INDUSTRIAL AND ENERGY USES OF ANIMAL BY-PRODUCTS, PAST AND FUTURE

S. A. McGlashan, Ph.D.
Manager, Environment and Co-Products
Meat and Livestock Australia, Ltd.

Summary

This chapter addresses the application of rendered products to the production of energy and other industrial uses. The high volume of rendered product generated precludes investigation into most high value/low volume markets. Future regulation relating to biosecurity and environmental protection has the potential to restrict traditional market access for rendered co-products. It is essential to develop product applications that demand large volumes of raw material to ensure the viability of the rendering industry.

Historically, tallow has had much wider energy and industrial application than protein-based meals. Fertilizer and soil conditioners were a minor avenue for animal by-products whilst there was widespread and profitable use of protein-based meals in the feed and food sector.

Rendered products have traditionally been used as a source of digestible protein, nutrients, and energy in the feed and food industries. There are physical/chemical methods for transforming that intrinsic energy value into a commercial fuel. Tallow-derived biodiesel is the most obvious alternative use for animal by-products. Use of protein meals as energy sources is technically feasible using pyrolysis, anaerobic digestion, and incineration/co-firing, but may have economic limitations.

The potential for industrial uses of protein meals is limited. Proteins are a potential raw material for bio-based plastics and carton board adhesives. Natural forms of hydroxyapatite, found in high-density leg bones of cattle, sheep, and goats, has application as an absorbent, a catalyst, a dental substrate, and as a bone substitute. If these industrial applications are to be realized there are several technical and economic hurdles to overcome.

Historical and Current Uses of Rendered Products

Historically, non-feed, non-food applications for rendered co-products, with the exception of tallow, has tended to be limited in their application to niche markets (Pearl, 2003). Generally, these markets were too small to support large volumes of meat and bone meal and poultry meal.

Hundreds of industrial chemical applications have used, and in some cases still use, fat and fatty acids as a feedstock, whereas relatively few applications were developed for meat and bone meals beyond adhesives, soil conditioners, and fertilizers. The onset of World War I and II saw significant demand for rendered glycerin for the production of explosives, specifically tri-nitroglycerin or TNT. The demand for rendered co-products for these applications (see Table 1 for more examples) has declined with the increase in use of widely available, and often cheaper, petroleum/synthetic-based products.

Table 1. Industrial Uses for Fats and Fatty Acids.

Explosives	Makeup	Paints
Saddle soap	Solvents	Industrial oil and lubricants
OLEO margarine & shortening	Chemicals	Rubber products
Crayons	Insecticides	Floor wax
Cosmetics	Paraffin	Herbicides
Ceramics	Dish and hand soap	Medicines
Creams and lotions	Mink oil	Antifreeze
Tallow for tanning	Shaving cream	Biodegradable detergents
Hair conditioner	Bone char to filter and decolorize sugar solutions	Bone china

Source: California Department of Food and Agriculture, www.cdfa.ca.gov/ahfss/mpi/by_products.mtm.

The process of rendering animal parts has been documented for at least 2,000 years (Grummer, 1992). The purpose of rendering was to produce tallow and other rendered animal fats to make soap and candles.

Energy Production

Tallow can be used directly as a boiler fuel or to manufacture biodiesel. Some systems may require filtration for fats and greases before use as boiler fuel. Inadequately filtered biofuel could cause fuel handing problems and increased gaseous emissions.

Agricultural and Industrial Applications

Soap making was a major use of tallow. In the nineteenth century the Industrial Revolution transformed the agriculture sector. The development of intensive livestock production led to a burgeoning disposal problem. Rendering became an attractive solution. Early twentieth century processes separated the fat and water from the protein, called tankage, which was then used as a fertilizer.

Protein streams from rendered co-products are well suited to adhesive applications due to the large number of available chemical functionalities for bond formulation. Animal-based adhesives have been used since the early 1800s and consumption peaked at 70 million kilograms (kg) (approximately two percent of current consumption of petroleum-derived adhesives) in 1948. Low cost synthetic adhesives quickly infiltrated the market after World War II, making its animal-based, and technically inferior, competitor economically non-viable.

Future Uses of Rendered Products

The high volume of rendered product generated precludes investigation into most high value/low volume markets. It is essential to develop product applications that demand large volumes of raw material to ensure the viability of the rendering industry. No differentiation is made between types of tallow or protein for future uses.

Energy

Rendered products have traditionally been used as a source of convertible protein, nutrients, and energy in the feed and food industries. There are physical/chemical methods for transforming that intrinsic energy value into a commercial fuel.

