ESSENTIAL RENDERING

All About The Animal By-Products Industry

Edited by
David L. Meeker

PREFACE

The first book written about the rendering industry was produced by the National Renderers Association in 1978 and was titled *The Invisible Industry*. In 1996, a second book entitled *The Original Recyclers* was published to tell everyone in government, academia, and the public what renderers are—environmentally aware producers of safe products—the original recyclers.

That book was to move us into the twenty-first century, but with the pace of change, we find ourselves already in need of a new book on the rendering industry. So much has happened in the past decade that it has become necessary to publish this book, *Essential Rendering.* This book documents the technologies, manufacturing procedures, capabilities, research, and infrastructure that make the industry so important to the United States and Canada.

Two cases of indigenous bovine spongiform encephalopathy discovered in the United States and eight in Canada, as well as high pathogenic avian influenza around the world, challenge renderers today. Thus, society needs to know how renderers handle, in a biosecure manner, over 59 billion pounds of the by-products from animal food production every year in the United States and Canada.

Government, which promulgates rules to answer today's diverse challenges, academia, which influences users of rendered products, and the public, which uses the products of the industry's operations, all need to know about rendering in today's world. They need to know how rendering prevents both animal and human diseases and what the ramifications are of not having rendering. Society should not take renderers' services for granted or forget that they operate in a free enterprise system.

David J. Kaluzny II, Chairman, National Renderers Association

ABOUT THE COVER

This painting is on display in the NRA office in Alexandria, Virginia. The artist, Edward Juarez, worked at the Omar Rendering Company in San Diego, CA his entire working career. He started working at age 12, picking up cattle hides. Mr. Juarez painted this scene in 1980, one of ten paintings he did in the plant where he worked. The renderer/artist said this scene was of workers loading the batch cooker with feathers at the end of the day. The previous batch was blood from packing houses made into blood meal. Edward Juarez said, "We worked as hard as we could—we worked our butts off—but we took pride in our work and it was fun for us. We would work all day and then go to the bar." He said he also had three brothers that worked in packing houses skinning cattle and they were "top butchers" because of their skill in producing flawless hides. Mr. Juarez lives in San Diego, CA and still paints. This image appears with his permission.

RENDERING ASSOCIATION WEB SITES

For updates and current industry information, visit the following sites:

www.renderers.org   www.animalprotein.org   www.fprf.org

ACKNOWLEDGEMENTS

Thanks to the officers and committees of NRA, APPI, and FPRF for providing the resources to make this book possible and to each of the authors for their academic contributions. Thanks especially to Tina Caparella, Nancy K. Cook, Tom Cook, Glenda Dixon, C. Ross Hamilton, David J. Kaluzny II, David Kirstein, Kevin Kuhni, and Sergio Nates for detailed reviewing this work at many stages.

This book contains information from highly regarded sources and industry experts. Sources are indicated wherever possible, reprinted material is quoted with permission, and hundreds of references are listed. Great care has been taken to publish accurate data and reliable information, but the authors and the publisher do not assume responsibility for the validity of all materials or the consequences of use.

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Robert Desnoyers; Lomex, Inc.
John Griffin; Griffin Industries, Inc.
Tim Guzek; Anamax Corporation
David Kaluzny II; Kaluzny Bros., Inc.
Tom Cook; NRA President
Neville Chandler; NRA Regional Director, London
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ISBN: 0-9654660-3-5

Printed in September of 2006 by
Kirby Lithographic Company, Inc.
Arlington, Virginia

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Lopa Basu is pursuing a Ph.D. in animal science (international foods) at Ohio State University under the direction of Dr. Ockerman. She is a native of India and has an M.S. in muscle biochemistry from the University of Bombay. She has served as a field scientist in the UN World Food Program in many countries and as a young professional officer in the UN Food and Agriculture Organization. She has received numerous academic awards in the United States and India.

Fred D. Bisplinghoff graduated from the University of Missouri in 1951 with a B.S. degree in animal nutrition and a D.V.M. He was a large-animal practitioner until 1956, and subsequently joined Faber Industries, an Illinois rendering company with six plant locations, where he served as general manager of animal feed, solvent extraction, and fat and protein blending operations. By 1959, Dr. Bisplinghoff was executive vice president with management of all rendering operations. Faber was purchased by National By-Products in 1965. Dr. Bisplinghoff was then responsible for all former Faber facilities, which included a barge terminal and hide operations. At the time of his retirement from National By-Products in 1985, he supervised all of National's operations in Illinois, Indiana, Ohio, Kentucky, Tennessee, and eastern Missouri, and had served in many rendering industry positions, including president of NRA 1971-1972. After retiring in 1985, he consulted for Holly Farms Poultry. He simultaneously filled three positions in the rendering industry for five years, including president and director of Technical Services of the Fats and Proteins Research Foundation (FPRF), 1988 – 1993; director of Scientific Affairs of National Renderers Association (NRA), 1988 – 1993; and president of Animal Protein Producers Industry (APPI), 1983 – 1993. From 1993 to 2006 he consulted for 11 rendering companies.

Richard E. Breitmeyer has been director of Animal Health and Food Safety Services, California Dept. of Food and Agriculture since 1993. He oversees an annual budget of $28 million and 250 employees engaged in programs for animal health, milk and dairy foods control, meat and poultry inspection, and livestock identification. He works closely with the California Animal Health and Food Safety Laboratory System that is operated by the School of Veterinary Medicine, University of California at Davis (UCD), under a contract with the department. He also serves as the state veterinarian, and has broad responsibility for animal health regulatory issues, including quarantine authority. Dr. Breitmeyer is a graduate of the School of Veterinary Medicine at UCD and also holds a master's in preventive veterinary medicine degree from UCD. He is an active member of many state and national animal health and veterinary medical associations and currently serves as chairman of the U.S. Animal Health Association's Food Safety Committee, is on the executive committee of the National Institute for Animal Agriculture, and is a former member of the USDA Secretary's Advisory Committee for Foreign Animal and Poultry Diseases.

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Gary L. Cromwell is a professor of nutrition at the University of Kentucky. He received a B.S. degree in agricultural education from Kansas State University and M.S. and Ph.D. degrees in animal nutrition from Purdue University. He joined the faculty at the University of Kentucky in 1967, where he is a professor in the Department of Animal Sciences. Dr. Cromwell has served the swine and feed industries through outstanding research for more than 35 years—research that has identified him as a world expert in swine nutrition. His broad-based research has included assessment of amino acid and mineral requirements of swine, copper as a growth promoter, efficacy and safety of antibiotics, nutritional value of genetically modified crops, and environmental aspects associated with use of phytase in swine diets. He developed a slope-ratio assay to determine the bioavailability of phosphorus in feedstuffs, allowing the formulation of diets on an "available phosphorus" basis. Dr. Cromwell is the author or co-author of more than 900 publications, including 137 refereed journal articles. He has directed 60 graduate students, many of whom have prominent roles in the feed industry or academia. He is the chair of the National Research Council's Committee on Animal Nutrition and chaired the subcommittee that prepared the 10th edition of *Nutrient Requirements of Swine* in 1998. He has received the American Society of Animal Science (ASAS) Industry Service Award, ASAS-AFIA Nutrition Research Award, and Morrison Award recognizing research excellence with direct importance to livestock production.

Jeffre D. Firman attended the University of Nebraska for both B.S. and M.S. degrees. He also worked for several years in the commercial turkey industry. He received his Ph.D. at the University of Maryland studying neural regulation of food intake in broilers. He has been at the University of Missouri in a teaching, research, and extension position for almost 20 years and has been at the professor rank for eight years. His research revolves around protein and energy utilization in meat birds as well as use of rendered products. He does consulting for a number of entities and has visited 27 different countries.

Don A. Franco has degrees in agriculture, veterinary medicine, and public health and has made concerted efforts during his professional career to heighten the linkages of these three disciplines to enhance the principles of biosecurity, food safety, and food borne disease control. Dr. Franco continues to work for the integration of all the basics of animal agriculture, proper animal disease control and prevention to ensure a safe food supply. He practiced for four years in a mixed veterinary practice in the country of his birth, Trinidad, before migrating to the United States to accept a position with the USDA Food Safety and Inspection Service in 1968, where he served in several supervisory positions throughout the country, culminating in his appointment as the director of Slaughter Operations in Washington, D.C. Dr. Franco received numerous awards during his tenure with the USDA over the years including a department's Superior Service Award from the Secretary of Agriculture in June 1990, "For notable authorship which has brought national and international recognition to the U.S. Department of Agriculture, Food Safety and Inspection Service." He co-authored two major texts, *Food Animal Pathology and Meat Hygiene and Poultry Diseases* and *Meat Hygiene*, and is published in major professional journals worldwide. He held adjunct academic professorial appointments at Emory University in Atlanta, George Washington University in Washington, D.C., and the University of Panama Central America School of Medicine in Washington, D.C. After his retirement from the USDA, Dr. Franco joined the National Renderers Association (NRA) as vice president for Scientific Services and the Animal Protein Producers Industry (APPI) as president.

After his retirement from NRA/APPI, he formed the Center for Bio-security, Food Safety and Public Health (CBFSPH) in Lake Worth, Florida.

C. Ross Hamilton is director of Government Affairs and Technology for Darling International, Inc. He earned his B.S. and M.S. degrees from Texas Tech University and Ph.D. in animal nutrition from the University of Missouri. He was on the faculty of South Dakota State University for 12 years as an extension specialist (1984-1988) and as an associate professor (1988 to 1996) with a teaching and research appointment. Dr. Hamilton joined Darling International, Inc., in 1996. He has co-authored more than 150 scientific papers and publications. He is a Registered Professional Animal Scientist, Charter Diplomate of the American College of Animal Nutrition and is active on the American Feed Ingredient Association (AFIA) Nutrition Council. Dr. Hamilton is the current chairman of the Board for the Fats and Proteins Research Foundation (FPRF) and is active on several National Renderers Association (NRA) committees.

Thomas C. Jenkins earned the B.S. degree in animal science and M.S. degree in animal nutrition at Pennsylvania State University and a Ph.D. in animal nutrition from Cornell University. He was a faculty member at Ohio State University prior to joining Clemson in 1986. At Clemson, he has received several patents for development of novel rumen-protected fat supplements. Also, Dr. Jenkins has maintained a basic research program studying the process of lipid biohydrogenation in ruminal contents using staple isotopes of unsaturated fatty acids and mass spectroscopy in metabolic tracer studies. Dr. Jenkins received the American Feed Ingredient Association Nutrition Research Award presented by the American Dairy Science Association in 1999 and the Godley-Snell award for excellence in agricultural research by Clemson University in 2005. Dr. Jenkins has given more than 60 invited lectures in six countries and has authored or co-authored more than 220 publications including book chapters, journal articles, and patents.

David Kirstein received his B.A. from Seattle Pacific University in 1975 with a double major in biology and chemistry, and his M.S. in nutrition from Washington State University in 1979. He has over 25 years experience working in animal agriculture. Currently, he serves as director of Technical Services for Darling International, Inc., as he did at National By-Products, LLC for 14 years prior to 2006. Darling International, Inc., is a leading independent renderer in the United States, producing animal fat and protein by-products used by feed and chemical manufacturers worldwide. Earlier in his career, Kirstein spent eight years with a ConAgra company formulating complete feeds and supplements for livestock and poultry that contained rendered products. However, he has gained an in-depth understanding of the nature of rendered products during the past 14 years. His current responsibilities include leadership for corporate and industry product safety initiatives, oversight for in-house research targeting new product development, and managing the corporate analytical laboratory. Kirstein is a former chairman of and currently serves on the steering committee of the American Protein Producers

Industry whose focus is on the biosecurity and safety of rendered products. He also serves on the research committees for the Fats and Proteins Research Foundation and as a vice chairman for the Animal Co-Products Research and Education Center at Clemson University.

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David L. Meeker is vice president, Scientific Services of the National Renderers Association (NRA). He serves as the scientific/technical advisor to the North American rendering industry on science, animal disease, and feed safety issues. He also served as president of the Animal Protein Producers Industry (APPI) prior to its merger with NRA in 2006. Dr. Meeker previously served in scientific and management positions at the National Turkey Federation and National Pork Producers Council, was director of the Board on Agriculture and Natural Resources for the National Research Council at the National Academy of Sciences, and was an associate professor at The Ohio State University. Over the past two decades he has served as an advisor and consultant to numerous governmental, professional, and business organizations in the United States and internationally. He is currently a member of the scientific advisory panel to the World Renderers Organization (WRO), a member of the newly appointed USDA Secretary's Advisory Committee on Foreign Animal and Poultry Disease, and a member of the advisory committee for the Beef industry Food Safety Council of the National Cattlemen's Beef Association. He received his B.S., M.S., Ph.D., and M.B.A. degrees from Iowa State University in Ames, Iowa.

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Gary G. Pearl retired in 2005 as president and director of Technical Services of the Fats and Proteins Research Foundation. He is currently an adjunct professor in the Department of Animal and Veterinary Sciences at Clemson University. Dr. Pearl received his D.V.M. in 1963 from Purdue University. He was given the School of Veterinary Medicine Distinguished Alumnus Award in 2001 for "his distinguished service to applied dietary research, to veterinary practice, to community service, to organized veterinary medicine, and to directing excellence in research."

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Trade Association were he was responsible for implementing international marketing programs and for trade dispute resolution and policy formulation. He also previously worked for the U.S. Grains Council as manager for international operations, Asia, and for the Continental Grain Company, Wayne Feeds Division. Currently, Swisher serves or has served on the USDA Agriculture Technical Advisory Committee on Trade for Animal Products; the AgTrade Coalition; Board of Directors of the Agriculture Export Development Council (USAEDC); and the Seattle Round Ag Committee. He graduated from Purdue University in agricultural economics and is finishing his thesis for a master's degree in agribusiness from Kansas State University.

Stephen Woodgate is the technical director of the European Fat Processors and Renderers Association (EFPRA). He is also managing director of Beacon Research, Ltd., a research and development consultancy. Previously, he was technical director of the PDM Group for five years and prior to this he managed his own consultancy business for eight years. Before that he worked with the PDM group as the product development manager and as a research assistant with Unilever plc. Woodgate has a wealth of experience in many of the technical aspects of the worldwide animal by-products industry. In particular, he has been involved with the development of EFPRA's Standing Technical Group (STG) into a source of expertise that interfaces industry, national governments, and the European Commission. The main areas of STG activity have been in conjunction with DG Sanco [animal by-products regulation and TSE regulation] and with DG's Environment and Transport/Energy in relation to uses of rendered products as energy sources. Woodgate also serves as chairman of the both the U.K. Renderers Association Technical Committee and as member of the scientific advisory panel to the World Renderers Organization.

Yu Yu is the Asian regional director of the National Renderers Association (NRA). Dr. Yu has successfully introduced non-marine animal protein meals to Asia's animal feed industry, with recent emphasis on the aquafeed industry. He has been active in shrimp and fish nutrition research projects in China, Vietnam, Thailand, and the Philippines, collaborating with various universities, research institutions, and aquafeed companies. He is a regular participant and speaker at international conferences and trade exhibitions related to the animal feed industry. Dr. Yu completed his B.S. degree in Taiwan, and received his graduate degrees from Michigan State University in the United States. Prior to joining NRA in 1997, he had worked for the feed industry in Canada since 1978. He is currently based in Hong Kong and continues to lead trade excursions from Asia to the United States.

AN OVERVIEW OF THE RENDERING INDUSTRY

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Summary

One-third to one-half of each animal produced for meat, milk, eggs, and fiber is not consumed by humans. These raw materials are subjected to rendering processes resulting in many useful products. Meat and bone meal, meat meal, poultry meal, hydrolyzed feather meal, blood meal, fish meal, and animal fats are the primary products resulting from the rendering process. The most important and valuable use for these animal by-products is as feed ingredients for livestock, poultry, aquaculture, and companion animals.

There are volumes of scientific references validating the nutritional qualities of these products, and there are no scientific reasons for altering the practice of feeding rendered products to animals. Government agencies regulate the processing of food and feed, and the rendering industry is scrutinized often. In addition, industry programs include the use of good manufacturing practices, hazard analysis and critical control point (HACCP), codes of practice, and third-party certification. The Food and Drug Administration (FDA) regulates animal feeds and prohibits certain ruminant proteins from being used in ruminant diets to prevent the spread of bovine spongiform encephalopathy (BSE). Though often frustrated by the attention it receives, the rendering industry clearly understands its role in the safe and nutritious production of animal feed ingredients and has done it very effectively for over 100 years.

The availability of rendered products for animal feeds in the future depends on regulation and the market. Renderers are innovative and competitive and will adapt to changes in both. Regulatory agencies will determine whether certain raw materials can be used for animal feed. The National Renderers Association (NRA) supports the use of science as the basis for regulation while aesthetics, product specifications, and quality differences should be left to the marketplace. Customer expectations, consumer demand, and economic considerations will dictate product specifications and prices.

Without the continuing efforts of the rendering industry, the accumulation of unprocessed animal by-products would impede the meat industries and pose a serious potential hazard to animal and human health.

Raw Material

A by-product is defined as a secondary product obtained during the manufacture of a principal commodity. A co-product is a product that is usually manufactured together or sequentially with another item because of product or process similarities. Some prefer the more positive connotation of the term co-product, but for simplicity, this book will mostly use the term by-product. A portion of the profit returned to animal production and processing industries depends on the utilization of the by-products or co-products ancillary to the production of meat, milk, and eggs for human food production. The FDA regulates which materials can be included in animal feed, and in 1997 banned the feeding of ruminant materials back to ruminant animals. Considerable debate has taken place recently on whether more bovine materials should be banned from all animal feeds.

The approximately 300 rendering facilities in North America serve animal industries by utilizing the by-products which amount to more than half of the total volume produced by animal agriculture. The United States currently produces, slaughters, and processes approximately 100 million hogs, 35 million cattle, and eight billion chickens annually. By-products include hides, skins, hair, feathers, hoofs, horns, feet, heads, bones, toe nails, blood, organs, glands, intestines, muscle and fat tissues, shells, and whole carcasses. These by-product materials have been utilized for centuries for many significant uses. The products produced from the "inedible" (meaning not consumed by humans) raw material make important economic contributions to their allied industries and society. In addition, the rendering process and utilization of these by-products contribute to improvements in environmental quality, animal health, and public health.

Approximately 49 percent of the live weight of cattle, 44 percent of the live weight of pigs, 37 percent of the live weight of broilers, and 57 percent of the live weight of most fish species are materials not consumed by humans. Some modern trends, such as pre-packed/table ready meat products, are increasing the raw material quantities for rendering. The current volume of raw material generated in the United States is nearly 54 billion pounds annually with another 5 billion pounds generated in Canada. Raw materials vary, but an overall approximation of content would be 60 percent water, 20 percent protein and mineral, and 20 percent fat before the rendering process. These organic materials are highly perishable and laden with microorganisms, many of which are pathogenic to both humans and animals. Rendering offers a safe and integrated system of animal raw material handling and processing that complies with all of the fundamental requirements of environmental quality and disease control.

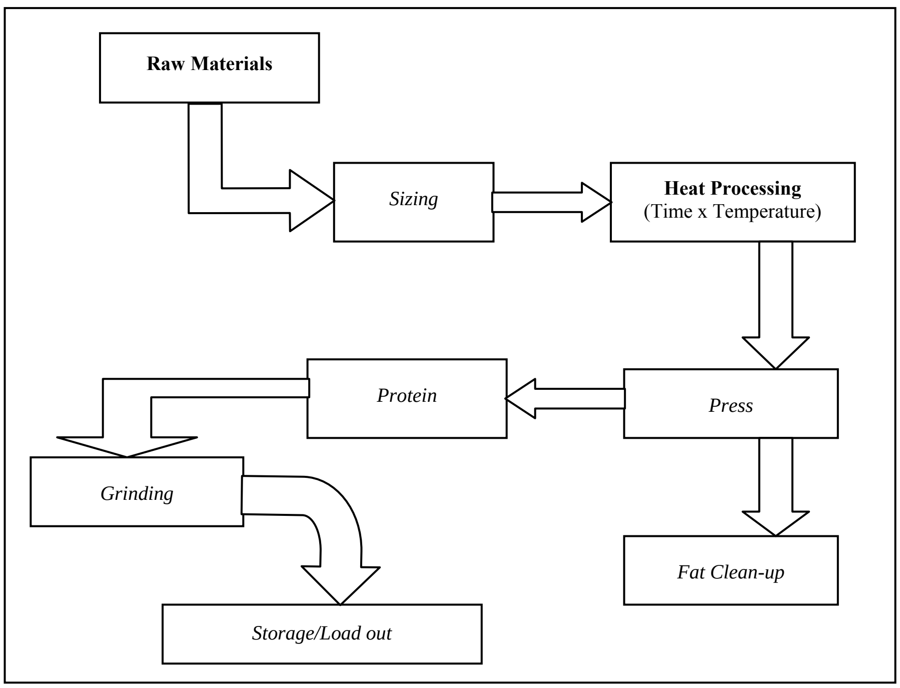
The Rendering Process

Rendering is a process of both physical and chemical transformation using a variety of equipment and processes. All of the rendering processes involve the application of heat, the extraction of moisture, and the separation of fat. The methods to accomplish this are schematically illustrated in Figure 1 (Hamilton, 2004). The processes and equipment are described in detail in the chapter in this book on operations.

