.00	10.00	10.00
Pulp & paper products	- Newsprint		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		860	860	860	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	No maximum or minimum price range available	38.78	36.74	34.70
Pulp & paper products	- Packaging linerboard		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		817	817	817	$/tonne	2002	AusNewz yearbook 2002	No maximum or minimum price range available	40.44	38.31	36.18
Pulp & paper products	- Corrugating medium		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		450	450	450	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	No maximum or minimum price range available	20.28	19.22	18.15
Pulp & paper products	- Sack papers		Mechanical pulp	0.646	0.612	0.578	tonnes/tonne		1172	1172	1172	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	No maximum or minimum price range available	52.82	50.04	47.26
Pulp & paper products	- Packaging materials		Chemimechanical	0.578	0.567	0.544	tonnes/tonne		882	882	882	$/tonne	2002	AusNewz yearbook 2002		39.05	38.29	36.76
Pulp & paper products	- Sack papers		Chemimechanical	0.578	0.567	0.544	tonnes/tonne		817	817	817	$/tonne	2002		Use mechanical linerboard as conservative estimate	36.18	35.48	34.06
Pulp & paper products	- Market chemimechanical pulps (bleached &		Chemimechanical	0.643	0.630	0.605	tonnes/tonne		658	658	658	$/tonne	2005	Personal communication with Robert Eastmont, IndustryEdge, 7/12/05 with 10% reduction for bagasse	Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	29.50	28.92	27.77
Pulp & paper products	- Tissue hardroll (bath & facial)		Alkaline/sulfite processes (inc AQ soda)	0.374	0.320	0.272	tonnes/tonne		1800	1584	1584	$/tonne	2002		AusNewz yearbook 2002. Maximum product price is a consevative estimate.	51.57	38.78	33.01
Pulp & paper products	- Converted tissue products (bath & facial)		Alkaline/sulfite processes (inc AQ soda)	0.299	0.256	0.218	tonnes/tonne		7002	7002	7002	$/tonne	2005		ref John Trewick 13/12/05, 2005 Industry Edge yearbook, $2.10 per box. 1 box measured at 271.32 g of tissue (exc box obviously) = $7780/t	146.19	124.92	106.32

Table A.3 Database output sheet for surplus bagasse and trash (part 2 of 4)

Primary product	Upgraded primary product	Co-product	Process	Product yield: On a units per tonne of dry ash free fibre basis OR Max	Mean	Min	Units (eg MWh) per tonne	Source of yield data	Product wholesale value (AUD): On an A$ per unit of product basis Max	Mean	Min	Units (eg $/kg)	Date of price data (eg 1998)	Source of price data	Comments	Additional industry revenue from surplus bagasse and trash ($/tonne of original cane supply with inflation set by CPI) Max	Mean	Min
Pulp & paper products	- Paper towelling hardroll		Alkaline/sulfite processes (inc AQ	0.374	0.320	0.272	tonnes/tonne		1584	1584	1584	$/tonne	2002	SRI estimates (TJR)	Awaiting firm numbers from industry	45.38	38.78	33.01
Pulp & paper products	- Converted paper towelling product		Alkaline/sulfite processes (inc AQ soda)	0.299	0.320	0.218	tonnes/tonne		7002	7002	7002	$/tonne	2005	SRI estimates (TJR)	Representative of maximum Source data - waiting firm numbers from industry	146.19	156.15	106.32
Pulp & paper products	- Fluff pulp		Alkaline/sulfite processes (inc AQ soda)	0.374	0.320	0.272	tonnes/tonne		838	838	838	$/tonne	2005	Personal communication with Robert Eastmont	Price for Aspen BCTMP delivered to asia. Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	21.87	18.69	15.90
Pulp & paper products	- Market pulp (bleached)		Alkaline/sulfite processes (inc AQ soda)	0.416	0.355	0.302	tonnes/tonne		718	718	718	$/tonne	2005	2005 (Nov) IndustryEdge newsletter	Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	20.83	17.80	15.15
Pulp & paper products	- White office papers		Alkaline/sulfite processes (inc AQ soda)	0.320	0.299	0.218	tonnes/tonne		1683	1683	1683	$/tonne	2005	2005 (Nov) IndustryEdge newsletter		37.53	35.14	25.55
Pulp & paper products	- Specialty papers (e.g. wax, cleansers)		Alkaline/sulfite processes (inc AQ soda)	0.320	0.299	0.218	tonnes/tonne		4590	4590	4590	$/tonne	2002	AusNewz yearbook 2002	Price is for thermal papers	112.38	105.21	76.51
Insulating products (inc. household insulation)			Depithing + mechanical pulping and air drying	0.643	0.630	0.605	tonnes/tonne	Britton P., The E. and Close D (2005). Proc ASSCT, 27,462:471	800	800	800	$/tonne	2005	Pers. comm between P. Britton (JCU) and T. Rainey		35.85	35.15	33.74
Dissolving pulp (rayon)				0.245	0.245	0.245	tonnes/tonne		1064	1064	1064	$/tonne	2000	Personal communications with John Trewick	Source data converted using 1 USD =1.33 AUD (exchange rate in Jan 2006)	21.35	21.35	21.35
Furfural C5H4O2 (commodity chemical)	-	-	IFT; (Rosenlew not in market)	0.109	0.109	0.109	tonnes/tonne	Watson, L.J. (2005) Personal communication.	1286	1000	714	$/tonne	2004	Watson, L.J. (2004) Personal communication.	Price is gate price (fob). IFT design has low effluent & high yields	10.02	7.79	5.56
Furfural	Furfural alcohol C5H6O2	-	Catalytic hydrogenation	0.939	0.939	0.939	t furfural	Zeitsch, K.J. (2000). The chemistry and technology of furfural and its many by-products. Vol. 13. Sugar Series. Elsevier, Amsterdam.	1420	1000	790	$/tonne	2006	Price estimate	65% of furfural used for furf. Alc.	9.89	6.97	5.50
Furfural	-	Acetic acid CH3COOH	TOPO extn or other techol.	0.045	0.023	0.000	t daf bagasse	Zeitsch; Lavarack	1786	1030	730	$/tonne	2004	Lavarack, B.P., Rainey, T.J., Bullock, G.E. and Falzon, K.L. (2004). Technical and economic feasibility of the Ecopulp process for Australian sugar cane bagasse. Confidential report to DSDI. SRI Job No. 3168.	Food grade.Technology dependent: uneconomic for low conc.	15.80	9.49	5.56
Furfural	-	Diacetyl (CH3CO)2	Rosenlew reactor with air	0.014	0.014	0.014	t furfural	Zeitsch	20000	20000	20000	$/tonne	2000	Zeitsch USD 14/kg	By-product from air oxid in Roselew reactor	12.51	10.28	8.05
Furfural	-	2,3 pentandione CH3COCOCH2CH3	Rosenlew reactor with air	0.002	0.002	0.002	t furfural	Zeitsch	430000	430000	430000	$/tonne	2000	Zeitsch USD 300/kg	By-product from air oxid in Roselew reactor	16.90	14.67	12.44
Furfural	-	Acetoin CH3COCHOHCH3	Catalytic hydrogenation	0.972	0.972	0.972	t diacetyl	Zeitsch	20000	20000	20000	$/tonne	2000	Zeitsch >USD 14/kg	Derivative of diacetyl, forms two different dimers	32.31	30.08	27.85

Table A.3 Database output sheet for surplus bagasse and trash (part 3 of 4)

				Product yield: On a units per tonne of *dry ash free* fibre basis OR units per tonne of intermediate product					Product wholesale value (AUD): On an A$ per unit of product basis							Additional industry ($/tonne of original cane supply with inflation set by CPI)		
Primary product	**Upgraded primary product**	**Co-product**	**Process**	**Max**	**Mean**	**Min**	**Units (eg MWh) per tonne**	**Source of yield data**	**Max**	**Mean**	**Min**	**Units (eg $/kg)**	**Date of price data (eg 1998)**	**Source of price data**	**Comments**	**Max**	**Mean**	**Min**
Biorefinery type 1			**Ethanol and lignin are co-products**															
Lignin (as a platform chemical)	- Native lignin only			0.131	0.131	0.131	tonnes/tonne	SRI confidential report. Yield is automatically adjusted such that lignin component of cane trash is assumed to be 50% of that due to bagasse	2774	2104	1434	$/tonne	2005	SRI confidential report	Based on a 1 to 1 substitution of butylacrylate at oil prices of $30, $40 and $70 US/bbl	25.35	19.23	13.10
	- Vanillin			0.033	0.033	0.033	tonnes/tonne	SRI confidential report.	350000	181000	12000	$/tonne	2005		Small market - 12,000 tonnes globally	0.00	0.00	0.00
	- Barrier coatings, films resins, adhesives, paint ingredients, floculants			0.131	0.131	0.131	tonnes/tonne	SRI confidential report.	1800	1450	1100	$/tonne	2005	ICIS LOR		0.00	0.00	0.00
		- Toluene, ethylene, phenol, benzene	Pyrolysis in reducing artmosphere	0.003	0.002	0.001	tonnes/tonne	SRI confidential report.	858	1221	1584	$/tonne	2005	ICIS LOR	Low yield, waste remediation	0.00	0.00	0.00
- Pharmaceuticals															Development horizon too long term to determine commercial yields and revenues			
		Ethanol	Based on NREL dilute acid prehydrolysis and enzymatic hydrolysis process	334.000	334.000	334.000	L/tonne	Aden A,Ruth M, Ibsen K, Jechura J, Neeves K, Sheehan J, Wallace B, Montague L, Slayton A and Lukas J (2002). Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover. NREL	0.59	0.47	0.36	$/L	2006	Based on LHV of ethanol (21.1 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document	Maximum, mean and minimum prices are determined assuming trade weighted crude oil prices of USD 30, 50 and 70 per barrel resepectively. The Federal Government's long term discount on fuel excise of 50% contributes to these values.	13.47	10.73	8.22
Total biorefinery 1																38.82	29.96	21.33
Biorefinery type 2																		
		Drylap pulp (bleached & unbleached)	Ecopulp	0.540	0.540	0.540	tonnes/tonne	SRI confidential report	718	494	270	$/tonne	2006	Upper price in range is based on the production of a high quality (chemical) bleached pulp. Work at SRI indicated that significant further R&D is required to achieve this quality. The lower price value is that estimated for the quality of pulp produced during bench scale tests at SRI		26.52	18.24	9.97
Lignin (as a platform chemical)	- Native lignin only			0.131	0.131	0.131	tonnes/tonne	SRI confidential report. Yield is automatically adjusted such that lignin component of	2774	2104	1434	$/tonne	2005	SRI confidential report		25.35	19.23	13.10
Lignin	- Vanillin			0.033	0.033	0.033	tonnes/tonne	SRI confidential report.	350000	181000	12000	$/tonne	2005	0.00	Small market - 12,000 tonnes globally	0.00	0.00	0.00
	- Barrier coatings, films resins, adhesives, paint			0.131	0.131	0.131	tonnes/tonne	SRI confidential report.	1800	1450	1100	$/tonne	2005	ICIS LOR		0.00	0.00	0.00
		- Toluene, ethylene, phenol, benzene	Pyrolysis in reducing artmosphere	0.003	0.002	0.001	tonnes/tonne	SRI confidential report.	858	1221	1584	$/tonne	2005	ICIS LOR	Low yield, waste remediation	0.00	0.00	0.00
Total biorefinery 2																51.87	37.47	23.07

Table A.3 Database output sheet for surplus bagasse and trash (part 4 of 4)

				Product yield					Product wholesale value (AUD)							Additional industry ($/tonne of original cane supply with inflation set by CPI)		
				On a units per tonne of dry ash free fibre basis OR units per tonne of intermediate product					On an A$ per unit of product basis				Date of price data (eg 1998)					
Primary product	Upgraded primary product	Co-product	Process	Max	Mean	Min	Units (eg MWh)	Source of yield data	Max	Mean	Min	Units (eg $/kg)		Source of price data	Comments	Max	Mean	Min
Bio-crude	- Upgrading to hydrocarbon fuels or extenders eg biodiesel		Hydrothermal liquefaction (HTU, CWT) then hydrodeoxygenation over zeolite catalysts, Fe oxydation, CO	521.000	455.500	390.000	L/tonne	Goudriaan F., van de Beld B., Boerefijn F.R., Bos G.M.,Naber J.E., van der Wal S. and Zeevalkink J.A. (2000) Thermal efficiency of the HTU process for biomass liquification. Tyrol, Austria. Proc. Progress in Thermochemical Biomass Conversion. (ISBN 0-632-0533-2), pp 1312-1325	1.06	0.83	0.61	$/L	2006	Based on LHV of diesel relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document	Two calculations are carried out to determine Maximum and minimum yield of diesel equivalent per tonne of fibre. The first is based on a simple efficiency of energy conversion (75% - Goudriaan, 2000) and assumes that the biocrude can be further upgraded with minimal loss in original energy content to produce a fuel additive equivalent to diesel (the minimum value). The second calculation uses the results of more detailed SRI models which assume that the biocrude is upgraded using H_2. This gives an apparently higher yield due to the added energy content in the H_2.	37.76	25.85	16.27
	- Fertiliser		Residual ash from liquefaction process															
Ethanol only			Based on NREL dilute acid prehydrolysis and enzymatic hydrolysis process	334.000	334.000	334.000	L/tonne	Aden A,Ruth M, Ibsen K, Jechura J, Neeves K, Sheehan J, Wallace B, Montague L, Slayton A and Lukas J (2002). Lignocellulosic biomass to ethanol	0.59	0.47	0.36	$/L	2006	Based on LHV of ethanol (21.1 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document	Maximum, mean and minimum prices are determined assuming trade weighted crude oil prices of USD 30, 50 and 70 per barrel resepectively. The Federal Government's long term discount on fuel excise of 50% contributes to these values.	13.47	10.73	8.22
Methanol			Fischer Tropsh	550.000	550.000	550.000	L/tonne	van Thuijl E, Roos C.J. and Beurskens L.W.M. (2003). An Overview of biofule technologies, markets and policies in Europe	0.50	0.40	0.31	$/L	2006	Based on LHV of methanol (15.65 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document		18.80	15.04	11.66
Ethanol			Pearsons Technology	745.000	745.000	745.000	L/tonne	Vantine B. (2004) Untitled presentation made at New Mexico Green Fuels symposium, May 13	0.59	0.47	0.36	$/L	2006	Based on LHV of ethanol (21.1 MJ/L) relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document		30.05	23.94	18.34
Hydrocarbons			Fischer Tropsh diesel using Co/Al_2O_3 catalysts	140.000	165.000	190.000	L/tonne	Kuester J.L. (1984). Diesel fuel from biomass. Paper presented at Energy from Biomass and Wastes VIII Symposium, Lake Buena Vista, Florida, January 30 – February 3.	1.06	0.83	0.61	$/L	2006	Based on LHV of diesel relative to petrol (32 MJ/L). Calculation is identical to that adopted by DIT&R (2003) but incorporating the alternative (which includes renewable) fuels discount rate scheme described in the federal government's recent (2004) energy policy document		10.15	9.36	7.92

