Australian Government

Rural Industries Research and Development Corporation

Biofuel Co-Products as Livestock Feed

Bioenergy, Bioproducts & Energy R&D Program

RIRDC Innovation for rural Australia

Australian Government

Rural Industries Research and Development Corporation

Biofuel Co-Products as Livestock Feed

A report for the Rural Industries Research and Development Corporation

by Andrew Braid

November 2007

RIRDC Publication No 07/175
RIRDC Project No CSW-44A/PRJ-000830

ISBN 1 74151 570 X
ISSN 1440-6845

Biofuel Co-Products as Livestock Feedk
Publication No. 07/175
Project No. CSW-44A/PRJ-000830

Researcher Contact Details
Andrew Braid
CSIRO Sustainable Ecosystems
GPO Box 284
GUNGAHLIN CRACE ACT 2601

Phone: 02 6242 1638
Email: Andrew.Braid@csiro.au

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

Published in November 2007

Foreword

The aim of this paper is to provide a comprehensive and relevant review of research literature into the use of biofuel co-products in a range of intensively managed livestock industries.

Although co-products from biodiesel production – canola and soybean meal – have been available as livestock feed for many years due to the production of vegetable oils, the planned development in Australia of an industry to produce bioethanol from cereal grains will make significant new feedstocks available to Australian livestock producers. These are the co-products of cereal ethanol production – wet distillers grain and distillers dried grain with solubles.

It is important that Australian livestock producers and their advisors recognise the possibilities as well as the limits to using these newly available livestock feeds, particularly if the production of ethanol impacts on the availability and price of feed grains. It is also important that those proposing to build ethanol plants in Australia recognise the value for their business and for livestock producers of producing quality co-products from the grain they use in the production of ethanol. To do this will require the installation and the operation of the best available new technology.

This report provides more detail on aspects of biofuel co-products for livestock that is provided in the synthesis report "Biofuels in Australia – issues and prospects" (O'Connell et al 2007). This research was funded from RIRDC Core Funds (which are provided by the Australian Government) in partnership with CSIRO's Energy Transformed Flagship (www.csiro.au/csiro/channel/ppch1d.html).

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/fullreports/index.html
- purchases at www.rirdc.gov.au/eshop

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

Abbreviations

ADF	Acid detergent fibre
ADG	Average daily gain
AID	Apparent ileal digestibility
CDS	Condensed distillers solubles
CF	Crude fibre
CIE	Centre for International Economics
CO_2	Carbon Dioxide
CP	Crude Protein
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Coefficient of variance
DDGS	Distillers dried grain plus solubles
DE	Digestible energy
DG	Distillers grain
DM	Dry matter
DMB	Dry matter basis
DMI	Dry matter intake
EPA	Environmental Protection Agency
kg	Kilogram
kt	Kiloton
Mcal	Megacalories
ME	Metabolised energy
MJ	Megajoule
MLA	Meat & Livestock Australia
N	Nitrogen
NEg	Net energy for grain
NDF	Neutral detergent fibre
NSW	New South Wales
RIRDC	Rural Industries Research and Development Corporation
SWDGS	Sorghum wet distillers grain plus solubles
TMD	Total mixed diet
TS	Thin stillage
USA	United States of America
WDG	Wet distillers grain
WDGS	Wet distillers grain with sollubles

Contents

Executive Summary

What the report is about and why the research is important
This report is about the co-products from the production of biodiesel and bioethanol and their use in livestock nutrition. In particular, it addresses the use of distillers grain, a co-product of cereal ethanol production, in the intensive livestock industries – feedlot beef, dairy, pigs, poultry and aquaculture. As the production of biofuels is an emerging industry in Australia, the information contained in this report is important so that the benefit from the proposed diversion of human and animal feed stocks – sugars, cereals and oilseeds – into biofuel production is maximised through the appropriate use of co-products in the livestock industries. It is also important that livestock producers and their advisors recognize the opportunities from the increased availability of biofuel co-products in Australia as well as the limits and potential environmental problems associated with their use.

The target audience for this report
The report was prepared to provide advice to the Australian livestock industry through a comprehensive review of the research literature available on biofuel co-products and their use in livestock nutrition. It has been written for the owners, operators, consultants, nutritionists, veterinarians and feed millers who make the decisions on what is fed to the animals and who are faced with changes in the availability of feed stocks as the biofuel industry grows in Australia. It is also hoped that this report will be considered by those entrepreneurs proposing to build and operate biofuel production facilities in Australia so that they recognise the value for their business and for the livestock industry in installing the best available new technology to ensure the production of quality co-products.

Background
Internationally, biofuels have been promoted as a response to greenhouse gas emissions, problems in the oil industry and energy security. In the USA, the increasing use of corn for the production of ethanol has led to significant increases in the feed corn price and protests from the intensive livestock industries. In Australia, with the biofuel industry in its infancy, questions have emerged on the effect the development of this industry will have on the feedstuffs available to the intensive livestock industries, and how the co-products or residues from the biofuel industries could be utilised. This report, originally prepared for the synthesis report "Biofuels in Australia – issues and prospects" (O'Connell et al 2007), provides detail on the issues specific to the use of biofuel co-products for livestock.

Biodiesel co-products, the meals left following the extraction of the vegetable oils – canola meal and soybean meal are currently being used by the Australian livestock industries. Bioethanol co-products, new to the Australian livestock industries, are those derived from the proposed expansion of cereal ethanol production based on the use of wheat, sorghum, barley and triticale.

In the production of cereal ethanol, approximately a third of the original grain (on a dry matter basis) is left following fermentation of the starch portion, with the remaining components – protein, fibre, fat and minerals concentrated threefold, which together with remnants of the fermentation yeast form the initial co-product known as stillage. This is centrifuged, the liquid portion concentrated and added back to form wet distillers grain plus solubles (WDGS), which may be used to feed cattle, or dried to produce distillers dried grain plus solubles (DDGS).

Aims and Objectives
The aim of the research was to provide an independent, referenced report on the use of biofuel co-products in livestock with the particular objectives of:

- Considering the nutritional quality of biofuel co-products and their useability in a range of livestock;

- Examining the issues related to the storage, transportation and drying of wet biofuel co-products;
- Considering the opportunities for intensive livestock producers to reduce their input costs by using biofuel co-products, and
- Identifying the research required to ensure the best utilisation of co-products from Australian grains used in new Australian biofuel production facilities.

This report will be of benefit to those in the Australian livestock industry and the emerging biofuel industry looking for opportunities from the production and use of biofuel co-products. In addition to the information set out in the report, it also provides a comprehensive list of references for those seeking further information when preparing advice for livestock owners or biofuel producers.

Methods
The report was derived from a review of research papers from refereed journals to provide an unbiased examination of the objectives as set out above. Although there is a large amount of material on the use of corn-derived DDGS available on USA based web sites, much of this is sponsored by the ethanol industry with the aim of promoting the use of DDGS and was discounted as secondary to the refereed research papers. Effort was made to locate papers on cereal ethanol co-products sourced from wheat and sorghum as these are the most likely cereal grains to be used in the production of cereal-ethanol in Australia.

Results/Key findings
Quality and Useability

- Research papers are available on the use of cereal ethanol co-products in the diets of a range of intensively farmed animals – beef and dairy cattle, pigs, poultry (broilers, laying hens and turkeys) and fish – and cover all the stages of production from weaning to finishing. There has been new research into the use of ethanol co-products over the past decade as the production of ethanol and associated co-products has increased, particularly in the USA. The quality of co-products from modern ethanol plants is much better than in the past with less variability and processing damage.
- In general, the research findings are positive about the value and use of cereal ethanol co-products to replace a portion of grain and/or protein meal in intensive livestock diets. DDGS is particularly useful for ruminants providing a combination of rumen by-pass protein, digestible fibre and energy. DDGS can be used in diets without affecting production or reducing the quality of animal products – meat, milk, eggs etc – at the following rates:
    - Cattle 20 – 40 %
    - Pigs 10 – 25 %
    - Poultry 9 – 15 %
    - Fish 15 – 22.5 %
- New technologies are being developed to enhance the value derived from source grains and to add value to the co-products. Technologies such as the Eluseive process can significantly reduce the fibre in DDGS while increasing the crude protein level, adding to the value of DDGS for use in pig and poultry diets.
- The production of ethanol from C molasses derived from sugar cane does not produce a co-product that is used by livestock. The impact to the livestock industries of increased production of ethanol from sugar cane in Australia will be the effect on the price and availability of C molasses as more is used in the production of ethanol.
- A feasibility study into the production of ethanol from sugar beet in north-east Tasmania has been undertaken. The co-product dried molasses beet pulp was identified as a useful product for the dairy industry that could replace up to 50% of the grain in high-concentrate dairy rations, significantly reducing the annual importation of feed grain into Tasmania.
- The co-products from the production of biodiesel, canola and soybean meals have been used in Australian pig and poultry diets for many years. The development of biodiesel production in Australia will increase the availability of these high protein meals for use in livestock diets.

