Life Cycle Strategies

Life Cycle Inventory of Ethanol Fuels

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1 Introduction

This report outlines the inventory development process for three different ethanol inventories in Australia. The inventories are based on the three major ethanol producers however they are not based entirely on industry specific data as there are gaps in the published literature of the operation and impacts of the Australian ethanol producers.

The three types of ethanol inventories developed are:

- ethanol from molasses based on the Sarina plant in Queensland
- ethanol from wheat and starch waste based on the Manildra plant in New South Wales
- ethanol from sorghum based on the Dalby plant in New South Wales

Ethanol source	Fraction of supply	Comment
Ethanol from wheat and starch waste	68%	300ML in market of 440ML
Ethanol, from molasses, at plant/AUU	18%	80 ML in market of 440 ML
Sorghum to ethanol distillery operation/AU U	14%	60 in market of 440 ML

2 Ethanol Inventory Development

2.1 Ethanol from Molasses

Molasses is produced as a by-product of the sugar production process. Data for this inventory were taken from comparison of transport fuels but adjusted to fit with the LCA results published by Sucrogen (Mitchell 2009).

2.1.1 Allocation

When solving the allocation issue between sugar and molasses to options are available. One is economic allocation which shares the burden of upstream production between the two products. The second is system expansion looks at how the supply of molasses effects the production of other products with which it competes.

Economic allocation

The prices for sugar and molasses have been taken from the AusAgLCI database which uses data supplied by Marguerite Renouf (Renouf, Wegner et al. 2010). Table 1 shows how the quantities and price of the commodities are used to calculate the allocation.

The use of economic allocation creates a problem for the embodied carbon balance through the inventory. A correction is applied to the allocated inventories to adjust the embodied carbon balance.

Table 2 shows the unit process for allocating the sugar production to Molasses. A correction to the embodied carbon flow from the sugar to the Molasses is applied based on the carbon contents of sugar and molasses.

Table 1: Economic allocation of sugar milling co-products

	Unit	Quantity	Price per unit	Value per 100t of cane	Allocation
Sugar	t per 100t of cane	13.52	400	$5,408	94.3%
Electricity	MWh per 100t of cane	1.862	100	$186	3.2%
Molasses	t per 100t of cane	2.84	50	$142	2.5%
Mill mud	t per 100t of cane	5.2	0	$-	0.0%
Total				$5,736	

Table 2: Unit process for molasses supply using economic allocation.

Flow	Unit	Value	Comment
Product			
Molasses, Sarina	kg	0.0284	Yield of Molasses per kg of sugar cane milled
Inputs from nature		0.	
Carbon dioxide in air	kg	0264	Adjustment for carbon absorbed by the crop and not passed through by economic allocation.
Materials and Energy			
Sugar cane milling, QLD/AU U	kg	0.0248	Allocation to Molasses from mill operation

System expansion

Molasses is produced as a by-product of the sugar production process. When solving the allocation issue between sugar and molasses with system expansion we have assumed the marginal use of molasses is in animal feed where it is used for its energy content. The alternative energy supply is taken as feed wheat (could be anything from Lucerne, sorghum or lupins) which provided predominantly and energy source in animal feed. However wheat provides more metabolisable energy and higher protein levels than molasses so a direct substitution is not appropriate as shown in Table 3. To balance this out, high protein lupins have been added to the molasses as shown in Table 4. The resulting allocation for molasses is shown in Figure 1.

Table 3:Energy and protein content of molasses, wheat and lupins

	Energy	Protein
Molasses	8.6	0.69%
Wheat	13.3	13%
Lupins	12	50%

Table 4: Assumption for supplementation of molasses with additional protein from lupins to meet nutrient balance of feed wheat substitute

	Amount used	Energy	Protein
Molasses feed	1.00	8.6	0.0069
Lupins protein supplemental	0.20	2.4	0.10
Nutrient value of mix	1.20	11.0	0.11
Wheat substitute	0.83	11.0	0.11