The temperature and length of time of the cooking process are critical and are the primary determinant of the quality of the finished product. The processes vary according to the raw material composition. All rendering system technologies include the collection and sanitary transport of raw material to a facility where it is ground into a consistent particle size and conveyed to a cooking vessel, either continuous-flow or batch configuration. Cooking is generally accomplished with steam at temperatures of 240º to 290ºF (approximately 115º to 145ºC) for 40 to 90 minutes depending upon the type of system and materials. Most North American rendering systems are continuous-flow units. Regardless of the type of cooking, the melted fat is separated from the protein and bone solids and a large portion of the moisture is removed. Most importantly, cooking inactivates bacteria, viruses, protozoa, and parasites. Alternative methods of raw material disposal such as burial, composting, or landfill applications do not routinely achieve inactivation of microorganisms.

Fat is separated from the cooked material via a screw press within a closed vessel. Following the cooking and fat separation, the "cracklings" or "crax," which includes protein, minerals, and some residual fat, are then further processed by additional moisture removal and grinding, then transferred for storage or shipment. Storage of the protein is either in feed bin structures or enclosed buildings. The fat is stored and transported in tanks.

Figure 1. The Basic Production Process of Rendering.



Processes and technology of rendering have changed over the years and continue to improve. Modern rendering facilities are constructed to separate raw material handling from the processing and storage areas. Process control is performed and monitored via computer technology so that time/temperature recordings for appropriate thermal kill values for specific microorganisms are achieved. Temperatures far in excess of the thermal kill time requirements are unnecessary and avoided because they can lower nutritional values and digestibility. Processes in North America generally do not incorporate cooking under pressure except for feathers and other high keratin containing tissues.

Research has demonstrated that raw material derived from food animal processing is heavily laden with microorganisms. Data illustrating the high incidence of foodborne pathogenic microorganisms within raw animal by-product material and the efficacy of the rendering process in killing these pathogens are listed in Table 1. It is recognized that handling of ingredients after cooking can be responsible for re-contamination—a concern for all feed ingredients and not restricted to animal protein. *Salmonella* is a bacteria species that is commonly associated with feed and often wrongly suspected of originating from the animal by-product ingredients. Data from around the world illustrate that all feed ingredients, including vegetable proteins and grain, may contain *Salmonella* (Beumer and Van der Poel, 1997; Sreenivas, 1998; McChesney et al., 1995; European Commission, 2003). Thus, it is important to follow industry feed safety guidelines or codes of practice in both pre- and post-handling of ingredients and manufactured feed.

Table 1. Efficacy of the U.S. Rendering System in the Destruction of Pathogenic Bacteria.

Pathogen	Raw Tissue % samples positive	Post Process % samples positive
Clostridium perfringens	71.4	0
Listeria species	76.2	0
L. monocytogenes	8.3	0
Campylobacter species	29.8	0
C. jejuni	20.0	0
Salmonella species	84.5	0

Source: Troutt et al., 2001. Samples from 17 different rendering facilities taken during the winter and summer.

Though research has demonstrated that rendering lowers the infectivity of the prion, the agent most commonly believed to be the cause of the transmissible spongiform encephalopathies (TSEs), is not totally inactivated with any of the currently available rendering processes (Taylor et al., 1995). This is why the FDA requires that raw materials containing ruminant by-products not be used to make ingredients used in ruminant feed.

The North American rendering industry recognizes its role in ensuring food safety and in protecting human and animal health and has developed programs for biosecurity, *Salmonella* reduction, and third-party certification for compliance to feed regulations. In addition, North American rendering companies have endorsed the APPI Code of Practice—a voluntary HACCP-based program.

Rendered Animal By-Products

The rendering process converts raw animal tissue into various protein, fat, and mineral products—rich granular-type meals and liquid fats with specific nutritional components. Annual volume in the United States is approximately 11.2 billion pounds of animal derived proteins and 10.9 billion pounds of rendered fats. About 85 percent of this production is utilized as animal feed ingredients. Applications for rendered fats in the chemical, metallurgy, rubber, and oleochemical industries combined account for the second largest market, with over 3,000 industrial uses identified. The manufacture of soaps and personal care products remain a major use for animal fats, especially tallow, and new uses such as biofuels are increasing.

Animal Fats and Recycled Greases

Fats are the most caloric-density feed ingredient available. The animal feed and ingredient industry is a major user of rendered animal fats and recycled restaurant and cooking oils which provide valuable dietary energy. Also, fats and fatty acids provide for essential and indispensable body functions separate from their caloric function. Including recycled vegetable oils from restaurants, the rendering industry processes some 10.9 billion pounds annually of fats (Table 2).

Table 2. Fats Produced by the U.S. Rendering Industry Annually.

Edible Tallow	1.8 billion pounds
Inedible Tallow	3.9 billion pounds
Lard	0.3 billion pounds
Yellow Grease	1.5 billion pounds
Other Grease	1.2 billion pounds
Poultry Fat	1.2 billion pounds
Fats Used in Pet Food[a]	1.0 billion pounds
Total	**10.9 billion pounds**

Source: U.S. Census Bureau Current Industrial Report M311K, 2005.

[a] Editor's note: Poultry, beef, and pork fats used in pet foods (estimated to be approximately 1.0 billion pounds) are not included in the U.S. Census Bureau categories.

The term lipid includes both fats and oils. Lipids are chemically structured primarily as triglycerides—a structure consisting of one unit of glycerol and three units of fatty acid. The fatty acids are the components that give the respective fats their individual chemical and physical characteristics. Most fatty acids found in natural fats vary in chain lengths from eight to 24 carbons. Feeding fats contain mostly fatty acids of 14 to 18 carbon lengths. Fatty acids are considered unsaturated if they have double bonds within their chemical structure. Structures without double bonds are saturated fatty acids. If more than two double bonds are present in the structure, fatty acids are referred to as polyunsaturated. As a triglyceride contains more saturated fatty acids, the melting point increases, and the physical nature of the fat is referred to as a "harder." A measure of hardness is titer, determined by the solidification point of the fatty acids. Iodine value (IV) is another measurement of hardness/softness with unsaturated fats having higher IV values than saturated fats. Table 3 provides a guide of various animal fats comparing titer and IV.

Table 3. Titer and Iodine Values for Fat from Various Livestock Species.

Species	Titer	Iodine Value
Sheep	111º – 118ºF (44º – 48ºC)	42 – 43
Cattle	108º – 113ºF (42º – 45ºC)	43 – 45
Hogs	97º – 104ºF (36º – 40ºC)	63 – 65
Poultry	89º – 95ºF (31º – 35ºC)	77 – 80

Source: Fats and Proteins Research Foundation Directors Digest No. 269.

Feed grade fats are often stabilized blends of animal and vegetable fats. They are produced (1) by rendering the tissues of mammals and/or poultry, and (2) through recycling cooking oils. Feed fats consist predominately of triglycerides of fatty acids and contain no added free fatty acids (NRA, 2003).

Products bearing a name descriptive of its kind or species origin must correspond thereto as beef, pork, or poultry. Poultry fat consists of fats derived from 100 percent poultry offal. Blended feed fat is a category that includes blends of tallow, grease, poultry fat, and restaurant grease/cooking oils. Blended animal and vegetable fats include blends of feed grade animal fats, poultry fats, vegetable fats, and/or restaurant grease/cooking oil. It may also include by-products such as soap stock. Fats within this category may be referenced as animal/vegetable blends.

Though specifications are clearly defined and guarantees specified under several references, including the Association of American Feed Control Officials (AAFCO), suppliers of feeding fats can provide products that are labeled and guaranteed outside the trading standards. Suggestions for quality specifications for animal feed fats are listed in Table 4. As with any feed ingredient, specifications should be thoroughly understood between supplier and purchaser. The following are common feeding fat guidelines:

1. Fats should be stabilized with an acceptable feed- or food-grade antioxidant added at levels recommended by the manufacturer. Stability tests can be performed to monitor.
2. No cottonseed soap stock or other cottonseed by-products should be included in fats for layer, breeder, or broiler rations.
3. Fats must be certified that polychlorinated biphenyls (PCBs) and pesticide residues are within the allowable state and federal limits.
4. The supplier should make every effort to provide a uniform fat structure in each delivery. A specification for minimum and/or maximum IV can be established for the type of fat purchased. Monitoring IVs can determine if the product's fat structure is uniform.

Table 4. Suggested Quality Specifications for Feed Fats.

				Blended Fat		
	%	Animal	Poultry	Feed Grade Animal	Animal/ Vegetable	Vegetable Soap Stock
Total Fatty Acids	min.	90	90	90	90	90
Free Fatty Acids	max.	15	15	15	15*	50
Moisture	max.	1	1	1	1	1.5
Impurities	max.	0.5	0.5	0.5	0.5	1
Unsaponifiable	max.	1	1	1	1*	4
Total MIU	max.	2	2	2	2	6

MIU = moisture, impurities, and unsaponifiables.

* When blended feed fats contain acidulated soap stock, this specification can be adjusted to allow higher free fatty acids found in this fat (i.e., five FFA per 10 percent added). Blended fats containing soap stock may also have higher unsaponifiable levels.

Fat Terminology

Total fatty acids (TFA) include both the free fatty acids and those combined with glycerol (intact glycerides). Fat is composed of approximately 90 percent fatty acids and 10 percent glycerol. Glycerol contains about 4.32 calories per gram compared with 9.4 calories for fatty acids. Since fatty acids contain over twice the energy of glycerol, the TFA content in fat acts as one indicator of energy.

One measure of fat quality is the FFA content. Fats are normally composed of three fatty acids linked to glycerlol via ester bonds. FFA are produced when those fatty acids are freed by hydrolysis. Therefore, the presence of high levels of FFA indicates the fat was exposed to water, acids, and/or enzymes. Fats should be processed to contain as low a moisture level as feasible so that hydrolysis does not occur during storage.

In the past, some have associated increased FFA with increased oxidation of the fat during processing or storage. Oxidation is not the same as hydrolyses and it occurs when oxygen and unsaturated fatty acids combine in the presence of a catalyst, such as heat, iron, copper or light. The role of heat in promoting both oxidation and fat hydrolysis may be the root of the confusion. Adding antioxidants, the most common practice to prevent oxidation, to prevent FFA production is not recommended because many antioxidants are acidic and may contribute to higher FFA measurements.

Insoluble impurities usually consist of small particles of fiber, hair, hide, bone, or soil. These can cause clogging problems in fat handling screens, nozzles, and other equipment, and contribute to the build-up of sludge in fat storage tanks.

Moisture is detrimental in fats since it accelerates corrosion of fat handling equipment and may promote the formation of rust, which is a powerful catalyst of oxidation and rancidity. Moisture also contributes no energy, lubricity, or other benefits to feed and should be kept to a minimum. Moisture settles in fat storage, making accurate sampling difficult.

Saponification value (SV) is an estimate of the mean molecular weight of the constituent fatty acids in a fat sample and is defined as the number of milligrams of potassium hydroxide required to saponify one gram of the fat. Higher SV indicate lower mean chain lengths of the triglycerides.

Unsaponifiable fats contain a number of compounds such as sterols, hydrocarbons, pigments, fatty alcohols, and vitamins, which are not hydrolyzed by the alkaline saponification. Normal unsaponifiables have unknown and variable feeding values comparable to the fats involved and can dilute the energy content.

Iodine value: Each double bond in a fatty acid will take up to two atoms of iodine. By reacting fatty acids with iodine, it is possible to determine the degree of unsaturation of the fat or oil. The IV is defined as grams of iodine absorbed by 100 grams of fat. Unsaturated fats naturally have higher IVs than saturated fats so IV can be used to estimate complete fat structures.

Titer value is determined by melting the fatty acids after a fat has been hydrolyzed. The fatty acids are slowly cooled and the congealing temperature in degrees Centigrade is the titer. Animal fats are referred to as "tallow" if they possess a titer of 40 or higher, and are considered "grease" if the titer is below 40, regardless of the animal origin, though most tallow is a by-product of beef processing.

Fat color varies from the pure white of refined beef tallow, to the yellow of grease and poultry fat, to the very dark color of acidulated soap stock. Color does not affect the nutritional value of fat but may be a consideration in pet foods and other consumer oriented products because of the potential to affect the appearance of finished products.

Fat stability and antioxidants: To prevent the development of oxidative rancidity, which can destroy vitamins A, D, and E and cause other problems in feeds, antioxidants are recommended for all feed fats. Rancidity is a descriptive or qualitative term that was derived from human thresholds in detecting off-flavors associated with the oxidation of fats. Rancidity is not chemically defined, nor is it quantifiable. As a result, the industry has tried to describe rancidity by measuring various intermediates or products of oxidation. Two such tests that are commonly used as indicators of the stability of fats are:

1. Peroxide value (PV) – This test measures the milliequivalents (me) of peroxide per kilogram (/kg) and reveals the current state of oxidative rancidity. A low PV (sometimes defined as less than 10.0 me peroxide/kg) indicates a non-rancid sample.
2. Active Oxygen Method (AOM) test for 20 hour stability – This is a measure of the peroxide value after 20 hours of bubbling air through the sample. This test is intended to determine the ability of the fat to resist oxidative rancidity in storage.

Tallow is primarily derived from rendered beef tissue but could contain other animal fat. Most chemical and soap manufacturers require a minimum titer of 40.5 to 41.0. A titer of at least 40 is required for a tallow designation.

Choice white grease is derived primarily from pork tissue. The soap industry requires color specifications, but color is less important for feeding fats.

Thus, considerable savings can often be acquired by developing feeding fat specifications that concentrate on the nutritional value of the respective fat.

Yellow grease has been a term used for a number of years and often confused with off-color choice white grease. Yellow grease is primarily restaurant grease/cooking oil sources but can contain other sources of rendered fat.

There are several documented benefits for use of animal fats in livestock, poultry, aquaculture, and companion animal diets including enhancing energy concentration of diets. Depending on the species to which it is being fed, the energy contributions of fat range from 2.6 to 3.8 times the energy content of corn. Energy values for the commonly used animal fats are listed in Table 5. In addition to the nutritional contribution, fat addition to animal diets contributes to dust control, feed mill cleanliness, worker comfort, enhanced pelleting efficiencies, improved palatability of feed, reduced respiratory disease, increased stability of fat soluble vitamins and other nutrients, and enhanced life of feed equipment.

Table 5. Energy Values for Fats Commonly Added to Swine and Poultry Feeds.[1]

Fat Source	Poultry ME, kcal/lb	Swine ME, kcal/lb[2]
Yellow Grease[3]	3,582	3,663
Poultry Fat	3,539	3,641
Choice White Grease	3,424	3,585
Brown Grease	3,332	3,534
Tallow	3,167	3,452
Palm Oil	3,069	3,401

[1] Calculated using equations from Wiseman et al. (1991) for poultry and Powles et al. (1995) for swine.

[2] These equations calculate digestible energy (DE). Metabolizable energy (ME) was calculated as 96 percent of DE.

[3] Recovered frying fat.

Animal Protein Ingredients

Proteins are essential constituents of all biological organisms and are found in all body tissues of animals. Proteins are found in higher concentrations in organ and muscle tissue, and range from very insoluble types in feather, hair, wool, and hoofs, to highly soluble proteins such as those in serum or plasma. Animal derived foods are primary sources of protein and other nutrients in human diets. Similarly, the tissues from animal production and processing not utilized in human food are processed into an array of protein meals used in animal feeds.

AAFCO defines the composition of all legally used feed ingredients including rendered animal products. The *2006 AAFCO Ingredient Manual* references some 125 individual animal by-products, and is updated annually. The primary animal protein by-products are meat and bone meal (MBM), meat meal, blood meal, poultry by-product meal, poultry meal, feather meal, and fish meal. Using MBM as an example, AAFCO defines it as the rendered product from mammalian tissues including bone but exclusive of blood, hair, hoof, horn, hide trimmings, manure, and stomach and rumen contents. MBM as defined by AAFCO must contain a minimum of four percent phosphorus with a calcium level not to exceed 2.2 times the actual phosphorus level. Ingredients of lower phosphorus content must be labeled meat meal.

Meat and Bone Meal

In addition to the above AAFCO description, MBM shall contain not more than 12 percent pepsin indigestible residue and not more than nine percent of the crude protein shall be pepsin indigestible. Pepsin is a proteolytic enzyme which is secreted by the stomach where it hydrolyzes proteins to polypeptides and oligopeptides. If a protein is pepsin indigestible, animals may not be able to digest it. MBM can be used in all species of livestock, poultry, and aquaculture feed, but only non-ruminant source material must be utilized for ruminant feed (by FDA regulation).

Poultry By-Product Meal

Poultry by-product meal (PBM) consists of ground, rendered, clean parts of the carcass of slaughtered poultry such as necks, feet, undeveloped eggs and intestines, exclusive of feathers, except in the amounts as might occur unavoidably in good processing practices. The label shall include guarantees for minimum crude protein, minimum crude fiber, minimum phosphorus, and minimum and maximum calcium. The calcium level shall not exceed the actual level of phosphorus by more than 2.2 times. The quality of PBM, including critical amino acids, essential fatty acids, vitamins, and minerals along with its palatability, has led to its demand for use in pet foods and aquaculture.

Hydrolyzed Poultry Feather Meal

Hydrolyzed poultry feather meal (FeM) is pressure-cooked, clean undecomposed feathers from slaughtered poultry, free of additives and/or accelerators. Not less than 75 percent of its crude protein content must be digestible by the pepsin digestibility method. Modern processing methods that cook the feathers under pressure with live steam partially hydrolyze the protein and break the keratinaceous bonds that account for the unique structure of feather fibers. The resulting feather meal is a free-flowing palatable product that is easily digested by all classes of livestock. Modern feather meals greatly exceed the minimum level of AAFCO required digestibility. In cattle, 64 to 70 percent of FeM protein escapes degradation in the rumen and remains highly digestible in the intestinal tract. A specific characteristic is its excellent source of the sulfur containing amino acids, especially cystine.

Blood Meal, Flash-Dried

Blood meal flash-dried is produced from clean, fresh animal blood, exclusive of extraneous material such as hair, stomach belchings, and urine, except as might occur unavoidably in good manufacturing processes. A large portion of the moisture (water) is usually removed by a mechanical dewatering process or by condensing by cooking to a semi-solid state. The semi-solid blood mass is then transferred to a rapid drying facility where the more tightly bound water is rapidly removed. The minimum biological activity of lysine shall be 80 percent.

Blood products are the richest natural sources of both protein and the amino acid lysine available to the feed industry. However, throughout the 1960s and 1970s its use was limited because blood meal was considered to be unpalatable. Blood meal is inherently low in the amino acid isoleucine and the vat-drying procedures used at the time to process raw blood were severe enough to lower the bioavailability of lysine. Processing changes have improved the product considerably. Newer methods of processing (ring or flash-drying) produce blood meals with amino acid digestibilities of 90 percent or greater. Improved amino acid availability, in combination with improved formulation techniques, allows nutritionists to balance more of the essential amino acids, including isoleucine, which also eases concerns about the palatability of blood meal. Today, nutritionists are interested in blood meal because it is high in protein and is considered to be an excellent source of lysine. Its properties as a high rumen bypass protein have been highlighted in research findings in dairy, feedlot, and range cattle.

Fish Meal

Fish meal is generally considered in the animal protein class of ingredients though it is described in the marine products section of AAFCO. Fish meal is the clean, dried, ground tissue of undecomposed whole fish or fish cuttings, either or both, with or without the extraction of part of the oil. It must contain not more than 10 percent moisture. If it contains more than three percent salt, the amount of salt must constitute a part of the brand name, provided that in no case must the salt content of this product exceed seven percent.

Menhaden and anchovy are the main wild-caught fish species used for meal manufacture, with lesser quantities of herring used for meal. With an increase in aquaculture directed at the human food industry, by-products from these processing sites are being utilized. Fish meal is usually an excellent source of essential amino acids and fat soluble vitamins. Digestibility of its amino acids is excellent, but as with other ingredients, highly correlated to processing. Fish meals can be used in all types of rations. In some products, such as companion animal food diets, the palatability factors and the fishy smell and flavors are benefits. When used for other species, strong fishy odors and flavors in eggs, milk, or meat can be a disadvantage.

Other Products

There are several other specialty ingredients of animal protein origin such as plasma. Plasma in recent years has become a common component of early pig and calf formulas. Plasma is a highly digestible protein source in addition to providing immune response benefits in young animals.

Nutrient Value of Proteins

The major animal protein ingredients, MBM, meat meal, and PBM, are important feed ingredients for livestock, poultry, aquaculture, and companion animal diets throughout the world. These products contribute over three million tons of ingredients annually to the U.S. feed industry. In addition to protein, these meals are also excellent sources of essential amino acids, fat, essential fatty acids, minerals, and vitamins. The typical nutrient composition of the four most common animal proteins is shown in Table 6.

As can be noted, all of these ingredients are higher in protein than soybean meal and other plant proteins. In addition, MBM is higher in phosphorus, energy, iron, and zinc than soybean meal. The phosphorus level in MBM is seven-fold greater than that found in soybean meal and is in a form that is highly available to livestock and poultry. The phosphorus in both MBM and poultry meal is similar in bioavailability to feed-grade mono-dicalcium phosphate.