Storage, transporting and drying of wet cereal ethanol co-products

- The wet cereal ethanol co-product, WDGS has a limited storage time of 3 – 5 days at 22°C. Research has been undertaken to develop methods of increasing the storage time for WDGS with limited success. WDGS has already undergone fermentation so will not ensile without the addition of fermentable material.
- On a dry matter basis, WDGS (30% DM) is expensive to transport and must also be handled according to EPA requirements.
- Drying WDGS to form DDGS uses 30 – 40 % of the total energy requirements of a cereal ethanol plant. However, DDGS can be readily transported, stored, added to pelleted feeds and is used in pigs, poultry and aquaculture as well as ruminants. This makes it more accessible to livestock industries and more marketable

Opportunities for intensive livestock producers to reduce their input costs by using biofuel co-products

- There are some good opportunities for the intensive livestock producers to gain from biofuels production. The increased availability of high-protein meal should moderate the price of livestock feed protein. High protein meal can supplement ruminants grazing low-protein pastures. DDGS will be ideal for this use as it is low in fermentable carbohydrates and consequently much safer than grain as a supplement.
- Vertically integrated systems of cereal cropping, ethanol production and co-located dairies or feedlots could be set up to use WDGS, replacing a portion of the grain (and offsetting reduced availability of grain) in the dairy or feedlot diets. Integrated ownership would provide the ethanol plant with some surety for the disposal of wet co-products. In addition, the installation of new technology for the production of biogas from the cattle manure combined with excess wet co-products would further contribute to the energy efficiency of the ethanol plant, the management of the environmental impact of animal waste and add to the cashflow of the venture.

Research opportunities

- Much of the research reviewed is from the USA and based on corn-ethanol co-products used in total mixed diets. Research will be needed in Australia to assess the co-products to be derived from Australian grains used in ethanol production and how they can be used under Australian conditions – i.e. other than in total mixed diets, for example as drought supplements. While some of this research can be undertaken through modeling based on composition of Australian grains, more specific nutritional research will be required to provide accurate information on the digestibility and nutritional value of co-products sourced from Australian grains.

Additional findings - Potential for environmental pollution

- While up to half of the grain (35 – 40% of the total diet) could be replaced with either WDGS or DDGS in beef feedlot diets without negatively impacting on growth rate performance or carcass characteristics, at this level of replacement the total dietary crude protein would be in excess of the maximum 15% recommended for Australian lot feeders. High protein diets in intensive livestock industries can cause environmental pollution due to nitrogen (N) excretion in urine and faeces. The potential for environmental pollution through the increased use of the high-protein co-products from the biofuel industries will need to be considered when formulating diets.

Implications for stakeholders:

Livestock Industry

- All the intensive livestock industries will be able to utilize the co-products from the production of biofuels to some extent, providing a partial offset to any reduced availability of grain.

- The increased availability of high-protein feedstock could lead to the formulation and use of high-protein diets in intensive livestock industries and environmental pollution.
- DDGS will provide a new, relatively safe, useful supplement for ruminants grazing low-protein pastures.

Biofuel Industry

- Quality control and the use of new technology could facilitate the marketing and add to the value of biofuel co-products.
- Integration and co-location of cereal-ethanol production with beef feedlots and/or dairies utilizing WDGS could provide opportunities for energy savings in the ethanol plant. The addition of biogas production technology could add value and reduce the environmental pollution problems associated with the use of high levels of WDGS.

Communities

- The integration of processes as described above would expand the local industry which could benefit of the local community.

Policy makers

- The research described in this report demonstrates that co-products from biofuel production are not waste products. Appropriately used they can increase the benefits derived from the diversion of human and animal feed stocks into biofuel production. Policy guiding the development of the biofuels industries could support this position.

Recommendations:

- A program of research will need to be undertaken to assess the nutritional value of cereal ethanol co-products derived from Australian grains. Information from this research will allow livestock consultants to properly advise their clients on the quality and use of the co-products.

Introduction

Internationally, biofuels have been promoted as a response to greenhouse gas emissions, problems in the oil industry and energy security. In the USA, the increasing use of corn for the production of ethanol has led to significant increases in the feed corn price and protests from the intensive livestock industries. In Australia, with the biofuel industry in its infancy, questions have emerged on the effect the development of this industry will have on the feedstuffs available to the intensive livestock industries, and how the co-products or residues from the biofuel industries could be utilised. This report, originally prepared for the synthesis report "Biofuels in Australia – issues and prospects" (O'Connell et al 2007), provides detail on the issues specific to the use of biofuel co-products for livestock.

The planned development of biofuel industries in Australia will not only produce biofuels, but also a range of co-products that will change the feed products available to Australian livestock producers. While biodiesel production from oilseeds will increase the amount of canola and soybean meal from the level currently available, the production of ethanol from cereal grains will add a significant new feedstock to those currently available in Australia.

The aim of the research was to provide an independent, referenced report on the use of biofuel co-products in livestock with the particular objectives of:

- Considering the nutritional quality of biofuel co-products and their useability in a range of livestock;
- Examining the issues related to the storage, transportation and drying of wet biofuel co-products;
- Considering the opportunities for intensive livestock producers to reduce their input costs by using biofuel co-products, and
- Identifying the research required to ensure the best utilisation of co-products from Australian grains used in new Australian biofuel production facilities.

This report will be of benefit to those in the Australian livestock industry and the emerging biofuel industry looking for opportunities from the production and use of biofuel co-products. In addition to the information set out in the report, it also provides a comprehensive list of references for those seeking further information when preparing advice for livestock owners or biofuel producers.

Co-products from Bioethanol

Bioethanol from cereals

Most cereal ethanol plants in the USA are rural based dry-grind mills (Fig. 1) that use corn to produce ethanol and whole stillage (Belyea, Rausch et al. 2004). Recently there has been some research into new technologies – decortication, modified dry-grind, quick germ quick fibre and elusieve (Singh 2001; Vijay Singh 2001; Srinivasan 2005; Corredor, Bean et al. 2006; Parsons 2006), that can produce additional corn-derived products and higher quality distillers dried grains plus solubles (DDGS). Cereal based Australian ethanol plants will probably be dry-grind mills using wheat, sorghum, barley or triticale. Inclusion of the new technologies in Australian mills will depend on the value and availability of the co-products from the grains used and the value of the DDGS.

Quality

Quality is based on composition and reliability (variability). With the expansion of the ethanol industry in North America and the consequent marked increase in the amount of co-products produced, two issues have become apparent in the published literature.

- Research to re-evaluate the composition, variability and useability of co-products from modern (post 1990) ethanol plants, and
- Development of new technologies to improve the range and value of co-products, particularly DDGS for pig and poultry nutrition.

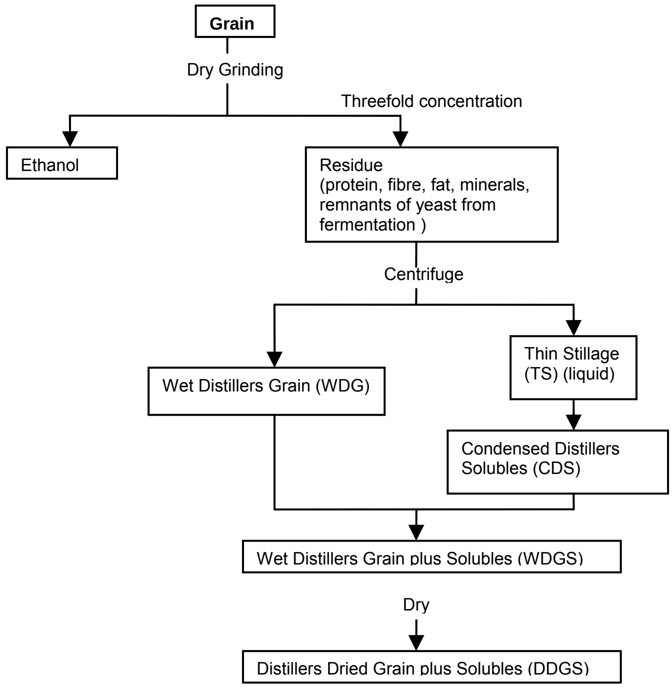
Composition

As a general rule, approximately a third of the original grain, dry matter basis (DMB), is left as residues following fermentation of the starch portion, with the remaining residues – protein, fibre, fat and minerals concentrated threefold (Klopfenstein 1996). The percentage of residues varies between grains (Table 1). The concentration of residues is evident in Tables 2 and 3 which compares the chemical composition of wheat and sorghum with wheat-based and sorghum-based ethanol co-products.

Table 1: Fermentation residues from alcohol distillation of cereals.
(Mustafa, McKinnon et al. 2000)

	Cereal grain			
	Wheat	**Barley**	**Corn**	**Sorghum**
Fermentation residues (% of grain)	35	41	29	32
Distillers' grains (% of residues)	74-76	72	69-72	71
Thin stillage (% of residues)	21-26	28	29-31	29

Figure 1. The process and co-products of a dry-grind cereal ethanol plant.



The co-products from dry-grind cereal ethanol plant (see Fig 1) are described as follows:

Whole stillage - the material left after the extraction of ethanol. A slurry, 10 – 25% Dry Matter (DM), it contains all the insoluble and soluble non-starch components of the grain together with the yeast remnants from fermentation. It is not used as such as a livestock feed, but is pressed or centrifuged to separate the liquid portion, thin stillage, from the ground grain solids, wet distillers grain.