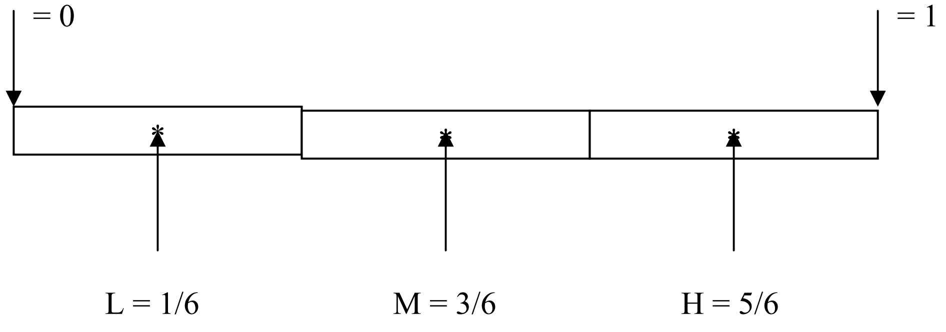
Appendix B Definition of terms used in the value adding process ranking procedure

1. **GROSS REWARD = Revenue *x* Market size**
   Where:
   Revenue = $/tonne of cane obtained from analysis
   and
   Market size refers to that available assuming the product can be successfully produced at the quality and price demanded by the target market.
   Also Market size = Large (H), Medium (M) or Small (S)
   Where:
   H = All available product from bagasse resource can be sold e.g. because of expanding market
   M = Some constraints on market e.g. competitive edge due to reduced costs of transport only for some locally manufactured product
   S = Limited/ untested/ undeveloped market

2. **RISK = Cost to commercialisation *x* (1 - Probability of success)**
   Where:
   Cost to commercialisation includes both R&D to take technology to commercial stage and capital cost of commercial plant.
   Also Cost to commercialisation = H, M or S
   Where
   : H = Either significant development costs or high capital costs or both.
   M = Moderate development and capital costs
   L = Off the shelf technology, minimal capital costs
   and
   Probability of success combines both technical and commercial factors
   Also Probability of success = H, M or S
   Where:
   H = Technology, costs and market well defined with no significant barriers to either
   M = Some uncertainty in costs, markets or ability of technology to deliver product at required specifications

L = Costs known to be prohibitive relative to returns or market totally undeveloped or most components of the technology are still at proof of concept stage.

Numerical values given to the terms H, M and L are as shown below.



Appendix C Tabulated results of the RISK v GROSS REWARD analysis excluding high value paper products

Primary product	Upgraded primary product	Co-product	Process	Normalised reward	Normalised risk factor
Electricity			Combustion, LPS & TA set	4.48	12.00
Electricity			Combustion, HPS & condensing TA set	15.06	12.00
Electricity			Combined cycle gasification	30.13	60.00
Mulch/poultry litter/dunnage			In-field drying (2-3 days) to 15% moisture before winrowing, raking & baling. No post-baling processing	20.78	4.00
Animal feed			Recovery of tops for cattle feed	26.69	4.00
Pulp & paper products	- Market chemimechanical pulps (bleached & unbleached)		Chemimechanical	46.32	60.00
Pulp & paper products	- Market pulp (bleached)		Alkaline/sulfite processes (inc AQ soda)	47.50	60.00
Insulating products (inc. household insulation)			Depithing + mechanical pulping and air drying	56.28	36.00
Dissolving pulp (rayon)				34.19	100.00
Furfural C5H4O2 (commodity chemical)	-	-	IFT; (Rosenlew not in market)	20.79	12.00
Furfural	Furfural alcohol C5H6O2	-	Catalytic hydrogenation	18.59	60.00
Furfural	-	Acetic acid CH3COOH	TOPO extn or other techol.	25.34	60.00
Furfural	-	Diacetyl (CH3CO)2	Rosenlew reactor with air	27.43	60.00
Furfural	-	2,3 pentandione CH3COCOCH2CH3	Rosenlew reactor with air	39.15	60.00
Furfural	-	Acetoin CH3COCHOHCH3	Catalytic hydrogenation	80.28	60.00
Activated carbon			CSIRO fluidised bed technology with steam activation. Also other similar pyrolysis processes	23.52	12.00
Charcoal			CSIRO fluidised bed technology	9.60	12.00
Total biorefinery 1 revenues				79.96	60.00
Total biorefinery 2 revenues				100.00	60.00
Bio-oil	- Fuel additive to staionary IC engines		Flash pyrolysis (Dynamotive, ENSYN etc)Ash removal + emulsification in diesel & kerosene	47.60	100.00
Bio-oil	- Electricity via co-firing in coal fired utilities			10.95	20.00
Bio-crude	- Upgrading to hydrocarbon fuels or extenders eg biodiesel		Hydrothermal liquefaction (HTU, CWT) then hydrodeoxygenation over zeolite catalysts, Fe oxydation, CO	68.99	60.00
Ethanol only			Based on NREL dilute acid prehydrolysis and enzymatic hydrolysis process	28.65	20.00
Methanol			Fischer Tropsh	40.15	20.00
Ethanol			Pearsons Technology	63.90	60.00
Hydrocarbons			Fischer Tropsh diesel using Co/Al2O3 catalysts	24.99	60.00

Appendix D Summary reports on generic technologies

D.1 Power generation

Processes

Two basic co-generation technologies and configurations are prevalent in the Australian industry:

1. *Low efficiency boilers with back-pressure turbines and minimal factory steam economy measures.*

This is 'traditional' technology within the industry and with a few exceptions is utilised for relatively low level opportunistic export of surplus power. This technology accounts for 77% of the 404 MW capacity installed in the Australian sugar industry. The widely used back-pressure turbine exhausts steam at pressures above atmospheric (typically 2.1 bar (abs)) such that sufficient energy remains in the steam to provide process heating in the factory. Power generation efficiency is low and generally dictated by the need to balance a surplus of incoming energy in the form of bagasse with the power and process steam requirements of the factory such that only a relatively small surplus of bagasse remains at the end of the crushing season (see for example Payne, 1991). The long term low price of power has with a few exceptions discouraged investment in steam efficient plant and power generation capacity. The low steam supply pressures and temperatures (again dictated by the need to achieve an energy balance and avoid bagasse surpluses) severely limit the thermodynamic efficiency associated with extracting power from the stream. Typical systems and outputs are given in table D.1.1.

Table D.1.1 Range of power generated per unit of dry ash-free (d.a.f.) surplus bagasse using low efficiency boilers with back-pressure turbines and minimal factory steam economy measures[11]

Efficiency range	**Export power per (d.a.f.) tonne of bagasse (MWh/tonne)**	**Typical operating conditions**
Lower	0.29	• Boiler efficiency - 50% (HHV basis) • Steam supply temperature - 260 ^{0}C • Steam supply pressure - 16 bar (abs)
Mid	0.37	• Boiler efficiency - 60% (HHV basis) • Steam supply temperature - 260 ^{0}C • Steam supply pressure - 18 bar (abs)
Upper	0.61	• Boiler efficiency - 66% (HHV basis) • Steam supply temperature - 450 ^{0}C • Steam supply pressure - 44 bar (abs)

2. *Dedicated high pressure, high temperature extracting/ condensing steam power generation*

Dedicated, relatively efficient power plants are rare in the industry with Rocky Point (30 MWe capacity) and Pioneer (63 MWe) mills being the only currently operating examples. Other similar plants at the construction or planning stage are Isis (25 MW), Condong (30 MW) and Broadwater mills.

Typical characteristics of these plants are:

- Export power[12] per (d.a.f.) tonne of bagasse – 1.27 MWh/tonne
- Boiler efficiency - 70% (HHV basis)
- Steam supply temperature – 520 ^{0}C
- Steam supply pressure – 65 bar (abs)

Markets

Power generated in the sugar industry is sold into two main wholesale markets:

1. *The National Electricity Market (NEM).*

Deregulation of the power industry commenced in 1994. As part of the deregulation process NEM was set up as a wholesale market for trading electricity between generators & retailers to be is managed by the National Electricity Market Management Company Ltd (NEMCO). Generators trade on the spot market or, as a means of managing the volatility of the market, enter into power supply contracts with retailers.

[11] Export power from SRI co-generation models using stated conditions
[12] From SRI co-generation model using stated conditions

Power sales from the sugar industry are almost exclusively through a power purchase agreement or contract with power retailers (Hodgson, Mackay Sugar, pers. comm. 2006). Typically under a bilateral hedge contract:

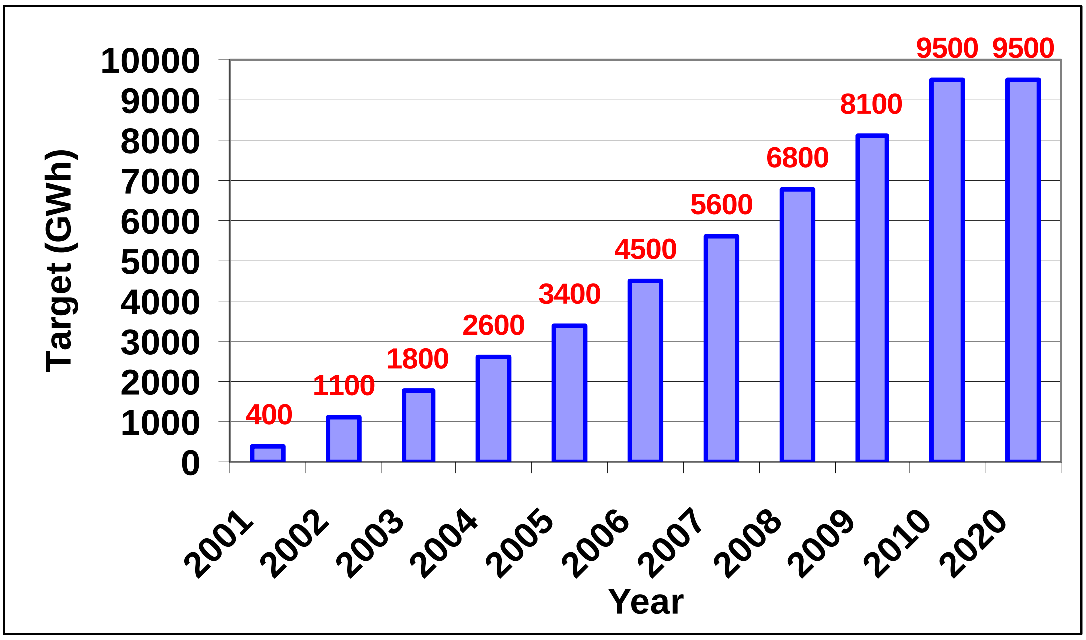
- A contract price is struck. This price can be time weighted to reflect the price changes that occur over the day and at different times of the year.
- When the spot price rises above contract price the generator pays the retailer the margin
- When the spot price drops below contract price the retailer pays generator the margin

Forward prices presented by Hodgson (2006) indicate current and near-future contract price variations in Queensland of between \$50/MWh (February) and \$29/MWh (May).

2. Renewable Energy Certificates (RECs)

RECs were introduced as a means of implementing the Renewable Energy (Electricity) Act (2000).Under this act Australia is to source 2% (9500 GWh) of its electrical power from new renewable capacity by 2010 via a predetermined set of interim capacity targets (Figure D.1.1). This (2%) target and associated penalty is to be maintained at a constant level to 2020.

Figure D.1.1 Power targets for new renewable capacity defined under the Renewable Energy (2000) act.[13]



[13] From data supplied on www.greenhouse.gov.au

The expectation within the sugar industry was that the Renewable Energy (2000) act would stimulate the development of numerous cogeneration projects with the value of RECs predicted to rise to $50 each by 20020 (McLennan Magasanic Associates Pty Ltd, 2000). This scenario has not eventuated with RECs after an initial rise, falling to a value in 2005 of $26 each.

Developmental stage and prospects for commercialisation

Current technology

Conventional high pressure, relatively efficient steam power generation plant is a mature technology. In terms of technical issues two factors dominate the design considerations during any feasibility stage of a potential sugar industry cogeneration project:

1. *Surplus fuel or steam availability*

To significantly increase power export capacity either additional steam has to be passed through a turbo alternator (TA) or surplus bagasse made available for a separate power generation operation. Both of these can be achieved by reducing factory demand for low pressure (LP) process steam. Operational and plant changes for increasing the steam efficiency of the factory are well established. A recent SRI study in which a wide range of steam efficiency measures were evaluated, established that an economic ‘optimum’ (the point beyond which capital costs dominate) under a co-generation scenario occurs at about 43% steam on cane.

Steam reduction to generate surplus bagasse for a ‘stand-alone’ power plant provides the flexibility to generate power beyond the crushing season and thereby increase the utilisation and reduce the size of the power plant relative to that associated with a crushing season only operation. Under this latter scenario the reduced capital cost and increased income (from exporting in the post-crush peak demand period) is offset by storage and retrieval costs.

Hodgson and Hocking (2006) show that although increased bagasse utilisation outside the crushing season (including the use of surplus bagasse from other mills) improves project returns, in none of the options investigated did revenue from power alone sufficiently offset costs.

Other studies (most recently Thorburn et al., 2006) have looked at whole of crop harvesting and factory separation technology (Schembri and Hobson, 2002) for the recovery of cane harvest residues (trash) as additional fuel. Thorburn et al (2006) concludes that with a recovery cost of between $13/ tonne and $24/tonne (inferred from the aforementioned paper), trash is not an economically viable source of fuel for new cogeneration projects where there is significant capital investment. The study also shows that marginal power production costs for existing co-generation plants are only just met by additional revenue when trash is recovered (at $13/ tonne), stored and subsequently burnt for power production.