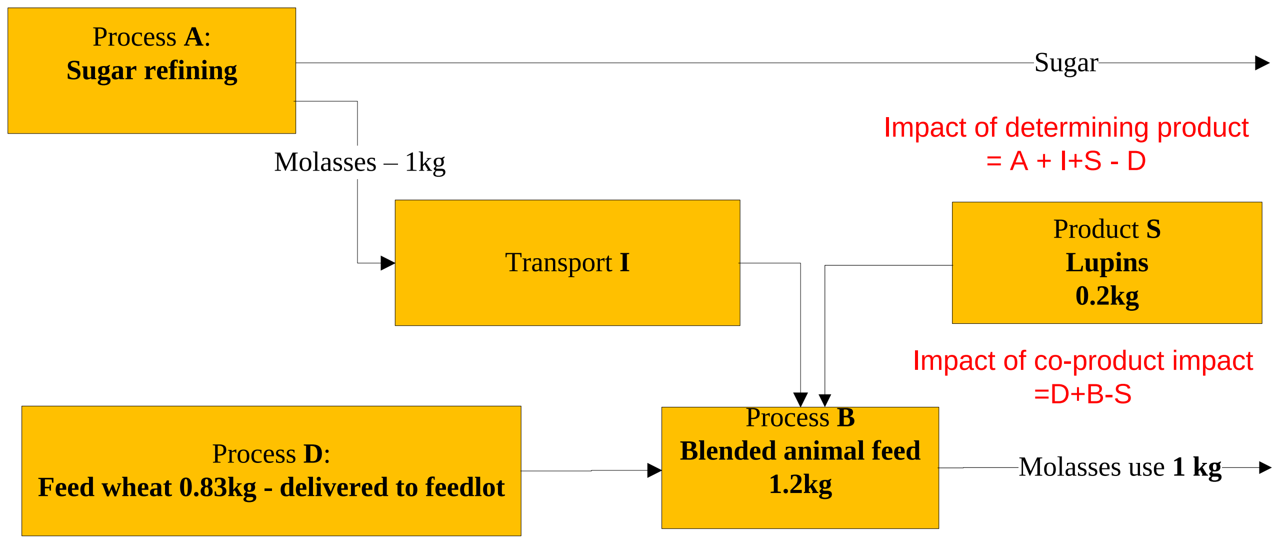


Figure 1: System expansion explanation for molasses use.

Error! Reference source not found. shows the inventory data used for lupins production in Central Zone west in NSW. The inventory is based on gross margin data produced by NSW Department of Primary Industry (NSW Department of Primary Industries 2012) as advice to farmers. Additional emission data have been added based on the National Greenhouse Gas Inventory (Department of Climate Change and Energy Efficiency 2010). Wheat production data are provided in the ethanol from wheat and wheat starch waste section of the report.

The inventory data required for sugar production is only required for the sensitivity analysis using economic allocation of molasses as a co-product of sugar refining. The data for this analysis is taken from a PhD thesis by Margurite Renouf (Renouf 2011).

Table 5 the unit process structure for molasses from Sarina using system expansion.

Table 5: Unit process for molasses supply using system expansion.

Flow	Unit	Value	Comment
Product			
Molasses, Sarina	kg	1	
Materials and Energy			
Wheat, Central East, NSW, at farm	kg	0.83	Required to fill place of molasses in animal feed market.
Lupins, Short Fallow (No-till), Central Zone West NSW, on farm	kg	-0.2	Protein source not required due to high protein value of wheat substituted for molasses.

Table 6 shows the unit process for ethanol production from Sarina

Table 6: Unit process for ethanol from molasses.