Thin stillage (TS) (4 – 8% DM) contains both suspended and dissolved nutrients. On a DM basis, it is high in Crude Protein (CP), fat, minerals and digestible fibre (see Table 2). The amino acid composition of a given cereal TS is close to that of the original cereal (Mustafa, McKinnon et al. 2000). In ruminants, 52% of thin stillage has been found to bypasses the rumen (Iwanchysko, McKinnon et al. 1999) which is then available for digestion in the lower gastrointestinal tract. The bypass process for TS is thought to be due to closure of the oesophageal groove and failure of the TS to equilibrate with the rumen contents.

Condensed distillers solubles (CDS) is concentrated TS (25 – 50% DM) following evaporative concentration using a multi-effect falling film method to conserve energy and to minimise heat damage to the nutrients. CDS has been trialled as an energy source for finishing cattle (Rust 1990), but is usually added back to wet distillers grain for use in the wet (WDGS) or dry (DDGS) form.

Wet distillers grain (WDG) also known as wet cake consists of ground grain and yeast solids left following the separation off of thin stillage from whole stillage. WDG has limited storage time and is costly to transport due its high moisture content (25 – 35% DM). Below 8°C it can be stored for 7 – 10 days, but at 22°C this is reduced to 3 – 5 days (Walker 2004). It is a good source of protein and energy for ruminants particularly when condensed distillers solubles are added back to form wet distillers grain plus solubles (WDGS).

Distillers dried grain plus solubles (DDGS): CDS and WDG are combined and dried to form DDGS, a dry meal containing approximately 90% DM that can be readily transported and stored. (Kohl). The drying process to produce DDGS is expensive in terms of energy, using 30 – 40% of the energy requirements of a dry-grind ethanol plant (Lurgi; Ham, Stock et al. 1994), but most dry-grind ethanol plants produce DDGS as it is a more marketable product than WDGS. The combination of high levels of protein, Neutral Detergent Fibre (NDF) and fat (ether extract) makes DDGS a useful feed that provides rumen by-pass protein (Grings, Roffler et al. 1992), digestible fibre and energy.

Table 2: Wheat: chemical composition of grain and co-products from the production of ethanol.

Component	Grain	Thin Stillage	Wet Distillers Grain	DDGS
Dry matter %	89.2	8.4		92.7 – 93.8
Crude Protein	12.5	48.5	26	32.9 – 36.9
Ether Extract	1.8	9.6	4	3.2 – 3.8
Crude Fibre	2.8			
NDF	11.2	34.5	74	33.3 – 34.2
ADF	4.1	3.4	22	18.0 – 21.6
Starch	58.7		2	
Ash	1.6	8.0	4	4.7 – 4.9
Reference	(ALFI 2004)	(Ojowi, Christensen et al. 1996)	(Mustafa, McKinnon et al. 2000)	(Nyachoti, House et al. 2005)

Table 3: Sorghum: chemical composition of grain and co-products from the production of ethanol.

Component	Grain	Thin Stillage	Wet Distillers Grain	Wet Distillers Grain	DDGS	DDGS
Dry matter %	88.0		35.3	23.5	91.4	91.4
Crude Protein	10.2		31.2	31.6	31.4	32.9
Ether Extract	2.8		13.3	11.3	11.8	13.0
Crude Fibre	2.8					
NDF	7.8		41.3	45.4	51.1	45.8
ADF	8.5		28.5			28.4
Starch	67.6			10.2	7.4	
Ash	1.6			2.5	1.8	
Reference	(ALFI 2004)	None found	(Al-Suwaiegh 2002)	(Lodge, Stock et al. 1997)	(Lodge, Stock et al. 1997)	(Al-Suwaiegh 2002)

Variability

Variation in the composition of DDGS reduces the quality and negatively impacts on the market value of DDGS. Because of variation, processors market DDGS with conservative estimates of nutrient content that undervalues the true potential of the DDGS for protein and energy (Belyea, Rausch et al. 2004).

Cromwell demonstrated the amount of variability from pre-1990 plants, using DDGS samples originating from beverage alcohol (7) and corn-ethanol (2) plants. DDGS samples were assessed for odour (normal, smokey, burnt) and colour, and these were correlated with growth performance for pigs and chicks (Cromwell, Herkelman et al. 1993). It was found that dark coloured DDGS with burnt or smokey odour were lower in nutritional value than light coloured, probably due to overheating of the DDGS during drying. The essential amino acid lysine had more than a two-fold difference between DDGS sources (0.43 to 0.89%), with the highest lysine concentrations in the lightest coloured DDGS samples.

Ten years later Spiehs et al. (2002) published a paper describing the nutrient variability between and within 10 new ethanol plants (less than 5 years old) producing corn-based DDGS in the Minnesota-

South Dakota region (Spiehs, Whitney et al. 2002). The results demonstrated that in general variation in nutrient levels was low with coefficient of variance (CV) less than 5% for DM and calculated Digestible Energy (DE) and Metabolised Energy (ME) and less than 10% for CP, fat, Crude Fibre (CF) and most amino acids. There were higher CVs for lysine (17.3%), methionine (13.6%) and mineral levels were highly variable as found in other studies (Batal and Dale 2003). There were some year-to-year differences during this three-year study probably as a result of differences in growing conditions for the corn, although another study of DDGS variation concluded that "The assumption that variation in composition of DDGS was due to variation in composition of corn was not supported by the data of this study" (Belyea, Rausch et al. 2004)

Although the Spiehs study demonstrated much less variation in DDGS than the earlier study of Cromwell, the conclusion was that nutritionists need to be aware of the variation, even within ethanol plants using the same processing technology and input grain and conduct a complete chemical analysis of DDGS at least once each year.

Variation occurs because DDGS are a by-product of a process designed for ethanol production. Variables such as variety of grain, type of fermentation process, separation and evaporative condensation of thin stillage, mix of condensed distillers solubles with wet distillers grain and drying temperatures and duration can all influence the nutritional and physical properties of DDGS (Spiehs, Whitney et al. 2002).

New Technologies

In the USA, a number of new ethanol plant technologies are being developed to produce more corn-derived products (e.g. corn oil from corn germ and phytosterols from corn fibre (Singh 2001)), to increase the nutritional value of DDGS, to improve the fermentation and yield of ethanol and increase the value derived from corn. Inclusion of these new technologies in Australian ethanol plants will depend upon the perceived market for co-products other than DDGS that can be derived from Australian grains and the need to value add to DDGS.

Of the new technologies, the reduction of fibre with the consequent increase in CP and fat percentage in DDGS via the Elusieve process shows the most promise for improving the nutritional value of DDGS for pigs and poultry. This process first separates DDGS particles according to size (sieving) then separates the lighter particles by elutriation, an upward flowing stream of air (Radhakrishnan 2005). The total dietary fibre of the DDGS can be reduced from 34.5 to 19.7% while the CP and fat increased from 31.3 to 40.8% and 11.8 to 15.0% respectively (Parsons 2006) through this process. The removed portion, high in fibre, is suitable for ruminants. DDGS with high fat (12.6%) and high protein (33.3%) is worth \$5 - \$20 US/ton more from a nutrient content basis than DDGS with lower fat (10.9%) and lower protein (28.0%) (Belyea, Rausch et al. 2004). In a paper on the economics of the elusieve process (Srinivasan 2006a) it was estimated that the price of DDGS based on the June 2005 price of \$87 US/ton, when calculated on an increase of protein content of 2.4% would increase to \$98 US/ton, and possibly more if the energy value due to the higher fat content and increased demand for this type of DDGS by the pig and poultry industries was also calculated.

Other new technologies being developed – modified dry grind and quick germ quick fibre processes that focus on collecting more co-products of corn may not reach Australia. However, research papers of the effect of decorticating wheat, triticale and barley (Wang, Sosulski et al. 1997) or sorghum (Corredor, Bean et al. 2006) on ethanol production and composition of DDGS may have relevance for Australian ethanol producers. Decorticating sorghum improves starch fermentation by removing tannins and other fermentation inhibitors in the bran and improves ethanol yield Although it reduces the yield of DDGS by as much as 12%, the protein content of DDGS from sorghum decorticated 0, 10 and 20% were 42.3, 49.9 and 54.2% while the fat content was 11.4, 12.2 and 13.0%.

While the new technologies promise improvement in nutritional value of DDGS for pigs and poultry (which will need to be tested), the addition of another process to the production of DDGS will add variability to the product, so an on-going assessment of DDGS will be necessary for optimal use of DDGS in livestock nutrition.

Useability in Ruminants

Beef Cattle

Although there is a significant body of literature on the use of cereal ethanol co-products in total mixed diets for feedlot beef and housed dairy cattle, there is little research information available on the use of these co-products as supplement for grazing cattle, either beef or dairy. There is also only limited information on the use of co-products from wheat or sorghum ethanol production, with most research papers based on corn ethanol co-products.