Biodiesel

In 1898, Rudolph Diesel first demonstrated his compression ignition engine at the World's Exhibition in Paris. Its fuel source was based on peanut oil, the first biodiesel. Diesel believed biomass fuel to be a viable alternative to the resource consuming steam engine. Vegetable oils were used in diesel engines until the 1920s when an alteration was made to the engine, enabling it to use a residue of petroleum - what is now known as diesel No. 2.

Biodiesel is a diesel fuel substitute produced from renewable sources such as vegetable oils, animal fats, and recycled cooking oils. Biodiesel is biodegradable and non-toxic, and has significantly fewer emissions than petroleum-based diesel when burned. Biodiesel functions in current diesel engines, and is a possible candidate to replace fossil fuels as a significant supplier to the world's transport energy.

Biodiesel is produced by the transesterification of animal fats such as tallow; the triglycerides react with methanol to produce methyl esters and glycerides. The process is typically catalyzed by either sodium hydroxide (NaOH) or potassium hydroxide (KOH) to increase reaction rates. The product of the process is a liquid fuel similar to regular diesel. Biodiesel has a gross calorific value of approximately 33.3 megajoules per liter and a density of 0.88 kg per liter (Khan, 2002). One advantage that biodiesel offers over some other energy sources (such as methane) is that the resulting fuel is already in liquid form and is therefore more easily stored and transported. Biodiesel is already in wide use around the world. It is blended with diesel in the same way that ethanol is blended with petrol. Biodiesel, however, has been found to be suitable for blending at much higher concentrations than ethanol without requiring engine modifications. The standard blend is 20 percent biodiesel, 80 percent diesel (Paisley, 2003). However, depending on its use, biodiesel production from tallow offers challenges that biodiesel production from traditional vegetable oils does not.

One disadvantage that biodiesel produced from tallow has as a liquid fuel is related to its cold flow properties. Crystallization in tallow esters (biodiesel) occurs due to the high melting points of the saturated fatty acid esters present in the biodiesel (Papadopoulos, 2005). Neat (100 percent) methyl tallowate biodiesels have been shown to crystallize at significantly higher temperatures than regular diesel (i.e., up to 15ºC). This is attributed to the high levels of saturated fatty acids present in beef tallow, leading to the production of methyl stearate by esterification (melting point of methyl stearate is 39.1°C).

Several options exist for the improvement of cold flow characteristics, including blending with regular diesel, use of branched chain alcohols, and the use of additives. Blending with regular diesel is the current preferred method due its simplicity and practicality (National Biodiesel Board, 2005). The use of branched chain alcohols in the esterification reaction (isopropyl alcohol instead of methanol) has been shown to improve cold flow properties. The resultant diesel will comprise isopropyl tallowate instead of methyl tallowate. This indicates that isopropyl esters have a crystallization point 7°C to 11°C lower than methyl esters produced from the same source (Wang, 2003). The problem with the use of branched chain alcohols is the increase in costs of manufacture. The use of additives similar to those used in regular diesel would be ideal. Currently, however, such additives do not exist.

A method for improving the cold flow properties of biodiesel is "winterization." This process essentially involves cycling the biodiesel through cooling stages and filtering out the crystallized components. This process reduces the amount of saturated (higher melting point) methyl esters and therefore improves the cold flow characteristics. However, it is impractical in mass production due to the large amount of product lost during the filtration and due to the energy requirements involved with the repeated cooling stages. Obviously, future improvements of cold flow characteristics are likely to come from methods that inhibit crystal formation and growth rather than from the removal of the low melting point components.

By-products of Biodiesel Production

Biodiesel would be produced from the animal fat extracted by the rendering process. The fats produced by the rendering process can be divided into two groups, edible and inedible. Edible fats are likely to attract a higher price in the food industry. Inedible rendering products typically attract a lower price and may be more suitable for biodiesel production.

Higher levels of free fatty acids (FFA) generally mean lower quality and value of the tallow. A higher FFA composition is likely to require more pre-treatment before biodiesel production, and will generate a lower quality glycerin by-product. Commercial operations do exist that convert FFA to biodiesel in the presence of acid-based catalysts where the FFA content is less than 20 percent.

Table 2 is a summary of the mass and energy balances used to calculate the economic viability of biodiesel production with a basis of one 400 kg steer input to the process, derived from the overall mass balance.

Table 2. Mass Balance for Bio-Diesel Production.