Table 6. Nutrient Composition of Animal Proteins.[1]

Item	Meat and Bone Meal	Blood Meal[2]	Feather Meal	Poultry By-Product Meal
Crude Protein, %	50.4	88.9	81.0	60.0
Fat, %	10.0	1.0	7.0	13.0
Calcium, %	10.3	0.4	0.3	3.0
Phosphorus, %	5.1	0.3	0.5	1.7
TME_N, kcal/kg	2,666[3]	3,625	3,276	3,120
Amino Acids				
Methionine, %	0.7	0.6	0.6	1.0
Cystine, %	0.7	0.5	4.3	1.0
Lysine, %	2.6	7.1	2.3	3.1
Threonine, %	1.7	3.2	3.8	2.2
Isoleucine, %	1.5	1.0	3.9	2.2
Valine, %	2.4	7.3	5.9	2.9
Tryptophan, %	0.3	1.3	0.6	0.4
Arginine, %	3.3	3.6	5.6	3.9
Histidine, %	1.0	3.5	0.9	1.1
Leucine, %	3.3	10.5	6.9	4.0
Phenylalanine, %	1.8	5.7	3.9	2.3
Tyrosine, %	1.2	2.1	2.5	1.7
Glycine, %	6.7	4.6	6.1	6.2
Serine, %	2.2	4.3	8.5	2.7

[1] National Research Council, 1994.
[2] Ring or flash-dried.
[3] Dale, 1997.
TME_N = true metabolizable energy nitrogen corrected.

Individual suppliers of animal protein meals can often provide more detailed specifications than derived from published papers based on averages or dated analyses. Analytical precision for chemical and nutrient availability values in animal protein ingredients is improving (Parsons et al., 1997). However, the most precise values have been derived from animal feeding studies.

Modern rendering processes, improved equipment, and computer monitored systems have resulted in significant improvements in the digestibility of animal proteins. Data collected from 1984 to the present demonstrate the digestibility improvements in the essential amino acids of lysine, threonine, tryptophan, and methionine. These data are summarized in Table 7.

Table 7. Digestibilities of Meat and Bone Meal Analyzed in Different Years Have Shown Improvement.

Amino Acid	1984 [a]	1989 [b]	1990 [c]	1992 [d]	1995 [e]	2001 [f]
Lysine, %	65	70	78	84	94	92
Threonine, %	62	64	72	83	92	89
Tryptophan, %	---	54	65	83	---	86
Methionine, %	82	---	86	85	96	92
Cystine, %	---	---	---	81	77	76

[a] Jorgensen et al., 1984.
[b] Knabe et al., 1989.
[c] Batterham et al., 1990.
[d] Firman, 1992.
[e] Parsons et al., 1997.
[f] Pearl, 2001.

Lysine digestibility in high quality MBM improved from 65 percent to over 90 percent during this time period. Dramatic improvements in the digestibility of tryptophan and threonine have also been documented. Cystine digestibility is between 76 percent and 81 percent but values were not reported in studies conducted prior to 1992. Similar improvements in amino acid digestibility have occurred in poultry meal, feather meal, and especially in blood meal.

Competition

Rendered protein meals and fats compete with vegetable products on a daily basis. Shifts in usage, as well as new developments can change the business atmosphere in the future. One example is the development of the fast growing fuel ethanol industry. Currently, there are 97 ethanol plants in production, with an additional 33 ethanol plants under construction. These ethanol plants have an annual production capacity of 4.5 billion gallons (Renewable Fuels Association, August, 2006). Dry-grind ethanol plants represent the fastest growing segment of the fuel ethanol industry in the United States, and produce the majority (60 percent) of fuel ethanol. By-products from dry-grind ethanol plants include wet and dry distiller's grains, wet and dried distiller's grains with solubles (DDGS), modified "wet cake" (a blend of wet and dry distiller's grains), and condensed distiller's solubles. Of these dry-grind ethanol plant by-products, distiller's grains with solubles is the predominant by-product being marketed domestically (Shurson, 2005). Approximately 40 percent of the distiller's grains with solubles are marketed as a wet by-product for use in dairy operations and beef cattle feedlots. DDGS is marketed domestically and internationally for use in dairy, beef, swine, and poultry feeds. More than 15.4 billion pounds of DDGS was produced in the United States in 2005. Corn is the primary grain used in wet mills and dry-grind ethanol plants because of its high fermentable starch content compared to other feedstocks. Shurson (2005) identified the following challenges facing DDGS in the animal feed marketplace.

- Product identity and definition
- Variability in nutrient content, digestibility, and physical characteristics
- Lack of a quality grading system and sourcing
- Lack of standardized testing procedures
- Quality management and certification
- Transportation
- Research, education, and technical Support
- International market challenges
- Lack of a national distiller's by-product organization and industry cooperation

There is considerable variation in nutrient content and digestibility among DDGS sources compared to soybean meal (Shurson, 2005). Tables 8 and 9 compare the nutritional characteristics of DDGS to meat meal and soybean meal. Research shows that higher levels of DDGS in swine diets increases the amount of unsaturated fat and reduces fat firmness in pigs, which impacts the quality of the meat and consumer acceptance (Shurson, 2001). Meat quality concerns may limit the amount of DDGS that can be used in swine diets and the relatively high fiber content of DDGS may restrict its use in poultry diets. Also, since DDGS contains polyunsaturated fats, there are concerns about high levels in cattle diets that can result in the accumulation of unwanted trans-fats in meat animals and depressed milk fat production in dairy cows.

Table 8. Dry Matter, Energy, and Fat Composition of Meat Meal, Dehulled Soybean Meal, and Dried Distiller's Grains with Solubles (DDGS).

Feedstuff	Dry Matter %	Digestible Energy kcal/lb	Metabolizable Energy kcal/lb	Net Energy kcal/lb	Fat %
Meat meal [a]	94	1,224	1,178	987	12.0
Soybean meal [a]	90	1,673	1,535	917	3.0
DDGS	89	1,819	1,703	829	10.8

[a] NRC, 1998.
[b] University of Minnesota, www.ddgs.umn.edu/profiles.htm

Table 9. Protein and Amino Acid Composition of Meat Meal, Dehulled Soybean Meal, and Dried Distiller's Grains with Solubles (Percent).

Feedstuff	Prot.	Lys	Thr	Trp	Met	Cys	Ile	Val
Meat meal [a]	54.0	3.07	1.97	0.35	0.80	0.60	1.60	2.66
Soybean meal[b]	47.5	3.02	1.85	0.65	0.67	0.74	2.16	2.27
DDGS	30.9	0.91	1.14	0.24	0.64	0.60	1.17	1.57

[a] NRC, 1998.

[b] University of Minnesota, www.ddgs.umn.edu/profiles.htm

While the rendering industry is much more mature than the fuel ethanol industry in the United States and renderers have faced many of these same issues, and have solved some, it is instructive to keep an eye on the competition.

Future Availability

The availability of rendered products for animal feeds in the future depends on regulation and the market. In the FDA Docket No. 2002N-0273, the agency's proposed rule on substances prohibited from use in animal food or feed, FDA announced its intent to prohibit brains and spinal cords from cattle 30 months of age or older from being used in all feed, including for non-food animals. They are also proposing to ban all dead and downer animals (they term these "cattle not inspected and passed for human consumption") from any feed unless the brains and spinal cords are removed. The FDA estimates the rule will decrease the annual production of MBM available for feed by about 15 million pounds, which would be a tiny 0.3 percent of the total volume produced in the United States (Federal Register, 2005). Many renderers believe this restriction on dead stock will end the service of dead stock collection all together (about 2.2 billion pounds of raw material; Informa Economics, 2004). If this were the case, the proposed rule could decrease the annual production of MBM available for feed by about four percent of the total volume produced in the United States.

Renderers are innovative and competitive and will adapt to changes in both regulations and the market. Regulatory agencies will determine whether certain raw materials can be used for animal feed. Customer expectations, consumer demand, and economic considerations will dictate product specifications and prices.

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A HISTORY OF NORTH AMERICAN RENDERING

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Introduction—"What Is Rendering?"

Rendering is the recycling of raw animal tissue from food animals, and waste cooking fats and oils from all types of eating establishments into a variety of value-added products. During the rendering process, heat, separation technology, and filtering are applied to the material to destroy microbial populations, remove moisture, extract fat from the protein, and remove moisture and proteinaceous material from the fat.

In the United States, approximately 54 billion pounds of inedible animal tissue are generated annually, which represents approximately 37 to 49 percent of the live weight of each slaughtered food animal. Rendering is the safest, most economical method of inactivating disease-causing microbes while recovering billions of dollars worth of marketable commodities.

The Beginning

The recycling of animal by-products into useful commodities is not a recent innovation. The cave people, the ancient Jordanians, the Eskimos, the Indians—one could go on and on—all ate far more of the animal than we do, but they also were innovative and utilized what they didn't eat to improve their way of life. The hides and skins provided them with clothing and shelter, bones and teeth provided weapons and sewing utensils and they burned the waste fat to cook the meat. Frank Burnham, author of *The Invisible Industry*, performed an excellent service for renderers by giving them an insight into the evolution of their industry in the book's first chapter, An Industry is Born. Burnham also wrote the first chapter of *The Original Recyclers,* The Rendering Industry: A Historical Perspective, and these documents served as the primary resource for the first section of this chapter.

As would be expected, tallow was sought after and became the principal commodity that drove the development of rendering. It continued to be the dominant economic force in rendering from the Galls, to the Romans, through the Middle Ages melters, to the twentieth century renderers through the early 1950s. In *The Invisible Industry,* Burnham tells the story of the Roman scholar, Plinius Secundas, otherwise known as "Pliny the Elder." He reported a cleansing compound prepared from goat's tallow and wood ashes; this, then, is the earliest record of soap and, ergo, the first record of rendering—the melting down of animal fat to obtain tallow.

During the Roman era, soap was described as a means of cleaning the body and as a medicament. In about AD 800, Jabir ibn Hayyan, an Arab chemist known as the "Father of Alchemy," wrote repeatedly of soap as an effective means of cleaning. Soap seems to have been limited to cleaning hair and body until the mid-1800s, when it became a laundry product.

It is important to understand that soap ultimately became the principal product made from tallow, but soap essentially was a by-product until the latter part of the nineteenth century. Candles were developed to meet a serious need—light—and since tallow was the major component of early candles, the demand for tallow contributed significantly to the development of rendering. Whether by dipping or using molds, tallow produced only a "pretty good" candle. Then, as now, there was fierce competition to find superior alternate products to replace a commonly used ingredient which led to bees wax replacing tallow, then palm oil, and finally paraffin wax.

Burnham brought forth an interesting trivia question about candle manufacturing when he described the "spermaceti" candle. This is a candle produced from oil from the head cavity of a sperm whale. The candle became the standard measure for artificial light, the term "one candle power" being based on the light given by a pure "spermaceti" candle weighing one-sixth of a pound and burning 120 grains an hour.

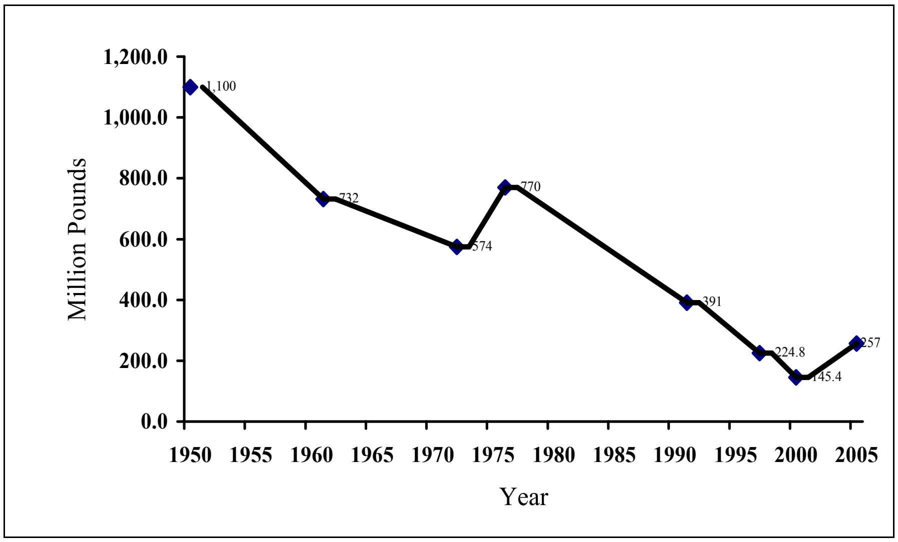
As mentioned earlier, soap ultimately became the principal product made from tallow. Marseille, France produced the very best soap and all soap, regardless of quality, was heavily taxed and was only for the wealthy. When the taxes were removed and it became available to the middle class, this gave rise to a greater demand, which led to more sophisticated rendering operations.

The world soap and rendering industry grew in tandem for over 100 years because the soapers used tallow as their principal ingredient. The superior quality tallows found their way into toilet soaps and the lower grades produced lower-priced bar and eventually flake laundry soap. Between 1950 and 1965, the rendering industry underwent an extremely traumatic period. The advent of synthetic detergents in the mid-1950s dealt the renderer a massive blow. Actually, synthetics (primarily based on the use of phosphates) were the result of research by the soap industry, aimed at resolving a growing problem with the use of natural soap powders in hard water. The driving force was to get rid of the curd which tended to remain in the material being washed and which built up from wash to wash.

In 1950, the U.S. rendering industry sold 1.1 billion pounds of fats to soap manufacturers. From that high point, it declined to a low of approximately 146 million pounds in 2000 before rebounding to 257 million pounds in 2005 (Figure 1). It was a linear decline from the 1950s until the mid-1970s, when due to increases in popularity and advertising investments, tallow registered a recovery. One factor in the brief boost was the introduction of Dial, a very popular bactericide toilet soap by Armour and Co. Currently many bar soaps are detergent based, and edible tallow is the predominant fat in top-quality toilet soaps.

The initial "discovery" of animal proteins was incidental to rendering animal fats for edible consumption, soap, and candle production. Generally, they were treated as wastes, and discarded. The American Indian, not wanting to waste any part of an animal, placed deer blood or offal from wild animals and fish around the stalks of their corn and experienced higher yields and larger ears, thus establishing an early use of proteins as fertilizer. At the turn of the century, as animal slaughter plants grew and expanded with the growth of trading centers, rendering also expanded, becoming a convenient disposal method not only for fats, but also for offal and bones. The use of animal fats continued with the solid, protein portion being generally spread on land for what fertilizer value it provided.

Figure 1. Use of Animal Fats in Soap Industry.



Meat and bone meal was the first protein supplement to be added to an all-grain ration for swine and it demonstrated the value of balanced rations. The initial use of animal proteins as a feed ingredient is related in the following story from *The National Provisioner's* historical *Meat for the Multitudes*, published July 4, 1981.

> "One of the most significant developments of the early 1900s was the discovery that digester tankage—previously used as a fertilizer material—was valuable as an animal feed constituent. At that time a minimum of nine months was required to produce a hog of marketable weight and finish. Corn alone was used for fattening, and farmers were able to raise only one pig crop per year because of the time needed to bring the animal to market weight."

In 1901, Professor C. S. Plumb of Purdue University—perhaps taking a hint from European feeding practices—added a quantity of animal protein material to the corn ration being fed to pigs at Purdue. The protein supplement used was tankage. Plumb's experiment induced such an acceleration of growth that his pigs were ready for market in seven months or less. About the same time other experimenters were mixing dried blood with various cereals to produce better feeding rations. Swift & Company took pride in the fact that the 1903 international car lot champion hogs, 52 animals averaging 365 pounds and dressing out at 84 percent, had been fed on the firm's digester tankage. Discovery of this new outlet for by-products was indicative of the advances being made in and for the industry through greater use of science and scientists.

The Emergence of a U.S. Rendering Industry

The first soap plants in the United States were located in New England and they were supplied by rendering operations associated with packing houses. The demand for soap grew dramatically after the Civil War, and small independent renderers sprang up to procure fallen animals and service the small slaughtering establishments. Boston was one of the major meat packing centers in the late 1600s, but most slaughtering was still done on the farm until around 1850 to 1875. The first record of a combined slaughter and meat packing plant in the United States was in Alton, Illinois in 1832.

While the meat packing, rendering, and soap industries became more organized in the eastern United States, there was the beginning of fat melting operations in the undeveloped western United States in the 1880s. The early western cattlemen had similarities to the professional buffalo hunters. Buffalo Bill and his associates only harvested the buffalo hides, leaving the carcasses to rot on the plains. The cattlemen also highly valued the cattle hide, but did render the fatty parts of the animals to produce tallow for shipment to the eastern U.S. soap plants. Burnham, in *The Invisible Industry,* included the notes of an early western cattle trader by the name of Cleveland Larkin. In 1846, Larkin was trying to arrive at the value of a steer. Hides were worth $2.00 and depending on the size of the animal you could produce two or three arrobas of tallow (25 lb per arroba) at $1.50 an arroba, thus netting $5.00 a head without the meat value. By salting or drying only the select cuts, the trader could sell approximately 50 lb of dried beef for 20 cents a pound, therefore receiving approximately $15.00 per head. The transition from just slaughtering the animals for their hides to rendering the fat and salting or drying the meat enabled enterprising cowboys to establish commercial businesses—custom slaughtering operations. These facilities in the western and eastern United States were the forerunners of the thousands of custom locker plants that sprang up in the United States in the 1900s. The charge for this service was $4.50 in 1850, and the same process without rendering was only $15.00 in 1975. The reason for this nominal increase was that the modern slaughtering plant received the value of the hide. Small slaughtering plants were one of the major suppliers of independent renderers until the beginning of their decline in the late 1980s. The closing of these small slaughterers (5 to 30 head per week) and the small packing houses (50 to 200 head per day) was a major factor that led to a decrease in the number of independent rendering plants over the past 20 years.

In 1865, the Chicago Stockyards were built, which led to the establishment of large packing house centers in cities such as St. Louis, Kansas City, Omaha, etc. The advent of central slaughtering centers created a demand for larger volume and more sophisticated rendering equipment to process the large quantity of raw by-products from the slaughter of livestock.

Technological Advances in Rendering Systems

The turn of the century brought on increased livestock numbers and a commensurate increase in fallen animals on farms. Farmers were still raising and slaughtering their own poultry and pigs, but grocery stores in urban areas began to generate a limited but growing volume of fat and bones for renderers. All of the above dictated the need for improved rendering systems, but it wasn't until the introduction of the dry rendered cooker in Germany in the 1920s that the industry began to produce quality proteins as well as fat.

The open kettle process, which was dangerous, gave way to the autoclave in the centralized packing house and independent rendering plants, but open kettle rendering on the farm continued until the World War II era. The autoclave is a metal vessel which could be charged with its load of fat, bones, and offal, sealed, and live steam injected into it. Conducting the melting process at higher than normal atmospheric pressure not only accelerated the process, but gave the renderer greater control of the end products. It also enabled him to extract even more of the fat from the raw material.

The system of rendering which called for adding water to the raw material (dumping it in the open kettles in the earliest days or injecting it in the form of steam in the sealed autoclave) was known as "wet rendering." Since the main objective of the rendering process, after all, is to separate the residual moisture in the raw material from the fat and solids, the introduction of additional moisture, which in turn would have to be removed, seemed to most renderers as counterproductive.

In wet rendering, the fat floated to the surface where it was skimmed off. The fat produced by this process was relatively light in color, but the long contact with water increased the free fatty acid content. The excess water (stick water) which contained soluble protein was discharged to the sewer or streams and rivers which adjoined early rendering facilities.

The first mention of a method to release the fat from the membranous material was in the London Encyclopedia in 1829. It noted that more fat could be sold if a manually operated press was used to press the meat material. The resulting cake was called greaves, or cracklings, and was found to be an excellent feed for dogs and ducks, the first record of feeding animal proteins to monogastric animals. The manual iron press was later replaced by the hydraulic press in about 1850, and in the late 1800s, the mechanical screw press was invented by V.D. Anderson.

For reasons of economy, particularly in the recovery of protein, the wet rendering process was completely replaced by "dry rendering." Many old time renderers described the change from wet rendering to dry rendering as going from cooking the raw material in water to cooking the by-products in their "own juices."

In batch dry rendering, the raw animal by-products are added (ground or un-ground) to a horizontal steam-jacketed cylinder equipped with an agitator. If the raw product is un-ground, the vents are closed and pressure is built up in the cooker to disintegrate the bones and other large particle raw material. This pressure cooking step is eliminated with ground raw material.

In dry rendering, the fat cells open due to changes in the cell walls of the tissue as moisture evaporates. Four quality-control procedures are especially important in this cooking process, just as in all modern continuous systems:

1. Grinding and charging of the raw material
2. Control of jacket steam pressure
3. Agitator operation (revolutions per minute or RPM)
4. End-point control, or cooking/drying temperatures

The end point in cooking is reached when the moisture content of the greasy tankage is reduced to the point which gives the best operation in removing the residual fat (pressing) and at the same time not overcooking and degrading protein quality.