2. Capital costs

There has been a sharp rise (within the last 5 years) in capital costs associated with cogeneration plant. This is due to a high demand for steel on the international market driven in turn by China's burgeoning manufacturing based economy. Hodgson and Hocking (2006) estimate that with current price levels for export power and RECs, capital costs would require a subsidy of between 48% and 59% to achieve a 15% internal rate of return (IRR). Some of this subsidy is required to overcome reduced future revenue beyond 2020 when income from RECs is no longer guaranteed.

In the current economic climate the viability of installing new co-generation capacity is contingent on government capital subsides as well as the amortisation of capital and operating costs over processes in addition to power. For example if a factory needs to replacing aging boilers and a decision is taken to install an extracting condensing co-generation plant, the associated costs can be amortised over sugar as well as power production.

Future developments

Significant work has been carried in evaluating both the technical and financial aspects of gasification technology for significantly increasing power export from the Australian sugar industry (Hobson and Dixon 1998, Dixon et al. 1998). Biomass integrated gasification/ Combined Cycle Gasification (BIG/CC) technology involves the thermal conversion of bagasse to produce a combustible fuel gas. This fuel gas is burnt in a high efficiency gas turbine to produce power. Heat from the gas turbine exhaust is used to raise steam which is used for further power generation and process heating in the factory. A recent study under the SIRE program (Hobson and Joyce, 2005) indicated that BIG/CC technology would potentially produce 6,254 GWh of export power (66% of the 2% government mandated target for new renewables) or double the power export capability of conventional high efficiency steam generation. Hobson and Joyce (2005) also show that the associated capital costs and returns from power are such that the technology is not currently economically viable.

References

Dixon, T.F., Hobson, P.A., Joyce, J.A., Pohl J.H., Stanmore, B.R. and Spero, C. (1998). Electricity cogeneration and greenhouse gas abatement in the sugar industry, Report by the Queensland Biomass Energy Group.

Hobson, P.A. and Dixon, T.F. (1998). *Gasification Technology – Prospects for large-scale, high efficiency cogeneration in the Australian sugar industry*. Proc. Aust. Soc. Sugar Cane Technol., 20; 1-9.

Hobson, P.A. and James, J.A., (2005). *Design and integration study of the transition to advanced gasification technology for large scale cogeneration in sugar mills*. Confidential

SRI report prepared under the Sugar Industry Renewable Energy (SIRE) program, SIRE Project 2, milestone report 5.

Hodgson, J., Lavarack, B.P. and Broadfoot, R (2004), *Technical and economic prioritisation of options to reduce process steam consumption in sugar mills including feedback from steam reduction workshops held in December 2003.* Confidential SRI report prepared under the Sugar Industry Renewable Energy (SIRE) program, SIRE Project 3, milestone report 3.

Hodgson, J. (2006) *Viability of sugar mill cogeneration projects*. Proc Australian Society of Sugar Cane Technologists, 28th annual conference, Mackay.

McLennan Magasanic Associates Pty Ltd (2000) *Projections of price of renewable energy certificates to meet the 2% renewable energy target.* http://www.greenhouse.gov.au

Payne, J.H. (1991) *Cogeneration in the cane sugar industry*. Elsevier Science Publishers B.V., ISBN 0444888268

Schembri, M.G., Hobson, P.A. and Paddock, R, (2002). *The development of a prototype factory-based trash separation plant.* Proc. Aust. Soc. Sugar Cane Technol., 24: 12-18.

Thorburn P.J., Archer A.A., Hobson P.A., Higgins A.J., Sandel G.R., Prestwidge D.B., Andrew B., Antony G., McDonald L.J., Downs P. and Juffs R. (2006), *Value cain analysis of whole crop harvesting to maximise co-generation*, Proc Australian Society of Sugar Cane Technologists, 28th annual conference, Mackay.

D.2 Animal feed

Processes

Raw bagasse has low digestibility, high lignin (>20%) and low nitrogen content all of which limits its value as a direct animal feed (FAO website). In order to overcome these limitations, various methods have been developed for the processing of bagasse and bagasse pith to animal feed. These include predigestion by chemical methods or physical heat treatment and mixing readily available sources of carbohydrate (molasses) and nitrogen or protein.

One method of treatment to increase digestibility which appears to have application on an industrial scale is the use of steam at high pressures. Wong et al. (1974) showed that treatment of sugarcane bagasse with high pressure (14 barg) steam for 5 minutes raised dry matter digestibilities from 28% to 60%. The characteristics of hydrolysed bagasse relevant to its efficacy as a feed are given in table D.2.1 (Cuban Research Institute of Sugarcane by-products, 2000).

Table D.2.1 Characteristics of hydrolysed bagasse as an animal feed

Component	Value	Units
Dry matter (%)	56 – 60	%
pH	3.4 – 3.6	
Total reducing sugars d.m.	6.8	%
Organic acids d.m.	13 - 16	%
Ash d.m.	2 – 3	%
Pentosans d.m.	3 – 5	%
Cellulose d.m.	30 – 41	%
Lignin d.m.	18 – 20	%
Gross protein d.m.	2 – 3	%
Metabolizable energy d.m.	10 – 11	MJ/kg
Digestibility d.m.	62 - 64	%

Experiments in Colombia (de la Cruz, 1990) using a diet of steam-treated bagasse (10 to 17 barg, 180 to 200 ^{0}C), supplemented with 2-3 kg per 100 kg live weight of *Gliricidia sepium*[14] foliage and 1-2 kg or *ad libitum* molasses/urea (10%) mixture, produced average daily growth in (Zebu) cattle 0.55-0.75 kg/day.

The Cuban sugar industry produces a ruminant feed supplement from bagasse derived pith using a sodium hydroxide treatment to improve digestibility (from 20% to 50%) and reduce the amount of molasses required (Cuban Research Institute of Sugarcane by-products, 2000). A 12% solution of NaOH (4% by dry weight of final dry product) is mixed with the

[14] A forage crop in common use in humid tropics including Southeast Asia and Sri Lanka.

pith (reaction time of 5 minutes) before adding molasses (24% by dry weight of final dry product) and urea (4% by dry weight of final dry product). The yield for feed produced by this process is 1.6 tonnes of feed per dry tonne of pith.

Cane tops has a dry matter digestibility of 54% (Naseeven, 1986) and in this respect is superior to unprocessed bagasse as an animal feedstock. The chemical composition and digestibility coefficient of sugar cane tops is given in table D.2.2.

Table D.2.2 Chemical composition and digestibility of sugar cane tops (Naseeven, 1986)

Component	Chemical composition		Digestibility coefficients	
	Mean (%)	SD ±	Sheep	Cattle
Dry matter	29.0	2.3	54.3	53.9
Organic matter	91.5	-	56.2	55.1
Ash	8.5	2.1	-	-
Crude protein	5.9	0.7	37.7	41.1
Crude fibre	33.5	2.1	56.5	54.1
Ether extract	1.7	0.3	-	56.2
Nitrogen free extract	50.3	3.9	56.6	57.8

Reports on the efficacy of cane tops alone as forage vary with Naseeven (1986) reporting that livestock in the Mauritius "… at best have very low levels of production" whereas Linton (pers. comm., December 2005) reports that trials carried out in Australia (final report pending) indicate that cane tops is a good drop-in substitute for Rhode Grass.

References

De la Cruz, H.O. (1990). Steam treated bagasse for fattening cattle. *Effect of supplementation with Gliricidia sepium and urea/ molasses.* Livestock Research for Rural Development, Vol. 2, No. 2.

Food and Agricultural Organisation of the United Nations (FAO), *Animal feed resources information system (Saccharum Officinarum)* http://www.fao.org/ag/aga/agap/frg/afris/DATA/552.htm

Cuban Research Institute of Sugar Cane by-Products (2000). *Handbook of Sugar Cane Derivatives (3rd edition)*, General Editors Luis and Taupier. Printed by MINAZ, Havana, Cuba.

Naseeven, M.R., *Sugarcane tops as animal feed*, Sugarcane as feed, Proceedings of an FAO Expert Consultation held in Santo Domingo, Dominican Republic from 7 – 11 July. Available from, http://www.fao.org/docrep/003/s8850e/S8850E00.htm

Wong Yon Cheong Y, D'Espaignet J.T., Deville J.P., Sansoucy, R. and Preston T. (1974). *The effect of steam treatment on cane bagasse in relation to its digestibility and furfural production.* Proceedings of the 15th Congress of the ISSCT. Hayne and Gibson, Durban, South Africa.

D.3 Furfural and furfural co-product manufacture

Processes

Furfural production

Furfural[15] is produced from the pentosans in bagasse or other agricultural raw materials (e.g. rice husks, straw, wood chip). The pentosans are the main component of hemicellulose in bagasse or agricultural raw materials. Pentosans are polymers of pentoses (C5 sugars). The pentoses found in the pentosan of sugar cane bagasse consist mainly of xylose, with lesser amounts of arabinose.

Pentosans can be removed from bagasse or other agricultural raw materials to form a variety of products. Furfural is one of these products. The simplest equation to describe the conversion of pentosan to furfural is:

PENTOSAN - 2n WATER → n FURFURAL
$(C_5H_8O_4)_n$ - 2n H_2O → n $C_5H_4O_2$

The stoichiometry in terms of formula mass is:
n * 132.114 - 2n * 36.032 → n * 96.082

The maximum yield for furfural production based on pentosan content is

Maximum theoretical yield = (96.082 / 132.114)
= 0.72727

In practice the yields of furfural are low because the high reactivity of furfural leads to the formation of a large number of decomposition products. The highest yields for commercial processes are reported to be produced using IFT's SupraYield[16] process. The Rosenlew process and the batch processes adopted in China for furfural production all have reduced yields. Yields in excess of 60% of the maximum theoretical yield are reported by IFT for furfural production from bagasse[17].

Approximately 100,000 tonnes of as is bagasse can produce about 5,000 tonnes of furfural.

100,000 tonnes as is bagasse = 100,000 * (1 - 0.50 - 0.02) * (1 - 0.04)

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[15] Furfural is sometimes called furfuraldehyde.

[16] IFT stands for International Furan Technologies. The company is represented by Proserpine Sugar Mill Co-operative in Australia. Details about IFT can be obtained from the website (www.ift.co.za).

[17] Higher yields are reported for other agricultural feed materials.

= 46,080 tonnes dry ash free bagasse
= 46, 080 t * 0.25
= 11,520 tonnes pentosan
= 11,520 * 0.72727 *0.60
= 5,027 t furfural
~ 5,000 t furfural

[Assumptions: 50 water%bagasse, 2 brix%bagasse, 4 ash%bagasse fibre, 25 pentosan%(dry ash free)bagasse, 60% furfural yield on pentosan]

The production yield of furfural from dry ash free (daf) bagasse is 0.109 (calculated: 5027 / 46080).

Furfural naturally polymerises to form polyfurfural, which discolours the furfural final product. Polyfurfural is produced in furfural during storage and it has a significant discolouration effect on the product. Furfural should be colourless, but is likely to be straw coloured because of traces of polyfurfural. Commercial grade furfural may be pitch black in appearance, but is likely to be more than 97% pure (Zeitsch, 2000). Polyfurfural is not a commercial product.

Co-product manufacture from furfural production

Furfural can be processed to form furfural alcohol, furoic acid and furan resins and polymers. Other co-products can be formed in the production of furfural. These include acetic acid, diacetyl, 2,3 pentandione.

1. Furfural alcohol

The reaction equation for furfural alcohol is:

FURFURAL + HYDROGEN → FURFURYL ALCOHOL
$C_5H_4O_2$ H_2 $C_5H_6O_2$

The stoichiometry in terms of formula mass is:
96.082 + 2.016 → 98.098

The production yield of furfural alcohol is 0.939 tonne per tonne furfural (about 92% of maximum theoretical) (Zeitsch, 2000).

2. Furoic acid

The reaction equations for furoic acid are:

2 FURFURAL + CAUSTIC SODA → FURFURYL ALC. + FURANCARBOXLATE
2 $C_5H_4O_2$ NaOH $C_5H_6O_2$ $C_5H_3O_3Na$

FURANCARBOXLATE + SULPHURIC ACID → FUROIC ACID + SALT
$C_5H_3O_3Na$ H_2SO_4 $C_5H_4O_3$ $NaHSO_4$

The stoichiometry in terms of formula mass is:
192.164 (furfural) → 112.082 (furoic acid) + 98.098 (furfuryl alcohol)

The production yield achieved for furoic acid is about 0.287 tonne furoic acid per tonne furfural (about 49% of maximum theoretical). Furfuryl alcohol is a co-product from furoic acid manufacture.

3. Furan resins and polymers

Furfural may be used as feed for the production of resins and polymers. Furfural readily forms polymers with phenol, aniline and acetone. The structures of the products formed in these polymerisation reactions are complex. Furfural can substitute for formaldehyde in phenol formaldehyde resins. The main advantage of the substitution is the elimination of volatile formaldehyde. Traces of formaldehyde remain in phenol formaldehyde resins.

Furfural may be used as a precursor for the production of Spandex (Lycra®). Furfural requires modification to be used as a feedstock for Spandex production. [The feedstock required for Spandex is commonly known as Polymeg® and is formed from polymerising tetrahydrofuran (THF). The polymer chains of Polymeg are terminated with acetyl groups. THF or similar derivatives can be produced from the hydrogenation of furfural.]

Furfural is converted to furfural alcohol (refer section 1) and the latter is used for the production of foundry resins.

n FURFURYL ALCOHOL - n WATER → FURAN RESIN
n $C_4H_3O\text{-}CH_2OH$ - n H_2O $-(C_4H_3O\text{-}CH_2)_n-$

The stoichimetry for the production of the foundry resin is described by a resin formulation. A typical formulation for a foundry resin comprises sand (100 parts), aqueous acid catalyst (25 parts) and furfural (1 to 2 parts) (Zeitsch, 2000).

4. Acetic acid

In the production of furfural, the glucuronic acid decomposes to form acetic acid. Glucuronic acid forms part of the hemicellulose fraction of bagasse.

The production yield for acetic acid ranges from 0 to about 0.045 tonne acetic per tonne of daf bagasse.

The acetic acid formed in the reaction is at low concentration, but may be extracted and refined. The recovery of acetic from furfural production using existing processes is viewed as marginal (Arnold, 2005). There is a major opportunity for the development of processes to extract acetic acid and other acids from furfural and other waste steams.