	Input	Output	Source
Tallow	37.20 kg		Overall mass balance
Methanol	3.72 kg		Stoichiometry (Duncan, 2003)
Glycerin		3.72 kg	Stoichiometry (Duncan, 2003)
Biodiesel		37.20 kg	Stoichiometry (Duncan, 2003)

The primary benefit would be the conversion of low value inedible rendered products to a higher value medium energy content fuel. Such a process could either reduce the overall energy demand of a site or provide a valuable liquid fuel for transport and sale. The rate of production of biodiesel is almost 1:1 input animal fat reacted in weight terms.

Currently, diesel prices are high enough to ensure significant industry profitably. However, current prices are significantly above historic averages, and a return to historic averages would make the industry unsustainable.

Given the relatively low effect of capital cost on the production cost of biodiesel, compared to the cost of the feed tallow, economic viability in the future will not be greatly enhanced by technological improvements in processing. The future viability of biodiesel production will be determined by the price of regular diesel fuel and the cost of the tallow feedstock. Additionally, the long-term economic viability of biodiesel production will be affected by the tax arrangements for alternative fuels. Overall, the viability of biodiesel fuels is heavily influenced by market trends, due to the low capital cost proportion of the investment, and the widely variable prices of both feed and product streams. The relatively inexpensive alternative of natural gas for on-site heating and the need for tax relief or sustained high diesel prices affect the viability of investments in biodiesel fuels.

Given the political instability of Middle East oil trading nations, the long term cost of crude oil (and therefore diesel) cannot reliably be predicted, thus increasing the potential risk of the investment. While the market for tallow remains, meat producers producing tallow from a rendering operation would be better off selling the tallow, possibly to a centralized biodiesel producer if the current trend of increasing oil prices continues, rather than taking on the potential economic risks associated with biodiesel production themselves. Renderers can potentially reap the benefits of biodiesel production from a centralized facility and take advantage of economies of scale benefits in the form of increased tallow prices, without incurring operation costs themselves.

The operating costs of biodiesel production estimated in "Potential Feedstock Supply and Costs for Biodiesel Production" (Nelson, 1994) indicate that most of the operating cost associated with typical biodiesel production is the cost of the raw material (oil/fat). The cost of methanol, labor, catalyst, and auxiliaries was deemed to be very low; in this study, the raw material cost was estimated as 85.8 percent of the total yearly operating costs.

The utilization of this technology depends heavily on the type of rendering that a plant is using, and therefore the possible feeds into the biodiesel production process. Considering the evaluation of Nelson (1994), economic viability of tallow to a biodiesel operation is most dependent on the cost of the primary feedstock. For this reason, a plant producing high-quality, high-value tallow capable of being sold for edible purpose is much less likely to benefit from this technology than one producing low grade tallow for livestock feed.

Hydrogen Production from Glycerol

Glycerol is a major by-product of the production of biodiesel via esterification of animal fats. While glycerol has its uses in the manufacture of soap and other chemicals, its value is expected to decline in the coming years as a result of increased biodiesel production worldwide. The U.S. Department of Energy predicted in 2004 that biodiesel production could reach two billion gallons per year after the implementation of renewable energy incentives. This level of biodiesel production would result in the co-production of two billion pounds of glycerol per year. The *Chemical Market Reporter* stated, also in 2004, that the worldwide demand for glycerol was 494 million pounds. This expectation that supply will outstrip demand resulting in lower glycerol prices gives reason to explore alternative uses, given that the economic viability of the biodiesel production process is at least in part dependant on the sale of glycerol.

Thus, entirely new applications for glycerol need to be developed. A promising process involves aqueous-phase reforming of glycerol to produce hydrogen (Liu, 2005). Hydrogen is a clean fuel and feedstock to the energy and industrial chemicals industries. One of the advantages of this process is that the reforming reaction and the water/gas shift reaction are both thermodynamically favorable at similar operating conditions. As a result, it is possible to have the reactions in this process take place in a single vessel. Liu (2005) indicates that an optimum temperature for reforming is approximately 250°C, and under these conditions the product gas from the reformer contains 63.8 percent hydrogen and 33 percent carbon dioxide with the remainder ethylene and methane. This gas could be used in combustion systems as is; however, pressure swing absorption can be used to generate a pure stream of hydrogen and a pure stream of carbon dioxide, which would represent more valuable products. The benefit of this operation is conversion of glycerol to a more valuable product, hydrogen. Hydrogen can be used as a chemical feedstock for the production of ammonia or methanol. Methanol production may be of particular interest as it is one of the reactants required to produce biodiesel upstream. Hydrogen can also be used as a fuel in fuel cells. Given the environmental benefits of fuel cells over standard internal combustion engines, it is likely that the demand for pure hydrogen may rise in the future, and glycerol reforming is likely to be a cost-effective method of producing pure hydrogen from a non-fossil fuel source. The pure carbon dioxide by-product also has a value to the food industry and as a refrigerant in the meat industry. Its supply is, however, relatively abundant. It should be noted that although the process has a carbon dioxide outlet stream, it is still considered carbon neutral as far as greenhouse gases. This is because the carbon released was previously absorbed during the creation of organic matter rather than sourced from fossilized fuels.