The only reported trial found where co-products were used as a supplement for grazing cattle, was a Canadian trial in which drinking water was replaced with wheat-based thin stillage (8.4% DM) for growing steers grazing crested wheat grass (Ojowi, Christensen et al. 1996). Over the 12 weeks of the trial, the average daily gain (ADG) of the supplemented steers was 53% greater than the control steers (1.39 vs 0.9 kg/day). The dry matter portion of the thin stillage contained protein (46.6% CP), digestible fibre (34.5% NDF) and 9.6% fat which provided protein and energy to the supplemented steers as the nutritional value (decreased protein, increased fibre) of the wheatgrass declined.

Replacement of drinking water with wheat-based thin stillage (6.7% DM) has also been trialled under feedlot conditions with growing and finishing steers (Fisher, McKinnon et al. 1999). While there was no significant difference in average daily gain (ADG), the animals replaced the dry basal diet with DM from the TS, giving a 31.6% increase in gain per kilogram of basal diet in the growing steers and 26.7% in the finishing steers.

Sorghum-based wet distillers grain plus solubles (SWDGS) was used to replace 50% of dry- rolled corn in a trial to determine energy content and to compare corn and sorghum ethanol co-products in finishing steers (Al-Suwaiegh 2002). The composite diets contained 30% SWDGS or 30% corn-based wet distillers grain plus solubles (CWDGS). The total CP of the diets was control 13.0%, 30% SWDGS 17.2% and CWDGS 16.1%. Steers fed SWDGS gained weight faster (10.1%) and more efficiently (8.5%) than controls. The calculated Net Energy for Gain (NEg) for SWDGS was 24.7% greater than for the dry-rolled corn (1.87 vs 1.28 Mcal/kg) although less than the CWDGS (2.00 Mcal/kg). Forty two percent (42%) of the improvement in NEg was attributed to the lipid in the WDGS and the remainder to other factors – the addition of yeast by-products, metabolisable protein and amino acids, non-fibre carbohydrates, added moisture and reduction in sub-acute ruminal acidosis. In a similar trial, co-products from an ethanol plant using an 80:20 sorghum:corn cereal blend were used in both wet (SWDGS) and dry (SDDGS) forms at 40% of steer finishing diets, replacing half of the dry-rolled corn and all of the feather meal, blood meal and urea (Lodge, Stock et al. 1997). The CP of theses diets were 13.0% control, 17.9% and 17.5% for the SWDGS and SDDGS diets. In this trial there was no significant differences between the diets in ADG although there was some increase in dry matter intake (DMI) in the steers fed the diet containing 40% SDDGS. The calculated NEg for SWDGS was 102% that of the dry-rolled corn. However, calculated NEg for SDDGS was only 80% due to an apparent lower digestibility of the dried product. Corn-based DDGS have been trialled at 40% of composite diets in finishing steers, again replacing half of the dry-rolled corn in the diets (Ham, Stock et al. 1994) with the calculated NEg for the CDDGS 21% higher than the dry-rolled corn. The CP for these diets were 12.60% for the control and 15.73% for the diet containing 40% CDDGS.

Carcass characteristics (fat thickness, quality, lean yield, marbling), and eating qualities – (shear force, tenderness, juiciness and flavour) were all unaffected by inclusion of cereal ethanol co-products in the trials that measured them (Shand, McKinnon et al. 1998; Fisher, McKinnon et al. 1999; Al-Suwaiegh 2002).

Dairy Cows

Under Australian conditions, lactating cows are generally grazed on quality pastures and supplemented with a high-energy grain supplement during milking. Unfortunately, the literature available on the use of cereal ethanol co-products in dairy cows is limited to their use in composite or total mixed diets (TMD) for housed, lactating cows.

Sorghum-based wet distillers grain (SWDG) has been tried at 15% and 30% in TMDs for dairy cows, replacing soybean, soybean meal, corn and wheat bran in isonitrogenous and isoenergetic diets (Chiou, Chang et al. 1999). There was no change in milk yield and milk fat, but a significant improvement in feed efficiency with cows requiring 6.3% lower DM intake than controls to produce a unit of 4% fat corrected milk. There was however, a decrease in milk protein, lactose and total solids yield as the percentage of SWDG increased, that may be attributed to an imbalance of amino acids and/or the high fat levels used in the diets.

Anderson compared the effect of wet or dry corn-based distillers grains plus solubles (CWDGS, CDDGS) fed at 10% and 20%, replacing ground corn and soybean meal in a TMD (Anderson, Schingoethe et al. 2006). The CP for these diets were control - 16.8%, 10% CDDGS - 16.3 and 20% CDDGS - 17.2%. They concluded that "both DDGS and WDGS can replace a portion of ground corn and soybean meal commonly fed to dairy cattle and maintain or enhance lactation performance. Cows fed distillers grain (DG) had greater feed efficiency and milk yield and maintained milk components concentrations. Either WDGS or DDGS can be used to feed dairy cows at 10% or 20% of diet DM." These conclusions are supported by others who fed corn-based DDGS at 20% or corn-based WDGS at 30% of the total diet DM (Birkelo, Brouk et al. 2004; Kleinschmit, Schingoethe et al. 2006).

One paper can be related to Australian dairying, particularly under the current drought conditions. In a diet based on alfalfa hay, alfalfa silage, beet pulp and whole cottonseed, ground corn was replaced with corn-based DDGS at 10, 20 and 30%, increasing the percentage of CP of the diets from 14% (control) to 16, 18 and 20% (Grings, Roffler et al. 1992). Milk, protein, casein and lactose yields all increased with the increase in CDDGS/CP including the 30% CDDGS diet where all ground corn had been replaced. As there was little additional benefit beyond 18% CP it could be concluded that a maximum of 20% DDGS be recommended for this type of diet. However, when formulating this type of diet on a least-cost basis it may be beneficial to replace all grain with up to 30% DDGS to achieve the same production.

Discussion – Useability in ruminants:

Diets used in beef feedlot usually contain 70 – 80% grain (Galyean 2001; Forster 2006). From the literature, it can be concluded that half of this grain (35 – 40% of the total diet) could be replaced with either wet or dried distillers grains plus solubles without negatively impacting on growth rate performance or carcass characteristics. Similarly with dairy cattle, from the literature, DDGS could be fed at 20 – 30% of total diet for dairy cows replacing grain and protein supplements such as soybean meal without affecting milk yield and quality.

However, at these rates of DDGS inclusion, there is a significant increase in dietary crude protein above the current recommendations of USA consultant nutritionists of 12.5 to 14.0% in feedlot finishing diets, 13.75 to 16.00% in feedlot receiving diets (Galyean 2001) and 14 to 16% in dairy diets. The amount of protein in ruminant diets, including urea which is used in feedlots as an alternative source of dietary nitrogen is directly related to the amount of urinary and faecal nitrogen excreted. Nitrogen in faeces and urine contribute to environmental pollution as ammonia and nitrous oxide in the air or as nitrate in soil and ground water and both beef feedlots and dairy farms are recognised as significant contributors to this form of pollution. The nitrogen cycle in the ruminant is complex, involving the growth of rumen micro-organism which is dependent on available energy and rumen degradable protein, and the animals own digestion of rumen by-pass protein, protein from micro-organisms and re-cycling of N via saliva. Formulating diets at a least-cost price for optimal performance while maximising protein utilisation and minimising N pollution is usually undertaken by limiting total crude protein in the diet to less than 15%. Research into dietary pollution and its mitigation by manipulating dietary protein is on-going and is yet to develop a model for N utilisation (Kebreab, France et al. 2001).

Comments on cereal ethanol co-products set out in two reports on the effects of establishing an ethanol industry in Australia were considered in addition to the peer-reviewed literature. A report prepared by the Centre for International Economics (CIE) for Meat & Livestock Australia (MLA) on behalf of the Australian beef industry lacks research and is dismissive of the useability of distillers grains, concluding that "distillers grains has virtually no energy content, and so has limited use in feedlots to a maximum of 20 percent of the dry ration" and by implication no use in other livestock industries (CIE. 2005). On the other hand, the report prepared for the Queensland Department of State Development and Innovation on the economics of a Queensland ethanol industry (Urbanchuk 2005) contains better researched and an accurate assessment of DDGS from grain sorghum. It particularly comments on the use of sorghum-derived DDGS in dairy cattle, stating; "The combination of by-pass protein, digestible fibre and fat in DDGS makes it a highly desirable feed for dairy cows". In the Australian dairy industry, based on pastures and grain concentrates, protein supplementation is required at certain times of the year as pasture quality recedes (Granzin 2005). DDGS with the combination of attributes as described above would be ideal to provide this supplementary feed. At the time of writing, wheat-based DDGS from the Manildra plant at Nowra, NSW is being used to supplement dairy cattle grazing drought affected pastures in southern NSW (Mark Honey, 'Riversdale', pers. com.)

Useability in non-ruminants

Pigs

In response to increased supplies of DDGS and conservative recommendations from nutritionists of a maximum of 5% inclusion of DDGS in pig diets based on research carried out between 1960 and 1980 (Whitney and Shurson 2004), there are a number of recent research papers that focus on the use of dried co-products from "new generation" ethanol plants, built during the 1990s. These plants use improved enzymes and yeasts in the fermentation process and lower temperatures during drying, processes to improve the nutritional value of the DDGS. As the Australian ethanol industry should be based on the latest technology, the useability of ethanol co-products in pigs has been based on these papers. Most research into the use of cereal ethanol co-products in pigs is based on corn, with little material on the use in pigs of co-products from sorghum or wheat.