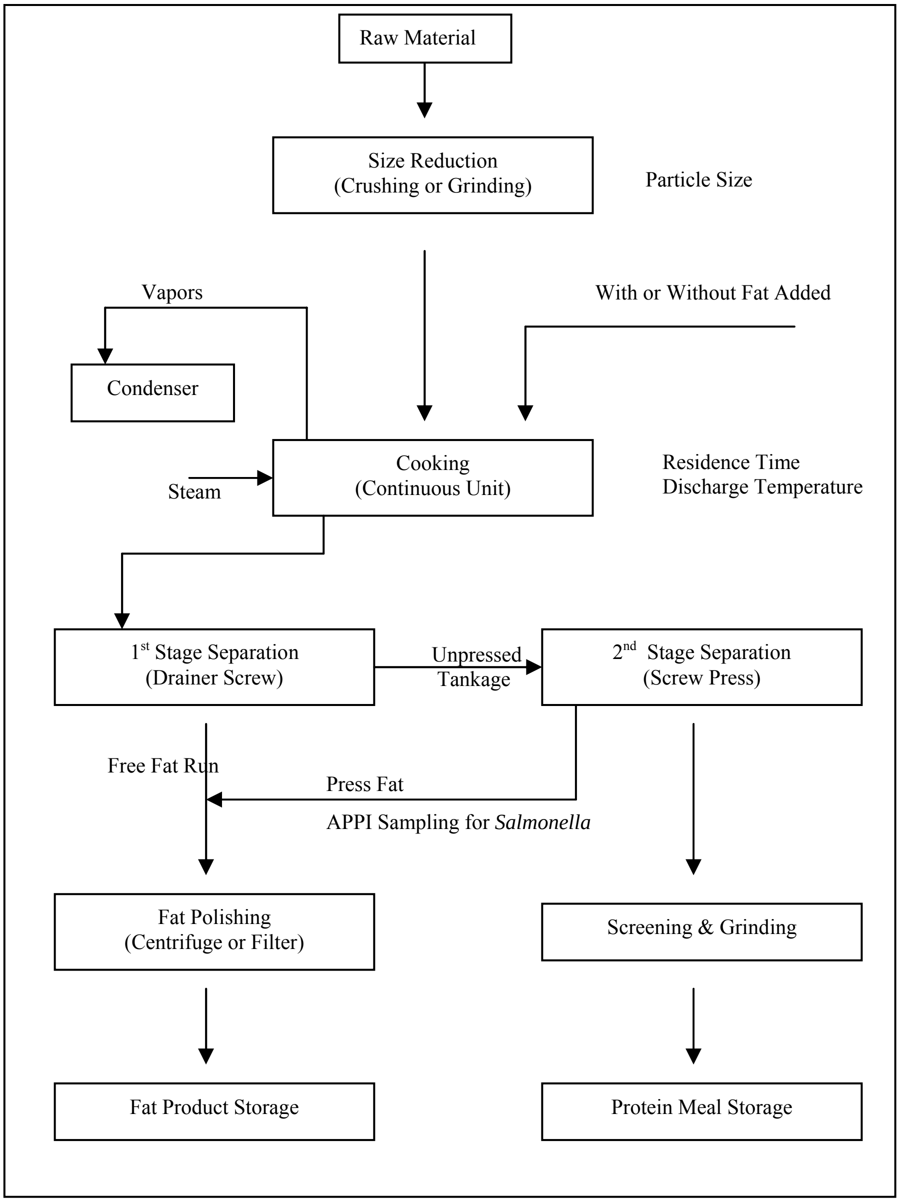
In the late 1950s, George Epsy, a maintenance man at Baker Commodities in Los Angeles, suggested to Frank Jerome, then owner of the company, that he believed a "continuous" cooking process could be developed with some engineering assistance. Jack Keith of Keith Engineering was contacted and the team determined that ground raw material could be conveyed through large metal tubes. Once that was accomplished, the first prototype of a continuous cooker was born which consisted of two pre-cookers (batch cookers in series) and three steam-jacketed tubes as finishers. It took several years to finalize the design, but after much dedicated effort, the single-vessel cooker, known as the continuous cooker, was developed. The very first continuous cooker was installed at Denver Rendering Company in the early 1960s. The steps in the batch and continuous rendering processes may be seen in the outline of a continuous cooker system (Figure 2).

Over the years, renderers added sophisticated filtering and bleaching operations, polishing centrifuges, refining equipment (removing free fatty acids), and additional processing equipment. Other continuous systems are the multi-stage evaporator (Carver-Greenfield or Stord Slurry), continuous preheat/press/evaporator (wet or low temperature rendering) and modified preheat/press/evaporator. Table 1 shows estimates of the various rendering systems utilized by U.S. rendering plants.

Table 1. Breakdown of U.S. Rendering Systems by Type.

Batch Cookers	41
Continuous Multi-Stage Evaporator	9
Preheat/Press/Evaporator	4
Tube and Disc Continuous	219

Figure 2. Continuous Cooker Rendering System.



An Industry Matures

In 1956, most rendering plants would have been described as manufacturing facilities in need of a lot of improvement. But in the last 50 years, major changes have been made in plant technology, housekeeping, finished product quality, and employee safety. Before World War II, rural independent renderers depended on diseased, dying, disabled, and dead (called 4-D or fallen animals) as the main source of raw material. It has been stated that every county in Iowa had at least one rendering plant. The urban renderers as far back as 1900 were establishing scrap routes that procured fat, bones, and offal from grocery stores and small slaughtering plants. Before 1920, the major packers controlled both their own captive tonnage and most street material as well. In 1920, an investigation by the Federal Trade Commission (which resulted in a now historic consent decree and the enactment of the Packers and Stockyards Act of 1921) appeared to break the existing monopoly and trigger a major expansion in the number of renderers then doing business. It was estimated there were 823 rendering plants in the United States at that time. In 1927, *The National Provisioner* estimated 913 plants, with Philadelphia and Baltimore having 15 each and Cincinnati supporting 14. Iowa had the most plants with 123 facilities. Removing the 4-D animals from the producers' premises in a sanitary manner made a significant contribution to reducing the spread of animal diseases.

The contribution of the renderer of yesterday and today to overall efforts to maintain a clean and healthful environment is staggering. Up until the advent of boxed beef in the late 1960s and early 1970s, the independent renderers had five principal sources of raw material: shop fat and bones from retail food outlets and fabrication plants; fallen animals; custom slaughterers' fat, bones, and offal; small packing house by-products; and waste cooking fats and oils. All of the above raw material sources, except cooking grease, began to decline in the 1960s.

With the emergence of large livestock-producing units with improved management and health care, and the development of other techniques to dispose of fallen animals, the rural renderer, in spite of increased livestock numbers, procured fewer dead animals. More important was the introduction of boxed beef, the breaking of carcasses at the large packer's plants that had their own rendering plants, into primal, sub-primal, and consumer cuts. The drop of quality tonnage at the supermarkets had a dramatic impact, not only in loss of tonnage, but in raw products that produced superior-quality fats. Small packers could no longer compete with the large packer slaughtering 4,000 cattle or 12,000 pigs a day. Commensurate with the decline of the small packer, rural housewives of the 1980s preferred purchasing their meat at the supermarket versus fattening a steer and having it slaughtered and packaged for her freezer.

During the 1980s and 1990s, we experienced a shift from the independent renderers handling the majority of the raw material to the large packer and integrated poultry processors rendering, approximately, more than 75 percent of the raw material tonnage (Table 2). The only growth areas enjoyed by the independent renderer over the past 20 years have been waste cooking fats and oils and raw poultry by-products. Unfortunately, only a few companies are strategically located to service the growing poultry industry.

Table 2. Trends in U.S. Raw Material Procurement.

	1970		**1990**		**2000**	
	Packer or Poultry Renderer	Independ-ent Renderer	Packer or Poultry Renderer	Independ-ent Renderer	Packer or Poultry Renderer	Independ-ent Renderer
Beef	56%	44%	71%	29%	85%	15%
Pork	60%	40%	65%	35%	70%	30%
Poultry	25%	75%	50%	50%	70%	30%

Source: Darling International, Inc.

All the above factors contributed to a consolidation of the independent rendering industry while the overall available rendering tonnage (Table 3) increased from approximately 30 billion pounds in 1977 to 40.5 billion pounds in 1995, and approximately 54 billion by 2006. After deducting for raw by-products used in pet food, renderers produce more than 11.2 billion pounds of animal derived proteins and 10.9 billion pounds of rendered fats each year. Table 4 shows the decline in the number of U.S. rendering plants since the early 1920s.

Table 3. Raw Material Available for Rendering Increased over the Years.

	1977	**1989**	**1995**	**1998**	**2004**	**2006**
Billions of Pounds	30	36	40.5	42	52	54

Table 4. Number of U.S. Rendering Plants Decreased over the Years.

	1921	**1927**	**1975**	**1997**	**2006**
Number of Plants	823	913	724	282	273

Note: Similar trends occurred in Canada, where there are currently 29 plants.

Several significant events came about in the 1950s and early 1960s that enabled the rendering industry to withstand the loss of sales to the soap industry:

- High energy rations for poultry, swine, and feedlot cattle (use of fats in feed)
- Emergence of the pet food industry that used fats and proteins
- Increased usage of tallow by fatty acid industry
- Growth of fast food outlets (making available waste cooking fats and oils)

The growth of the poultry industry not only provided an excellent customer for proteins and fats, but also created raw material for many independent renderers. Research at the University of Maryland and by Dr. Oliver Wilder of the American Meat Institute Research Foundation demonstrated that poultry could utilize high energy rations if the nutritionists maintained the proper caloric-to-essential amino acid ratio. Along with the increase of fats in feed, the industry developed a method to process feathers into a high-nutrient ingredient that added another commodity for renderers to market. Table 5 illustrates the usage of fats in feed by species.

Table 5. Estimated Usage of Fats in Animal Feeds (Millions of Pounds).

	1987[1]		1991[2]	
	Type of Feed		Type of Feed	
	Yellow Grease	**Added Fat**	**Yellow Grease**	**Added Fat**
Swine	160	250	250	300
Beef Cattle	195	240	200	250
Dairy Cattle	55	100	50	200
Broilers	310	1,025	400	1,200
Layers	15	30	20	35
Turkeys	120	350	300	500
Dogs	90	365	50	400
Cats	20	75	10	100
Other Species (Veal)	20	40	25	50
TOTAL:	985	2,475	1,305	3,035

[1] SRI International 1987. [2] Fats and Proteins Research Foundation.
Editors note: Current usage data by species are not readily available.

When pet owners moved away from feeding table scraps to their companion animals, there was a significant expansion of pet food manufacturing plants. With the introduction of nutrient dense extruded pet food, this industry consumed large quantities of tallow, meat and bone meal, poultry by-product meal, and poultry fat. Table 6 gives a species breakdown of animal protein utilization.

Table 6. Animal Protein Utilization by Species.

Dogs and Cats	Poultry	Swine	All Cattle	Miscellaneous
39%	38%	15%	5%	3%

Table 7. Fatty Acid and Lubricant Usage (Millions of Pounds).

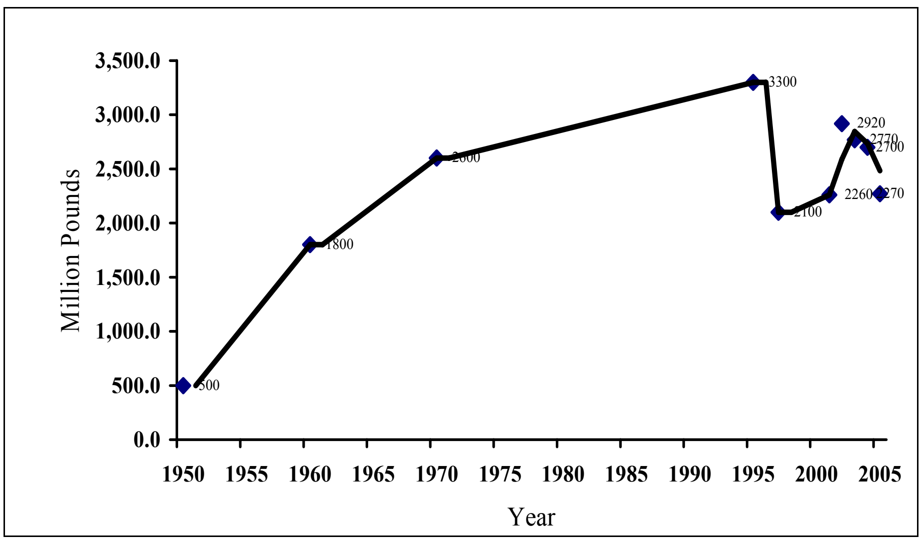
	2001	2002	2003	2004	2005
Fatty Acids	2,060	2,178	2,235	2,374	2,271
Lubricants	119	112	110	112	364

Source: U.S. Census Bureau Current Industrial Report M311K, 2005.

As the population exploded in the 1960s and 1970s, there was an increased demand for products that included fatty acids from animal fats. Competitively priced animal fats were an excellent source for fatty acids since the 1950s. Even with the increase in animal fat prices and fierce competition from other lipids, usage of rendered animal fats in the fatty acid and lubricant industry is being maintained at a reasonable level. Table 7 illustrates the usage pattern in this industry over the past several years.

By 1950, the rendering industry was producing more than 2.3 billion pounds of tallow and grease annually. A healthy export market developed, with the assistance of the USDA's Foreign Agriculture Service, and in 1950 the U.S. rendering industry exported one-half billion pounds of animal fats. In 1960, the production figure had increased to more than 3.5 billion pounds and exports were up to nearly 1.8 billion pounds. In 1970, the same figures stood at 5.4 billion and 2.6 billion pounds, respectively. 1995 was the high water mark for animal fats exports.

Figure 3. Exports of Inedible Fats.



Source: USDA Foreign Agricultural Service.

As U.S. production of animal fats continued to increase, the proportion exported steadily declined in recent years, except for 1995. In contrast to this decline, animal proteins have demonstrated a continued increase in exports over the past 20 years (Figure 3) until the Asian financial crisis of 1997 and 1998. China's growing protein market helped offset the loss of tonnage in Southeast Asia, until they became concerned about ruminant material, including cattle, sheep, and goat tissue in mixed specie meat and bone meal imported for poultry and swine feed. The level of sheep and goat product in U.S. meat and bone meal is infinitesimal, but there are sophisticated DNA tests that can detect parts per billion.

There is no scientific evidence that indicates that scrapie-infected (scrapie is a transmissible spongiform encephalopathy disease) tissue causes bovine spongiform encephalopathy (BSE), the so-called "mad cow disease." BSE is just another trade barrier. Only two indigenous U.S. cows have been diagnosed with BSE, and those were born well before the 1997 ruminant feed ban. But this has been an excuse for many foreign customers to ban U.S. beef, tallow, and meat and bone meal without scientific justification. This challenge will be discussed in more detail in other chapters.

The rendering industry's ability to address its many challenges would have been severely hampered without the excellent associations organized within the industry. With the assistance of many dedicated volunteer renderers and skilled professional leadership, the National Renderers Association, Fats and Proteins Research Foundation, and Animal Protein Producers Industry have all become organizations that renderers can point to with pride. These groups have commanded the respect of both the business and government communities. Publishing this book illustrates the strength and contribution of these organizations. Industry maturity and prosperity are assured by the ability of these trade groups to properly represent U.S. renderers domestically and throughout the world.

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Early Organization Record.

THE MIDDLE ATLANTIC RENDERERS ASSOCIATION, INC.

WAIVER OF NOTICE OF FIRST MEETING OF INCORPORATORS AND ACTIVE MEMBERS

WE, THE UNDERSIGNED, incorporators and Active Members of THE MIDDLE ATLANTIC RENDERERS ASSOCIATION, INC., a not-for-profit corporation of the State of Delaware, do hereby severally waive notice of the time, place and purpose of the first meeting of incorporators and Active Members of said Association and consent that the same be held in the City of Baltimore, State of Maryland, on the 22nd day of April, 1959, at o'clock . M., and we do further consent to the transaction of any and all business that may come before the meeting, including the adoption of By-Laws and the election of Directors.

Dated: April 22, 1959
Baltimore
Maryland

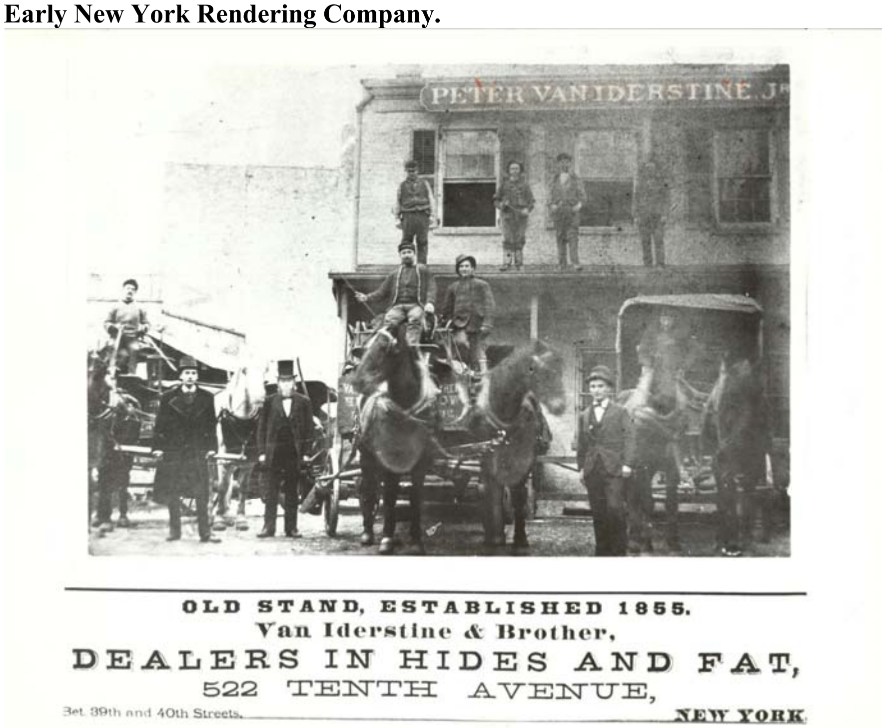
R. C. Sage
R. C. SAGE

Edw. F. Tolzman
EDWARD F. TOLZMAN

W R Malloy
W. R. MALLOY

R E Smith
R. E. SMITH

Early New York Rendering Company.



Syracuse Rendering (Corenco), 1912.

RENDERING OPERATIONS

Douglas P. Anderson
Vice-President, Rendering
Smithfield Foods, Inc.

Summary

Whether rendered products are used in feed for ruminants, poultry, swine, pets, or aquaculture, or for industrial uses of fatty acids, rendering operations and how they are performed will influence production costs, sales quality, and financial success. This chapter will include systems descriptions, a brief operating overview of each system, and challenges, present and future. Also described are systems for management of the process to fulfill regulatory requirements and ISO- or HACCP-like systems.

Energy consumption, production methods, quality control, process control, and the resulting products are all primarily dependent on the raw material and the condition in which it enters the respective processing system. Although it is still impossible to make a "silk purse from a sow's ear," the selection and operation of a particular system can lead to the highest quality finished product possible from a given raw material. Conversely, any system poorly maintained and operated can ruin even the highest quality and freshest of raw material. Environmental repercussions discussed in another chapter are also highly influenced by operations parameters, the system, and the way it is controlled for its process efficiency.

Through the years, various techniques have also been employed to alter the finished quality of the rendered products. Various bleaching techniques, antioxidants, additives, and sometimes adulterants can facilitate chemical detection methods used to classify finished products higher on the quality and price scale than would be possible otherwise. Hence, the basic need for a complete understanding of each raw material, processing system, operating technique, and quality control method used in order to maximize the economic gain, while complying with all requirements and regulations at the same time.

Rendering Systems

Wet Rendering

Wet rendering is a system which leaves a high amount of moisture in the product, until, or if, it is to be dried. It is most commonly applied today in the rendering of edible fats and oils and in the production of items such as partially defatted chopped beef or condensed beef. The earliest of these was an open kettle fired with wood or coal. Fat rising to the top was skimmed off for use. Open kettle wet rendering was quite common on a small scale. There is more detail on this process in the chapter on edible rendering.

Dry Rendering

Dry rendering is done with or without an initial pressurization stage (sterilization) and it is the most common system used today. In the middle third of the twentieth century, the dry rendering batch cooker came to nearly universal use. In the beginning, before adequate pre-breaking or pre-crushing was used, large pieces of animals or offal could be pressurized in the batch cooker prior to drying. This had the same effect as a home pressure cooker and would cause the bones to become more brittle, softer, and easier to handle. Particle size reduction technology eliminated the need for the pressure step for size reduction. However, this pressurization system was re-deployed in Europe as an extra log reduction factor for their bovine spongiform encephalopathy (BSE) control programs. It is unlikely that it will be used again in North America, as other control schemes have been employed to control BSE. There is more detail on the dry rendering process in the chapter on edible rendering.

Pressure is regularly used for hair and feathers to achieve protein digestibility. This can be in a batch or continuous process. Drying of hair meal today is not prevalent, as most of the hydrolyzed hair is added back to the raw material pit and rendered with the rest of the raw material. This has a negative effect on fat yield, yet it is the most practical and energy efficient way of handling the hair. Feathers need the pressure treatment to break the difficult keratin protein bonds. Digestibility levels of nearly 100 percent can be achieved chemically, but that may destroy the availability of the amino acids. Research in the 1970s and 1980s demonstrated a level of 68 to 75 percent digestibility by a pepsin test actually provided the maximum feed value of feather meal. More information on digestibility of feather meal is presented in the chapter on the use of rendered products in poultry nutrition.