Flow	Unit	Value	Comment
Product			
Ethanol, from molasses, Sarina	l	1	23% yield from Molasses
Materials and Energy			
Water, drinking,	l	13.3	From ecoinvent (Jungbluth, Chudacoff et al. 2007)
Molasses, at distillery	kg	0.7	
Bagasse combustion	MJ	6.55	0.56 MJ/MJ ethanol produced with 50% being from Bagasse - taking 0.56*23.4 MJ/l ethanol =13.1/2
Energy, from coal	MJ	6.55	0.56 MJ/MJ ethanol produced with 50% being from coal- taking 0.56*23.4 MJ/l ethanol =13.1/
Electricity, low voltage, QLD	kWh	0.0085	(Beer, Grant et al. 2001)
Steam, from natural gas	kg	0.05	(Beer, Grant et al. 2001)
Emissions to water			
Waste water	kg	2.204	
Final waste flows			
Ash	kg	0.176	

2.2 Ethanol from Sorghum Grain

In the absence of better information sorghum supply was taken as an unweighted average of three Sorghum growing systems which are in the northern part of New South Wales – not far from the Dalby plant which is located in Southern Queensland. The inventories are based on data published by the Department of Primary Industries in NSW. (NSW Department of Primary Industries 2012) The three sorghum production inventories are shown in **Error! Reference source not found.**,**Error! Reference source not found.** and **Error! Reference source not found.** with the supply mix being shown in Table 7 with associated transport.

Table 7: Sorghum supply process.

Flow	Unit	Value	Comment
Sorghum supply	1	kg	
Materials and Energy			
Sorghum, Dryland North West NSW, on farm	kg	0.33	25000 BTU per US gallon of ethanol
Sorghum, Dryland North East NSW, at farm	kg	0.33	1kWh per Gal
Sorghum, Irrigated, Northern Zone NSW, on farm	kg	0.33	2.8 Gallons per bushel of sorghum

Grain transport in B double	kgkm	200	Estimate based on region geography.

The data on ethanol production from sorghum grain was provided by the Dalby Bio- Refinery as typical data for the type of plant they are operating (pers comm, Derek Peine , General Manager, Dalby Bio- Refinery Limited) and was checked against the results in comparison of transport fuels(Beer, Grant et al. 2001) and (Wang, Han et al. 2012). The distillery produces both ethanol and dried distillers grains and solubles (DDGS) which are used in the animal feed industry.

Table 8: Ethanol from sorghum unit process data.

Flow	Unit	Value	Comment
Ethanol, from sorghum, Dalby	kg	0.79	1 litre
Animal Feed DDGS	kg	0.671	28% of sorghum input
Materials and Energy			
Energy, from natural gas	MJ	7	25000 BTU per US gallon of ethanol
Electricity, low voltage, NSW	kWh	0.264	1kWh per Gal
Sorghum supply	kg	2.397	2.8 Gallons per bushel of sorghum
Electricity, low voltage, QLD	kWh	0.0088	Energy for dehydration
Steam, from natural gas, in kg	kg	1	Steam for dehydration