5. Diketones and acetoin

In the production of furfural using the Rosenlew process, small quantities of oxygen are introduced into the reactor. The oxygen causes side reactions to occur and several impurities are formed. The products from the side reaction products include diketones:

DIACETYL	2,3 PENTANDIONE
$CH_3CO{-}COCH_3$	$CH_3CO{-}COCH_2CH_3$

The production yields for these diketones are 0.014 tonne diacetyl per tonne furfural and 0.002 tonne per tonne furfural respectively.

Acetoin is produced by the hydrogenation of diacetyl, which is formed as a by-product by the Rosenlew process. The production yield for acetoin is 0.972 tonne per tonne diacetyl.

DIACETYL	+	HYDROGEN	→	ACETOIN
$CH_3CO{-}COCH_3$		H_2		$CH_3CO{-}CHOHCH_3$

The stoichiometry for acetoin production is:

86.036 2.016 → 88.052

Development work would be required to modify IFT's SupraYield® process for increased production of diketones (Watson, 2006). There is a major opportunity for the modification of the SupraYield process to increase yields of diketones.

Markets

Furfural and co-product supply

The supply of furfural to the world market is reliant on furfural production levels in China. The primary feedstock for furfural production in China is corn cobs, which is used as a fuel for heating in winter. Given the escalation of oil prices, the abundance of corn cobs for furfural production has reduced and has led to decreased production of furfural destined for the world market. Furfural production in China will likely increase with reductions in the price of oil. Consumers of furfural have been known to express concern regarding the lack of consistency in the quality of furfural produced in China. However this does not imply that all producers in China have poor quality standards.

There are a few major producers of furfural outside China. These suppliers include Central Romana Corporation in the Dominican Republic (~35,000 t/y) and Illovo Sugar (Sezela

Mill) in South Africa (~20,000 t/y). There are some smaller suppliers in India and in the former eastern block countries. All four major production facilities in the USA have closed in the past ten years. The reasons given for the closure of the USA factories are varied, and include environmental (problems of effluent disposal), low price product from both China and South Africa and availability of feed material for the process.

Furfural and its co-product, furfuryl alcohol, are normally produced near the source of the agricultural feedstock (viz. at the sugar factory). The production of other value added co-products (resins, pharmaceuticals) are usually undertaken away from the agricultural site (viz. sugar factory) near to main consumer markets and sources of the other raw materials required for co-product manufacture. Economics, the nature of the production technology and markets for the co-products will dictate the location of the value adding production facilities.

Furfural demand

The uses for furfural (Watson 2006; Zeitsch, 2000; Sharp, 1990) include:

1) conversion to furfural alcohol;
2) as a solvent in oil refining;
3) production of pharmaceuticals;
4) as a nemacide for the control of nematodes;
5) wood treatment;
6) value added products such as resins, plastics and polymers;
7) decolourising rosin; and
8) solvent extraction of mineral oils.

Watson (2006) has given the existing world demand for furfural as 215,000 t/y. The data is based on marketing studies for IFT. About two thirds of the production of furfural is consumed in furfuryl alcohol manufacture.

Furfural has a potential market advantage over other carbon based chemical feed stocks since furfural is produced from renewable resources. Most large scale carbon based chemical products are manufactured from chemical feed stocks which are non renewable in nature (e.g. coal and oil).

Furfural pricing

Pricing for furfural and its co-products are difficult to establish in view of the recent rapid escalation of the oil price. A gate price for furfural of about AU$1000/tonne FOB may be used for establishing the viability of a plant (Watson, 2004). In investigating the economics of furfural production, it should be noted that substantial handling and agents fees should be factored into an assessment if market pricing is used as the basis of the study. The handling and agents fees can lead to doubling of the gate price. The market price for furfural is said to range from US$1650 to US$2000 per tonne (Watson, 2006). Assessments for Australia should use gate pricing.

The diketones produced in the Rosenlew process have high commercial value. Zeitsch (2000) notes that the commercial value of diacetyl is $US14/kg and that for 2,3 pentandione is $US300/kg. Acetoin is produced from diacetyl. The products are used as flavour enhancers. Diketones are produced in the Rosenlew process, more by accident than by design. It is not known if it is possible to modify the IFT process for the production of diketones. IFT do not have immediate plans for modifying the process design to increase the output of diketones.

Detailed market assessments can be provided by IFT through Proserpine Sugar Milling Co-operative (PSM). The commercial rights to market IFT technology in Australia are held by PSM. Mr Laurie Watson of PSM should be contacted for further information regarding furfural production and marketing.

Developmental stage and prospects for commercialisation

IFT Technology

PSM are proposing to establish a furfural plant at the Proserpine Mill site. The SupraYield technology supplied by IFT will be adopted for the process. The engineering for the production plant at Proserpine is well advanced and initial production planned for Proserpine is about 5,000 t/y. However production at Proserpine Mill is conditional to both financial and other hurdles. If these hurdles can surmounted in due time, furfural production will likely commence in 2007.

PSM plan to increase the annual production capacity through the installation of additional reactors and through extension of production into the maintenance season.

Large amounts of capital has been expended by PSM on the development of the SupraYield technology and extensive pilot plant trials of the reactor have been undertaken at the University of KwaZulu Natal in Durban South Africa. The capital costs for the project are inflated for these reasons. It is anticipated that the second and later plants will have reduced capital costs due to lessons learnt from the operation of the first IFT plant.

The main advantages of the IFT technology are the reduced emissions of liquid effluent and high yields..

Other Technology Providers

Rosenlew are no longer in the market for supplying technology for furfural production. Also, Illovo Sugar who have adapted the Rosenlew process and have many years of experience of operating a furfural production facility at Sezela Mill, do not market any of these technologies (Lavarack, 2006).

Technology for the production of furfural from agricultural residues can be purchased from China. Internet searches can reveal the names and addresses of these suppliers. Chinese furfural technologies have low yields and produce large quantities of effluent.

Other organisations may be capable of suppling designs for furfural plants. These designs are likely to be derivatives of the Rosenlew process or processes designed in the former Eastern block countries. These technologies are likely to be mature and are not competitive in terms of yields or environmental considerations. Nevertheless, for any investigation into furfural manufacture, it would be highly recommended to investigate at minimum, IFT and Chinese technologies.

References

Arnold, D. (2005). *Personal communication from University of KwaZulu Natal, Durban.*

Lavarack, (2006). *Report on travel and learning opportunity: feedback on visit to South Africa.* SRI Job No. 3470.

Watson, L.J. (2004). Personal communication: discussion of furfural price for Ecopulp project.

Watson, L.J. (2006). Personal communication: update on furfural.

Zeitsch, K.J. (2000). *The chemistry and technology of furfural and its many by-products.* Sugar series 13. Elsevier, Amsterdam.

D.4 Thermochemical production of biofuels

Processes

Gasification for fuel synthesis

Hydrocarbons and fuel alcohol production via gasification and subsequent Fischer-Tropsch (F-T) synthesis is currently carried out on a large scale using fossil fuel derived feedstocks and well-established technologies. Most notable of these technologies are those developed by SASOL. The first of SASOL's plants was put into commercial operation in South Africa in 1955. The company now has 3 commercial plants consuming 36 million tonnes per year of coal and producing more than 200 fuel and chemical products including gasoline, diesel, waxes, hydrocarbon lubricants, natural gas, phenol, ammonia and detergents (Spath and Dayton, 2003).

The conditions and catalysts required for the manufacture of these products are no different for biomass or fossil fuel derived syngas. Despite this neither commercial or demonstration plants the production of hydrocarbons from F-T processes exist although an extensive laboratory scale study of the production of diesel fuel from biomass has been carried out at the Arizona State University (Kuester, 1984).

The F-T process for the production of alcohols from biomass has been implemented at the demonstration scale. The basic processes involved differ from those for the production of hydrocarbons only in the type of catalysts and associated syngas reforming pressures and temperatures. The following is a description of the integrated biomass gasifier and F-T ethanol synthesis pilot plant developed by Pearson Technologies Inc (PTI). The general process sequence is known for this technology but catalysts and operating conditions are confidential to PTI (Pearson, 2001). Conceptually, the process involves injecting dried (about 15% moisture) and finely ground (< 5mm) biomass together with a small amount of steam into the gasifier vessel. The mixture is heated for a short time, the resulting gas is quenched and inorganic material removed by filtration. The cooled and cleaned gas is compressed to the pressure required by the F-T alcohol reactor. The feed gas is mixed with recycled gas from the gas-liquid separator, preheated and returned to the reactor. The partially reacted gas and alcohol produced exits the reactor is cooled and the liquids (alcohols) removed in the separator. The liquids are sent to storage and the un-reacted syngas is recycled to the reactor. The crude liquids are taken from storage and sent through 3 distillation columns where the light ends are removed and sent back to the reactor loop. The second column produces ethanol and the third column produces a small amount of higher molecular weight alcohols.

A proprietary catalyst patented (Jackson and Mahajan, 2001) and owned by Power Energy Fuels Inc (PEFI - Colorado, USA) has been developed which converts the gaseous products of gasification to a mixture of predominantly ethanol and higher alcohols. This product has been branded Ecalene®. The brand name covers the products of the patented catalyst and therefore includes a range of alcohol mixtures determined by the pressure, temperature and degree of recycle at the synthesis stage. Typically Ecalene® has the composition shown in table D.4.1.

Table D.4.1 Typical composition of Ecalene®

Component	Weight (%)	Mole (%)
Methanol	0.3	0.4
Ethanol	75.0	81.9
Propanol	9.0	8.1
Butanol	7.0	4.8
Pentanol	5.0	2.8
Hexanol and higher	3.7	2.0
TOTAL	100.0	100.0

The patented PEFI catalyst is a modified form of the MoS_2 based chemistry developed originally for the production of butanol in the 1980s by Dow Chemical. One of the advantages claimed for this catalyst is its resistance to poisoning by sulphur and other trace contaminants. The basic process components required in the production of Ecalene® are similar to those described above for the PTI system.

Pyrolysis to produce bio-oil

Pyrolysis is a thermochemical process that converts biomass into liquid (bio-oil), charcoal and non-condensable gasses. The bio-oil is a highly oxygenated cocktail of pyrolignin, acetic acid, acetone and methanol Demirbas (2001). The process involves the heating of biomass to about 480 ^{0}C in the absence of air and is generally carried out at near-atmospheric pressure. If the purpose is to maximise the yield of liquid products, a low temperature, high heating rate, short gas residence time process is implemented (flash or rapid pyrolysis). To maximise the yield of fuel gas lower heating rates, high gas residence times and high temperatures are necessary (essentially gasification conditions). Low temperatures and low heating rates maximise the production of a solid fuel product with a high organic volatile fraction (charcoal). The current review will focus on flash pyrolysis for the production of bio-oil.

Bio-oil is composed of a complex mixture of oxygenated compounds that provide both the potential and challenge for utilisation. Some of the key characteristics of this liquid as reported by Bridgewater (2002) are summarized in table D.4.2.

Bio-oil is readily substituted for coal, fuel oil or diesel in static applications including boilers and furnaces (Sturzl, 1997). In terms of its direct use as a fuel for conventional prime-movers, Dynamotive are currently constructing a demonstration combined heat and power plant based around a 2.5 MWe Orenda gas turbine modified to burn 70 tonnes/day of bio-oil produced on site from wood waste (Dynamotive, 2004).

A proprietary process BDM Process® for producing stable emulsions of between 5% and 40% of bio-oil in diesel has been developed at CANMET[1] The developers claim the process produces a stable bio-oil/ diesel mixture with properties similar to those of No. 2 fuel oil. The product is claimed to be suitable for combustion in “most boilers, turbines and power generation stations … without major modifications”.

Table D.4.2 Typical properties of wood derived crude bio-oil (Bridgwater 2002)

Physical property	Typical values	Characteristics
Moisture content	15-30%	➢ Liquid fuel
pH	2.5	➢ Ready substitution for conventional
Specific gravity	1.20	fuels in many static applications
Elemental analysis	C 55-58%	such as boilers and furnaces
	H 5.5-7.0%	➢ Heating value of 17 MJ/kg at 25%
	O 35-40%	wt. water, is about 40% that of fuel
	N 0-0.2%	oil / diesel
	Ash 0-0.2%	➢ Does not mix with hydrocarbon
HHV as produced	16-19 MJ/kg	fuels
Viscosity [40°C, 25% water]	40-100 cp	➢ Not as stable as fossil fuels
Solids [char]	1%	➢ Quality needs definition for each
Vacuum distillation residue	up to 50%	application

Full deoxygenation to high-grade products such as transportation fuels can be accomplished by two main routes namely hydrotreating and catalytic vapour cracking of pyrolysis products over zeolites (Bridgwater (1996), Bridgwater (1994)).

Hydrocarbon fuels from hydrothermal liquefaction

One of the notable disadvantages associated with fast pyrolysis of biomass is the high degree of un-saturation and high oxygen content in the bio-oil product (typically 40% - see table 2.2). These give the product a relatively low heating value and high degree of corrosiveness (low pH).

Hydrothermal liquefaction is a relatively low temperature high-pressure process as compared to pyrolysis, which is a high temperature low-pressure process. Oxygen removal leads to a product with an increased heating value (relative to the original feedstock) and more hydrocarbon-like properties. In contrast to pyrolysis (in which thermal treatment only leads to depolymerisation of the macro-molecules of biomass) further reactions are introduced in liquefaction that results in oxygen being removed either as water or carbon dioxide. Removal as water leads ultimately to carbon as the remaining product (as for example in the manufacture of charcoal by slow pyrolysis). Removal of the oxygen as carbon dioxide leaves a product with an increased H/C ratio. The latter in its unrefined state is usually termed ‘biocrude’ (as distinct from bio-oil which is the product of flash pyrolysis). Biocrude shares some of the characteristics of mineral crude oil.