Edible Rendering

Edible fats and oils are designated as high temperature or low temperature, as is the resulting tissue. Tissue with enough meat processed at low temperature is beef or pork with the meat-like definitions. High temperature product that is not to be designated as “cooked” or “ready to eat”, will generally wind up as meat and bone meal through another rendering system, or possibly go to pet food. Condensed beef is a newer term, and has certain production characteristics that are specialized. Please refer to the chapter on edible rendering.

Batch Rendering

When a system is operating in a batch manner, it becomes a batch system. Even a continuous cooker can be operated in a batch mode. A batch cooker is designed to be loaded, processed to a percentage dry, and then discharged for fat separation. A batch cooker can function as a cooker, dryer, hydrolyzer, or processor, yet it is still the same piece of equipment. With minor modifications, and with or without internal pressurization, a batch cooker can be used for each purpose. It can have a heated shaft as well as shell, increasing the heating surface and efficiency of heat transfer. When used as a sterilization step, the heated shaft can minimize the time required to attain temperature and pressure parameters.

Continuous Rendering

Generally defined as continuous in-feed and continuous out-feed with many still in use, there have been a number of continuous systems employed in the past. One of the first was the Anco Strata-Flow system. By connecting a series of modified batch cookers in a unique fashion, this became the first real continuous system.

Carver-Greenfield systems came on the scene at about the same time that Dupps, along with Keith Engineering, created the DUKE system. Today known as Equacookers, they are the most commonly employed units in North America. The ease of operation before sophisticated computer controls was a major factor in their success.

Companies such as Atlas and Stord-Bartz brought their fish meal know-how to North America in the late 1970s, and became well-known in the 1980s. By using their unique disc dryer/cookers, waste heat evaporators, mechanical vapor recompression, and improving on the original Carver-Greenfield design, they developed a large market share in the poultry and red meat industries.

Consolidation has occurred in equipment supply as with the rendering industry as a whole. Dupps, and now Haarslev (consolidating Haarslev, Svaertek, Stord Bartz, and Atlas-Stord), along with Anco-Eaglin (the modern ANCO), are the major providers of equipment to the North American market. Several other companies provide specialized equipment, rebuilding and repair services, centrifuges, and other options for the industry. With nearly round-the-clock operations, it is essential to have a plant and system that remains in an operating condition, with low downtime and energy efficiency.

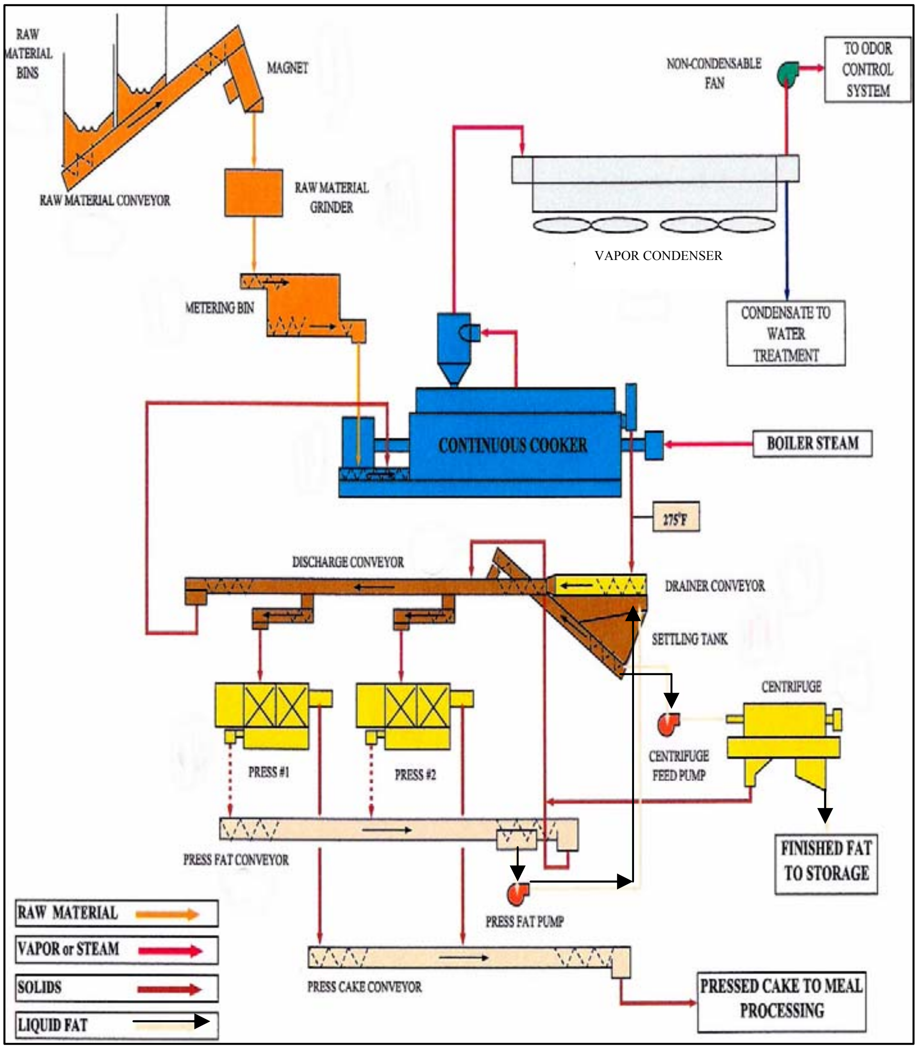
Continuous Rendering Material Flows (Figure 1)

Material to be rendered is received for temporary storage in raw material bins. Raw material is conveyed from the bins by a raw material conveyor and discharged across a magnet to remove ferrous metal contaminants. A raw material grinder then reduces the raw material to a uniform particle size for material handling and improved heat transfer in the cooking step. The ground raw material is fed at a controlled rate from a metering bin into a continuous cooker.

The continuous cooker is an agitated vessel generally heated by boiler steam. It brings the raw material to a temperature between 240º and 290ºF (approximately 115º to 145ºC), evaporating moisture and freeing fat from protein and bone. Dehydrated slurry of fat and solids is discharged from the continuous cooker at a controlled rate.

The discharged slurry is transported to a drainer conveyor. The drainer conveyor separates liquid fat from the solids, which are then conveyed from the drainer conveyor by a discharge conveyor. In the discharge conveyor, solids from the drainer conveyor are combined with the solids discharge from the settling tank

Figure 1. Schematic Diagram of a Continuous Dry Rendering Process.



Adapted from a drawing from The Dupps Company.
Available in color at www.renderers.org/Continuous_rendering_system/index.htm

and from the decanter-type centrifuge. The solids from the discharge conveyor go to the screw presses, which reduce the solids' fat content to about 10 to 12 percent. Solids that bypass the screw presses are recycled back to the cooker. Solids discharged from the screw presses in the form of pressed cake go to the pressed cake conveyor for transport to further processing into meal. The fat removed in the screw presses goes to the press fat conveyor, which separates large particles from the liquid fat and returns them to the discharge conveyor. The fat from the press fat conveyor is pumped to the settling tank. Fat discharged from the drainer conveyor goes into the settling tank. In the settling tank the heavier bone and protein particles settle to the bottom, where they are discharged by screw conveyor into the discharge conveyor. Liquid fat from the settling tank is pumped to the centrifuge, which removes residual solid impurities from the fat. The solids from the centrifuge go to the discharge conveyor. The clarified fat is transported to further processing or to storage as finished fat.

Water vapor exits the continuous cooker through a vapor duct system that generally includes an entrainment trap to separate and return entrained particles to the continuous cooker. The vapor duct system transports the vapor stream to a vapor condenser. Non-condensable gases are removed from the condenser by a non-condensable fan. Odorous gases generated at various points in the process are collected by a ductwork system and are transported along with the non-condensable gases from the condenser to an odor control system for neutralization of odorous components.

Waste Heat Evaporation

Employing an evaporator with a continuous cooker, a waste heat system offers energy savings that will continue to be very important as the global energy balance continues to shift. Some systems installed in the early 1980s are still operating efficiently. Waste heat is also very important to the meat processing industry for generation of hot water. Rising energy costs have a negative effect on plants that do not employ waste heat to generate their hot water.

Low temperature separation, originally used in fish meal production, allowed many of these waste heat systems to achieve very low energy consumption numbers, especially on materials with high water content. Finished product fat quality is also enhanced in any low temperature system. However, care must be taken to prevent rancidity in this fat. Generally heating the dry fat past 250ºF, one time, will accomplish this. It also serves to dry the fat to a lower moisture level.

Waste heat recovery evaporators can be falling film, rising film, or forced flash designs. All have certain advantages and disadvantages, and selection for the characteristics of the liquid is critical. Pre-heating the feed liquid may be required for coagulation of the soluble protein generated in the preheating process, and a glue breaking step may have to be added to allow the easy use of the concentrate into a dryer or cooker. Fish and porcine materials typically have more issues with glue due to the temperatures at which it is released from the material.

Continuous Slurry Systems

These were the various systems such as Carver-Greenfield, and have undergone subsequent changes and improvements by a number of manufacturers. Both designs by Dupps and Atlas-Stord, as well as others, created slurry evaporators that have been supplied successfully. These high capacity systems produce a meal with very good digestibility, as well as good fat quality. They are highly energy efficient, but did not get good results on log reduction of BSE prion infectivity in European tests because of the very short residence time.

Fish Meal Systems

Although not employed in a large number of plants, this predominantly mechanical system is extremely energy efficient and, without a doubt, produces the highest quality fats and oils from any raw material that is possible to obtain. Capable of large capacity throughput and energy efficiency, their use may increase in the North American market in the future.

Low temperature separation is utilized for high product quality in finished meals and fat. The meals are still subjected to a long drying process, but the low temperature yields enhanced quality of fats due to a lower thermal stress.

Combination Systems and Retrofits

The innovation of the North American rendering industry is no more visible than it is in the various combinations of systems that have been created by connecting equipment from the different equipment companies. Combinations have been applied to provide the most economical, viable, and operable systems possible to process each combination of unique raw materials available to the industry.

Many companies employ pieces of equipment from various manufacturers, constantly seeking the best system to process the unique raw material stream they may have. There is no “one system fits all” in modern rendering. Selection of the “ultimate” system for each operation will continue to be a challenge in the future.

Managing BTUs

British thermal units (BTUs) are a way of measuring heat energy output. As any thermodynamic engineer will tell you, BTUs are BTUs, and they all cost money. Therefore, the loss of BTUs in any operating system is a revenue loss to the operating company. The paper industry is always held up as the best at hunting, capturing, and utilizing stray BTUs. The rendering industry has done a good job in the past, but success in the future will definitely depend on each company’s ability to use each BTU with the utmost efficiency. Energy will continue to be one of the top three cost categories in every operation.

Steam

As the main driving force in the evaporation of water from the raw material, steam is the single most costly part of the energy balance. Steam usage for the evaporation is a main consideration in the selection of a rendering system. As energy costs appear to be on the rise for the future, it is essential that steam usage be evaluated, controlled, and conserved. Any leak must be addressed immediately.

Hot Water Generation

Waste heat recovery through hot water generation is a major energy advantage to meat processors or others that have a need for large amounts of hot water on-site. The cost of hot water may outweigh the use of other recovery systems, and dictate hot water recovery as the best recovery method. Engineering a site for energy efficiency must include all of these comparisons.

Anaerobic Digestion for Methane Production

Rendering wastewater and condensate usually contain sufficient nutrients to necessitate further wastewater treatment. Anaerobic digestion not only reduces odor levels, but can provide valuable methane for use in the boiler system. Cost justification of biogas recovery and use becomes easier as energy prices soar. More systems based on this principle appear every year.

Availability and Choice of Fuel

The availability and choices of fuels can make or break success in locating a new plant, or retrofitting an old one. It is helpful to analyze and try to predict the variability in the future energy market. Any recoverable or recyclable fuel will be a plus. Risk management in the cost of energy will always be a challenge.

Stand-by or Alternative Fuel

As with the main fuel for a facility, the stand-by capacity must also be available in good supply. Without such consideration in the stand-by fuels, the facility may not be able to operate continuously.

Refuse Boilers

Environmental Protection Agency (EPA) regulations may or may not allow the choice of refuse boilers. However, the significant energy savings possible justify their consideration in the continual plant evaluations necessary today.

Heat Sink for Co-generation

Rendering plants are a perfect heat sink for cogeneration plants as they have a large steam requirement, and typically operate most hours in a week. A heat sink captures heat that would otherwise be wasted and uses it for production.

Waste Heat Thermal Oxidizers

A new facility must compare this option, especially if a zero-discharge facility may be required.

Using Fat as Boiler Fuel

In order to manage supplies and market gluts, fat can often be used directly as fuel in boilers on the same site at which it is rendered.

Nearby Opportunities

Collecting landfill gas for steam production and cogeneration of electricity is one way to capitalize on available alternatives.

Managing Quality

Much of this management has to occur at the source of the raw material, because the fresher, the better. Selecting the balance for economic viability is always a challenge. Cost of capital and geographic location will have the most effect on finished product quality. Selection of the processing system is also critical. Establishing the balance for individual company success creates the puzzle to be solved.

A number of other chapters refer to uses and suitability of rendered products for various purposes. The quality of that rendered product will determine its ability for a given purpose. Proper operation of the system selected is essential for achieving quality, as well as the raw material used for production. Nutritional uses will demand standards of production that guarantee high quality. Some non-nutritional uses have equally stringent quality requirements.

MIU (moisture, insolubles, and unsaponifiables) requirements have now seen further refinements. The 0.15 percent insoluble requirement for tallow from the OIE (Office of International Epizootics, now known as the World Organization for Animal Health) necessitates increased process techniques to achieve. New technologies will continue to be introduced, and rendering operations must continually embrace new developments in order to maintain the use of rendered products in as many areas as possible. Recovering the costs incurred by these upgrades becomes difficult.

Although expensive, refrigeration is still an alternative to manage the freshness of the raw material, and hence the quality of the finished products made from that material. Within an integrated facility of a meat processor, it is much easier.

Antioxidants in raw material play a key role in maintaining the quality of the finished products, especially in the poultry industry. When added to raw material, oxidation is retarded, and good quality pet food grade products can be recovered from a larger volume of the material. Of course, there is an added cost for these additives.

Bactericides can be effective in preserving raw material from degradation. No matter what method is used, retarding putrefaction results in higher quality products. Research continues in this and many other areas to provide solutions to everyday problems.

Raw Material

Selecting an operating system can be dependent on the freshness and type of raw material available. Downstream use is also dependent on properly processed raw material. Operating, maintaining, and constantly evaluating the "raw material collection system" is mandatory. And, as strange as this may sound, this holds true for on-site rendering at a meat processor. The cleanest, freshest, and most valuable raw materials can be ruined on-site, as well as being degraded due to weather, time of hauling, distance, and equipment breakdowns. Natural putrefaction begins immediately upon death, and there are no exceptions. Methods exist to retard this process, yet they also add to the cost and must be evaluated accordingly.

Regulatory Influence

Although the North American industry has been successful in cooperation with the regulatory agencies, it has not been without difficulty. As one of the most highly regulated industries before and after the advent of BSE, and after watching the European debacle, the industry has survived by continuing its proactive work with all of the regulatory agencies. Operations, and operating costs, can be influenced every day by the regulatory environment. Operations personnel must therefore be trained in the severe consequences resulting from non-compliance.

The availability of raw material for rendering can also be stopped by regulation. BSE has caused tremendous upheaval in rendering in many areas around the world. The "precautionary principle" will likely continue to alter the way the industry functions in the future.

Figure 2. Raw Material Receiving.

Evaluating a System from Beginning to End

Raw In-feed

Condition of the Raw Material: Consider worst case scenarios.

Type of Raw Material: A system can be modified if there are changes in materials (hard, soft, hair, blood, feathers, restaurant grease, other). Choosing a flexible system will reduce future costs.

Capacity of the System: Typical plans are made for full production plus cleanup each 24 hours. In a packinghouse environment, cleanup must occur each day to satisfy federal inspection requirements. If rendering is on the same site as slaughter and meat processing, a separate building may relieve the daily cleanup requirements, but cleanliness is still a requirement.

Capacity of Raw Material Holding Bins: Plans must be made to allow the incoming raw material to be stored with "buffer capacity" for fluctuations in volume. Requirements will vary greatly depending on the type of operation as well as the type of raw material. The cost of downtime to a meat processing facility has to be understood. Decisions on repair, replacement, and alternative means can only be made properly if good information is available.

Covered or Uncovered Bins: The latest designs in covered bins with hydraulic closure can help eliminate even more of the odors associated with the raw material. They are not mandatory, but offer an excellent opportunity to make a plant more fully enclosed and odor-free.

Product Storage Tanks: Storage logistics often depend on the geographic location of the plant. Heating coils and good insulation are mandatory for Minneapolis or Calgary, but these considerations are much different in Houston.

Confined Space Creation and Management: Work spaces such as tanks, bins, and pits, and their design mandate rules of use for confined spaces. Because of the possible accumulation of harmful gases, treat the area or item with respect. The Occupational Safety and Health Administration (OSHA) and other North American agencies have issued many guidelines for worker safety and health.

Bin Drainage: Raw material composition will dictate the level of drainage necessary in bins. Bin design will also impact their ability to convey any watery substance. Pumps can move liquids efficiently and can overcome some bin or pit design problems.

Floor Drainage: Scupper systems (a type of drain) added to the original building design will permit the most effective collection of liquids from the floor surface to be treated or reprocessed. Dry cleanup is preferred in meal areas, but liquids must be able to reach a collection pit or sump.

Truck and Floor Wash Waters: Plant economics drive the decision to either cook this protein-laden water, or deal with it in a waste treatment system. The level of sanitation required, biosecurity, and other disease or disaster issues may alter the need and method. For example, an animal disease outbreak may require a higher level of pathogen control.

Grinding Raw Material

Single Stage: Some grinding systems will allow one simple grinding step that fulfills all requirements of the raw material processed. It is important to make that decision in consideration of all of the parameters for the plant. Maintenance of close-tolerance grinders without metal detection can be extremely costly.

Multi Stage: Some process systems employed today require multiple grinding steps to achieve the optimum particle size. Slurry evaporator systems are a good example of systems in which small-sized raw material is necessary.

Size Control for HACCP-like Programs: Grinders require enhanced maintenance to produce consistent results. Any quality control system will include the grinding step as critical to process outcome. Ultimate particle size dictates the thermal efficiency of the system and is important to meet regulatory requirements.

Ease of Maintenance: Maintenance is always a decision factor, whether for raw material or finished product equipment.

Thermal Requirements of Regulations: Time and temperature may become part of the regulatory requirements in the future. These can be precisely controlled in modern rendering systems.

Pressure Cooking: This is a regulatory requirement in other countries as a disease control measure. Hair and feathers will continue to be processed with pressure cooking to improve digestibility and product quality.

Figure 3. Grinder/Pre-breaker.

Conveyance of Materials - Raw or Cooked

Cold Materials: Screw conveyors and pumps can be effectively utilized to convey cold products. Maintenance and cost of capital are part of the decision process.

Hot Materials: Cooked products can be effectively pumped, and pumps have become an alternative to conveyors for that purpose. This technology will continue to improve.

Salmonella and Other Pathogen Control: APPI has published many guidelines for the control of *Salmonella*. The rendering process effectively eliminates it, yet preventing meal from being re-contaminated continues to be challenging.

Conveyors: Construction is a critical factor and there are many levels of quality and construction. This can be one of the most confusing choices to make in a plant. Carbon versus stainless, longevity, and maintenance costs must be evaluated.

Pumps: Both raw materials and cooked products can be pumped effectively. The type, style, capacity, and material of construction should all be considered when a choice is made.

Distance Restrictions: Transportation costs have significantly reduced the service area of a rendering plant. This will certainly continue as energy costs escalate.

Cost Comparisons: The basic economics have to be carefully studied, and all variables must be evaluated in predicting the overall cost structure of the process.

Materials of Construction versus Cost: Longevity of equipment will make or break the financial model of a business. The ability of a constructed plant to outlive its depreciation schedule is important. Thin carbon steel screw conveyors, although very prevalent in initial construction due to costing, are not the economic answer in all cases. In fact, they may actually increase the cost of operation over the initial five years. Use of stainless steel and other alloys to increase the service life of equipment can be compared economically to achieve the most cost-effective mix for an operation.

Pressurization/Sterilization

Requirements for Regulations: Europe instituted pressure sterilization requirements to help stem the amplification of BSE. These requirements were intended to add extra logs of reduction in infectivity of contaminated materials. (Since BSE was not able to establish or amplify in North America, these requirements have not been instituted as of September 2006.)

Requirements for Optimum Use (Hair/Feathers): The keratin protein characteristics of feathers and similar characteristics in hair have necessitated the pressure hydrolysis of these products to increase their digestibility and amino acid availability to animals so they can be used as feedstuffs. Subjected to pressure over time, the tough protein bonds are severed, and the product is nearly indistinguishable from other protein meals.