Nyachoti (Nyachoti, House et al. 2005) examined the energy and nutrient digestibility in wheat-based DDGS using grower pigs, cannulated for apparent ileal digestibility (AID) studies. In the chemical analysis, the gross energy of the wheat grain was lower than both the wheat-based DDGS samples (16.9 vs 20.5 and 20.3 MJ/kg). However, the overall results indicated that the digestible energy (DE) content of wheat-based DDGS in pigs is about 7.5% lower than the DE content of wheat grain. It was also found that the AID for almost all amino acids in the wheat-based DDGS was lower than for wheat. This was consistent with similar studies in corn. The wheat-based DDGS had considerably higher fibre than wheat which could reduce feed intake, nutrient utilisation and growth rate, particularly in young pigs. It was concluded that with sufficient knowledge on the digestibility and availability of nutrients from wheat-based DDGS in pigs, this ethanol co-product could be effectively utilised in pig diets.

In growth performance trials in which nursery pigs were fed corn-based DDGS from new generation ethanol plants at 5, 10, 15, 20 and 25%, replacing corn in the diet, it was found that dietary treatments did not significantly affect growth rate, feed intake or feed efficiency during the 35 days of the trial (Whitney and Shurson 2004). The researchers concluded that " the corn DDGS used in this experiment seems to be an acceptable amino acid, energy and phosphorus source for weaned pigs weighing more than 7 kg and can be included in Phase 2 and Phase 3 nursery diets at levels up to 25% without negatively affecting feed intake, growth rate or feed conversion".

The same research group (Whitney, Shurson et al. 2006) carried out a similar study with grower-finisher pigs (initial weight 28.4 kg) in which corn-based DDGS, sourced from the same plant as that use in the nursery pig trial, was included in trial diets at 10, 20 and 30%, replacing corn and soybean meal in diets standardised on a total amino acid basis. This study examined both growth performance and carcass composition. The results indicated that while the grower-finisher pigs readily consumed diets containing 30% CDDGS, the final weights for the pigs fed the control and the 10% CDDGS diets were greater than pigs fed the 20% and 30% CDDGS diets. This was attributed to the replacement of soybean meal as the primary source of protein with CDDGS. In those diets containing 20% or 30% CDDGS, there was an imbalance of available amino acids, with available lysine low and other amino acids in excess, requiring energy to deaminate and excrete the excess amino acids reducing feed efficiency and growth rate and increasing nitrogen in the manure. The authors concluded that the inclusion of 10% high quality corn DDGS in conventional swine grower finisher diets has no detrimental effect on pig performance, carcass quality and pork quality.

Even though research has demonstrated that nursery pigs weaned onto liquid diets have better weight gains (Kim, Heo et al. 2001) and liquid feed containing 20 – 30% DM from food industry residues are used extensively around the world, there is little current literature on the use of wet cereal ethanol co-products in pigs. In a Swedish study (Pedersen, Roos et al. 2005), wheat-based thin stillage was used to replace water in mixing liquid diets for nursery pigs. The most interesting result from this trial was the effect that the wheat-based thin stillage had on the incidence of diarrhoea. In the group receiving the TS based liquid diet, 1 of 16 piglets had diarrhoea compared to 11 of 16 in the control group. The reduction in incidence of diarrhoea was attributed to the probiotic effect of the lactobacilli in the thin stillage.

Poultry

Most recent literature on the use of cereal ethanol co-products in poultry is restricted to corn ethanol co-products, but covers a range of use from day-old to market weight broilers, laying hens and turkeys and included the use of wet and dry co-products.

Wet corn stillage (25 – 55% DM) has been trialled to test whether undried ethanol co-products can be used in poultry thereby saving the energy and costs associate with drying (Hunt, Lyons et al. 1997). The conclusions from these trials were that broiler chicks can efficiently utilize diets containing 8% stillage (DMB) and turkey chicks diets containing 16% stillage (DMB) and that the poultry industry could effectively utilize high-moisture stillage as an ingredient.

As with pigs, there has been interest in testing corn-based DDGS from modern ethanol plants in poultry diets at levels greater than the 5% that has been recommended for many years. CDDGS from an ethanol plant built in the early 1990s has been tested in all phases of broiler diets from day-old to market weight broilers and in grower-finishing turkeys. The conclusion from these trials were that the CDDGS could be used to feed broilers in starter diets from 9% to 12% and in grower-finisher diets up to 15% without affecting growth rate, feed efficiency or carcass yield (Lumpkins, Batal et al. 2004) and in turkeys at 10% (Roberson 2003).

On the same basis, CDDGS from a modern corn ethanol plant have been trialled in laying hen diets (Lumpkins, Batal et al. 2005). The results showed that replacing corn and soybean meal with 15% CDDGS in a high density commercial diet had no significant difference in egg production and egg characteristics – weight, shell strength, yolk colour and interior egg quality, but did depress egg production in a low-intensity diet. From these results, the researchers recommended that maximum inclusion levels of 10% to 12% CDDGS in standard commercial laying hen diets.

Aquaculture

Feeding fish high protein diets accounts for 50 - 60% of the total production costs (Wu 1996; Cheng 2004). Traditionally, the source of protein has been fish meal, but with increased availability and interest in the use of cereal ethanol co-products, these have been considered as a cheaper, plant-based source of protein for use in warm-water aquaculture.

Of interest for Australian aquaculturalists is the use of DDGS in the diets of Rainbow Trout (*Oncorhynchus mykiss*) (Cheng 2004). Corn-based DDGS were trialled as a replacement for herring meal in a pelleted fish food with this species. Weight gain, feed conversion and phosphorous retention were assed. The excretion of phosphorous from farmed fish fed high phosphorous fish meal can cause freshwater pollution. The conclusions from this trial was that the replacement of 50% of the fish meal in the diet by the inclusion of CDDGS at 15% of the total DM made no significant difference to body weight gain and feed conversion and could be increased to 22.5% of the diet replacing 75% of the fish meal with supplementation of lysine and methionine. The retention of phosphorous increased as fish meal was replaced with CDDGS in the diet.

Papers are available in the literature that describe the use of DDGS in aquaculture diets with channel catfish (Webster 1993), Tilapia (Wu 1996) and Australian red-clawed crayfish (*Cherax quadricarinatus*) (Thompson, Metts et al. 2006).

Discussion - Useability in non-ruminants

Research that has recognised the improved quality of DDGS from modern ethanol plants in the USA has increased the recommended percentage of inclusion of ethanol co-products in the diets of pigs and poultry in that country. For example, the research findings of Whitney (Whitney, Shurson et al. 2006) have been used as a basis of an article in the November 2006 issue of the Iowa Farm Outlook to advocate the use of 10, 20 or 30% DDGS in the diet at three different feed price scenarios to lower feed cost of gain (Lawrence 2006). Further improvement in the quality of DDGS with new technologies such as Eluseive will allow for greater utilisation of DDGS in non-ruminants as the amount of fibre in the DDGS is reduced.

Table 4: Summary of research literature recommendations on the maximum percentage of DDGS that can be included in intensive livestock diets while maintaining growth and other performance indicators.

Class of livestock	Percentage of DDGS in Total Mixed Diets	Comment
Beef cattle Feedlot finishing steers	40%	This level of inclusion of DDGS will produce a diet that exceeds the current recommended maximum crude protein level (15%) for feedlot finishing diets leading to excess N excretion and environmental pollution.
Dairy cows – lactating	20%	20% is the accepted level although use up to 30% has been reported in the literature. High protein diets (18% CP with 20% DDGS in diet) will lead to environmental pollution.
Pigs – nursery greater than 7 kg	25%	The high fibre in wheat-based DDGS can lead to reduced feed intake and reduced growth rates in young pigs
Pigs – grower-finisher	10%	Corn-based DDGS at greater than 10% inclusion in the diet led to imbalance of amino-acids in the diet and reduced performance.
Poultry – Broilers – starter diet	9 – 12%	
Poultry – Broilers – grower-finisher diet	15%	
Poultry – Turkeys – grower-finisher diet	10%	
Poultry – Laying hens	10 – 12%	
Aquaculture – Rainbow trout	15 – 22.5%	Use at the higher level required supplementation with Lysine and Methionine

Bio-ethanol from sugars

At this time the co-products from converting sugars to ethanol in Australia are not used in the livestock industries.

The production of ethanol from C molasses derived from sugar cane has two co-products: bagasse (sugar cane residue) which is used as a fuel for the generation of heat and electricity in sugar mills, including as a source of heat energy in the distillation phase of ethanol production from C molasses, and dunder, the residue from the process of fermentation and distillation of C molasses for ethanol. CSR at their Sarina distillery at Mackay have produced a liquid fertilizer based on high-density, high potassium ‘bio-dunder’ that is blended with nitrogen and other elements to form a complete, one-shot liquid cane fertilizer (Naughten 2001). The impact to the livestock industries of the production of ethanol from sugar cane will be the effect on the price and availability of C molasses as more is used to produce ethanol.