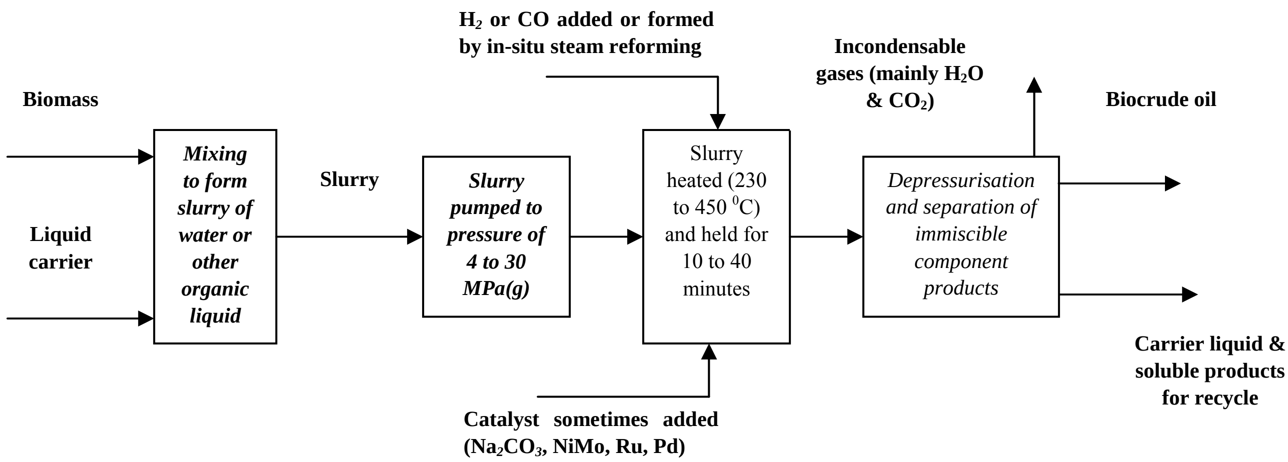
[1] www.nrcan.gc.ca

Significant research effort was directed in the 1980s towards biomass liquefaction processes. A review by Meier and Rupp (1991) of this early work identified four basic liquefaction concepts:

1. High pressure reaction in an aqueous medium with carbon monoxide and carbonate as catalysts
2. High pressure reaction in recycle oil with hydrogen and hydrotreating metal catalysts
3. High pressure steam treatment followed by high pressure hydrotreatment of the tar extract and
4. Medium pressure solvolysis in an organic medium and distillation of the solvent followed by high pressure hydrotreatment of the tar residue

The above liquefaction concepts all involved the generically similar processes indicated in figure D.4.1 (Hobson and Dunn, 2004).

Figure D.4.1 Generic hydrothermal liquefaction process



Variations on this generic system included in some cases an acid pre-treatment stage to facilitate the formation of slurries and/ or an up-grading process to further reduce the biocrude O_2 content.

The thermal efficiency, that is the fuel value of the biocrude product as a percentage of the fuel value of the feedstocks and external fuel associated with the HTU® process, a near-commercial hydrothermal liquefaction technology, is given as 74.9% (Goudriaan et al., 2000). The Biocrude product is a heavy organic liquid with an oxygen content of 10% to 15% by mass and a heating value of 30-35 MJ and is immiscible with and therefore readily separated from water. Due to the low oxygen content bicrude can (reportedly) be further upgraded cost-effectively by hydrodeoxygenation (conventional petroleum refining technology)to a clean diesel-type fuel with high cetane number Goudriaan and Naber, 2003).

Biofuel yields used in the current study
These are summarised in table D.4.3.

Table D.4.3 Biofuel yields used in the current study

Fuel	Yield per (d.a.f.) tonne of bagasse (L/tonne)	Source of data
Process - Gasification for fuel synthesis		
Hydrocarbons (diesel)	165	Kuester J.L. (1984)
Ethanol/ Ecalene®	745	Vantine B. (2004), Pearson (2001)
Methanol	550	van Thuijl et al. (2003)
Process – Flash pyrolysis		
Bio oil	555	Farag et al. (2002)
Process – Hydrothermal liquefaction		
Biocrude	455	Goudriaan et al. (2000)

Markets

The value of all alcohol and hydrocarbon fuels produced from biomass can be linked to the Trade Weighted Oil price using the approach adopted by DITR (2003) and incorporating the alternative (which includes renewable) fuels excise discount rate scheme described in the federal government's recent energy policy document (Australian Government, 2004). The latter makes provision for a transition from no excise on alternative fuels until 1 July 2011 followed by a ramping up of the excise in five equal annual steps to equal 50% of the full excise rate by 1 July 2015. Fuel excise rates will be based on energy content rather than volume. These excise discount rates in effect allow a higher price to be demanded for renewable fuels.

Using the federal government's longer term 50% discount rate and a range of oil prices of between 30 USD/bbl and 70 USD/bbl the pre-excise energy based values shown in table D.4.4 can be calculated.

Table D.4.4 Indicative wholesale (pre-excise) prices of renewable fuels assuming the federal government's long-term excise discount of 50%

Fuel	Crude oil price of 30 USD/bbl	Crude oil price of 70 USD/bbl
Methanol	0.31	0.50
Ethanol	0.36	0.59
Diesel	0.61	1.06

Similar energy-based values for bio-oil (from pyrolysis) and biocrude (from hydrothermal liquefaction) can be determined. However a direct market for these as liquid fuels does not yet exist (other than as fuels for co-firing in coal power generation plants) and they require upgrading to (for example) diesel before their energy value can be realised on the market.

A range of specialty chemicals can be derived from bio-oil as well as commodities such as food flavourings, resins, fertilizers, wood preservatives and fuel additives to improve NO_x and SO_x emissions from furnaces and boilers (BioLime®).

Many of the chemicals that can be derived from bio-oil yield a potentially higher economic return compared to fuels and energy products. This raises the possibility of a bio-refinery concept (Hogan, 2002) in which the optimum combinations of fuels and chemicals are produced. The processes to extract and markets to sell these products are however still at a fledgling stage and difficult to assess in terms of technical and/ or financial viability.

Developmental stage and prospects for commercialisation

Gasification for fuel synthesis

The use of renewable (biomass) rather than fossil fuel feedstocks is driven primarily by relatively recent greenhouse gas concerns. Biomass could not previously compete with the relatively high energy density, ready availability low cost and ease of handling of fossil fuel feedstocks. As a result of this situation no commercial biomass derived F-T fuel production plant is currently in operation.

Near term prospects for the synthesis of liquid fuels from biomass derived syngas can be readily evaluated in terms of the status and suitability of biomass gasification technologies. The suitability of a gasifier technology is defined to a large extent by the syngas feed requirements of the thermochemical conversion process. A recent extensive review (Ciferno and Marano, 2002) identified 14 commercially available biomass gasifiers on the world market. In this context the term 'commercially available biomass gasifiers' refers to a technology offered by a manufacturer or designer of industrial scale gasifiers. These gasifiers may not necessarily be designed specifically for but have been trialled using a biomass feedstock. In summary a pressurised, bubbling fluidised bed fed with O_2 enriched air represents the gasification technology that most closely meets the requirements of thermochemical liquid fuel synthesis in terms of relative cost, syngas conditions and technology development. At a minimum further downstream steam reforming, CO_2 removal, quenching and gas compression stages would be required to produce methanol. Of the 14 commercial biomass gasifiers reviewed by Ciferno and Marano (2002) only 2 systems (GTI and Tampella – both RENUGAS technologies) come close to meeting the above criteria and neither of these technologies have been tested with biomass throughputs appropriate to raw sugar factory applications.

A demonstration plant for the production hydrocarbons from F-T processes has to date not been built. An extensive laboratory scale study of the production of diesel fuel from biomass has been carried out at the Arizona State University (Kuester, 1984). The results of this study are included here as the experimental facility utilised fluidised bed reactors and the results are therefore likely to be indicative of demonstration and commercial scale operations.

The only integrated biomass gasifier and F-T fuel synthesis plant to be advanced to the demonstration stage is that developed by Pearson Technologies Inc (PTI). The primary product from this technology is ethanol although higher alcohols can be preferentially produced. The demonstration plant in Aberdeen (North Mississippi, USA) has the capacity to produce 30 tonnes of ethanol per day (Pearson, 2001). Yields of 745 litres per tonne of dry biomass - equivalent to 98% conversion of available biomass carbon - are claimed for this technology. Taken at face value, this efficiency is difficult to reconcile with reported conversion efficiencies to syngas alone which at best are around 80%. A range of biomass feedstocks has been successfully trialled with this plant including wood waste, bagasse, rice hulls and manure.

Pyrolysis to produce bio-oil

Flash pyrolysis is currently a highly active research field and the literature abounds with reports relating to its process kinetics and the downstream upgrading of the bio-oil product. An extensive summary of the issues and current research developments in the area of flash pyrolysis is given by Yaman (2004).

Four flash pyrolysis technologies (table D.4.5) have been developed to the pilot plant stage (Bridgewater, 2002). These plants differ primarily in the way heat is transferred to the biomass and to a lesser extent, the means for controlling residence time of the preliminary oil product. The latter is essential in preventing secondary reactions or cracking (gasification) of the bio-oil to produce lower molecular weight gases.

Significant work has been carried out in the area of chemical and physical upgrading of bio-oil. This has been thoroughly reviewed by Diebold (2002). Hot-gas filtration using ceramic or sintered steel filters (rather than simple cyclone separators) can reduce the ash content of the oil to less than 0.01% and the alkali content to less than 10 ppm. Chemical/catalytic upgrading processes to produce hydrocarbon fuels that can be conventionally processed are more complex and costly than physical methods. In terms of providing a drop-in liquid fuel substitute, the critical properties that adversely affect bio-oil fuel quality are incompatibility (immiscibility) with conventional fuels, solids (char and ash) content, high viscosity, and chemical instability. Full deoxygenation to high-grade products such as transportation fuels can be accomplished by two main routes namely hydrotreating and catalytic vapour cracking of pyrolysis products over zeolites. (Bridgwater (1996), Bridgwater (1994)). Non of these chemical upgrading processes have been proven at the commercial or demonstration scale.

Table D.4.5 Features and status of pyrolysis technologies at the pilot plant stage

Developer	Pilot plant capacity (kg/h)	Description	Status
Fortum[1] (Finland)	500	Proprietary technology developed by Fortum and Vapo in collaboration with VTT. No further details available.	Produced over 25,000 litres of bio-oil between 2002 & 2003. Bio-oil product was to be marketed as Forestera®. Commercialisation plans have been postponed.
BTG[2] (Netherlands)	200	Rotating cone reactor. Biomass stream mixed with hot sand and fed on to rotating cone (300 rpm). Centrifugal force increases thermal contact between sand and feedstock. Ablative action of cone continually exposes fresh reaction surface.	Developed at University of Twente in early 1990s. Over 1000 hours testing using bagasse, palm residues, rice husks, dried sludges, woods and switch grass. Produced over 50 tonnes bio-oil. Plans to develop a 50 tonne/day demonstration plant by 2003 - not yet eventuated.
Wellman[3] (UK)	250	Shallow bubbling fluidised bed technology.	Developed by consortium including Wellman Process Engineering, Aston University (UK) & Inst of Wood Chem. (Hamburg, Germany). Pilot plant construction was completed and cold commissioning started in 2000 but ceased in January 2001 due to costs associated with the issuing of an operating permit (pers. comm. McLellan, Wellman, 2004). Wellman have abandoned development.
Dynamotive[4] (Canada)	400	Uses patented BioTherm® technology (Piskorz et al., 1998). Deep (relatively high temperature) bubbling fluidised bed technology.	Developed by Dynomotive Energy Systems in consortium with Resource Transforms International (RTI). Plant commissioned in and operational since 1998. Basis of first Dynamotive commercial plant currently under construction.

Hydrocarbon fuels from hydrothermal liquefaction

[1] www.fortum.com
[2] www.btgworld.com
[3] www.wellman-process.co.uk
[4] www.dynamotive .com

Studies subsequent to those reported in the 1980s have focussed on optimising catalysts and carrier liquids as well as pressure and temperature levels, combinations and sequences of the generic process shown in figure 2.1. Examples of more recent laboratory scale optimisation studies in this area include Rustamov et al. (1998), Demirbas (2000) and Catallo and Junk (2001). In stark contrast to much of the bench scale work reported in the literature is the existence of two technologies utilizing hydrothermal liquefaction which are currently well advanced in terms of their commercialisation. These, the hydrothermal upgrading (HTU®) and Thermal Depolymerisation Process (TDP), are both technologies which have been implemented and currently being trialled at pilot and demonstration scales respectively.

References

Australian Government (2004). *Securing Australia's energy future*. Section 4, pp 96. Policy document available on http://www.dpmc.gov.au/energy_future

Bridgwater A.V. (1996) *Production of high grade fuels and chemicals from catalytic pyrolysis of biomass*. Catalysis Today, 29, 285-295

Bridgwater A.V. (1994) *Catalysis in thermal biomass conversion*, Applied Catalysis A, 116, [1-2], pp5-47

Catallo W.J. and Junk T. (2001). *Transforming biomass to hydrocarbon mixtures in near-critical or supercritical water*. United States Patent Number US 6,180,845 B1.

Ciferno J.P and Marano J.J. (2002). *Benchmarking biomass gasification technologies for fuels, chemicals and hydrogen production.* Report prepared for U.S. Department of Energy, National Renewable Energy Laboratory. Available from http://www.netl.doe.gov/coalpower/gasification/pubs/pdf/BMassGasFinal.pdf

Demirbas A. (2000) *Conversion of biomass using glycerin to liquid fuel for blending gasoline as alternative engine fuel.* Energy Conversion and Management, Pergamon, vol. 41, pp 1741 – 1748.

Demirbas A. (2001) *Biomass resource facilities and biomass conversion processing for fuels and chemicals.* Energy Conversion and Management, Pergamon, vol. 42, pp 1357 – 1378.

Department of Industry, Tourism and Resources (2003). *Report into appropriateness of 350 million litre biofuels target.* CSIRO, ABARE, BTRE report commissioned by DITR. December. Available from: http://www.btre.gov.au/docs/biofuels/BiofuelsStudy_MainReport.pdf

Diebold J.P. (2002) *A Review of the Chemical and Physical Mechanisms of the Storage Stability of Fast Pyrolysis Bio-oils.* Fast pyrolysis of biomass: a handbook, Edited by A.V. Bridgwater, CPL Press. Vol. 2, Chapter 11.

Dynamotive (2004) *Dynamotive announce ground breaking for innovative green power plant in West Lorne, Ontario, Canada.* Dynamotive news release, April 14. Available at http://www.dynamotive.com/news/newsreleases/040414.html

Farag I.H., LaClair C.E. and Barrett C.J. (2002). *Technical, environmental and economic feasibility of bio-oil in New Hampshire's North Country*. Final project report, University of New Hampshire project number 14B316 UDKEIF or ABAN-URI-BO43. Available from http://www.unh.edu/p2/biooil/bounhif.pdf

Goudriaan F., van de Beld B., Boerefijin F.R., Bos G.M, Naber J.E., van der Wal S. and Zeevalkink J.A. (2000). *Thermal efficiency of the HTU® process for biomass liquefaction.* Proc. Progress in thermochemical biomass conversion. Ed Bridgwater A.V. (ISBN 0-632-05533-2) pp 1312-1325.