Figure 4. Feather Cooker Hydrolyzers.

Cooking Step

System Dependent Characteristics: Different systems require different parameters in the cooking step to achieve good finished product quality.

Quality Control Parameters: Temperature, condensing capacity, fat content, and others must be used to control the quality parameters of the finished product. Some of these are due to inherent advantages or disadvantages of the system employed.

Heat Transfer Comparisons: Evaluating heat transfer must include the materials of construction of the heating vessel, as there are significant and insignificant differences in the metals used. Other factors such as longevity are also part of this economic calculation.

Operating Cost Comparisons: It is always good to have benchmarks to compare to when possible. Companies with multiple plants have access to such data. Single plant operations must continually compare only against their past performance. Using simple engineering calculations for BTU consumption is the easiest. However, the BTU consumption of electricity must be added to the BTU consumption of the steam or liquid heating in order to have an accurate comparison. Only then can evaporator systems be effectively compared to cooker systems in their overall efficiency. Theoretically you will not achieve better than 0.76 pounds of steam to evaporate a pound of water, and anything over 1.50 pounds may indicate poor efficiency. If you can achieve BTU usage of 800 BTU per pound of water evaporated, it is fantastic. Usage should not exceed 1,500 BTUs per pound of water evaporated.

Ease of Use: Control systems today are far advanced from the batch cooker days. Trend lines and nearly instant control have made a quality output easier to obtain. However, this does not eliminate the human factor that can introduce errors and variability in performance.

Multi-Stage Evaporators or Cookers: As capacity requirements increase, the size of the system must increase also. All of the considerations discussed in this and other chapters become inputs to these decisions.

Residence Time for HACCP-like Quality Controls: Modern systems allow easy tracking of time and temperature requirements needed to satisfy any regulatory authority as well as product quality specifications.

Particle Size Required by System Consistent with Preparation Step: In the selection of the operating system, particle size has to be viewed from beginning to end to ensure that all parts of the system have size requirements satisfied.

Drainage Post Cooking

Static Screens: Static screens can be effective for certain products, but provide difficulties with others. Each method has its proper place in modern systems.

Drainage Screws: Efficiency of drainage screws must be judged by their mechanical tolerance, drainage hole size, downstream fat handling, whether inclined or not, and other factors. The efficient separation of the fats and oils from the cooked product is a measure of profitability when the value of fat versus meal is considered.

Rotary Screens: In high volume slurry systems, rotary screens have been successful in fat separation and often have been less expensive alternatives to centrifuges.

Vibrating Screens: Their smaller size and high efficiency have proved effective in this separation step. Modern designs are leak-proof and made to easily control the vapors emitted.

Percolation Pans: All drainage options other than centrifuges are modifications of the original percolation pans used in front of batch cookers. The more modern means have proven superior to this old technology.

Centrifuges: In high-volume slurry systems, centrifuges have been used to make the initial separation before high-pressure pressing. Expensive in capital cost as well as operating cost, discussion of alternative means continues.

Waste Heat Usage

Evaporation: The use of waste heat evaporators on low yielding raw material will find favor when energy costs rise. Technology available today will continue to improve and be employed in plants as energy costs continue to escalate and yields fall.

Hot Water: Using steam to generate hot water gives an easily replaceable energy gain to any processor that has the cooker vapors available. Condensers to heat water are reasonable in cost, and the savings are substantial. Virtually all hot water needs of a processing plant can be met with the waste heat from an on-site rendering plant.

Other: Potential uses for waste heat include tank heating, raw material pre-heating, and building heat. Each plant and site will have a different matrix to use in their comparisons of energy cost and use to analyze in choosing equipment.

Pressing

Fat Residual Goals: High-pressure pressing comes with a relatively high maintenance cost. Therefore, good data must be kept to compare the myriad of choices that exist today.

Types of Presses: High pressure presses for cooked material are varied as much in size as they are in original equipment manufacturer. There are many good options. Careful evaluation of options and past practices need to be part of the selection process. Maintenance accessibility and wear part longevity dictate the economics.

Cost/Benefit Analysis: As more refined measurement systems have come into being, more data have become available for analysis.

Meal Fraction

Cooling: Cooling meal in a controlled fashion to prevent contamination with *Salmonella* and other pathogens can improve both yield and quality.

Sizing: Since customers have different requirements in their systems, the finished meal sizing will be varied as well. It may require separate systems for different customers or regular maintenance changes of screens and so on to comply with customer needs.

Grinding: A variety of choices also exists in the selection of the best means for grinding the product. Is the product ground hot or cold? Is a hammer mill, cage mill, or roller mill used? What does the customer want? What is the specification an industry standard, or a differentiation?

Classifying: High-quality, low ash, pet food grade meals can be achieved by classifying poultry meal. Raw material selection is also important. There are a number of different ways to physically classify the meal, including air classification.

HAACP-like Programs – Identifying Hot Spots for Pathogen Control: Post-process contamination of meals must be addressed in order to eliminate pathogens. This requires a system of timely maintenance to eliminate any "hot spots" where the pathogens can multiply. APPI education programs provide good insights into this issue and solutions.

Storage Capacities: The length of time lapse before finished products are shipped is important when planning storage capacity. Weather, geography, transportation, service availability, and natural disasters all affect that decision. Whatever the decision made, it will be soon tested. A balance must be made between risk and reward while considering cost.

Load-out Requirements (Trucks, Rail, or Container): A company's customer base will influence load-out capability. Capacity and speed of transfer are also important to satisfactorily service customers.

Figure 5. High Pressure Press.

Fats/Oils Handling

Settling Tanks: Allowing insoluble impurities to settle out is still one of the most successful means of achieving good quality finished quality fats and oils. Various washing techniques and additives are also available to achieve desired results.

Centrifuges: Whether horizontal or vertical, clarifier or polisher, two-phase or three-phase, centrifuges are the most common means of producing finished fats and oils with a low MIU result.

OIE Purity Requirements: The upper limit of 0.15 percent MIU set by the OIE for fats and oils in trade is prompted by BSE. Trade in the fats and oils should not be impeded if this specification is met. Contractually avoiding this requirement may not be allowed in the future.

Fines Handling: Centrifuges separate fines that will accumulate in tanks over time. Handling them immediately is the best quality solution, and the method used becomes yet another choice for the renderer.

Figure 6. Hammer Mill.

Figure 7. Centrifuge.

Tank Storage Capacities: As with the meals, the same criteria apply. Careful calculation and deliberation are necessary to meet the intended goals.

Load-out Capabilities: As with protein meals, the amount of time allowable before shipping impacts the planning of storage capacity as does weather, geography, transportation, service availability, and natural disasters.

Tank Designs (Heated Coils): Climate must be considered in tank design. Shape (whether cone bottom or not) is as critical as heating coils, recirculation pumps, and the piping configuration chosen. Ease of use and maintenance requirements are important.

Agitation: Exposing fats and oils to heated coils in a stagnant environment can degrade quality. Agitation can be a solution.

Odor Control

Air Scrubbing: This technology has been around for a long time and it is effective. Chemicals have changed, been modified, and have been specifically implemented for different sources of odor. Regulatory requirements can often be met with scrubbing systems.

Incineration of Odors: Incineration achieves the most complete destruction of odors. Thermal oxidizers, with or without waste heat recovery, are extremely effective in eliminating odors. The costs are substantial, but may be justified if a high volume of volatile organic compounds are present.

Biofilters: Biofilters are one of the most cost effective means of eliminating the odors associated with rendering. Properly designed biofilters include a good air humidification system. The medium used in the biofilter is also critical to the effective operation of the unit.

Waste Heat Incinerator Boilers: This form of heat recovery has become the accepted standard in Europe, and can also provide a means of creating a zero-discharge facility for wastewater.

Figure 8. Air Condensers on Roof.

Water Treatment

There are multiple choices for wastewater treatment. Fortunately, there are a large number of reputable firms that possess a good understanding of the wastewaters created by rendering processes.

Publicly Owned Treatment Works (POTW): A public system can be as much of a burden as a blessing if the plant cannot meet their discharge requirements. It bears mention that anyone going into a new city needs to physically evaluate the municipal system, no matter the representations made. The wastewater stream from rendering can prove to be more than the municipality can handle.

Direct Discharge: Obtaining a National Pollutant Discharge Elimination System (NPDES) permit is one of the most difficult items on a plant's list. Maintaining that permit, once obtained, is tantamount to the survival of the business at that location.

Zero Discharge: With the new waste heat incinerator boilers, zero discharge is possible, but at significant cost. Backup systems are required in the event of a problem, and the operating cost may prove prohibitive to evaporate some of the water streams. However, the cost to construct and maintain a wastewater system is far from insignificant.

Lagoons and Spray Fields: Under the new nutrient management plans required by EPA, lagoons and spray fields will still offer an acceptable alternative for wastewater management in the future. The nitrate loading in many of the first systems employed has surpassed critical levels and must be re-evaluated.

Nutrient Management Plans: Although the concept of nutrient management plans has been around farming for a long time, it was not given consideration because of the high concentration wastewaters generated by rendering. These may be useful in the future.

Novel Systems Created for Special Purposes

Enzymatic Hydrolysis: This may not be a novel concept, but it will continue to be evaluated for certain raw material streams.

Chemical Hydrolysis: Alkaline hydrolysis technology (WR^2) was designed as an alternative disposal method for contaminated tissues and dead animals, and it has certainly proven to be effective. The economic justification of such a system without government intervention will be difficult.

Mesophilic-Thermophilic Digestion: This process is a new two-step concept for treating municipal wastewater sludges. Much more research is needed in this area to adapt technologies to materials diverted away from rendering. Since most composting alternatives do not seem to provide sufficient pathogenic reduction, it is essential that this means of disposal receive some attention. Our society is also now forced to look at potential bioterrorism acts that could create huge disposal problems. We await that research with much impatience.

Major Equipment Suppliers

Anco-Eaglin, Inc. — www.ancoeaglin.com
The Dupps Company — www.dupps.com
HAARSLEV — www.haarslev.dk or www.atlas-stord.com

Equipment Suppliers

AC Corporation — www.accorporation.com
Advance Industrial Mfg., Inc. — jimwintzer@advanceind.com
Alloy Hardfacing & Eng. — www.alloyhardfacing.com
Andritz Bird, Inc. — www.andritz.com
Bliss Industries, Inc. — www.bliss-industries.com
Brown Industrial, Inc. — www.brownindustrial.com
Clapper Corporation — www.clappercorp.com
Crown Iron Works Co. — www.crowniron.com
DGA & Associates — dgaassociates@qwest.net
Duske Engineering — www.duskeengineering.com

Forest Air, Inc. — www.forestair.com
Frontline International, Inc. — www.frontlineii.com
Gainesville Welding & Rendering Equip. — gwrenderingequipment@alltel.net
Genesis III — www.g3hammers.com
Gulf Coast Environmental Systems — www.gcesystems.com
Industrial Filter & Pump Mfg. Company — www.industrialfilter.com
Industrial Steam — www.industrialsteam.com
KWS Manufacturing — ww.kwsmfg.com
Millpoint Industries, Inc. — millpnt@aol.com
Onkens, Inc. — www.onkens.net
Par-Kan Company — www.par-kan.com
Redwood Metal Works — www.redwoodmetalworks.com
Scan America Corp. — www.scanamcorp.com
SCP Control, Inc. — info@scpcontrol.com
Summit Trailer Sales, Inc. — www.summittrailer.com
Superior Process Technologies — www.superiorprocesstech.com
Travis Body and Trailer, Inc. — www.travistrailers.com
V-Ram Solids — www.vram.com
Weiler & Company, Inc. — www.weilerinc.com
Brandt Southwest Centrifuge — www.brandt-southwest.com
Centrifuge Chicago Corporation — www.centrifugechicago.com
Jenkins Centrifuge Company, LLC — www.jenkinscentrifuge.com
United Centrifuges — www.unitedcentrifuge.com
C.A. Picard, Inc. — www.capicard.com
Industrial Hardfacing, Inc. — www.industrialhardfacing.com

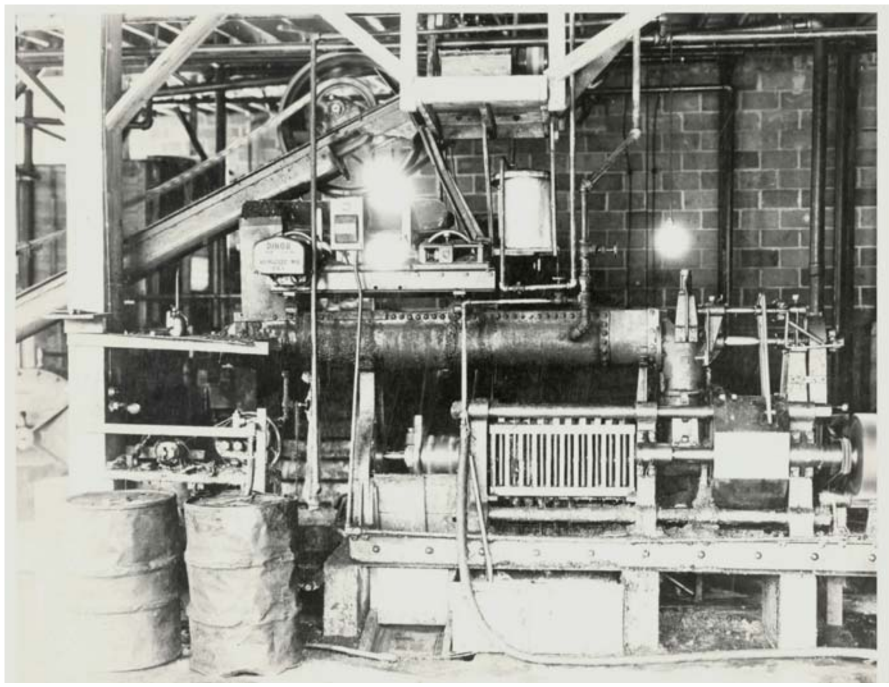
There are many engineering firms that also provide consultation to the rendering industry and specialize in certain parts of the process. Each company must select the combination they deem necessary to provide the results they seek. Many firms supporting the rendering industry are associate members of the National Renderers Association and are listed in the member directory on the Internet found here: www.renderers.org/Member_Directory/index.htm.

The Complete Business

Operating an independent rendering plant is indeed a complete business, with similar issues encountered in any business. Management, plant operations, air and water environmental quality, marketing, quality control, accounting, legal, and every other aspect challenge the renderer. Captive plants have the same issues, yet are a part of a larger entity that may centralize many of these areas.

Recycling is the renderers' way of life, as it has been for centuries since the first soap makers. Only after recycling was defined in the twentieth century were renderers ordained as the "original recyclers."

G.A. Wintzer & Son Co., Wapakoneta, Ohio, 1938.



Rendering Truck, Circa 1909.

THE RENDERING INDUSTRY'S ROLE IN FEED AND FOOD SAFETY

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Summary

The role of the rendering industry in feed and food involves the formulation and administration of progressive, forward-looking programs under the auspices of the Animal Protein Producers Industry (APPI), the biosecurity arm of the rendering industry. While end-product testing for *Salmonella* has played a historic role in the industry's endeavors to assure the safety of feed ingredients of animal origin, the industry recognizes that the current and future challenges of feed/food safety necessitate innovation and new modeling. The industry has approved a robust Code of Practice that mandates long-term commitment and accountability, while accepting that the success of such a program could only be realized through a comprehensive third-party certification audit. The production of safe feed ingredients for the manufacture of feed/food for livestock, poultry, aquaculture, and pets is the ultimate goal.

Introduction

A little over two decades ago, the industrialized societies of the world recognized the urgent necessity to address the broad realm of issues linked to safe food production. In the United States, this was exemplified by two major conferences in 1984. At the National Conference for Food Protection held in Washington, D.C., sponsored by the Food and Drug Administration (FDA), the keynote speaker extolled the country's "plentiful, wholesome, nutritious, and safe food supply" (Knauer, 1984), recognizing that the benevolent food supply took hard work, imagination, and cooperation among the food producing industry, consumers, and government.

This initial conference was followed three months later by an international symposium on *Salmonella* held in New Orleans, Louisiana, where the keynote speaker highlighted the challenging dimensions of *Salmonella* control internationally that "confronts government, industry, and the scientific community as both a challenge and a reproach. It is a challenge because it taxes our ingenuity in dealing with its various dimensions. It is a reproach because it sometimes appears that with our science and technology we are better able to strive toward a certain well-defined objective, like the moon, than to overcome a chronic, food-poisoning hazard" (Houston, 1984). This symposium was one of the earliest proponents, using *Salmonella* as a prototype, to heighten the interrelationship of animal feed, food animal production, food processing, public health, and global trade.

These two conferences clearly had an impact on the policy-making directions that government agencies took during that period, including the subsequent consideration of hazard analysis and critical control points (HACCP) as an interactive, scientifically based protocol that can be used to eliminate food safety hazards, or at least reduce them to acceptable levels. It is interesting to note, although not necessarily surprising, that HACCP was operational as a concept in the private sector (the Pillsbury Company) as early as 1973, and was later embraced by FDA as a regulatory mandate for canned acidified and low acid foods packed in hermetically sealed containers (Corlett, 1998).

These two early conferences had a definite impact on the United States' direction of food safety policy. Amplification followed in 1989 at an international symposium of the World Association of Veterinary Food Hygienists held in Stockholm, Sweden, and co-sponsored by the European Association for Animal Production, the International Union of Food Science and Technology, and the World Health Organization. The theme of the symposium was: Healthy Animals, Safe Food, Healthy Man. One of the keynote addresses reviewed the challenges of the coming decades and included the need to control latent infections in livestock and poultry, including those that are readily transmitted to humans (zoonoses) through monitoring programs. It was also stated that future initiatives should prioritize detection methods through monitoring the health status of farm animals through the process of slaughtering and processing, including the assessment of risk using the HACCP concept (Grossklaus, 1989).

While it is obvious that conferences/symposia were not the sole factors in molding the food safety agenda at the time, they played a significant role in bringing together in a transparent environment, a broad spectrum of academia, government, research, consumers, and the industry to examine the changing dimensions of feed/food safety and the establishment of priorities. It was recognized that the complexities of food production needed the elements of cooperation, collaboration, and communication to succeed and that no one group could do it alone. Since each segment of the food chain had distinct challenges, working together in unison was the most logical and progressive approach.

The purpose of this chapter is to review the rendering industry from a holistic perspective and profile the contributions the industry makes in supplying safe feed ingredients and sources of energy to enhance the health of livestock in producing safe food. Clearly inherent to safe food production is the acceptance and responsibility that feed ingredients meant for livestock, poultry, and aquaculture are part of the food chain. Manufacturers must conform to standards of sanitation and hygiene in production to preclude hazards that could impact the health of animals and humans, directly or indirectly.

Historical Background

The historical record clearly demonstrates that feed and food safety policy progressed because of cumulative influencing factors to create change. While dramatic and distinct changes were clearly evident in the early 1980s, these developments were related to earlier events that brought new or changing dimensions to the broad realm of both policy and safety issues. In essence, no single force has the capability to create a long-lasting momentum in complex industrialized societies such as the United States and Canada. However, a policy decision at the FDA in 1967 by then Commissioner Goddard served as a significant force for change. Goddard's policy expanded the meaning of adulteration that was hitherto limited to human food, to include food for animals. Therefore, ingredients used in food for animals are included within the definition of food in Section 201 (f) of the Federal Food, Drug and Cosmetic Act. Further, *Salmonella* contamination of such animal feeds having the potential to produce infection and disease in animals must be regarded as an adulterant within the meaning of the Act (Franco, 1999). This established the genesis of the regulatory implications associated with *Salmonella* microorganisms in animal feed.

Interestingly, prior to Goddard's *Salmonella* adulteration policy, the U.S. Department of Agriculture (USDA), Animal Health Division, had already started surveillance sampling of animal by-products and meals at varying periods from 1965-1970 for the incidence of *Salmonella* (Franco, 1999). This active surveillance program was done in collaboration with FDA, the agency with regulatory responsibility for feed safety. It is logical to assume that Goddard's decision in 1967 was based on some of the initial findings of the collaborative surveillance-testing program. Additionally, over a period of years starting in the late 1950s, there were several research publications that could have added impetus to Goddard's policy.

Research by Boyer and colleagues (1958) found that some serotypes identified in animals and man can be isolated from feed ingredients and animal feeds. In another study, Watkins et al. (1959) recovered 28 different serotypes from 37 (18.5 percent) of 200 samples of poultry and other animal by-products used in feeds. Pomeroy and colleagues (1961) reported on one comprehensive study in which 43 different serotypes of *Salmonella* were recovered from 175 (18 percent) of 980 samples of by-products of animal origin used in animal feeds from 22 states.

The National Academy of Sciences Committee on *Salmonella* of the National Research Council (NRC) published a scholarly text, "An Evaluation of the *Salmonella* Problem" (Anon., 1969) that examined the concerns of *Salmonella* in the United States with the intent of advising both the USDA and FDA on the aspects of the problem relating to both regulatory agencies' responsibilities in animal and human health. The study also made comprehensive assessments of feed ingredients from a risk perspective, indicating that prior to the report, it was generally accepted that animal feeds were of little importance of transmitting *Salmonella* to animals. This theory was promoted based on the observation that *S. Typhimurium*, the most common isolate of both animals and man, was infrequently isolated from feeds. Nonetheless, the report further implied that rendering plants could play a role in the transmission of *Salmonella* because of investigations that affirmed the presence of various serotypes in finished processed meals of animal origin. Similarly, *Salmonella* serotypes were also isolated from protein meals of vegetable origin used in animal feed rations.