Ultimately, the viability of this process is dependant on the value of the feed, glycerol, which is expected to decrease with future surplus supply.

Uses for Meat and Bone Meal

Meat and bone meal (MBM) revenue is an important aspect to the profitability of rendering operations and meat industry in general. The ramifications of a total feed ban needs special consideration. If a feed ban were implemented, it would be essential to have alternative, profitable, avenues for the use of MBM.

Pyrolysis

Pyrolysis is a similar technology to gasification. However, pyrolysis occurs in the absence of air and the product is a liquid rather than a gas. The product of pyrolysis is called bio-oil and has a heating capacity of around 16 to 19 megajoules per kg (Paisley, 2003). Bio-oil yield rates are strongly enhanced by providing heat at a faster rate into the reactor, which in turn enhances the pyrolysis reaction rate. This reaction is rapid thermal pyrolysis, or RTP. In order to achieve these fast reaction rates, the feed is typically ground into fine particles (less than two millimeters) (Paisley, 2003). In order to aid reaction speed and decrease moisture content in the bio-oil, the feed typically needs a moisture content of less than 15 percent. Particle size reduction and drying technology may also be required depending on the waste to be treated.

Table 3. Mass Balance for Pyrolysis—Output from Input of 32 kg MBM (Approximate Yield from Steer).

	Output	**Source**
Bio-oil	20 kg	Based on 560L/ton input (Wisconsin Biorefining)
Char	8 kg	Based on 15 - 25% yield (DynaMotive)
Non-condensable gases	4 kg	Based on 10 - 15% yield (DynaMotive)

Table 3 is a summary of the mass balance used to calculate the economic viability of pyrolysis with a basis of one 400 kg steer input to the process, derived from the overall mass balance.

The major potential of pyrolysis is the production of a liquid fuel suitable for storage and transport. An advantage of this technology over other methods of energy extraction from waste streams is the milder operating conditions, typically around 500°C, compared to 800°C to 900°C for gasification, and the very short processing times compared to the several weeks required for anaerobic digestion.

The capital investment required for this technology would be similar to that of gasification in that both require a fluidized bed combustor. The materials of construction may be cheaper for pyrolysis given the lower operating temperature. Much larger capital costs will be involved if drying or size reduction is necessary. Capital cost estimates vary and are largely dependant on feed pre-treatment requirements. McArthur (1996) indicates that the portion of the capital costs attributed to the furnace itself is relatively small, with material preparation, drying, and pre-treatment costs accounting for approximately half the capital cost. As expected, the current processing conditions and, therefore, potential feeds will largely dictate viability.

The bio-oil yield is expected to be around 560 liters per ton dry feed (Wisconsin Biorefining Development Initiative), with a calorific value of 16 to 19 megajoules per kg (Paisley, 2003). Given recent escalations in oil prices, analysis into its use as a liquid fuel may be warranted; however, its relatively low energy density and incompatibility with standard internal combustion engines may cause problems. Its overall economic viability is also dependent on alternate uses for its feedstock, particularly in relation to the pyrolysis of MBM, which is currently a valued feed product. Fortuitously, MBM typically is a fine powder and has very low moisture content of about five percent, making it an ideal feed for pyrolysis. A basic financial analysis indicates this use of MBM is not viable and the process will not be considered while a market for MBM as a food animal feed ingredient remains.

The most mature and suitable technology for implementation within the meat processing industry is a fluidized bed reactor. Unfortunately, the small feed size requirements (small particles are needed to aid reaction rate) may be a problem in consideration of the energy that is required for particle size reduction, with the exception of MBM. Fluidized bed technology is well understood and could be scaled up from the current demonstration size to commercial size.

Few companies have built and operated a commercial biomass to bio-oil facility using RTP technology. The commercial success of these operations is based on the generation of multiple products:

- Higher value chemical products extracted from the bio-oil
- Bio-oil for lower value energy uses
- Char for internal energy use, or for sale.