Goudriaan F. and Naber J.E. (2003) *Transportation fuels from biomass via the HTU® process.* Presented at the 4th European Motor Biofuels Forum, Berlin, 24-26 November. Available from: http://www.novem.nl/default.asp?MenuId=10&documentId=109897

Hogan E. (2002) *The pyrolysis biorefinery concept for the production of green fuels and chemicals.* Bio-oil Briefing Workshop, CANMET Energy Technology Centre, Ottawa, Ontario, Canada.

Jackson G.R. and Mahajan D. (2001) *Method for production of mixed alcohols from synthesis gas*. United States Patent no US6,248,796. June 19.

Meier D. and Rupp M. (1991) *Direct catalytic liquefaction technology of biomass: status and review.* Biomass pyrolysis liquids upgrading and utilisation. Ed Bridgewater A.V. and Grossi G. E. Pub Elsevier. pp 93-102

Pearson S. R. (2001). *The manufacture of synthetic gas and ethanol from biomass using the Pearson thermo-chemical steam reforming and catalytic conversion process.* 5th International Biomass Conference of the Americas (cancelled), Orlando, Florida. Available from http://bioproducts-bioenergy.gov/pdfs/bcota/abstracts/28/z253.pdf

Rustamov V.R., Abdullayev K.M. and Samedov E.A. (1998) *Biomass conversion to liquid fuel by two-stage thermochemical cycle*. Energy Conservation and Management. Pergamon, vol. 39, No. 9, pp 869-875.

Spath P.L. and Dayton, D.C. (2003). *Preliminary screening – Technical and economic assessment of synthesis gas to fuels and chemicals with emphasis on the potential for biomass-derived syngas.* Report prepared for U.S. Department of Energy, National Renewable Energy Laboratory. Report number NREL/TP-510-510-34929. Available from http://www.nrel.gov/docs/fy04osti/34929.pdf

Sturzl R. (1997) *The commercial co-firing of RTP® bio-oil at the Manitowoc public utilities power generation station.* Available from http://www.ensyn.com/docs/manitowoc.htm

Van Thuijl E, Roos C.J. and Beurskens L.W.M. (2003). An Overview of biofuel technologies, markets and policies in Europe. Publication of the Energy Research Centre of the Netherlands. January. Report number ECN-C-03-008. Available from http://www.ecn.nl/docs/library/report/2003/c03008.pdf

Vantine B. (2004) Untitled presentation on the Pearson Technology for ethanol production made at New Mexico Green Fuels symposium, May 13

Yaman S. (2004) *Pyrolysis of biomass to produce fuels and chemical feedstocks.* Energy Conversion and Management, Pergamon, vol. 45, pp 651 – 671.

D.5 Biorefinery options

Processes

Biorefining or total biomass utilization covers processes that convert the whole cane plant or the by-products of conventional sugar manufacture (viz., molasses, bagasse, field trash and mil mud) to value-added products. Examples of products include alcohols, biofuels, fibre products, biopolymers, biosurfactants, industrial enzymes and renewable bio-commodities to replace petrochemical commodities such as those used in the manufacture of plastics. Two biorefinery processes that add value to the bagasse by-product are identified in this study, viz. the process where bagasse is converted to pulp and lignin products and the process where bagasse is converted to ethanol and lignin products. This study assumes that opportunities to value add to lignin form these processes are identical. In the biorefinery process that produces pulp, a chemical short fibre pulp is considered to be the sole cellulosic product. Opportunities to value add to pulp (i.e. to manufacture paper products) are considered in greater detail in other sections of this study. In practice a biorefinery approach to total sugarcane biomass utilization would likely integrate ethanol production from molasses with production from bagasse, and produce additional products from other streams (e.g. waxes from mill mud). Such complexity is not considered here.

A schematic of a biorefinery process is shown in Figure D.5.1. In this schematic bagasse is converted to a number of value-added products by separation into carbohydrate (cellulose and hemicellulose) and lignin fractions, and subsequent fermentation or chemical modification of the fractions. The pretreatment and fractionation technologies considered here include soda and organosolv pulping, and dilute acid and enzymic hydrolysis. While the fermentation of lignin to bioactives is not considered in this study, it is shown in Figure 1 to illustrate that there exists an opportunity to develop very high value products from this platform technology.

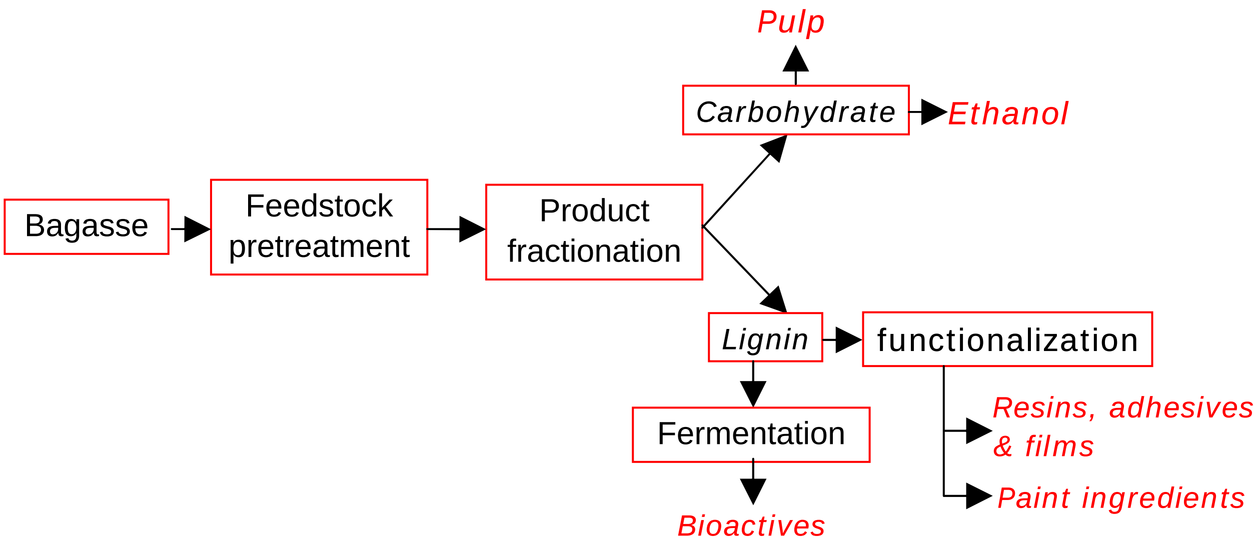


Fig. D.5.1-A biorefinery module for bagasse value-adding.

The yields and values of the biorefinery products are shown in Table D.5.1. In the case of lignin, the broad range of values includes unmodified 'native' lignin and as a minimum value and the replacement of butyl acrylate in water-based paints with lignin as the maximum value. The ethanol value used in the financial analysis of this study is based on the lower heating value of ethanol relative to petrol according to the calculation adopted by DIT&R (2003) and includes the renewable fuels discount rate described in the Federal Government's energy policy document (2004). A value of 0.50/L (range: AUD0.37/L to AUD0.63/L) must be considered conservative. European Union nations and especially Sweden import fuel ethanol from Brazil. In recent months the price of this ethanol delivered to Rotterdam has been as high as AUD1.07/L (AUD0.732/L FOB Santos, Brazil)(ICIS-LOR, 2006). The maximum value for pulp is based on the production of high quality chemical bleached pulp. Work at SRI indicates that such high quality product may not be easily produced. The low value is indicative of pulp quality from SRI pilot scale testing.

Table D.5.1 Biorefinery product yields and values

Product	Yields on dry ash-free bagasse (tonnes^{-1})	Value		
		Maximum	Mean	Minimum
Lignin	0.190 tonnes	\$1800 tonnes^{-1}	\$270 tonnes^{-1}	\$800 tonnes^{-1}
Ethanol	334 Litres	\$0.63 Litres^{-1}	\$0.50 Litres^{-1}	\$0.37 Litres^{-1}
Pulp (dry lap)	0.54 tonnes	\$798 tonnes^{-1}	\$534 tonnes^{-1}	\$270 tonnes^{-1}

Markets

The markets for lignin-based biomaterials are those of various petrochemicals that the biomaterials would replace. These markets are paint polymers, adhesives and binders, and films and coatings.

The Australian paint market is ca. 100 million litres p.a. The largest segment of the consumer paint market is for water-based emulsion paints based on acrylate polymers. Most existing paint polymers are derived from petrochemical origins, whereas lignin polymers are primarily products from renewable resources. Butyl acrylate is the reference material. The market in Australia for paint polymers is understood to be ca. 25,000 tonnes p.a of dry polymer ingredients, valued at ca. $34.25 million p.a. A substitution rate/market share of 30% has been assumed, after discussion with industrial sources, giving lignin polymers in paints a potential annual value of $10.28 million. This market could be readily captured in a short timeframe through the early involvement of end users in the development of a biorefinery. The worldwide market is very large but entry into this market would be achieved over a longer timeframe

The Australian plastics market generates annual revenues of ca. $6.6 billion (Plastics and Chemicals Industries Association Inc., http://www.pacia.org.au/). The plastic products are produced from 780,000 tonnes of locally produced resins and 420,000 tonnes of imported resins. Lignin-based biomaterials would target the bag and film and possible the injection moulding markets. The plastic raw materials usage by market is shown in figure 6.2. The packaging and building materials markets are the largest and account for 61% (732,000 tonnes) of raw materials consumption

If large volumes of ethanol are produced from lignocellulosics in biorefineries, then this ethanol is most likely to be consumed as fuel rather than as potable alcohol. The future Australian market for fuel ethanol is not certain. While a mandated E10 fuel (10% ethanol in petrol) would create a market for 1.6 billion litres p.a., the challenge of the biofuels industry is to produce ethanol that meets the market price expectation without government subsidy. Certainly, at low end of the ethanol price range in Table 1 the blending of ethanol with petrol would be attractive to the fuel industry. As Asian countries commit to greenhouse gas abatement, a very large export market for ethanol will be created. The Brazilian industry has recognised this potential and plans to export ethanol to Japan. In the Asian market Australia should have a geographical advantage over Brazil. In the medium term the Australian and Asian markets for ethanol is considered to be large enough to consume all ethanol produced in Australia from any biomass source.

Markets for pulp and paper products are described in the section on paper manufacture.

Developmental stage and prospects for commercialisation

Processes for biorefining lignocellulosics to fuels and other commodities are at the demonstration stage. The first large scale processes are likely to be commissioned within the next 5 years. The platform technologies for thses biorefineries are likely to be solvent or dilute acid pretreatments and enzymic hydrolysis. These platforms are considered to be the most promising in the medium term for reducing the costs of fuel ethanol production (Aden *et al.*, 2002).

References

Aden, A.,Ruth, M., Ibsen, K., Jechura, J., Neeves, K., Sheehan, J., Wallace, B., Montague, L., Slayton, A. and Lukas, J. (2002). Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover. NREL report number NREL/TP-510-32438.

Edye, L.A., Doherty, W.O.S., Blinco, J.A. and Bullock, G.E. (2005) The sugarcane biorefinery: Energy crops and processes for the production of liquid fuels and renewable commodity chemicals, Proc. Aust. Soc. Sugar Cane Technol. 27:9-22.

ICIS-LOR (February, 2006). *Drinking in the fuel of the future,* Independent Commodity Information Service – London Oil Report, http://www.icis.com/Articles/Article.aspx?liArticleID=1041240

D.6 Pulp and paper products

Processes and products

There exist literally hundreds of pulp and paper products that can be manufactured from sugarcane bagasse. Depithed bagasse can be manufactured into pulp which can be sold as a market pulp or used for the manufacture of paper reels. Paper reels can be further value-added into consumer materials for households or businesses. The more value-adding that is performed, the greater the reward but capital cost also increases and the market size generally decreases. This is shown diagrammatically in figure D.6.1.

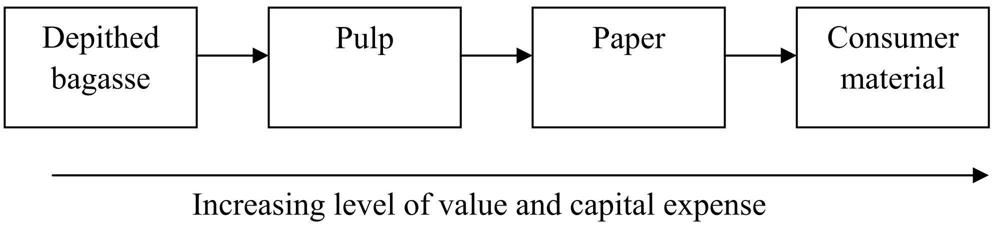


Figure D.6.1 The value chain from depithed bagasse to final consumer materials

This fact sheet discusses pulp products and reels of paper. Consumer materials, such as boxes of tissues or reams of photocopier paper, are not discussed.

Table 1 presents a summary of the wide variety of pulp and paper products that may potentially be manufactured from bagasse. Since yield data on paper products are rarely reported on the basis of the raw fibre material due to the large number of processing steps (losses occur at the pulp mill, the papermachine and the converter), the yields are SRI estimates based on dry, ash-free bagasse. Please refer to Tom Rainey at SRI (38641400) for further details.

1. Pulp products

Pulp is categorised by its production method; either by chemical, mechanical or chemi-mechanical means. The production of chemical pulp is performed by subjecting depithed bagasse to a range of chemicals at elevated temperature and pressure. Mechanical pulps are produced by subjecting the depithed bagasse to high shear forces, such as achieved by grinding. Chemi-mechanical pulps are manufactured by both impregnation with chemicals and subjecting the bagasse to high shear forces. Chemical pulps are higher quality than mechanical pulps in terms of strength and brightness and so achieve a much higher value but the capital and operating costs of a chemical pulp mill is also much higher than for a mechanical pulp mill. Both chemical and mechanical pulps can be bleached to further improve the value, but again, comes at the expense of capital and operating costs.