Concurrent with the National Academy of Sciences *Salmonella* report in 1969, and the resulting heightened visibility of the subject, scientists of the Bacterial

Diseases Branch of the Center for Disease Control (now Centers for Disease Control and Prevention) in Atlanta, Georgia, reported on the epidemiology of an international outbreak of *Salmonella agona*. The authors cited *S. agona* as a public health problem in the United States, the United Kingdom, the Netherlands, and Israel during 1969 and 1970 (Clark et al., 1973). The investigators stressed that "in each country an initial isolation from Peruvian fish meal was followed by recovery of *S. agona* from domestic animals and subsequently from man. By 1972, *S. agona* was the 8th most commonly isolated serotype in the U.S.A……and the second most common serotype in the U.K." Investigation of a food borne disease outbreak in the United States associated with this serotype occurred in Paragould, Arkansas, that traced infections between March and May 1972, to 17 residents of a town of 10,500 people. The source of the outbreak was traced to a local restaurant, and then back to a Mississippi poultry farm that fed Peruvian fish meal. The epidemiological data indicated that Peruvian fish meal was the vehicle of introduction of *S. agona* into the United States. This was the first inference that implicated an animal by-product as a potential source of disease transmission to humans.

The outbreak also heightens the complexity involved in the transmission of human salmonellosis and illustrates problems inherent in making finite conclusions (Clark et al., 1973; Franco, 1999). Nonetheless, the Clark report has been used by regulatory authorities to authenticate concerns for the use of rendered animal proteins in feed rations as a potential for disease transmission in animals and man. Unfortunately, the evidence remains anecdotal and nothing more than a hypothesis, because even though the assumption implicated a possible common source, a link between Peruvian fish meal and the Mississippi poultry farm was not substantiated by the isolation of *S. agona* from the feed. The study of the outbreak provided an excellent and provocative discussion of *Salmonella* epidemiology but did not contribute to a conclusive determination of cause and effect.

In September 1990, the FDA Center for Veterinary Medicine (CVM) announced a goal of zero *Salmonella* contamination in animal feed ingredients and finished feed. While zero tolerance remains a contentious issue, the philosophy of a concerted program to limit contamination was a definite message from the CVM, and it was recommended that preventive controls could be realized by applying the principles of HACCP to the manufacturing process (Franco, 1999).

A publication by Crump et al. (2002) stated that contaminated animal feed results in infection or colonization of food animals and this could result in human illness. Unfortunately, the theme of the inferences highlighted the *Salmonella agona* report of Clark and colleagues inappropriately. The 1973 study contained interesting analogies, but lacked validity and affirmation necessary for a causal linkage. In reality, the work of Clark and colleagues was nothing more than a compelling hypothesis worthy of professional consideration.

The Rendering Industry's Food Safety Programs: Responding to Change

The subject of food safety in the 1980s took on a definite holistic approach, and different themes emerged in the discussions during that period. The emphasis started to examine safety assurances from the farm to the table, or farm to fork, with accompanying suggestions that the country needed new approaches to address the challenges. Consumers and consumer groups began to become more actively involved in the food safety movement as a result of what was perceived to be an increase in the incidence of food borne diseases. The rendering industry, cognizant of the changing dimensions of safety and the emerged new order, began to examine formal options to ensure the safety of the ingredients produced by the industry for farm animal nutrition.

With a goal to be futuristic and proactive, the industry founded APPI in 1984. APPI has become the arm of the industry responsible for the broad realm of biosecurity with specific and well-defined objectives: the administration of a *Salmonella* testing program; the coordination and provision of advice on chemical residues that could adulterate product and the needed testing methodologies; the development of guidelines to assure product integrity, such as HACCP; and the presentation of diversified continuing education programs for the membership.

Especially challenging, and a form of mockery to the industry's resolve, shortly after APPI had started to function, bovine spongiform encephalopathy (BSE) was diagnosed in 1986 in the United Kingdom. The concurrent epidemiological hypothesis was that meat and bone meal (MBM) of ruminant origin fed to cattle was the likely cause. That theory of causation had gained wide acceptance as a logical assumption based on the investigative findings of government epidemiologists.

This incident still has an impact on the rendering industry to this day, characterized by regulatory changes and perceptions of risk. While the United States did not have any evidence of the disease based on extensive surveillance and risk assessments, the anxiety and concerns initially demonstrated by the U.K. government had direct and indirect inferences globally for all industrialized societies because of the likelihood that the newly defined cattle disease could have human health implications. This all transformed into reality when it was announced in the Spring of 1996, approximately a decade after the first diagnosis of BSE, that there was compelling evidence that the new disease had infected an identified "cluster" of 10 people linked to the consumption of beef products of affected cattle. This new development, with the supporting conviction of the scientific community that BSE could cause disease in humans, added unknown dimensions to the subject that would influence regulatory changes for future years, including those specific to the rendering industry.

During these frenetic times, the industry became hyper-conscious about every conceivable aspect of biosecurity. APPI decided to modify the organization's by-laws in December 1994 to include safety aspects of animal fats and oils as an extension of the traditional surveillance responsibility. The rapidly changing circumstances of the industry forced APPI to establish a HACCP Council, a

Regulatory Affairs Committee, and a Forward Planning (21st Century) Committee to address the diverse issues of the future while introducing innovative measures to conform to the new challenges.

Dioxin remains a major concern in the food safety cycle because of its classification as a carcinogen. Dioxin's potential source as a contaminant was exemplified by a global food safety issue in the Spring-Summer of 1999 after the government of Belgium banned the slaughter of poultry and pork and placed about 1,000 farms that bought and fed dioxin-contaminated feed under quarantine. Preventive controls were examined because of the potential for inadvertent dioxin ingestion by animals. While dioxin contamination is rare, the rendering industry is conscious of its responsibility and has traditionally tested for pesticides (including a dioxin screen) using company laboratories or contract laboratories prior to shipment of fats to feed mills and pet food manufacturers. The industry is equally aware that dioxin is a natural by-product of combustion generated by the elements of life and living—motor vehicles, wood stoves, medical waste incinerators, garbage burning, and even cigarettes. The compound, therefore, is just another toxic component of natural origin that must be considered in context, while recognizing the serious implications for regulatory concerns and the importance of the potential effects to public health especially associated with accidental or malicious contamination.

APPI also established training initiatives during this period to familiarize the industry with the concepts and principles of HACCP in different regions of the country. This expanded the organization's educational efforts beyond the *Salmonella* testing, prevention, and control objectives of the time. APPI published basic HACCP guidelines in 1994 to assist companies considering the implementation of HACCP or HACCP-like programs prior to any formal government requirements. APPI considered an industry voluntary commitment to product safety a logical necessity, since government promoted the attributes of HACCP but did not establish a timeframe for whether HACCP would be the acceptable program for assuring product safety. As of this writing, FDA/CVM is still assessing options for a mandated Feed Safety System.

While these educational innovations were positive and gained much support and encouragement from the membership, APPI's leadership considered it a mandate to keep moving forward and formed an institute charged with the development and oversight of a training program in 1998. Founding the Institute for Continuing Education was to actively address the current challenges to the rendering industry associated with product safety and the prevention and control of hazards with a comprehensive program. A diversified faculty brought academic, industry, regulatory, and research experience to the presentations. The forum provides an interactive environment for participants and opportunities for discussion of the topics. This ambitious program set the stage for acquainting the rendering industry with the concepts of biosecurity to address the current and future needs of the industry. As a result of these introductory educational offerings, many member companies established HACCP or HACCP-like programs within their operations that would benefit them long into the future.

Research Assessments of the Safety of Animal Protein Ingredients

Salmonella

There has been a substantial amount of data indicating rendered protein meals are free from *Salmonella*, other genera of bacteria, molds, and viruses coming out of the cooker. This can be maintained if the product can be handled to prevent recontamination and the potential for microbial growth after processing. The most pertinent aspect of recontamination is the control of moisture. Ideally, meals contain moisture levels of four to seven percent, so the water activity of protein meal would be too low to support microbial growth. For organisms like *Salmonella* and other pathogens to grow, moisture content of meal must be around 40 percent. Thus, even if contaminated material (*Salmonella)* is accidentally introduced into the cooked product, proliferation will not take place unless the meal is moist (Meat Research Corporation, 1997).

During the period between 1978 and 1989, researchers at the University of Minnesota reported findings of the ten most frequently isolated *Salmonella* in MBM: *S. montevideo, S. cerro, S. senftenberg, S. johannesburg, S. arkansas, S. infantis, S. anatum, S. ohio, S. oranienburg,* and *S. livingstone* (Franco, 1999). These were compared with the four major serotypes isolated from cattle, representing 64.3 percent of total isolates during July 1992 and June 1993, and none were compatible. A similar comparison of the MBM isolates were made to the four major serotypes of swine during the same period, representing 82.9 percent of the total clinical swine isolates, and there was similarly no compatibility with the MBM isolations. The same was done with clinical isolates of chickens for the same period (July 1992-June 1993), representing 54.9 percent of total isolates, and there was also no compatibility to Minnesota's MBM isolates (Franco, 1999).

An assessment of the isolates found during the 11 year research initiative in Minnesota were compared to findings in Japan and the United Kingdom during the same approximate timeframe, and the only two serotypes isolated from MBM in all three countries were *S. livingstone* and *S. senftenberg*. This becomes an important consideration in the ongoing debate on serotype comparisons. The question is this: Does MBM in feed rations, at inclusion rates varying from three percent to five percent contribute to clinical salmonellosis in livestock and poultry? Existing data do not support the extrapolation that *Salmonella* in MBM is the cause of salmonellosis in food animals. In reality, the major serotypes isolated from MBM throughout the world appear to be relatively innocuous, and do not contribute to clinical salmonellosis in animals, nor are they significant in human food borne illnesses.

Comprehensive research work by Davies and Funk (1999) on *Salmonella* epidemiology and control indicates that while feeds of animal origin tend to receive the most intense scrutiny, often overlooked is the extent to which vegetable protein feed ingredients are contaminated. While the identified *Salmonella* serotypes exceed 2,300, only a few have been linked to clinical manifestations in animals and man, in spite of the acceptance that all feed ingredients may be contaminated with *Salmonella*. Additionally, *Salmonella* organisms are not highly resistant to either physical or chemical agents, being killed at 55ºC in one hour or at 60ºC in 15 to 20 minutes (Franco, 1999).

In field trial studies, Troutt and colleagues (2001) demonstrated that samples of raw materials going into the rendering stream from 17 rendering plants in seven mid-western states were highly contaminated with *Salmonella* species, *Listeria monocytogenes, Campylobacter jejuni,* and *Clostridium perfringens,* all index-potential food borne pathogens. In another trial, processed protein materials from the expeller were sampled at nine rendering facilities in six mid-western states during winter and summer months. The researchers were unable to isolate any of the same group of index pathogens that were source contaminants in the raw material—showing that the time-temperature rendering process readily inactivated this broad range of potential food borne pathogens of public health relevance.

In an evaluation of the role of contaminated feed in *Salmonella* transmission in swine, Davies (2004) posited that "feed is only one of many potential sources of *Salmonella* introduction to farms, and risk of infection from non-feed sources appears to greatly exceed the risk presented by contaminated feed on modern U.S. swine farms." These findings have been substantiated by other research workers, both domestically and globally. In extensive longitudinal studies using two modern multiple site production systems, Harris and colleagues (1997) demonstrated an insignificant role of feed in transmitting *Salmonella* to swine. According to work done by Cooke (2002) and Lo Fong Wong (2001), testing of commercial animal feeds in several European countries generally indicates a low level of *Salmonella* contamination (less than one percent), and serovars of greatest concern to transmitting human disease (*S. typhimurium* and *S. enteritidis)* are very rare in feed isolates.

A publication (Franco, 2005a) described a research survey by APPI to determine the pertinence of *Salmonella* population numbers and serovar identity in 197 animal protein meal samples that tested positive over a 12-month period. The *Salmonella* most probable numbers/gram (MPN/g) values ranged from less than 0.03 to 1,100, with a mean MPN/g value of 16.3 and a median MPN/g value of 0.09. The 10 most common serovar isolates in order of occurrence were: *S. senftenberg, S. livingstone, S. mbandaka, C2 Group Salmonella, S. havana, S. lexington, S. agona, S. arkansas, S. infantis,* and *S. johannesburg.* These top 10 serovars accounted for 48 percent of the serovars isolated. Four serovars associated with food borne illness—*S. typhimurium, S. enteritidis, S. infantis,* and *S. agona*—accounted for only 7.5 percent of the *Salmonella* isolated.

The isolates of rendered animal protein meals, in general, have historically not been linked to the customary cause of clinical syndromes in animals and man. An evaluation of the 10 most frequently isolated serovars in this study affirms this inference. In both animals and man, three clinically significant isolates serotyped were: *S. enteritidis* (0.5 percent), *S. typhimurium* (0.5 percent), and *S. infantis* (1.0 percent) of the total samples serotyped (Franco, 2005a).

Viruses

Viruses are submicroscopic infectious organisms that are incapable of independent existence but can grow and reproduce when they enter the cell of a host (plant or animal) causing altered metabolism or cell death as they multiply. Since viruses are important transmitters of disease, it was prudent for the rendering industry to assess viral inactivation, even though the logical assumption was that the time and temperature of the rendering process would inactivate all viruses that are normally associated with diseases in domestic animals.

Since the United States slaughters approximately 100 million pigs annually, the Fats and Proteins Research Foundation (FPRF) thought that determinants of the stability of an important viral disease of pigs, pseudorabies virus (PRV), could be used as an ideal prototype and be evaluated for the likely presence in intermediate rendering products and the finished product in the manufacture of MBM.

The research was completed in a series of six experiments at Iowa State University to determine whether PRV could survive the rigorous processing steps of rendering. The experiments varied from a worst-case scenario of swine heavily infected with PRV being rendered, to an end phase of finished product surveillance of MBM for the presence of PRV. The findings showed there was little or no possibility that PRV survived the rigorous processing steps in the production of MBM (Pirtle, 1999).

Using PRV as a disease model for other potential viral pathogens of interest to animal agriculture and the rendering process, the research findings substantiated what has commonly been assumed but never researched—that the time and temperature of the rendering process inactivates viruses readily, and a viral load is unlikely to exist in rendered protein meals to transmit disease to livestock or poultry.

Prions

The diagnosis of BSE was confirmed in the United Kingdom in 1986. It was suggested that MBM produced from sheep infected with scrapie was the source of origin of the newly described disease. Since sheep are known reservoirs of the infectious agent, the prion, it seemed reasonable to assume that BSE was caused by scrapie infection of cattle via contaminated feed (Kimberlin, 1990).

Research by scientists at the USDA Agricultural Research Service in Ames, Iowa, was undertaken to test the hypothesis that scrapie infectivity does not survive the rendering process and is not transmitted orally to cattle through the use of MBM and tallow as feed ingredients. Neonatal calves were fed raw brain or rendered MBM and tallow from sheep infected with scrapie and subsequently observed for a varying period from one to eight years for signs, lesions, or prion protein deposits resembling either scrapie or BSE (Cutlip et al., 2001).

Twenty-four experimental calves were fed MBM at six percent of the ration for 12 months starting at three months of age and tallow at three percent of the ration for 20 months, starting at four months of age. Twelve claves were euthanized one year after the start of the trial, five were euthanized because of leg and digestive problems five to seven years in the trial, and the other seven were euthanized at the end of eight years. During the feeding regimen, cattle were checked for clinical signs of disease twice daily. Necropsy of all calves were performed by collecting brain and spinal cord samples and fixed in a 10 percent formaldehyde solution for at least three weeks prior to staining and detection of prions using the immunohistochemistry method (Cutlip et al., 1994, Miller et al., 1993).

Experimental calves fed at the maximum amount of MBM and tallow that would normally be consumed by calves at that age did not exhibit any clinical signs during the trial period, nor were lesions present that were compatible with a transmissible spongiform encephalopathy (TSE). Additionally, sections of the spinal cord and brain that were examined did not reveal the presence of prion protein (Cutlip et al., 2001).

It should also be of general interest to all concerned with TSE research that representatives (Pearl of FPRF and Franco of NRA/APPI) of the North American rendering industry visited with government officials in the United Kingdom intent on obtaining BSE infected tissue, even by purchase, and bring those tissues back to the United States for trials that could have provided answers to some of the complex issues linked to BSE. As industry representatives, we felt too dependent on external research findings and wanted to have some research done in North America, especially on inactivation of the prion and transmission studies. This objective was never realized because the U.S. government was in the "abundance of caution" mindset, even though all the tissues would have been turned over to them and subject to whatever controls they deemed necessary.

It is unfortunate that government officials seem to be reluctant to have industry professionals involved in an activity that makes them uncomfortable, in spite of the continuing rhetoric how much we need each other, and that we should collaborate and cooperate with mutual concern for the protection of animal and human health. It is time that this barrier is examined with the hope of establishing a system where the industry, government, consumers, and other interested sectors could truly work together in unison, devoid of old prejudices. The complexity of the prion diseases would provide an opportunity accomplishment together. If this turf guarding continues, we will all lose because disease control, food safety, and public health are everybody's business.

The rendering industry was especially interactive in the process of collection and submission and the handling of samples from predominantly high-risk animals (including "downers" and animals dead on farms) to assist the government's BSE surveillance and testing program. This form of response was responsible for the Animal and Plant Health Inspection Service (APHIS) meeting the objectives of testing the high-risk cohorts and provides a perfect example for the need to communicate and collaborate in disease control initiatives. In some sectors of the country, the program would not have accomplished its objectives without the rendering industry's support.

Current and Future Industry Initiatives

While the core of APPI's current program remains *Salmonella* testing, biosecurity issues, and training, the organization was convinced that to stay ahead of the entire feed and food safety paradigm, it had to be innovative and forward-looking. The programs were in need of a new vision to conform to the discussions throughout industrialized societies about food product safety. In 2000, this prompted APPI to explore the feasibility of a Code of Practice for the North American rendering industry "to promote the safety of animal proteins and rendered fats for feed use through the establishment of recommended industry programs and an accreditation process." This proposal was carefully studied by a dedicated group who worked diligently over the years considering the options, modifying the "Code" and consulting with diverse sources with an interest in the subject. The initiative was formally approved by the organization's board of directors in October 2004 (APPI, 2004).

The heart of the Code of Practice was to institute a system of process controls to preclude hazards, conceptually similar to HACCP principle, and it would be linked to requirements for accreditation with the following objectives:

- Promote the safety of rendered products.
- Legitimize the Code of Practice.
- Provide credibility to the industries.
- Promote consistency and conformity with accepted industry practices.
- Preserve existing markets and facilitate development of new markets.
- Provide assurance to regulatory agencies.

This is a dedicated commitment by the rendering industry to meet established standards of good manufacturing practices and to assure product safety through a third-party certification process. This sends a clear message that the rendering industry continues to be an active leader in the holistic approach to food safety.

The audit and certification process for the Code of Practice is administered by a third party, the Facility Certification Institute (FCI) of Arlington, Virginia, and is a comprehensive system of inspection requirements conducted by professionals with expertise and knowledge in the field of inspection auditing. The system uses a detailed matrix of operational procedures to be assessed on-site and covers all the salient features expected of a rigorous audit to assure that feed safety guidelines are followed, and the end products manufactured are safe and free of hazards that could likely impact animal or human health.

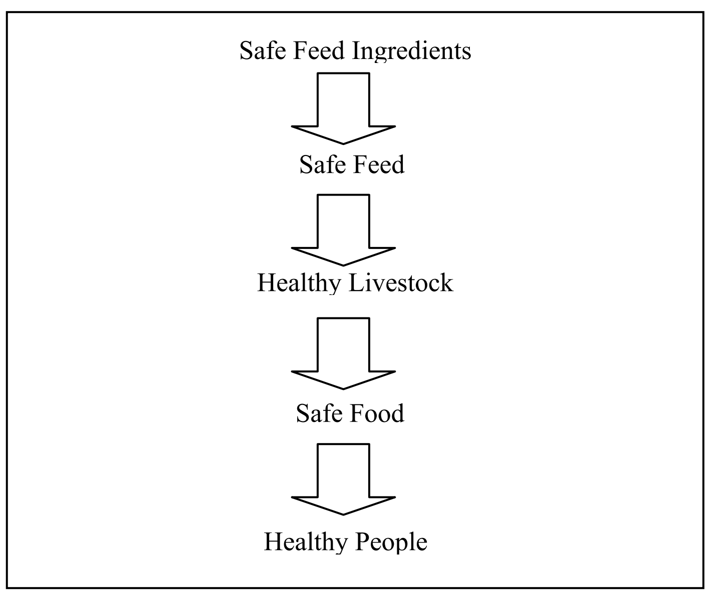
It should be of interest to note that this rendering industry/FCI relationship is expensive and exemplifies the commitment of the industry to the feed/food safety initiatives. This is especially so for multi-plant facilities and large companies. But, the industry has used independent third-party auditors before—to assess compliance with the FDA's BSE feed rule, in spite of the associated cost. The plants were found predominantly in compliance with the rule in the audit program as well as by inspections by FDA and state inspectors.