Key to commercial success seems to be extraction of higher value chemical by-products that occur naturally during the pyrolysis of biomass, in addition to the bio-oil itself. Furthermore, the feedstock biomass used in this process is generally from waste timber product. Research into possible by-products that could occur from the pyrolysis of typical abattoir biomass is warranted.

Anaerobic Digestion

Anaerobic digestion does not deactivate pathogens as the maximum temperature attained in commercial composting is below that required for pathogen and bovine spongiform encephalopathy (BSE) prion inactivation. MBM may require prior heat treatment (pasteurization) in order to meet further use regulations. Pasteurization of a feed stream of this size would incur significant additional costs to the anaerobic digestion process. The feedstock would also require cooling and inoculation with fresh bacteria for the digestion to proceed. Anaerobic digestion produces methane and carbon dioxide gas and fertilizer, so it is possible that the presence of “high risk” materials (i.e., brain, spinal cord, etc.) may not be allowed to enter the process stream given that the fertilizer would find its way back into the ecological system.

Co-firing/Incineration

Examples of co-firing/incineration of MBM can be found in Europe; Lagan Cement, Ltd., has plans to co-fire as much as 45 percent MBM with coal in their kilns. Castle Cement also has plans to substitute MBM for some coal. This substitution offers several advantages over other disposal options. It not only provides a method of energy recovery, but reduces net greenhouse gas emissions by replacing coal with a "carbon neutral" fuel. A carbon neutral fuel is a fuel derived from a biomass. It is considered carbon neutral because the carbon released upon combustion was absorbed from the atmosphere during the growth of the organism. As mentioned, treatment at high temperatures has been shown to have the best results in deactivation of the BSE prion (USDA, 2005). Another advantage is the resultant ash is incorporated in the final cement product. The amount of solid waste that ends up in landfills is therefore reduced.

Meat and Bone Meal Inclusion in Concrete and Asphalt Construction Composites

It appears that the application of MBM in concrete and asphalt construction applications may have some promise and warrants further study. The higher end applications may become more attractive upon the utilization of a fractionated meal product.

The most attractive short-term solution lies in developing construction applications. As mentioned, the calorific value of MBM makes the economics of energy recovery marginal, yet both of these solutions are far more attractive than the expense of landfill disposal.

Few issues are anticipated with using MBM in construction applications. Perceived environmental issues of energy recovery via incineration may generate negative public opinion and considerable pressure to close this disposal avenue.

Electricity Generation via Fuel Cell Technology

Fuel Cell Applications

Fuel cells are electrochemical devices that convert chemical energy directly to electricity. Fuel cells offer a significant inherent advantage over typical combustion cycles. In a typical internal combustion engine, efficiency is lost due to the conversion of stored chemical energy first to heat energy, then to mechanical energy, and finally to electricity. Fuel cells have a potential for significantly higher efficiencies than internal combustion engines as they are not subject to Rankine/Carnot cycle efficiency limitations. There is a common misconception that fuel cells are energy carriers, like batteries. They are, in fact, energy converters, similar in application to boilers/engines though they have a more direct conversion path from the stored energy of the fuel to electricity. In theory, a fuel cell can continue to produce power indefinitely if a fuel stream such as hydrogen is constantly provided. A battery, however, can no longer produce power when the stored chemical energy is expended. This is an obvious attraction for virtually any power consuming process. A higher conversion efficiency of stored chemical energy to electricity brings along with it reduced operating costs. The problem fuel cells have commercially is related to their very high installed costs and processes that are typically more complicated and sensitive to variation than standard power generation.

Issues of reliability and capital cost are expected to decline as demand for alternate power increases, thus allowing the manufacturers to take advantage of economies of scale and increased volume. With an increased demand, manufacturers are expected to be able to optimize their production process. Much research is being undertaken into fuel cell configurations and materials of construction in order to reduce capital costs.

Figure 1. Basic Fuel Cell Configuration, from Hydrogencommerce.com.