Table D.6.1 Summary of pulp and paper products on a dry ash free fibre basis after depithing

Mechanical	**Yield per tonne dry ash free fibre**
- Newsprint	0.612
- Packaging linerboard	0.612
- Corrugating medium	0.612
- Sack papers	0.612
- Market mechanical pulp (unbleached)	0.680
Chemimechanical	
- Newsprint	0.567
- Packaging materials	0.567
- Market chemimechanical pulps (bleached & unbleached)	0.630
Chemical	
- Tissue hardroll (bath & facial)	0.320
- Converted tissue products (bath & facial)	0.256
- Napkin hardroll	0.320
- Napkin converted product	0.256
- Paper towelling hardroll	0.320
- Converted paper towelling product	0.320
- Fluff pulp	0.320
- Market pulp (bleached)	0.355
- Converted moulded grades (e.g. plates)	0.256
- White office papers	0.299
- Specialty papers (e.g. wax, cleansers)	0.299

The fibre length of pulped bagasse is quite short, around 0.8 mm, which is similar to hardwoods such as eucalypt (1.0 mm), and much shorter than softwood, around 3.0 mm. This makes bagasse more suitable as a chemical pulp, however it does not preclude its use as a mechanical pulp. Mechanical pulping of bagasse does occur in India (Tamil Nadu), Egypt (Naga 1999) and South Africa (Sappi) for example.

Any form of pulp can be baled and sold as a market pulp, however it is more common for higher value pulps to be sold into the market because the transport costs involved detract from the profitability of the venture. Two specialty pulps that exist are fluff pulps and dissolving pulps. Fluff pulps are used in the manufacture of products that require high water absorptivity and brightness, such as in nappies and feminine hygiene. Dissolving pulps are used in the production of synthetic fabrics such as rayon.

2. Paper products

Paper products are loosely divided into four main categories: newsprint; packaging; printing and writing papers; and tissue products. It should be noted that bagasse is rarely utilised entirely for the manufacture of these categories. A minimum of 15% of some form of chemical softwood pulp is usually required to improve the strength properties to the desired level.

Newsprint is used for printing newspapers, is high volume, is relatively low value and requires lower quality pulp as a feedstock. Packaging grades are used to transport goods, such as food, is also high volume, relatively low value and also require lower quality pulp. Printing and writing papers are those used in the office, such as photocopier paper, is medium volume, high value and requires a higher quality pulp. Tissue includes napkins and paper towels, is low volume, very high value and requires higher quality pulp.

There is an endless number of specialty paper products from coated papers for magazines to wax papers used in baking.

Table D.6.2 shows the general paper categories and the pulps required to manufacture these products. Also presented is the location where these products are currently made in Australia and examples of locations where bagasse is used to make these paper grades. The list of overseas location is by no means exhaustive; it is known that over 30 countries produce bagasse paper products.

Table D.6.2 Summary of paper products

Paper product	Typical main pulps required	Australian production location using wood	Example overseas producer using bagasse
Newsprint	Mechanical, Chemi-mechanical	Albury, NSW, Tasmania	Hindustan Newsprint Mills, India (Covey 2005) Tamil Nadu, India (Rangan 1998) Quena, Egypt (Naga 1999)
Packaging	Mechanical	Tumut, NSW Brisbane (x2) Melbourne	Sappi, South Africa
Printing and writing papers	Chemical, Chemi-mechanical	Maryvale, Vic Tasmania	Malaysia India (Rangan 1998) Quena, Egypt (Naga 1999) Argentina
Tissue	Chemical, Chemimechanical	Brisbane (x2) Millicent, SA Melbourne	Tamil Nadu, India Kimberly Clark, Mexico

		Sydney	

Market

Table D.6.3 shows a summary of the wholesale values of pulp and paper products.

Table D.6.3 Wholesale values for pulp and paper products

Mechanical	AUD/tonne	Reference
- Newsprint	956.00	(IndustryEdge 2005)
- Packaging linerboard	908.00	(IndustryEdge 2005)
- Corrugating medium	500.00	(URS_Forestry 2002)
- Sack papers	1302.00	(IndustryEdge 2005)
- Market mechanical pulp (unbleached)		
Chemimechanical		
- Newsprint	980.00	(URS_Forestry 2002)
- Packaging materials	908.00	
- Market chemimechanical pulps (bleached & unbleached)	731.50	(Eastmont 2005)
Chemical		
- Tissue hardroll (bath & facial)	1760.00	(URS_Forestry 2002)
- Converted tissue products (bath & facial)	7780.00	(Trewick 2005)
- Napkin hardroll	1760.00	
- Napkin converted product	7780.00	
- Paper towelling hardroll	1760.00	
- Converted paper towelling product	7780.00	
- Fluff pulp	931.00	(Trewick 2005)
- Market pulp (bleached)	798.00	(IndustryEdge 2005)
- Converted moulded grades (e.g. plates)	-	
- White office papers	1870.00	(IndustryEdge 2005)
- Specialty papers (e.g. wax, cleansers)	5100.00	(URS_Forestry 2002), price is for thermal papers
- Dissolving pulp	USD800 (2000)	(Trewick 2005)

1. Pulps

In Australia, there has been a tightening supply of fibre over the last few years. Gunns Limited for example is planning to build a large pulpmill in Tasmania to capitalise on the available resources still present there. Visy, which makes packaging materials, and Norske Skog, who produce all of Australia's newsprint, are both looking for new sources of cheap fibre. Due to geographical considerations, Visy have been looking at pulping wheat straw for several years, however bagasse is becoming increasingly attractive due to its relatively low silica content (3% compared to 13% for wheat straw). It is suspected that Visy plans to export mechanical pulp to China.

A market bagasse chemical pulp in Australia could have two avenues: local consumption by either a tissue manufacturer (ABC Tissue, Merino in Brisbane, Queensland Tissue, Encore, Carter Holt Harvey or Kimberly Clark) or Australia's only printing paper company (Australian Paper); or international consumption (e.g. China). One interesting possibility is to convert market bagasse pulps into party consumables (such as paper plates) at Merino in Brisbane. Swanbank paper is a company planning to start manufacturing printing and writing papers near Ipswich. This company will be looking for a short fibre market chemical pulp. Construction is being planned for 2007/2008.

2. Paper products

Paper reels produced from bagasse still need to be converted into consumer materials. The market for reels of paper reels are generally either local converting companies or international markets. Entering the local market would normally mean entering a long term supply contract with local converting companies. The current situation for each of the main grades is as follows.

Newsprint could have a difficult time finding a market because of the dominance of Norske Skog who also convert their material for the end user, however production near Brisbane would have a transport cost advantage to the Queensland market as the nearest newsprint production facility to Brisbane is Albury. The possibility of selling newsprint into the international market is not known.

Production of packaging materials locally would be in competition to Visy and Amcor, who also convert their materials for the end-user. These companies are both facing the ACCC over collusion in the packaging market in order to create artificially high prices. However, export of packaging materials to China is a distinct possibility.

Reels of printing and writing papers produced from bagasse pulps would be competing in Australia with the large volume of imported generic products from south east Asia. The Australian manufacturer of writing papers, Australian Paper, mainly focuses on producing premium papers, such as reflex, and as such would not be a competitor in this market. The perceived "green" aspect of bagasse writing papers could create a niche within the broader writing paper market within Australia. Selling reels of writing paper into the international market is unlikely to succeed due to stiff competition.

Tissue rolls could be consumed in the local market by a local converting company, such as Merino or ABC Tissue. The perceived "green" aspect of tissue is most valued for this grade of paper than any other and would likely attract a premium if marketed correctly by the converting company. The possible market for selling tissue rolls into the international market is not known.

Developmental stage and prospects for commercialisation

There are a wide range of issues that have prevented bagasse being used for pulp or paper manufacture in Australia. The predominant reason is that there are adequate hardwood plantations with fewer processing issues, despite the higher raw material cost (chips at $130 per tonne). The three arguments generally used against bagasse pulp or paper manufacture in favour of eucalypt are: deterioration of bagasse fibres during storage; depithing; poor properties of the pulp; poor drainage characteristics during paper manufacture due to pith; and high silica content making chemical recovery difficult.

The problems of bagasse deterioration during storage have largely been resolved by using the Ritter process, circulating the bagasse with water inoculated with suitable microorganisms to ferment residual sugar. Similarly depithing is normally achieved through a combination of moist and wet depithing methods and has been practised for many years (Covey 2005).

Research into bagasse pulp and papermaking was mainly done in the period 1950-1980. Improving the physical properties of bagasse pulps to make high quality paper products (printing and writing papers; and tissues) is basically mature. The required physical properties are normally achieved through blending with some softwood pulp fibre. The quality is suitable for generic products, but will always be inferior to eucalypt due to anatomical reasons. Most current research into improving the physical properties of bagasse pulps is in the realms of mechanical pulps, particularly for newsprint production (Rangamannar 1990; Rangan 1995; Rangan 1998).

Although much work has been done to improve the drainage characteristics of bagasse pulps at the pulp mill in the period 1950-1980, a limited amount of research is now focussing on methods to improve the drainage properties of bagasse pulps in the paper mill.

The argument over the high silica content scaling the evaporators which are required in the chemical recovery system has been largely overcome by three main methods: precipitating the silica from the chemical mix ("black liquor") with flue gas (Covey 2005); using a spare evaporator; and conditioning the bagasse prior to pulping with sodium hydroxide (Gupta 1997). In the non-woods pulping community, silica is considered to be only a minor problem in the pulping of bagasse compared with wheat straw for example. Much work is being done on one-stage chemical recovery systems to decrease the high capital cost associated with a chemical recovery unit (Chaudhuri 1993; Das Gupta 2004), required under Australian environmental legislation. Although cheap one stage recovery units for bagasse pulping is available as an off-the-shelf item, based on fluidised bed technology is available, it is not clear whether the performance would be suitable for Australia.

These issues have been overcome in the overseas context. However, further research into improving the drainage properties of Australian bagasse pulps, such as optimising drainage aids, will help overcome cultural resistance from the Australian paper industry.

References

Chaudhuri, P. B. (1993). *A concept of a viable alkali recovery system for a non-wood pulp mill*. Tappi pulping conference.

Covey, G., Rainey, T.J., and Shore, D. (2005). *The potential for bagasse pulping in Australia*. Appita conference, Auckland, New Zealand.

Das Gupta, S., and Ramani, J. (2004). "*Low temperature incinerator systme for agro based paper mills*." IPPTA **16**(47-54).

Eastmont, R. I. (2005). *Personal communication*.

Gupta, H. K., Shivare, P., Roy, T.K., and Rao, N.J. (1997). "*Alkaline extraction of bagasse to get rid of silica*." IPPTA **9**(2): 29-35.

IndustryEdge (2005). "*Newsletter*." Pulp & Paper Edge **November**(15).

Naga, M. a. E., M. (1999). *Modern bagasse pulp mill in egypt*. Tappi pulping conference.

Rangamannar, G., Michelsen, J., Silver, L. (1990). *Developments in bagasse newsprint technology*. Tappi Pulping Conference.

Rangan, S. G., and Rangamannar, G. (1995). *Development in mechanical pulping of bagasse for manufacture of newsprint*. Tappi Pulping Conference.

Rangan, S. G., and Rangamannar, G. (1998). *Development in bagasse fiber preparation for the manufacture of fine papers and newsprint- A review of facilities in two successful Indian mills*. Tappi Pulping Conference.

Trewick, J. (2005). *Personal communication*. T. J. Rainey.

URS_Forestry (2002). *AusNewz Pulp and Paper Yearbook*. Melbourne, URS Forestry.

Appendix E Facilitators report on the Bagasse and Trash Utilisation workshop prepared by T. Scott (Human Factor Australia) with assistance from P. Hobson and T. Rainey (QUT)

Report on the Bagasse and Trash Utilisation Workshop
Mackay Entertainment Centre
5 May 2006

1. Introduction

I was engaged by the Sugar Research and Development Corporation to help facilitate the above workshop. I was initially briefed by Les Robertson. Les arranged for me to talk to Phil Hobson about the proposed program and the technical issues to be covered. The program finally agreed on is shown as Attachment 1. Phil e-mailed me copies of the various presentations as they became available. I expressed concern at the amount of material attempted to be covered in the time available. Phil subsequently pared down his material and asked the other presenters to be brief. I prepared a questionnaire for distribution to the "break-out" groups at the end of forum 1 and a feedback questionnaire for the delegates to complete at the end of the workshop.

Initial indications were that there would be approximately 50 attendees. However discussions with Les on the day indicated there might be more likely to attend than had officially registered.

The workshop was scheduled for a 12:30pm start. Les, Phil and myself arrived an hour or so early to check the venue and ensure it was properly laid out. We secured extra chairs to cater for the expected additional numbers. Eventually over 60 attendees arrived.

I had suggested that we have someone type up on a word document and display via a data projector to the audience issues identified during forum discussions. Phil had organised for Tom Rainey to carry out this task.

The body of this report records my impressions of the various principal components of the workshop and finally a summary of my recommendations for future such events.

2. Conduct of the Workshop

I. A Summary of the QUT/Industry Report on Bagasse and Trash Utilisation Options

The material delivered by Phil engaged the audience very well. Because Phil was scheduled to talk for an hour, we had previously decided that it would be prudent to break half way through his presentation to allow some questions. This worked well with the audience eager to ask questions and seeking more detailed information in many areas. We did not have the computer set up to record this discussion but I manually took notes of the principal issues raised.

After the completion of Phil's presentation there were further questions and answers. Because of the level of interest it was difficult to bring this to a halt and when we eventually did we were fifteen minutes behind our published schedule.

II. **Open Forum**

We then broke the audience into 8 groups and put to them the questions outlined in Attachment 2. The discussion was lively with good participation by most delegates. Each table answered the questions given and recorded salient points on butcher's paper. After 20 minutes we brought the groups together and allowed each group a few minutes to report. The principal issues arising from the subsequent discussion were recorded and displayed via the data projector.

The forum allowed for considerable delegate input but I had to curtail some of the discussions in order to meet the schedule. There would have been benefits from allowing more discussion at this point.

III. **Technical and Market Issues for Value Adding Options**

As expected, this proved to be the most difficult segment. The material presented was relevant and interesting but attention gradually flagged. This was due to the following factors:

a. It was a long and intense technical section, lasting for almost an hour and a half.
b. The air conditioning system was ineffective and the room became warm and muggy.
c. One of the speakers spoke softly, and despite prompting him to speak louder, many found him difficult to hear.