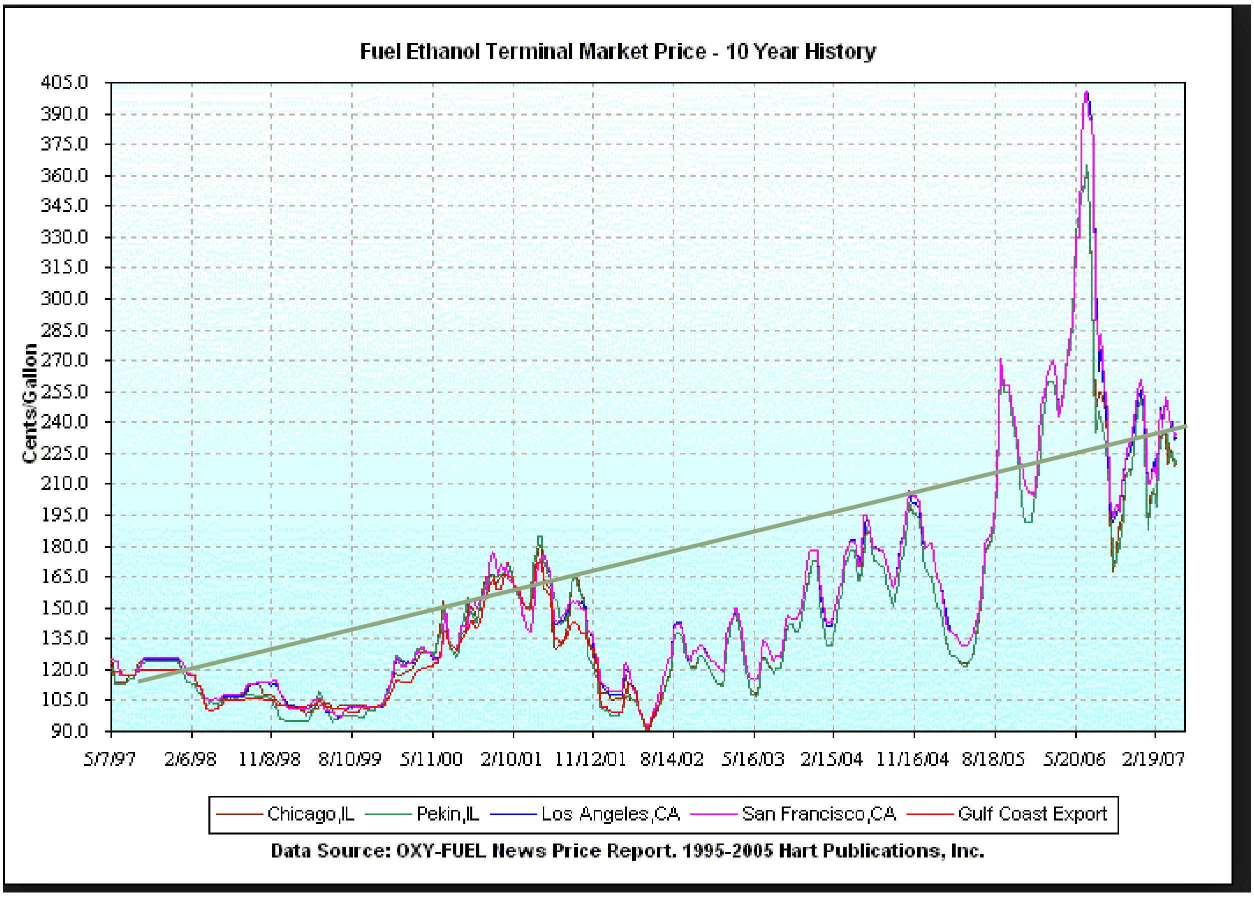
Source: (pers comm, Derek Peine , General Manager, Dalby Bio- Refinery Limited) except for dehydration which is taken from

2.2.1 Economic Allocation

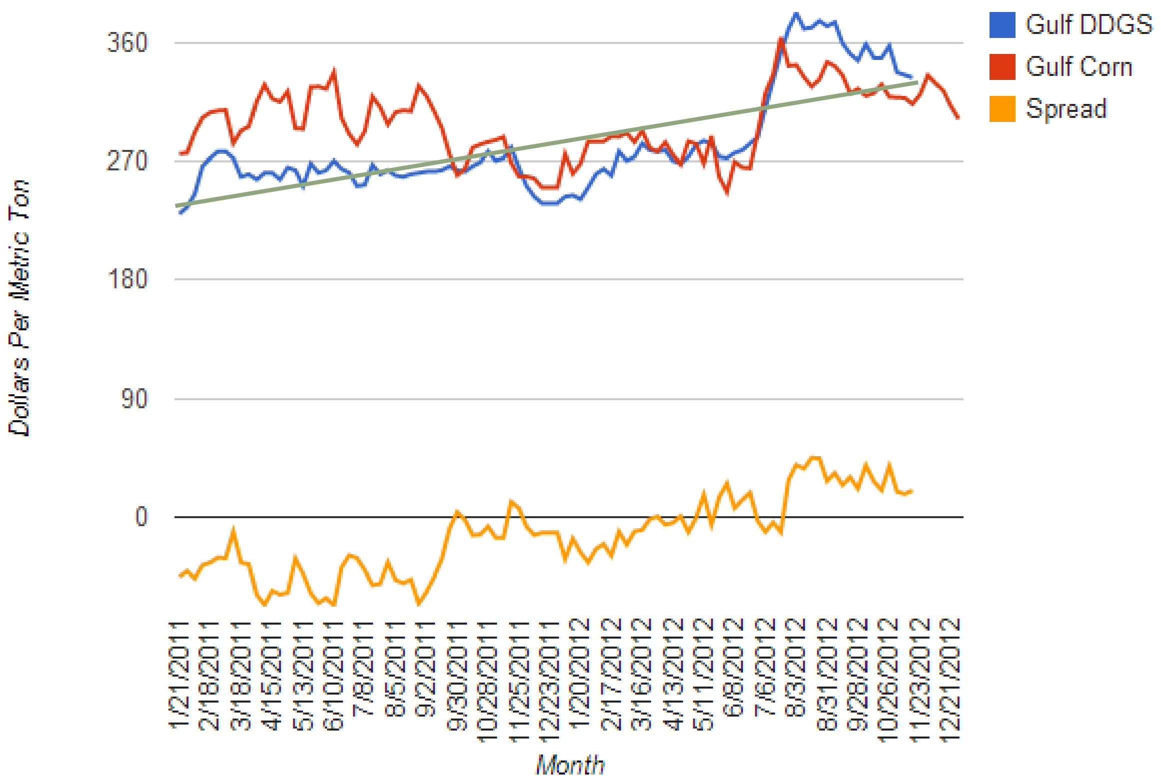
The allocation between ethanol and DDGS's is based on prices estimate for the two products outlined in