The production of ethanol from sugar beet may be a possibility in southern Australia. A report to the Rural Industries Research and Development Corporation (RIRDC) sponsored by RIRDC, CSR Ltd and the Tasmanian Department of Primary Industries, Water and Environment, released in February 2005 (Thompson 2005) examined the feasibility of ethanol production from sugar beet in North-east Tasmania. In the appendices to the report there is a comprehensive literature review on the effect of sugar beet and fodder beet on animal production and the implications for Tasmania.

In summary, production of sugar from sugar beet in Europe has produced considerable literature on the use of all parts of the sugar beet – crown, tops and roots. The leafy tops can be fed in limited amounts although they are quite laxative and contain some potentially toxic compounds – oxalates and nitrates. At some times of the year they can contain oestrogens and have also been reported to produce milk-taint. They can be strip grazed by cattle and sheep or made into silage which reduces the nitrate toxicity. For the production of ethanol, the sugar beet plants would not be grazed but be harvested whole, as grazing can reduce the sugar content of the roots, and the combined crown and leaves removed, chopped and ensiled. The use of the ensiled tops can be limited by the amount of labour required and the level of knowledge necessary to use these feeds safely.

Following the extraction of sugar from the sugar beet roots, three forms of highly palatable fibrous co-product are available as livestock feed – pressed beet pulp, dried shredded beet pulp and dried molasses beet pulp. Beet pulp is high in fibre but low in protein, fat and phosphorus. Addition of beet molasses to the shredded pulp before drying produces dried molasses beet pulp which is a high energy, carbohydrate-rich feed.

Pressed beet pulp, a wet feed containing 18 to 28% dry matter, has a 5 to 7 day shelf life. It can be fed directly to beef and dairy cattle as a portion of a mixed diet but is usually ensiled as a secondary forage source with grass or maize to overcome the short shelf life.

Dried molasses beet pulp is a useful product, particularly for dairy cattle. The high fibre, low starch material reduces sub-acute rumenal acidosis and low milk-fat syndrome. A number of studies have shown that it can be used to replace grain in high-concentrate dairy rations, in one experiment up to 50% cracked wheat, without compromising overall milk yield, milk composition or tainting milk.

In the Executive Summary of the report to RIRDC (Thompson 2005) under Economic Assessment of By-Products, the authors state:

> An assessment was made of the value of the by-products following beet processing. Advances in processing technology enable the pulp to be available as a high value animal feed. This pulp can be fed in the wet form or pressed and dried. The energy value of this feed is similar to that supplied by grain hence the retail price of both products should be comparable. A local market for the pulp was identified and if developed would result in significantly less feed grain being annually imported into Tasmania.

Co-products from biodiesel

Biodiesel in Australia will be derived from imported palm oil, re-cycled cooking oils, tallow and vegetable oils from canola and soybean. Co-products of interest to the livestock industries are the meals left following the extraction of the vegetable oils – canola meal and soybean meal. In 2004 – 2005 Australia produced more than 1533.0 kiloton (kt) of canola seed which, assuming all of it was used for the extraction of canola oil, provided approximately 900 kt of canola meal, all of which was used in Australia. Although 55.7 kt of soybean was grown in Australia in the same period, 377.16 kt of soybean meal was imported (ABARE 2005). From these figures, it appears that Australia is currently short of high protein meals for intensive livestock production. Development of both biodiesel and bioethanol industries in Australia will improve the availability of high protein feedstock.

Both canola and soybean meal are used as livestock protein supplements. Soybean meal has higher protein (46.2% vs 33.6%), lower fibre (6.1% vs 13.6%) and higher amino acid levels than canola meal (ALFI 2004). These high-protein meals are mainly use in pig and poultry diets although depending on price and availability they are used as protein supplements for dairy cows (Granzin 2005). They are not used in beef feedlot diets where grain protein is usually supplemented by the addition of urea which can be utilised by the rumen micro-organisms or cheaper protein sources such as whole cottonseed.

Methods have been developed to treat both meals to produce rumen-bypass proteins. Soybean meal-based rumen by-pass protein is commercially available in the USA as Soy Pas (Lignotch USA) and a canola-based product Rumentek® is available in Australia. Improvement in performance due to the inclusion of these oilseed meal-based rumen by-pass proteins have been demonstrated in dairy cows (White, Staines et al. 2004; Kalscheur, Baldwin et al. 2006), prime lambs (Wiese, White et al. 2003) and for wool production (White, Young et al. 2000).

The production of biodiesel from oilseeds with the consequent increase in availability of good quality protein meals should benefit the livestock industries. However, if this coincides with significant cereal ethanol production, a reduction in feed-grain availability and an increase in high protein DDGS, it could become difficult to formulate high energy, low protein livestock diets that minimise nitrogen excretion and environmental pollution.

Viability of transporting, storage and drying co-products from cereal ethanol

For a dry-grind cereal ethanol plant, wet stillage is a waste product that presents an acute disposal problem due to its high organic content and the consequent biological oxygen requirements making it difficult to dispose of. On the other hand, it also presents an opportunity to market a livestock feed product.

The minimum treatment required is separation of the thin stillage from the wet distillers grain then dispose of these products. Thin stillage can be fed directly to cattle as a water source, sprayed onto land if sufficient land is available or condensed to form condensed distillers solubles, a process that can recycle water and heat back into the ethanol production process. The useability of wet distillers grain, with or without the addition of condensed distillers solubles has been described. In ruminants, the wet product, WDGS, has a slight advantage in digestibility and rumen by-pass protein and generally has a higher calculated net energy for gain (NEg) as has been shown in comparative trials with DDGS. However it has disadvantages in transportation and storage.

Transportation

To move the same amount of dry matter for livestock consumption, approximately three times the weight of WDGS (30% DM) compared to DDGS (90% DM) needs to be transported. In addition, transportation and storage of wet organic material requires compliance with EPA regulations such as the use of leak-proof trucking and storage bins. The cut-off distance after which it is uneconomical to transport and feed WDGS is dependent upon both the transport price and the relative price of alternative feedstuff such as DDGS, cereal grains and high-protein oilseed meals.

Storage

The main problem in using WDGS, particularly under Australian conditions, is that it is a good medium for mould growth and cannot be stored in the form in which it is delivered from the ethanol plant for more than 3 – 5 days (Walker 2004) before it is no longer usable. A number of methods have been developed to overcome this problem.

Ensiling

As WDGS has already undergone a fermentation process, it will not ensile without the addition of fermentable material. Ensiling with Napiergrass, a fast-growing tropical grass with low nutritive value has been shown to give good results in laboratory trials, with the inclusion of up to 60% sorghum WDG in the mix (Chiou, Chang et al. 2000). The inclusion of sorghum WDG improved the silage quality, increasing the water soluble carbohydrates and lactic acid concentration and lowering the silage pH. While adding WDGS into material being laid down for silage is a method of storing WDGS, it is limited to the seasonal availability of the additional fermentable material required.

Mould inhibitors

Organic acids and mould inhibitors such as ZeniPRO™ from Kemin Americas Inc. are commercially available in the USA and claim to extend the storage time for WDGS to more than 21 days without affecting cow performance (Drackley 2004).

Vacuum storage

WDG can be stored in silage bags for up to 14 days without deteriorating, but much longer storage times have been achieved through vacuum storage. In one trial, up to 70 tons of freshly produced WDGS (36.5% DM) was bagged using thick plastic with a vacuum pump connected to each bag. Vacuum was maintained by running the pump three times each day. Although the WDG did not ensile, the data suggested that by using this system WDG could be stored for up to 260 days. However, once the vacuum was broken to allow feeding of the stored WDG, invading mould spores limited the time during which the material could be fed out and led to some wastage (Walker 2004).

Drying

Despite the energy cost, drying is the most common method of ensuring disposal of WDG. DDGS, a crumble meal with 90% DM, is able to be stored, transported, mixed into dry rations, incorporated into pelletted feed and used in both ruminants and non-ruminants and is thus much more marketable than WDG. As has been noted (see Variability) the drying equipment used in new ethanol plants is more reliable, causing less variability and damage to essential amino acids, particularly lysine and methionine that are subject to the Maillard reaction, a response to heating that reduces the availability of these amino acids to the digestive process.

While from an energy perspective it appears preferable to avoid drying ethanol co-products, in practice there appears to be advantages for an ethanol plant to be able to dry and distribute co-products into the livestock feed marketplace instead of relying on disposal of wet product via local feedlots and dairies. The ability to dry co-products allows a plant to avoid being placed in a situation where the continual necessity to safely dispose of wet co-product allows the price to be set by the users or being unable to dispose of wet product due to factors beyond their control e.g. the closure of a feedlot.

Opportunities for intensive livestock producers to reduce their input costs

As the production if biofuels has expanded in America and Europe, one issue gaining attention is the implication for livestock feed supplies as corn or other grains are used for ethanol production and diverted from animal feed or exports. This issue is also of concern for Australian intensive livestock producers (CIE 2005). However, there are potential opportunities for livestock producers to take advantage of the development of biofuels in Australia.