IV. **Open Forum**

By the time we arrived at this juncture many of the audience had wilted and maintaining their attention was difficult. Most interest was shown in the presentation by Bruce Lamb and the Northern NSW experience of bringing trash into the factory. Towards end of this session a number of people began leaving.

V. **Workshop Feedback Questionnaire**

Prior to closing we asked participants to fill in their Workshop Feedback Questionnaires. Attachment 3 outlines delegates response to the questionnaire and their comments are collated in Attachment 4. It was gratifying that 37 delegates filled out a questionnaire even though quite a few had left by this time. The feed back was generally positive.

3. Commentary

Despite some shortcomings, the workshop was very well received as the feedback questionnaire attests. There was great interest in the main body of material and the audience was particularly well engaged by the first presentation and the subsequent small group work. Some delegates seemed to me to be unrealistic in the amount of detail that they expected be delivered in the time frame. Nevertheless a large majority felt that the workshop was useful. As is usual in such audiences, some had particular sectoral interests that they expected to be met and by and large the material was diverse enough to engage most.

The interest of the audience in the material is also reflected in the collated questions and responses and "break-out" group comments in Attachment 5.

The second half of the workshop fell away somewhat for the reasons that were mentioned above. A little more thought in the planning may have avoided this. However it is a big ask to expect the total attention of an audience that has been inundated with technical material and data, particularly when for many it was the tail end of a long week.

Overall, the workshop seemed to me to be a very worthwhile exercise.

4. Summary Recommendations

Some of the actions that could have helped improve the workshop might have been to:

- Involve the facilitator earlier in the planning phase to help with the overall workshop design.
- Ensure adequate time is given to deliver the material, or trim the material realistically to match the time available. (As a rule of thumb, I always allow at least 2 minutes per PowerPoint slide.) With a little more audience involvement we could have comfortably taken a full day to deliver the quantity of content provided.
- Provide a microphone to ensure all speakers and commentators are properly heard.
- If possible schedule a "dry-run" a week or so before hand to enable critique of material and ensure good timing.
- Give ample opportunity for audience participation. People like to come away from these events believing they have had a chance to have a say. (I suspect one of the reasons the workshop was well-received was the success of the "break-out" groups.)
- As someone suggested in the comments, it would have been useful to circulate a summary paper before the event. Failing that it would have satisfied some of those clamouring for more detail if they had something to take away from the workshop.

Attachment 1.

Bagasse and Trash Utilisation Workshop
Mackay Entertainment Centre
Friday 5 May 2006

Program

12:30 Light lunch

1:00 Workshop opening and introduction (Andrew Barfield, SRDC)

1:15 A summary of the QUT/industry report on bagasse and trash utilisation options (Dr Phil Hobson, QUT)

- Aims and scope of the study
- The approach adopted
- Sources of information
- An overview of the products and processes for value adding to bagasse
- Short listing the most promising opportunities
- A brief overview of some of the assumptions used in evaluating costs and returns for the short listed processes
- A summary of indicative capacities, costs and revenues for the short listed processes

2:15 Open forum (facilitated by Ted Scott, Human Factor Australia)

3:00 Afternoon tea

3:15 Technical and market issues for value adding options:

- Availability and costs associated with surplus bagasse (Dr Bryan Lavarack, QUT)
- Recovery of trash (Dr Bruce Lamb, NSWSMC)
- Presentations on processes and technologies for value adding to bagasse and trash
    - Furfural production (Dr Laurie Watson, Proserpine Mill)
    - Biorefineries (Dr Graeme Bullock, QUT)
    - Thermochemical production of biofuels (Dr Phil Hobson, QUT)
    - Paper/ pulp production (Tom Rainey, QUT)

4:45 Open forum (facilitated by Ted Scott, Human Factor Australia)

5:30 Summing up and workshop close

6-30 SRDC hosted dinner for workshop participants
Shamrock Hotel – Pavilion Room
Guest speaker - Dr Peter Twine CEO, CRC for Sugar Industry Innovation through Biotechnology

Attachment 2

Open Forum

Questions for consideration by Break Out Groups

1. Are there other products or processes (other than those identified in Phil Hobson's paper) that warrant investigation?
2. Do you generally agree that the 6 priority uses are the ones that warrant further detailed assessment? If not, what would you add to or subtract from the list?
3. Are the criteria used for prioritisation appropriate?
4. Briefly comment on the usefulness of the process undertaken.

Attachment 3

(Note: The numbers shown are the number of responses in each of the categories by question.)

Bagasse and trash utilisation workshop
Feedback

Question 1. The workshop was helpful in advancing your understanding of the issue of bagasse and trash utilisation?

Strongly Agree				Strongly Disagree
13	19	5	0	0

Question 2. The workshop gave you sufficient information for you to have an informed opinion on the best options for trash and bagasse usage?

Strongly Agree				Strongly Disagree
4	13	9	9	2

Question 3. You were given adequate opportunity to have your opinion heard?

Strongly Agree				Strongly Disagree
18	15	4	0	0

Question 4. The workshop process and venue were appropriate for the purpose?

Strongly Agree				Strongly Disagree
9	13	9	6	0

Have you any comments on how future such events could be improved?

Attachment 4

Comments

Microphones needed
Hard copies of the PowerPoint presentations would have been helpful
SRDC is funded by the Australian Sugar Industry and overseas visitors should not be allowed
Room a bit warm
Looking forward to more detail
Still a long way to go
Must keep funding options for the future
Hearing difficult without microphones – especially table feedback
More time would have been better
Hot & too tiring – presentations need to be shorter
A discussion paper beforehand would allow better preparation by delegates
Availability of a brief summary document prior to the workshop would be useful
More analysis/research needed
Provide reading material prior to workshop
Handouts would be useful
Need to provide handouts/briefing materials
Process confused
Quite good overall
The issue is both important enough and complex enough to warrant spending more time on it – a full day's workshop at this stage of the project would have been worthwhile.
Should use this process for other industry issues
Air conditioning would help
Generally a worthwhile workshop

Attachment 5

Bagasse and trash utilisation workshop
Feedback and evaluation

<u>Initial question and answer session during presentation of main findings</u>

Q How is the trash cut up prior to being fed into the boiler?
A It is already partially chopped by the harvester (~200 mm) during whole of crop harvesting. Trials were run on the Condong trash separator in which trash was fed through a conventional cane shredder to produce a fuel with the consistency of grass clippings. Chopped trash will be blended with conventional before being fed to the boiler. (PAH)

Q What are the capital cost assumptions associated with the installation of the high efficiency co-generation boiler?
A These are based on cost data presented at this year's ASSCT conference in a paper by John Hodgson (Mackay Sugar). Details will be included in the final report. (PAH)

Q What does the $20/ tonne cost for trash include?
A It includes additional agronomic, harvesting and transport costs incurred as a result of whole crop harvesting of cane and trash but excludes capital and operating of the cane separation plant. The latter is included separately as a cost associated with the value adding process. (PAH)

Q Is the cost of trash given on a dry or wet basis?
A An as-received (wet) basis. This is typically about 50% moisture with little opportunity after harvesting to dry out before separation and storage. (PAH).

Q Did you look at bagasse displacing other fuels such as gas or coal?
A No, other than the case of biodiesel from bagasse to replace conventional fossil derived hydrocarbons. (PAH)

Q Was the outcome of the analysis sensitive to levels of trash in cane?
A Yes. There are many variables which will also affect the outcome. The level of trash in cane was kept constant as it was not deemed to significantly effect the relative outcomes (ranking) of the options investigated. The value of 13% trash in cane used in the analysis is based on the mean of a large data set collected by CSIRO. (PAH)

Q In the case of the viability of ethanol production as a function of oil price, was the capital cost of the plant also assumed to increase with oil price?
A No (PAH)

<u>Collated group responses to questions posed in the first open forum</u>

Q1 Are there other products or processes that warrant investigation?

- Co-generation should be considered as an integral part of some of the other processes options considered
- Particle board
- Masonite board
- Automotive brake pads
- Un-bleached pulp only
- Infield biomass processing
- Composting
- Animal feeds including treated bagasse and molasses
- The use of the whole cane plant rather than simply fibre from bagasse and trash
- Opportunities using supplementary biomass feedstocks including woodchips, kenaf, high fibre canes and high density planting
- Genetically modified cane
- Integrate cane and wood plantations for composite materials production
- Ethanol from fibre could have been integrated with ethanol from cane juice
- Garden mulch
- Levinilic acid
- Adding reagents such as lime to increase the digestibility of bagasse and trash as an animal feed. For bagasse this could be done at the final mill.
- Bio polymers (e.g. rayon)
- 'Cow candy' – chipped cane stalk for cattle feed
- Should consider paper from mixed wood (long fibre) and bagasse (short fibre) pulps. A viable paper industry based on this pulp mix exists in Argentina.
- Bioplastics
- Hemicelluloses for packing material
- Methane production from biodigesters
- Soluble food fibres

Q2 Do you generally agree that the 6 priority uses are the ones that warrant further detailed assessment? If not, what would you add or subtract from the list?

- Agree but there is potential for refinement by considering multiple co-processes
- Fischer Tropsch (Pearson Technology) to produce ethanol from fibre should have been included
- Some of the options with strongly negative outcomes should not have been pursued further – the number of options should have been culled to three.
- Activated carbon should have been one of the options considered
- Paper and pulp worth further investigation
- Assumptions queried that were deemed to impact on the 6 chosen options
    - The viability of refining biocrude to diesel at a sugar factory
    - That the price of ethanol was based on it having 66% of the energy value of petrol on a volumetric basis
    - The agronomic costs associated with harvesting cane tops for cattle feed.

- o The cost of future (fibre to ethanol) plants
- ➢ Does the industry have the necessary skills to run a (hydrothermal liquefaction) bagasse to diesel plant
- ➢ Hydrothermal liquefaction production of diesel from bagasse is too 'blue sky'
- ➢ Selection (Risk/ Reward) process should include a sensitivity analysis on inputs

Q3 Are the criteria used for prioritisation appropriate?

- ➢ Appropriate
- ➢ Appropriate for stand-alone project assessment
- ➢ A need to also focus on individual mill needs (more site-specific)
- ➢ Market dynamics should form part of the selection criteria
- ➢ Environmental impact an additional relevant factor
- ➢ The analysis should include capital expenditure limits based on the net worth of the existing business
- ➢ Scale (mill/ crop size) should have been one of the criteria

Q4 Briefly comment on the usefulness of the process undertaken

- ➢ Valuable but sobering
- ➢ Different assumptions that may affect the conclusions of the more detailed analysis
  - o A hurdle rate higher than the 10% used – 20% would be more realistic
  - o Other factory steam economies may be worth investigating. The analysis assumed a fixed value of 45% steam on cane to determine the amount of surplus bagasse available.
- ➢ Additional information that would have been useful
  - o Assumptions regarding power and steam supply to stand-alone processes
  - o Trash transport costs
  - o Agronomic value ascribed to trash if left in the field
- ➢ Excellent
- ➢ Broad brush – a useful starting point for further work.
- ➢ Worthwhile
- ➢ Next phase will presumably be more detailed
- ➢ The study should be extended to include social factors (part of a triple bottom line analysis)

<u>Questions directed at individual presenters and comments made in the second open forum session</u>

Questions directed at Bruce Lamb:

The Caribbean industry is breeding cane for high fibre content to go into their cogeneration plants. (Bernard Milford, Canegrowers).

Q Does the transportation of trash in cane take bin weights up to the transport (axle loading) limits. (Joe Linton, Grower).

A 50% of it does. The average bin weights is 21-22 tonnes. Cane and trash density in bins is 150-300kg/m3. Scope to improve. Harvester shredding of trash before putting it back onto cane improves bulk density.

Also short-chop harvesting improves bulk density. Choppers were trialled using 3 to 5 blades per drum to decrease billet length. A forage harvester chopper concept (single drum) to vary billet length is ideal.

Q Ideally you would not want to recover tops with the trash. How do tops in the cane supply effect the project? (Chris Norris).
A The project economics have been worked out based on bringing in all the trash including tops. Whole of crop harvesting was selected over higher cost options.

Q Some areas require more trash at certain times of the year. How does this affect operations? (Graham Kingston, BSES)
A Growers tend not to trash blanket in NSW.

Q What are the incremental transport costs associated with bringing in trash? (Chris Canavan, Grower)
A A 20% larger road transport fleet is required.

Q Are there extra dollars for the farmer to send in trash?
A Farmers are payed $16 per tonne for trash. There is 20% more cane (by weight) being transported

Questions directed at Laurie Watson:

Furfural production is a great start for biorefinery. Possible co-products include levulinic acid and vanillin. (Laurie Watson)

Q Does producing furfural leave you with a shortage of bagasse for the boilers? (Chris Canavan)
A Residue from furfural can be burnt in the boilers to supplement fuel

Q What are the capital costs of the furfural units being installed? (Bryan Lavarack, SRI)
A The first stage (5000 tonnes furfural) will cost $30M although the cost to Proserpine has been reduced by $15M in grants. The second stage (an additional 5,000 tonnes capacity) will cost between $12M and $15M. These costs are approximate and based on conservative yields (50% of theoretical maximum). Improvements in technology (achieving up to 90% of theoretical maximum furfural yield) are expected to increase revenues from and reduce costs of future plants.

Q How will the plant be scaled up? (Ted White, Chemical engineer)

A A modular approach is being adopted. Sufficient space has been allocated at the front end of the factory to accommodate four digesters.

Questions directed at Graeme Bullock:

The first (biorefinery) plant will always be the most expensive. It is also difficult to determine nth-plant capital costs when you haven't yet established a standardised design. SRI has a grant of $3.1 for the construction of equipment required to demonstrate critical technologies. (Graeme Bullock)

Questions directed at Phil Hobson:

Q Do thermochemical rather than fermentation technologies represent a 'better' path for the production of biofuels (Chris Norris)

A In terms of biofuel yields per tonne of feedstock, thermochemical processes are clearly well ahead (approximately double) those of fermentation. Cost data developed by Biofuel BV (Netherlands) based on a detailed engineering design of the HTU technology indicate favourable economics.

Questions directed at Tom Rainey:

Q Why is paper manufacture from bagasse carried out in other countries but not in Australia?

A In the past, most bagasse to paper plants operated in developing countries where environmental standards are low and effluent treatment (a high cost operation) is minimal. Such low levels of effluent treatment would not be acceptable in Australia. More recently, tightening up of environmental legislation and technology development in overseas plants has occurred to the extent that the technology could potentially meet Australian emission standards.