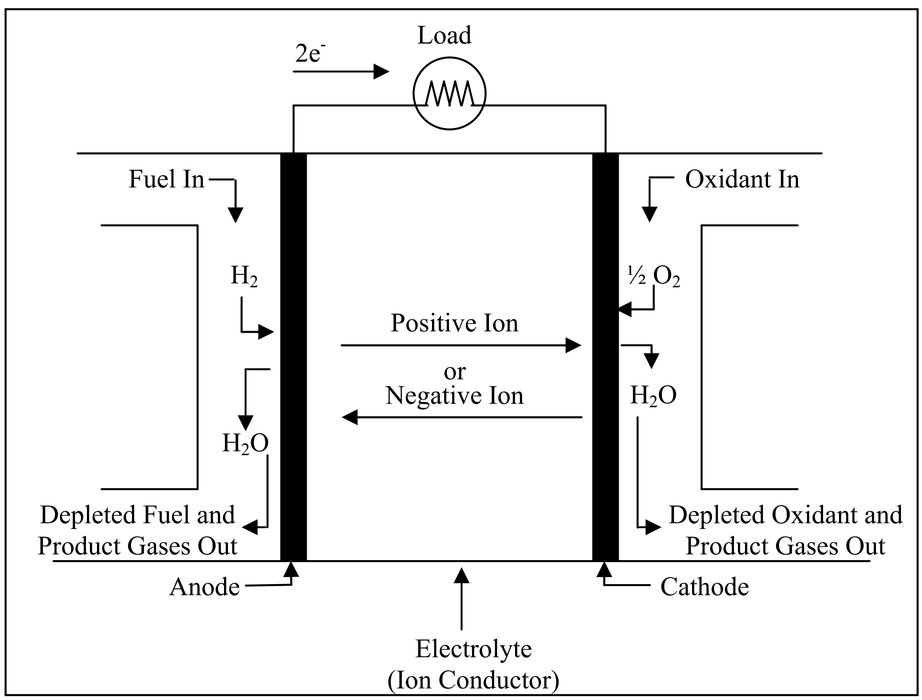

Figure 1 shows the basic cell configuration. The electrochemical reactions occurring within the cell are:

at the anode:
$\frac{1}{2}\, O_2 + 2e^- \rightarrow O^{2-}$

at the cathode:
$H_2 + O^{2-} \rightarrow H_2O + 2e^-$

with the overall cell reaction:
$\frac{1}{2}\, O_2 + H_2 \rightarrow H_20$

In order to produce energy from the cell, a constant source of hydrogen and oxygen are required. Of particular interest in terms of applications to the meat industry is an integration of fuel cell technology with anaerobic digestion. Unlike other energy conversion options, fuel cells do not lose efficiency as the unit size is scaled down. An immediate application to the industry is the conversion methane generated by anaerobic digestion into energy, carbon dioxide, and water.

It is expected that the fuel cell would operate at temperatures high enough to facilitate the reforming of methane to hydrogen and carbon dioxide within the fuel cell. There are low temperature fuel cell options that could operate with an external reforming stage. Generally speaking, research is still required to quantify the performance and durability of a high temperature internal reforming fuel cell powered by methane.

High temperature fuel cells are expected to be of great interest. A growing demand for fuel cells will correspond to an increased demand for the precious metal catalysts required for low temperature fuel cell operation. Typically, platinum catalysts are required for low temperature fuel cells, whereas nickel or perovskites can be used to catalyze high temperature fuel cells.

Proteins for Plastics

Demand and use of environmentally friendly plastics manufactured from renewable resources is increasing annually. Currently, the most mature technologies use wheat and cornstarches, soy proteins, and oil-derived esters as feedstock.

Few commercially produced biodegradable plastics are price competitive with traditional oil-derived plastics such as polyethylene and polystyrene. Legislation, in the form of an environmental tax, typically is required to give bio-based plastic a competitive edge. Bio-based plastic derived from fermentation processes (as for protein-based plastics) are generally more expensive than those manufactured via chemical processes. Current low conversion rates of protein to bio-based plastic are a significant stumbling block to being price competitive.

Most biodegradable plastics are inherently mechanically inferior to polyethylene and polystyrene. However, polyethylene and polystyrene are significantly “over engineered” for most applications. For example, the plastic shopping bag can be filled with groceries to a point where it is quite difficult to lift, yet the bag is intact.

A wide range of proteins can and have been used to produce edible and/or biodegradable casings and coating for food, pharmaceuticals, and industrial products. For example, small intestines (predominantly collagen) were the original casing for sausages. A recently edited book by Gennadios (2002) provides a comprehensive review of the subject. Forming mostly relies on solvent casting, using water, acidic water, alkaline water, or aqueous ethanol as the solvent (depending on the type of protein). Extrusion is used for collagen products—a purified and acidified aqueous suspension is extruded into a coagulating bath. Thermoplastic extrusion, as used commonly in the plastics industry, is not employed for protein-based films. However, there is evidence that some proteins can display thermoplastic properties, and inducing these properties to enable the use of more "traditional" extrusion technology is an area of research (Gennadios, 2002).