Co-location for the utilisation of wet distillers grain and energy efficiencies

Wet distillers co-products (WDGS) can be fed to beef cattle in feedlots (Al-Suwaiegh 2002) or to dairy cows (Chiou, Chang et al. 1999) in total mixed diets. The energy saving in not having to dry, together with the imperative to move a potential waste co-product should be reflected in the price to provide a relatively inexpensive but useful feedstock. However, problems of transportation and storage as described would require location of the feedlot or dairy near the ethanol plant. Rural cooperatives could set up vertical integration of cereal cropping, ethanol plant and co-located dairies or feedlots using WDGS. The use of WDGS to replace a portion of the grain normally included in the diets would offset increased grain prices and the integrated ownership provide the certainty necessary for a plant to rely on livestock production for the disposal of wet co-products.

The production of biogas through the anaerobic digestion of cattle manure combined with excess wet co-products (Tafdrup 1995) could further contribute to the energy efficiency or the cash-flow of a co-located ethanol plant and feedlot or dairy.

Increased availability of protein meals

The production of biofuels in Australia should significantly increase the amount of high protein meals (oil seed meal and DDGS) available for Australian livestock industries. This should moderate the price of these meals, a benefit to the pig, poultry and dairy industries. There is also a big potential to use these to supplement ruminants grazing low-protein pastures, not only for survival during drought, but also strategically to improve breeding and other production traits. DDGS would be ideal for this use as it is low in fermentable carbohydrates and consequently much safer than grain as a supplement as it will not cause rumen fermentation and acidosis.

Research Opportunities

What needs to be known that will encourage those proposing to develop biofuel plants in Australia to install the technology required to produce co-products that are of value to livestock industries? How can co-products such as Australian made DDGS be assessed for quality, useability and marketability prior to building and operating plants in Australia?

Modelling

From the compositional data available on several varieties of Australian grains that may be used in ethanol production, CSIRO has modelled the composition of the DDGS that could be produced from these grains (Peter Kennedy pers.comm.). Using the Cornell Net Carbohydrate and Protein System that predicts feed requirements, feed utilization, animal performance and nutrient excretion in dairy and beef cattle he was able to model the use of these virtual DDGS from Australian grains in beef feedlot diets. This is indicative of the possibilities for using modelling to assess the likely quality and useability of DDGS from Australian grains in Australian livestock industries. Modelling could also be extended to predict the effects of new technology such as the Eluseive process on the useability of co-products.

Product Testing

While modelling will be useful, prediction of the nutritional value of DDGS based on laboratory measurement of composition is limited. In nutritional research, techniques such as rumen-fistulated cows, ileum-cannulated pigs and caecectomized chickens are required to provide accurate information on the digestibility and uptake of nutrients. This type of nutritional research, together with performance trials will be necessary to fully evaluate the usefulness of Australian produced biofuel co-products in all the intensive livestock industries.

Drought supplements

There is little specific information in the literature about the use of biofuel co-products as feed supplements for grazing animals e.g. drought supplementation, with most research based on the use of the products in total mixed diets. Development of advice and knowledge on the use of the co-products as supplements would be useful for their utilization. The use of wheat-based thin stillage to supplement grazing steers described above suggests that condensed distillers solubles could be stored and transported in sealed containers and used with molasses in drum rollers to supplement digestible fibre, energy and rumen-bypass protein for ruminants grazing low quality pastures.

High nitrogen feeds and environmental pollution

One of the issues raised in this review of the use of biofuel co-products in livestock, is the environmental pollution associated with the use diets containing high levels of protein. Biofuels utilise the energy of fats, sugars and starches from grains leaving the nitrogen-rich protein portion of the original grain concentrated in oilseed meals or distillers co-products. How these high protein co-products are used and how the consequent nitrogen excretion is handled is already being considered but still represents a significant knowledge gap in the utilisation of biofuel co-products.

References

ABARE. (2005). "oilseeds.xls." from http://www.abareconomics.com/interactive/acs_2005/htmlversion/excel_acs/oilseeds.xls - 251k - [xls] -

Al-Suwaiegh, S., Fanning, K. C., Grant, R.J., Milton, C.T., and Klopfenstein, T.J. (2002). "Utilizatiion of distillers grains from fermentation of sorghum or corn in diets for finishing beef and lactating dairy cattle." J. Anim. Sci. **80**: 1105-1111.

ALFI. (2004). "Australasian livestock feed ingredient database [computer file]."

Anderson, J. L., D. J. Schingoethe, et al. (2006). "Evaluation of dried and wet distillers grains included at two concentrations in the diets of lactating dairy cows." Journal of Dairy Science **89**(8): 3133-3142.

Batal, A. and N. Dale (2003). "Mineral composition of distillers dried grains with solubles." Journal of Applied Poultry Research **12**(4): 400-403.

Belyea, R. L., K. D. Rausch, et al. (2004). "Composition of corn and distillers dried grains with solubles from dry grind ethanol processing." Bioresource Technology **94**(3): 293-298.

Birkelo, C. P., M. J. Brouk, et al. (2004). "The energy content of wet corn distillers grains for lactating dairy cows." Journal of Dairy Science **87**(6): 1815-1819.

Cheng, Z. J., Hardy, R. W. (2004). "Nutritional Value of Diets Containing Distiller's Dried Grain with Solubles for Rainbow Trout, *Oncorhynchus mykiss*." Journal of Applied Aquaculture **15(3/4)**: 101-113.

Chiou, P. W. S., S. H. Chang, et al. (1999). "Studies on the use of wet sorghum distiller's grains in lactating cows." Asian-Australasian Journal of Animal Sciences **12**(6): 895-900.

Chiou, P. W. S., S. H. Chang, et al. (2000). "The effects of wet sorghum distillers' grains inclusion on napiergrass silage quality." Journal of the Science of Food and Agriculture **80**(8): 1199-1205.

CIE. (2005). *Impact of ethanol policies on feedgrain users in Australia.* Prepared for MLA on behalf of the Australian Beef Industry.**:** 50-51.

Corredor, D. Y., S. R. Bean, et al. (2006). "Effect of decorticating sorghum on ethanol production and composition of DDGS." Cereal Chemistry **83**(1): 17-21.

Cromwell, G. L., K. L. Herkelman, et al. (1993). "Physical, Chemical, and Nutritional Characteristics of Distillers Dried Grains with Solubles for Chicks and Pigs." Journal of Animal Science **71**(3): 679-686.

Drackley, J. K. (2004). Efficacy of a Preservative Product (ZeniPro) for Wet Distiller's Grains. Final Report to Kemin Americas, Inc.

Fisher, D. J., J. J. McKinnon, et al. (1999). "Evaluation of wheat-based thin stillage as a water source for growing and finishing beef cattle." Journal of Animal Science **77**(10): 2810-2816.

Forster, S. (2006). "Beef cattle feedlots - diet formulations." DPI&F Note, from http://www2.dpi.qld.gov.au/beef/3439.html.

Galyean, M. L., Gleghorn, J. F. (2001). Summary of the 2000 Texas Tech. University consulting nutritionist survey., Texas Tech University, Department of Animal and Food Science.

Granzin, B. C. (2005). "Effect of timing of protein supplementation on the performance of lactating dairy cows." Australian Journal of Experimental Agriculture **45**(4): 337-345.

Grings, E. E., R. E. Roffler, et al. (1992). "Responses of Dairy-Cows to Additions of Distillers Dried Grains with Solubles in Alfalfa-Based Diets." Journal of Dairy Science **75**(7): 1946-1953.

Ham, G. A., R. A. Stock, et al. (1994). "Wet Corn Distillers by-Products Compared with Dried Corn Distillers Grains with Solubles as a Source of Protein and Energy for Ruminants." Journal of Animal Science **72**(12): 3246-3257.

Hunt, J. H., J. J. Lyons, et al. (1997). "Corn stillage as a feedstuff for broilers and turkeys." Journal of Applied Poultry Research **6**(3): 310-318.

Iwanchysko, P., J. J. McKinnon, et al. (1999). "Feeding value of wheat-based thin stillage: In vitro protein degradability and effects on ruminal fermentation." Journal of Animal Science **77**(10): 2817-2823.