Table 9: Economic allocation of for 2.397 kg of Sorghum input

	Amount produced	Price per unit	Total value	Allocation percentage
Ethanol	1 litre	$0.634/litre (240 cents per gal)	$0.634	75%
DDGS	0.676kg	$0.33c per kg (330 per tonne)	$0.223	26%
Total			$0.857	



Source:(The Californian Energy Commission 2014) – suggesting - convert the green strait fitted line in cents or $/litre



Source:(U.S. Grains Council and Chicago Board of Trade 2014)

Parameter	Value	Unit/ Comment
Carbon content Sorghum	0.44	C mass/Dry mass. Dry matter carbon content of sorghum - estimate
Carbon content Ethanol	0.5214	C mass/Dry mass. Dry matter carbon content of ethanol
Carbon content DDGS	0.5	C mass/Dry mass. Dry matter carbon content of ethanol - estimate
Dry matter content ethanol	0.99	Mass dry matter/Mass, Dry matter content of ethanol
Dry matter content Sorghum	0.87	13% moisture is safe for storage.
Dry matter content DDGS	0.9	10% moisture suggested by literature.

2.3 Ethanol from Wheat and wheat starch waste

The distillery at Manildra's Bomaderry began treating starch production waste to produce ethanol in 1991. It has since expanded to produce ethanol from a mix of wheat grain and the by-product from wheat starch production. From the report into the plant expansion in 2008 (GHD 2008) wheat supply is 290.000 tonnes suggesting it makes up around 40 per cent of the feed to the ethanol plant. The waste from the wheat starch plant contains considerable value being high in energy, although low in fibre. It's difficult to get specific information on the wheat starch waste, however a starch text book suggest it is mostly starch, washed away from the gluten – which is protein – in gluten production. (Maningat, Seib et al. 2009). Other potential uses for this waste include anaerobic/aerobic digestion, spray irrigation and concentration by evaporation and drying for animal feed (Maningat, Seib et al. 2009).

On a dry basis this starch waste is assumed to have yield ethanol at a rate of 1 litre per 1.12kg of dry starch waste which was used in the comparison of transport fuels. (Beer, Grant et al. 2001). For the system expansion for starch waste supply the same processes used for molasses is applied. The energy content of the starch is assumed to be 16.7MJ/kg and protein content assumed to be zero.

Table 10 shows the calculation of the wheat required to offset the starch waste energy value and the lupins required to rebalance the protein requirements when wheat starch waste is used as animal feed.

Table 10: Assumption for supplementation of starch waste with additional protein from lupins to meet nutrient balance of feed wheat substitute

	Amount used	Energy	Protein
Starch waste	1.00	16.7	0
Lupins protein supplemental	0.40	4.6	0.2
Nutrient value of mix	1.40	21.3	0.2
Wheat substitute	1.6	21.3	0.2

See Table 3 for data on lupins and wheat energy content.