Protein films themselves tend to be quite brittle, so a range of plasticizers can be used, such as glycerol, propylene glycol, triethylene glycol, sorbitol, sucrose, and polyethylene glycol. The use of plasticizers tends to decrease film stiffness and tensile strength, while increasing elasticity and permeability. The properties of protein films can also be modified by cross-linking the protein molecules and modifying the molecular structure using various physical and chemical processes such as heat, pressure, shear, irradiation, or acid or alkali treatment.

In general, the hydrophilic nature of protein films means they have poor moisture barrier properties, though structural modification and/or the addition of waxes or lipids can decrease water vapor transmission rate (Tharanathan, 2003). They also tend to have poor mechanical properties compared to synthetic and polysaccharide-based films. However, in low to medium relative humidity applications, they can provide excellent barriers to oxygen, aroma, and oils.

In order to be successful, the major technical issue of film stability under thermal processing would need to be solved. The major technical challenge of thermal stability of the protein during processing needs to be overcome in order to develop significant production capability.

Hydroxyapatite as a Catalyst

Hydroxyapatite (HAP) is found in high-density leg bones of cattle, sheep, and goats. Some current uses of synthetic HAP are as an absorbent, a catalyst, a dental substrate, and as a bone substitute. Clearly, public perception eliminates the use of animal products in biomedical applications; hence, the focus applications for HAP are as a catalyst and absorbent.

The market for solid catalyst car exhausts and fuel cells is a high value-added area and seems set for future growth on the back of exponential growth in the nanotechnology sector. There is prior art in the use of synthetic HAP as a catalyst support (e.g., Lewis et al. (U.S. Patent Office, 2003)). However, the catalytic specificity differs between the many forms of the material. This specificity may enable animal-derived HAP to be differentiated from its synthetic rival.

A patent search on the subject revealed a large number of references relating to different uses of HAP. Freedom to operate will depend on finding a path through the maze of Japanese patents published in recent years.

It will be very difficult to penetrate and develop the human medical market for reconstructive bone and dental applications. Non-human markets for HAP ceramics and catalysts eliminate the perceived health impact with human contact. At this stage there is too little information in the public domain to reach a conclusion on future opportunities. However, this is a moderate risk application area with the potential to add value to the MBM co-product stream. Key research and development challenges are:

- Process scale-up
- Natural variation in raw materials
- Performance testing against synthetic alternatives.

If HAP could fill even a niche application in the ceramic or catalyst market, the demand for its supply would have a considerable impact on the co-products industry.

Proteins as Adhesives

As mentioned earlier in this chapter, protein streams from rendered co-products are well suited to adhesive applications due to the large number of available chemical functionalities for bond formulation. The primary target market is for protein-based adhesive formulations that may act as substitutes for formaldehyde resins and, particularly, urea-formaldehyde resins in applications for adhesives for wood composite products, such as plywood, particleboard, and chemical additives for paper making and coating. Animal protein-based adhesives can be derived from animal blood, although some involve the use of specific proteins primarily selected from collagen and blood albumin.

The use of waste protein as a raw material in the manufacture of adhesives for wood composites has been the subject of extensive study in many countries over the past 50 years. Despite this fact, there are few, if any, large-scale uses of waste animal proteins in this way.

The bulk of the non-water resistant, lower strength adhesives are at the lower end of the cost scale and find use in interior housing construction products, principally flooring. The relatively low value of the bulk of adhesive products coupled together with the costs of transforming waste animal protein into a form that is suitable for use in adhesive formulations makes this use economically unattractive.

By comparison with wood composite adhesives, the potential application of waste animal protein products to the manufacture of paper and carton board products is a poorly explored subject. Significant performance shortcomings in many currently used chemicals and their relatively high value combine to make this an attractive potential product for waste proteins.

The barrier to wood composite market applications is the inherent low water resistance of protein-based adhesives and resulting accelerated bio-deterioration of the product. Research into cross-linking processes and reactive addition or modification of functional groups may overcome some aspect of the adhesives poor water resistance, but is unlikely to produce an epoxy-resin to match synthetic resins on either performance or cost basis. There is real potential in short-term (one to three months) storage packaging paper and carton board.

Adhesives are used to reduce creep (fatigue or progressive stress-dependent failure) in stackable boxes, but as a result the container cannot be recycled. Pressure is mounting to recycle all forms of paper. There is the additional problem that recycled carton boxes exhibit four times as much creep (U.S. Patent Office, 2003). If a protein-based adhesive replaces the current non-recyclable version, inoculation with a protease (to make the adhesive water soluble) could enable recycling of the used item possible.