Kalscheur, K. F., R. L. Baldwin, et al. (2006). "Milk production of dairy cows fed differing concentrations of rumen-degraded protein." Journal of Dairy Science **89**(1): 249-259.
Kebreab, E., J. France, et al. (2001). "Nitrogen pollution by dairy cows and its mitigation by dietary manipulation." Nutrient Cycling in Agroecosystems **60**(1-3): 275-285.
Kim, J. H., K. N. Heo, et al. (2001). "Liquid diets accelerate the growth of early-weaned pigs and the effects are maintained to market weight." Journal of Animal Science **79**(2): 427-434.
Kleinschmit, D. H., D. J. Schingoethe, et al. (2006). "Evaluation of various sources of corn dried distillers grains plus solubles for lactating dairy cattle." Journal of Dairy Science **89**(12): 4784-4794.
Klopfenstein, T. (1996). "Distillers grains as an energy source and effect of drying on protein availability." Animal Feed Science and Technology **60**(3-4): 201-207.
Kohl, S. (July 2002 - June 2004). "Ethanol 101." EthanolToday, from www.ethanoltoday.com.
Lawrence, J. (2006). Impact of Hog Feed Cost on Corn and DDGS Prices. Iowa FArm Outlook. **November 15, 2006**.
Lodge, S. L., R. A. Stock, et al. (1997). "Evaluation of corn and sorghum distillers byproducts." Journal of Animal Science **75**(1): 37-43.
Lumpkins, B., A. Batal, et al. (2005). "Use of distillers dried grains plus solubles in laying hen diets." Journal of Applied Poultry Research **14**(1): 25-31.
Lumpkins, B. S., A. B. Batal, et al. (2004). "Evaluation of distillers dried grains with solubles as a feed ingredient for broilers." Poultry Science **83**(11): 1891-1896.
Lurgi. from http://www.lurgi.com/website/fileadmin/user_upload/pdfs/13_Bioethanol-E.pdf.
Mustafa, A. F., J. J. McKinnon, et al. (2000). "The nutritive value of thin stillage and wet distillers' grains for ruminants - Review." Asian-Australasian Journal of Animal Sciences **13**(11): 1609-1618.
Naughten, B. (2001). *Viability of Sugar Cane Based Fuel Ethanol*, ABARE Report to AFFA, Canberra.
Nyachoti, C. M., J. D. House, et al. (2005). "Energy and nutrient digestibilities in wheat dried distillers' grains with solubles fed to growing pigs." Journal of the Science of Food and Agriculture **85**(15): 2581-2586.
O'Connell, D., Batten, D., O'Connor, M., May, B., Raison, J., Keating, B., Beer, T., Braid, A., Haritos, V., Begley, C., Poole, M., Poulton, P., Graham, S., Dunlop, M., Grant, T., Campbell, P. & Lamb, D. (2007). *Biofuels in Australia - issues and prospects*, Rural Industries Research and Development Corporation, Canberra Australia.
Ojowi, M. O., D. A. Christensen, et al. (1996). "Thin stillage from wheat-based ethanol production as a nutrient supplement for cattle grazing crested wheatgrass pastures." Canadian Journal of Animal Science **76**(4): 547-553.
Parsons, C. M., Martinez, C., Singh, V., Radhakrishman, S., Noll, S. (2006). Nutritional Value of Conventionl and Modified DDGS for Poultry. Mult-State Poultry Nutrition and Feeding Conference, Indianapolis, IN.
Pedersen, C., S. Roos, et al. (2005). "Performance, feeding behaviour and microbial diversity in weaned piglets fed liquid diets based on water or wet wheat-distillers grain." Archives of Animal Nutrition **59**(3): 165-179.
Radhakrishnan, S., Moreau, R. A., Rausch, K. D., Belyea, R. L., Tumbleson, M. E., Singh, V. (2005). "Separation of Fibre from Distillers Dried Grains with Solubles (DDGS) Using Sieving and Elutriation." Cereal Chemistry **82(5)**: 528-553.
Roberson, K. D. (2003). "Use of Dried Distillers' Grain with Solubles in Growing-finishing Diets in Turkey Hens." International Journal od Poultry Science **2**(6): 389-393.
Rust, S. R., Newbold, J. R., Metz, K. W. (1990). "Evaluation of Condensed Distillers' Solubles as an Energy Source for Finishing Cattle." Journal of Animal Science **68**: 186-192.
Shand, P. J., J. J. McKinnon, et al. (1998). "Eating quality of beef from animals fed wet brewers' grains and wheat-based wet distillers' grains." Canadian Journal of Animal Science **78**(1): 143-146.
Singh, V. (2001). Modified Dry Grind Ethanol Process. Publication of the Agricultural Engineering Department, University of Illinois at Urbana-Champaign.

Spiehs, M. J., M. H. Whitney, et al. (2002). "Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota." Journal of Animal Science **80**(10): 2639-2645.

Srinivasan, R., Moreau, R. A., Rausch, K. D., Belyea, R. L., Tumbleson, M. E., Singh, V. (2005). "Separation of Fibre from Distillers Dried Grains with Solubles (DDGS) Using Sieving and Elutriation." Cereal Chemistry **82(5)**: 528-553.

Srinivasan, R., Singh, V., Belyea, R. L., Rausch, K. D., Moreau, R. A., Tumbleson, M. E. (2006a). "Economics of Fibre Seperation from Distillers Dried Grains with Solubles (DDGS) Using Sieving and Elutriation." Cereal Chemistry **83**(4): 324-330.

Tafdrup, S. (1995). "Viable energy production and waste recycling from anaerobic digestion of manure and other biomass materials." Biomass & Bioenergy **9**(1-5): 303-314.

Thompson, K. R., L. S. Metts, et al. (2006). "Effects of feeding practical diets containing different protein levels, with or without fish meal, on growth, survival, body composition and processing traits of male and female Australian red claw crayfish (Cherax quadricarinatus) grown in ponds." Aquaculture Nutrition **12**(3): 227-238.

Thompson, R., Campbell, S. (2005). *Sugar Beet - Preliminary feasibility of ethanol production from sugar beet in NE Tasmania.* Report for the Rural Industries Research and Development Corporation.

Urbanchuk, J. M., Barker, G., Wells, W. (2005). *Economics of a Queensland Ethanol Industry.* Prepared for the Queensland Department of State Development and Innovation.

Walker, P. (2004). "Vacuum Preservation: A Method for Storing Wet Distillers Grains." from http://ilift.traill.uiuc.edu/distillers/research/storage.cfm.

Wang, S., K. Sosulski, et al. (1997). "Effect of sequential abrasion on starch composition of five cereals for ethanol fermentation." Food Research International **30**(8): 603-609.

Webster, C. D., Tidwell, J. H., Goodgame, L. S. (1993). "Growth, body Composition and Organoleptic Evaluation of Channel Catfish Fed Diets Containing Different Percentages of Distillers' Grains with Solubles." The Progressive Fish-Culturist **55**: 95-100.

White, C. L., M. V. Staines, et al. (2004). "Protected canola meal increases milk protein concentration in dairy cows fed a grass silage-based diet." Australian Journal of Experimental Agriculture **44**(9): 827-832.

White, C. L., P. Young, et al. (2000). "The effect of dietary protein source and protected methionine (Lactet) on wool growth and microbial protein synthesis in Merino wethers." Australian Journal of Agricultural Research **51**(2): 173-183.

Whitney, M. H. and G. C. Shurson (2004). "Growth performance of nursery pigs fed diets containing increasing levels of corn distiller's dried grains with solubles originating from a modern Midwestern ethanol plant." Journal of Animal Science **82**(1): 122-128.

Whitney, M. H., G. C. Shurson, et al. (2006). "Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant." Journal of Animal Science **84**(12): 3356-3363.

Wiese, S. C., C. L. White, et al. (2003). "Growth and carcass characteristics of prime lambs fed diets containing urea, lupins or canola meal as a crude protein source." Australian Journal of Experimental Agriculture **43**(10): 1193-1197.

Wu, V. Y., Rosati, R. R., Brown, P. B. (1996). "Effects of Diets Containing Various Levels of Protein and Ethanol Co-products from Corn on Growth of Tilapia Fry " Journal of Agriculture and Food Chemistry **44**: 1491 - 1493.

Biofuel Co-Products as Livestock Feed

by Andrew Braid

RIRDC Publication No. 07/175

This report is about the co-products from the production of biodiesel and bioethanol and their use in livestock nutrition. It addresses the use of distillers grain—a co-product of cereal ethanol production in the intensive livestock industries, feedlot beef, dairy, pigs, poultry and aquaculture.

The report provides advice to the Australian livestock industry through a comprehensive review of research literature available on biofuel co-products and their use in livestock nutrition. It has been written for the owners, operators, consultants, nutritionists, veterinarians and feed millers who make the decisions on what is fed to the animals and who are faced with changes in the availability of feed stocks as the biofuel industry grows in Australia.

It will also be of interest to those entrepreneurs proposing to build and operate biofuel production facilities in Australia so that they recognise the value for their business and for the livestock industry in installing the best available new technology to ensure the production of quality co-products.

RIRDC's Bioenergy, Bioproducts and Energy R&D Program aims to meet Australia's research and development needs for the development of sustainable and profitable bioenergy and bioproducts industries, and to develop an energy cross-sector R&D plan.

The Rural Industries Research and Development Corporation (RIRDC) manages and funds priority research and translates results into practical outcomes for industry. Our business is about new products and services and better ways of producing them. Most of the information we produce can be downloaded for free from our website: www.rirdc.gov.au.

RIRDC books can be purchased by phoning 02 6271 4166 or online at: www.rirdc.gov.au/eshop.

This publication can be viewed at our website—www.rirdc.gov.au. All RIRDC books can be purchased from:

www.rirdc.gov.au/eshop

Contact RIRDC:
Level 2
15 National Circuit
Barton ACT 2600

PO Box 4776
Kingston ACT 2604

Ph: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au
web: www.rirdc.gov.au