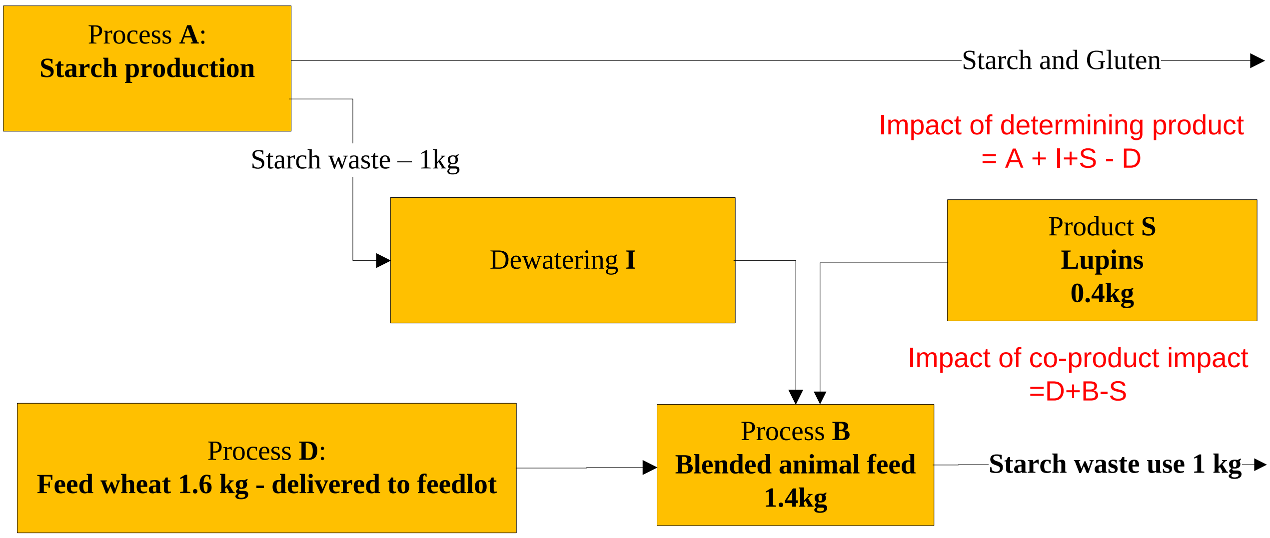


Figure 2: System expansion explanation for wheat starch waste use.

Data for wheat supply was taken from Central eastern NSW in the general catchment area of the starch plant and distillery at Bomaderry NSW. The inventories are based on data published by the Department of Primary Industries in NSW.(NSW Department of Primary Industries 2012) . The inventory data are show in **Error! Reference source not found.**.

Table 11: Ethanol production from Wheat and wheat starch waste

Flow	Unit	Value	Comment
Ethanol, from wheat and WSW, Bomaderry	kg	0.79	1 litre
Materials and Energy			
Wheat, Central East, NSW, at farm	kg	0.96	GHG report(GHD 2008) 290.000 tonnes grain use which at 2.4 tonne per litre of ethanol gives 120ML of ethanol from grain out of 300ML total ie 40%.
Wheat starch waste	kg	0.72	60% of ethanol coming from wheat starch waste.
Energy, from natural gas	MJ	6.3	1.2kg per litre of ethanol.
Energy, from coal	MJ	2.7	30% of energy from coal –inferred from GHD report
Electricity, natural gas, cogeneration, at power plant/AU S	MJ	0.1	Electricity assumed from gas cogeneration plant
Electricity, low voltage, for dehydration, Vic	kWh	0.0085	Dehydration is undertaken in Victoria – based on Beer, Grant et al 2001.
Steam, for dehydration	kg	0.05	Dehydration is undertaken in Victoria– based on Beer, Grant et al 2001.

2.4 Ethanol average production for Australia

An average ethanol production inventory have been developed based on the plant capacities published by the Biofuels Association of Australia (Biofuels Association of Australia 2013)

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