Successful research into, and development of, a cross-linking agent that significantly reduced the overall creep in recycled boxes would make waste animal protein-based adhesives a commercial reality. Elimination of formaldehydes, particularly for indoor formulations, is a very positive step forward in public perception. The drive to be environmentally friendly and the fact that this adhesive would be manufactured from a waste stream would combine to give a significant marketing advantage over traditional products.

The market for carton board packaging would have the largest product use, thus development of an adhesive suitable for this application will generate significant increasing demand for protein-based co-products.

Incentives for Discovery

The preamble for the Clemson University Animal Co-Products Research and Education Center dedication conference (April 2006) states, “It is imperative to society that the rendering industry remains viable.” As stated in this book’s first chapter, “Overview of the Rendering Industry,” the availability of rendered products for animal feeds in the future depends on regulation and the market. Future regulation relating to biosecurity and environmental protection has the potential to restrict traditional market access for rendered co-products. Hence, it is essential that new applications and avenues for profitable disposal of co-products are discovered, researched, developed into a viable commercial process, and widely adopted by the industry in order to maintain rendering as a viable and valuable service to the meat processing sector.

References

California Department of Food and Agriculture. 2006. Beef by-products. www.cdfa.ca.gov/ahfss/mpi/by_products.htm

Duncan, J. 2003. Costs of Biodiesel Production. Energy Efficiency and Conservation Authority, New Zealand. www.eeca.govt.nz/eeca-library/renewableenergy/biofuels/report/cost-of-biodiesel-production-03.pdf .

DynaMotive. 2006. www.DynaMotive.com.

Freel, B., and R. Graham. 2000. Commercial Bio-oil Production via Rapid Thermal Processing. Ensyn Group, Boston. www.ensyn.com/info/11122000.htm.

Gennadios, A. 2002. *Protein-based films and coatings*. 1st ed. CRC Press.
Grummer, R.R. 1992. Chapter 6: Inedible Fats and Greases. *Inedible Meat By-Products*. Eds. Pearson, A.E. and T.R.Dutson. Elsevier Applied Science, London and New York. pp. 113-148.
Hanlon, J., R. J. Kelsey, and H. E. Forcinio. 1998. ***Handbook of Package Engineering.*** 3rd ed. CRC Press.
Khan, A. 2002. Research into Biodiesel Kinetics and Catalyst Development. The University of Queensland.
Liu, B., Y. Zhang, J.W. Tierney, and I. Wender. 2005. Hydrogen by Catalytic Reforming of Glycols. Department of Chemical Engineering, University of Pittsburgh.
McArthur, K. 1996. Financial Feasibility Analysis of Alternative Potential Biomass Based Products. University of Nevada, Reno. www.ag.unr.edu/uced/reports/technicalreports/fy1995_1996/9596_12rpt.pdf
National Biodiesel Board. 2005. Cold weather blending study. www.biodiesel.org/resources/reportsdatabase/reports/gen/20050728_Gen-354.pdf
Nelson, R.G., S.A. Howell, and J. Weber. 1994. Potential Feedstock Supply and Costs for Biodiesel Production. Presented at the sixth national bioenergy conference in Nevada, October 2-8. www.biodiesel.org/resources/reportsdatabase/reports/gen/19941006_gen-290.pdf
Paisley, M. 2003. Biomass Energy. Kirk-Othmer Encyclopaedia of Chemical Technology.
Papadopoulos, E., and S. Clarke. 2005. Modification of Tallow for Better Performance as Biodiesel. Flinders University, Adelaide, Australia.
Pearl, G.G. 2003. Non-feed, non-food applications for animal by-products. ***Render.*** 32(1):22-25.
Tharanathan, R.N. 2003. Biodegradable films and composite coatings: past, present and future. *Trend in Food Science and Technology*. 14:71-78.
USDA. 2005. General Guidelines for the Disposal of Carcasses. www.aphis.usda.gov/NCIE/oie/pdf_files/tahc-carcass-disp-jan05.pdf.
U.S. Patent Office. 1996. Patent number 5569482, Process for producing edible proteinaceous film.
U.S. Patent Office. 2003. Patent number 6544439, Low coke formation catalysts and process for reforming and synthesis gas production.
Wang, P. 2003. The production of isopropyl esters and their effects on a diesel engine. Iowa State University. www.me.iastate.edu/biodiesel/Technical%20Papers/Wang%20Intro.pdf.
Wang, Y., and G.W. Pauda. 2003. Tensile Properties of Extruded Zein Sheets and Extrusion Blown Films. ***Macromolecular Materials and Engineering.*** 228:886-893.
Wisconsin Biorefining Development Initiative. 2006. www.wisbiorefine.org.