Discussion

Rendered animal proteins and fats are an important component of feed rations and are an integral part of the feed manufacturing chain, playing an important and significant role in the entire feed/food production cycle. Animal proteins serve as concentrated sources of protein and amino acids and have been a standard in feed rations for over 100 years in agriculturally advanced societies of the world. Fats and oils have been historically potent feed energy sources and have also been used for years to increase the caloric density of rations. These products have been subjected to safety assessments and evaluations for decades, including regulatory scrutiny through inspection audits, but it remains imperative for the industry to continue to be proactive and transparent in responding to the current challenges to the use of its products. The higher public profile of the rendering industry in this new era of food safety is timely, providing assurances of product safety while addressing the prevailing misconceptions about the industry.

The "equation" that best addresses the safe food chain from the rendering industry's perspective is safe feed ingredients – safe feed – healthy livestock – safe food – healthy people (Figure 1). This was the crux of the highlighted theme of the World Association of Veterinary Food Hygienists international symposium in 1989, and its applicability is still very germane and appropriate to the holistic food safety movement that has developed in the past two decades. It is fitting that it would be used to define the rendering industry's role in producing safe feed ingredients leading to the ultimate objectives of safe food and healthy people.

Figure 1. A Holistic Perspective.



The presence of different *Salmonella* serovars in feed has been an ongoing element in the feed/food safety debate for decades. What does it mean, and what is the relevance to animal and human health? It is important because *Salmonella* has been used as the indicator organism for determining contamination or adulteration in feed or food by most industrialized societies intent on control. But, while isolates of *Salmonella* in feed ingredients and finished feed have been reported, the animal and human health impacts are only anecdotal inferences. APPI's *Salmonella* reduction program includes a very rigorous testing program for *Salmonella* in animal protein meals. This has been a continuous initiative for over 20 years, and demonstrates a progressive long-term program that used HACCP or similar concepts that enhance ingredient and feed safety. This is in recognition, however, that raw agricultural commodities are all potentially contaminated with microbes, including *Salmonella*, but processes like extrusion, pressure conditioning, high-temperature/short time treatment, and pelleting employed by feed manufacturers serve as additional controls to ensure feed safety (Sreenivas, 1998).

While conceding that *Salmonella* are a resourceful and defiant group of microorganisms capable of parasitizing a broad range of hosts, and that serovars possess distinctive host ranges, unique patterns of virulence, and geographic distribution patterns that complicate both the epidemiology and control, the historical record still supports the safety of feed ingredients and feed (Franco, 1999). The problems associated with asymptomatic carriage of the organism by livestock and poultry and linkages to farm environmental contamination by rodents and other vectors magnify the challenges of the entire *Salmonella* complex beyond the dimensions of feed. This serves as a reminder that while there is an excellent history of feed safety in North America, we must still combine our resources to pursue workable initiatives to counter the different avenues of contamination. End product testing by the rendering industry is simply an adjunct to the other controls recommended by APPI in the quest to assure ingredients of animal origin are safe and are not a hazard to animal or human health.

Research evidence shows that viruses normally linked to disease transmission in animals are readily inactivated by the time and temperature of the rendering process. Nonetheless, the rendering industry is challenged to operate in disease outbreaks caused by viruses normally associated with high mortalities and often reportable by law (e.g. high pathological avian influenza or foot and mouth disease). The ideal approach is for government agencies at the federal, state, or provincial levels to institute collaborative programs to assure that the industry can play a meaningful role to dispose of carcasses in compliance with government policies to assure safe disposal. The industry has played an exemplary role in the past, working with USDA disease control officials to assist the pseudorabies eradication program in swine. The joint effort was a success and could be applicable to other disease control programs if properly planned and coordinated. Since carcass disposal is an important regimen in disease control, government and the rendering industry should establish and maintain a working relationship to accomplish this objective.

From the onset, the rendering industry in North America was responsible and proactive as BSE presented risk implications for the United States and Canada. For example, a representative (Dr. Fred Bisplinghoff) from the rendering industry in 1989, in a joint meeting with government officials and invited members of the agricultural sector, made a public commitment to stop the rendering of all adult sheep material to remove it from the ruminant feed chain. Equally important, this became the industry's policy for years, albeit voluntary, long before any regulatory decision was made for that requirement. Of course, the rendering industry, totally conscious of the happenings, consequences, and uncertainty of what was taking place in the United Kingdom, and not knowing how reactive the U.S. government (and Canada) was going to be, wisely decided that commitment and cooperation in an environment with duress had distinct advantages. With utmost candor, and a source of interim comfort to the industry, was that the cessation of mature sheep rendering was a minimal economic factor overall. But, more than economics was involved; the rendering industry was genuinely concerned because of the uncertainty of the newly defined and complex disease. The industry honestly felt that overtures to assist were logical based on the existing theory that MBM of sheep origin could have caused BSE. [Given the effectiveness of the 1997 feed rule and that the sheep industry has implemented a scrapie eradication program, NRA discontinued the policy against rendering adult sheep material in 2004.]

The leadership of the rendering industry in North America was cognizant of what was taking place nationally and globally relative to the prevalence of BSE in the United Kingdom, and the subsequent spread of the disease to Europe and elsewhere via imported cattle or contaminated MBM from the United Kingdom. Modesty aside, many in the industry became well informed of the nature of the disease and were rightfully convinced that the evolving epidemiology, even though limited to hypotheses, was defined enough to elicit concern. The possibility of disease transmission was affirmed by a causal chain proposed by the World Organization of Animal Health (OIE): the consumption of MBM by cattle; the importation by countries of cattle and MBM that were infected or contaminated with the infectious agent of BSE, and animal feeding practices (Franco, 2005b). The industry readily recognized the disease was associated with an infectious process and unless the United States and Canada were subjected to the factors linked to exposure, the risk to generating the disease was minimal. This assumption was validated by numerous in-house risk assessments performed by APHIS staff epidemiologists and reported as early as 1993 in agency publications.

After the 1996 report of a "cluster" of unusual cases of a newly identified syndrome in humans linked to BSE in the United Kingdom, and defined as variant Creutzfeldt-Jakob disease (v-CJD), the disease dimensions changed rapidly. Additionally, the supporting epidemiology of the linkage influenced the U.K. government to institute change and new challenges emerged as a result. This advent had serious implications for the entire food safety network and heightened the hysteria-like reactions from some sectors of the media and government, and involved industries started to examine the immediate and long-term inferences.

The rendering industry, fully conscious that North America was a minimal risk region, nonetheless started to examine a series of logical options. There were meetings of agricultural coalitions, with all organizations intent on highlighting its biases in spite of the recognized acceptance that BSE risk, assessed from varying and diverse perspectives, was not a problem at this juncture. But, the concerns at the time were more intense than the evolving information, and included concerns about global trade and other political implications. In this changed environment, politics and the media frenzy also played an active role.

A detailing of the circumstances at the time would be impossible, but they took on frenetic dimensions and culminated in the FDA's feed rule of 1997. In the interim, nonetheless, the rendering industry assumed a pragmatic approach, collaborating with FDA, and engaging in joint ventures, including numerous public meetings to receive updates on the direction and interpretation of the rule, aspects of compliance, and training modules to ensure that the rule went through a smooth implementation. Not only did the rendering industry fully support the rule from its inception, but officially committed its full support to the measures during a joint FDA-industry meeting at the agency's headquarters in Rockville, MD.

The rendering industry, regardless of its conviction that BSE would not transmit and amplify in a manner that would impact animal or human health as it did in the United Kingdom, nonetheless, took the rule (21 CFR 589.2000) very seriously. As a result, the industry experienced a 99 percent compliance with the requirements during the agency's inspection audits. The industry, in a cautionary mode, introduced its own third party audit through an APPI contract with an auditing organization. Participation of U.S. rendering plants in the 2001 audit program in was 99.8 percent. The exemplary compliance with the feed rule found by the third-party audits in 2001 was very similar to FDA compliance findings.

Despite the existing minimal to non-existent risk of BSE in the country, FDA, because of the initial 2003 diagnosis of the disease in Washington State in an imported Canadian cow, and the subsequent case 18 months later in a Texas cow (although tested negative for the immunohistochemistry (IHC) test, the alleged "gold standard," this cow was subsequently considered positive after extensive deliberations), published a proposed rule to mitigate the perceived risk in the *Federal Register* on October 5, 2005, with solicitation of comments to the proposal by December 20, 2005. The comments by interested parties are presently being evaluated by the agency for likely consideration of formatting another final rule. As per custom, the rendering industry, through its organizational components, NRA, FPRF, and APPI, submitted well-studied recommendations for the agency's assessment, affirming the rendering industry's continuing efforts to be both responsible and accountable as efforts are sought to prevent any possible transmission and amplification of the infectious agent of BSE from infecting indigenous livestock, and, in the process, protecting human health.

Conclusion

Prevention of health risks due to food intake is central in food safety policy and demands an integrated approach, defining the role of all stakeholders and their individual responsibilities. Cooperation, collaboration, and communication among the affected parties are prerequisites to success. Food safety must be based on sound and verified science, and continued progress is dependent on the commitment of every level of production to ensure the absence of hazards—from feed ingredient manufacturers that supply feed companies to processors responsible for the safe production of finished products for the table. This is a realization and acceptance of the farm-to-fork analogy promoted today by the industrialized countries of the world using a holistic concept to ensure a safe food supply.

The quality of feed ingredients produced by the rendering industry plays an important role in this complex system because the practices of the industry are a reflection of the food cycle of production. Raw materials processed by the rendering industry are the food residuals that did not enter human food channels, but are recycled through innovative processing technology to produce proteins and fats of animal origin for livestock, poultry, aquaculture, and pets. In reality, we are describing the alpha and omega of the food chain. As a result, the rendering industry is conscious of its responsibility in this program of progressive integration.

The industry concedes that feed ingredient safety is an important and attainable factor in total food safety objectives, thus, the rationale for proactive testing for pathogens and toxins that could influence product integrity. It is also the reason for educational offerings to train the workforce to achieve safety, including the applicability of HACCP, the internationally accepted concept for safety assurance, and the promotion of the APPI Code of Practice, carefully constructed, with an adjunct program of third party certification to demonstrate accountability, and the industry's significant role in sustainable food safety. This assures that safe feed will produce healthy livestock that contributes to safe food, and healthy people.

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A Variety of Rendered Products (courtesy of Rothsay).

THE RENDERING INDUSTRY'S BIOSECURITY CONTRIBUTION TO PUBLIC AND ANIMAL HEALTH

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Summary

Animal proteins are a valuable class of ingredients for animal nutritionists to use in feed formulas. The U.S. rendering industry manufactures products that are highly digestible, do not contain antigrowth factors, and are safe to use in livestock, poultry, pet, and aquaculture feeds. Conserved nutrients within rendered products help sustain animal agriculture and protect marginal lands from misuse. The primary outlet that gives economic value to these products is as ingredients in animal feeds. Restricting feed use of rendered products may inadvertently result in severe economic and environmental problems, spread of disease to humans and animals, and a loss of valuable nutrients with consequential health risks for animals, especially young animals and those in intensive production (FAO, 2002).

Rendering is society's best available control technology for addressing the disposal of animal by-products and mortalities. An examination of traits, such as process controls, infrastructure, volume reduction, and timely processing, inherent to the industry, plus regulatory requirements, such as traceability and environmental regulations, validate this statement and make rendering the preferred method for the collection, transportation, and processing of animal by-products and mortalities. The rendering industry is uniquely structured to provide the critical components necessary to handle all raw animal materials safely and responsibly, including those that are considered, by science or perception, to be unsuitable to use in animal feeds. To accomplish this, it may be necessary for the rendering industry to develop a two tier system consisting of dedicated facilities. Feed-grade facilities can process materials for use in animal feed. Disposal facilities can destroy unsuitable raw animal materials after first removing all or a portion of the unrestricted components in order to reduce their total volume.

The U.S. rendering industry, through the National Renderers Association (NRA) has encouraged the Food and Drug Administration (FDA) and Animal and Plant Health Inspection Service (APHIS) to carefully consider the impact new regulations will have upon the viability and survivability of independent renderers that serve a vital role in monitoring, controlling, and eradicating animal diseases in the United States. Agencies must seriously consider creating policy and regulations that will ensure that these perishable animal by-products are disposed of properly. Some level of funding may be required to provide the incentive necessary to maintain a viable infrastructure. Without attention to their disposition, further regulation of specific finished rendered products will exacerbate the improper and illegal disposal of animal by-products and mortalities. In effect, efforts to prevent the spread of bovine spongiform encephalopathy (BSE) in the United States will

inadvertently weaken the rendering industry and pathogenic agents that have been controlled by rendering in the past will become an increasing threat to both animal and human health.

The Rendering Industry

On a global scale, modern efficient rendering facilities are concentrated in countries and regions possessing strong and well-established animal production industries. This is especially true in the United States where the rendering industry is closely integrated with animal and meat production (Figure 1). These industries generate approximately 54 billion pounds per year of animal by-products and on-farm mortalities that are subsequently collected and processed by the rendering industry.

Figure 1. Interrelationships of Rendering with Animal Agriculture.

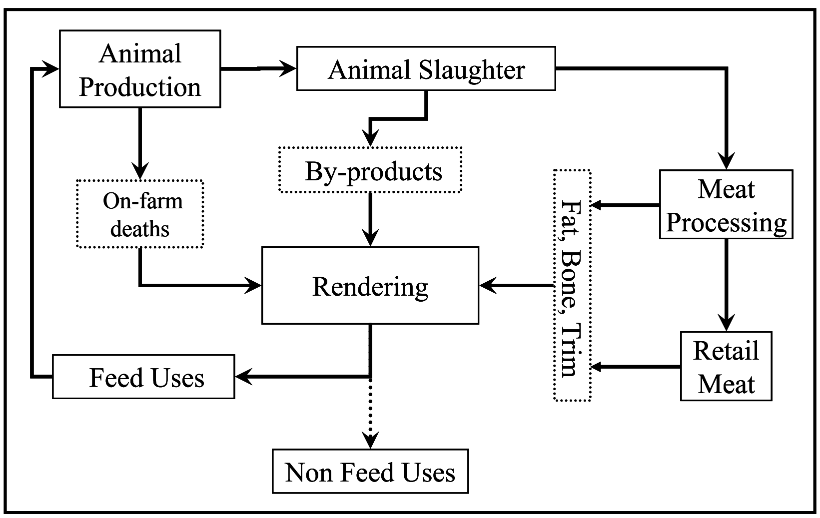


Table 1. Edible and Inedible Portions of Animals, Percent of Live Weight.

	Edible	Inedible
Cattle	51	49
Swine	56	44
Poultry	63	37

Animal by-products are derived directly from the meat processing industry. Between 37 and 49 percent (Table 1), of the live animal weight is removed during slaughter and when the meat is further processed (the inedible portion is even higher for fish). These animal by-products, which include fat trim, meat, viscera, bone, blood, and feathers are also collected and processed by the rendering industry. On-farm mortalities are an unfortunate fact associated with animal production. Each year, more than 4 million cattle and calves, 7 million pigs, and 100 million chickens and turkeys die and must be disposed of (ERS, 2001; NASS, 2001). The U.S. rendering industry has a long history of efficiently handling, processing, and disposing of animal mortalities, used cooking oils, and by-products from the meat packing and meat processing industries. Historically, these materials have been used to produce high quality fats and proteins for use by the animal feed and oleochemical industries around the world.

Feeding is the Primary Use for Rendered Proteins

Rendering adds nearly $1 billion in value to the U.S. livestock production sector in the form of proteinaceous feed ingredients alone. This value approaches $2 billion when contributions from rendered fats and greases are also considered. In addition, rendering removes the need to dispose of by-products in landfills or by other methods that might pose potential environmental risks, health risks, or strain existing space (Sparks, 2001) and/or facilities. The economic value of this service is certainly high, but difficult to measure.

Due to rapid population growth in the world and increased demand for animal products (such as meat, milk, eggs, etc.), the global requirement for vegetable as well as animal protein sources that can be used in animal feed is increasing (FAO, 2002). Animal proteins have traditionally been important sources of proteins and other nutrients for livestock and poultry in the United States and acceptance in Latin America and Asia grew substantially up until December, 2003 when BSE was first reported in the United States. Total domestic use of meat and bone meal (MBM) in animal feeds was approximately 5.7 billion pounds per year (Table 2) before the export markets for MBM closed in late 2003. Changes in domestic and export use of all animal proteins since the year 2000 are discussed in a subsequent chapter of this book.

Table 2. Domestic Use of Animal Proteins by Various Animal Species.[a]

	Meat and Bone Meal		**Blood Products**	
Species fed	Million pounds	Percentage	Million pounds	Percentage
Ruminant animals[b]	567.4	10	158.55	70
Swine	737.6	13	45.3	20
Poultry	2439.6	43	22.65	10
Pet food	1304.9	23	------	---
Other	624.1	11	------	---
Total	5673.5	100	226.5	100

[a] Sparks, 2001.

[b] All meat and bone meal consumed by ruminant animals is from nonruminant origin.

The poultry industry uses the largest percentage of domestic MBM, followed by the pet food industry (Table 2). Significant amounts are used in swine and ruminant feeds. While there are no restrictions on feeding MBM to poultry and swine, cattle and other ruminant animals are fed only MBM that is strictly of nonruminant origin. A serious disposal problem will result if animal proteins and animal fats are not used in feeds for pigs, poultry, pets, and/or aquaculture (FAO, 2002).

Usage patterns for blood products differ from MBM, as shown in Table 2. Ruminants, especially cattle, are fed most of the blood products, usually as blood meal, produced in the United States. Most usage in the swine industry is for spray-dried products such as plasma proteins.

Continued usage of animal proteins as feed ingredients is largely due to the rendering industry's on-going commitment to improve the nutritional value of these products. For example, new processes and processing technology, improved equipment, and greater understanding of the effects of time, temperature, and processing methods on amino acid availability have resulted in significant improvements in the digestibility of animal proteins. Data published since 1984 demonstrate that the digestibility of essential amino acids, especially lysine, threonine, tryptophan, and methionine, in MBM have improved (Table 3). Better understanding how best to use animal proteins in commercial formulas and improved formulation procedures have also improved nutritional value.

Table 3. Digestibility of Meat and Bone Meal Since 1984.

Amino Acid	**1984** [a]	**1989** [b]	**1990** [c]	**1992** [d]	**1995** [e]	**2001** [f]
Lysine, %	65	70	78	84	94	92
Threonine, %	62	64	72	83	92	89
Tryptophan, %	---	54	65	83	---	86
Methionine, %	82	---	86	85	96	92
Cystine, %	---	---	---	81	77	76

[a] Jørgensen et al., 1984. [c] Batterham et al., 1990. [e] Parsons et al., 1997.
[b] Knabe et al., 1989. [d] Firman, 1992. [f] Pearl, 2001.

The conservation of nutrients contained in animal by-products helps sustain animal agriculture in the United States by minimizing the need to farm marginal lands or environmentally sensitive areas, as well as by moderating the price of competing nutrient sources like corn and soybean meal.

MBM is an especially strategic feed ingredient since it contains economical sources of both protein and phosphorus. The incorporation of MBM into livestock and poultry diets spares the annual use of 2.6 billion pounds of mined and industrially manufactured feed grade phosphate compounds like dicalcium phosphate and deflourinated phosphate. Loss of animal based phosphorus sources would double the use of mined phosphorus for animal feed supplements. The annual protein contributed by MBM is equivalent to 12.2 billion pounds of 48 percent soybean meal. In 2002, this amount of MBM protein represented over 11 percent of the soy protein produced in the United States. In other words, another

8.4 million acres of soybeans would have been required to produce the same protein equivalent as MBM.

The amount of metabolizable energy contributed by animal fats and MBM is equivalent to more than 474,000 truckloads of corn each year. In 2002, it would have required nearly three million more acres of corn production. The combined number of acres of additional soybeans and corn needed to produce the protein and energy contributed by animal fats and MBM is equal to 33.6 percent of Iowa's farmable land, the leading state in the production of corn and soy in the United States.

Biosecurity

The U.S. rendering industry recognizes its role in ensuring food safety and in protecting human and animal health. The rendering process is an effective method for ensuring biosecurity because processing conditions assure the destruction of pathogenic viruses, bacteria, and other microorganisms. Rendering is the most logical method for collecting and processing animal by-products and mortalities because it has the infrastructure in place to safely and responsibly recycle or dispose of these products, allow traceability, and produce safe, biosecure finished products that comply with all federal and state regulations.

Processing

Unprocessed animal by-products and mortalities contain large numbers of microorganisms, including pathogenic bacteria and viruses. Unless properly processed in a timely manner, these unstable materials provide an excellent environment for disease causing organisms to grow and potentially threaten animal health, human health, and the environment. If allowed to accumulate and decompose without restraint, these tissues would become a substantial biohazard, promoting disease, attracting and harboring rodents, insects, scavengers, and other disease vectors, and attract predatory animals into densely populated areas.

Temperatures of between 240° and 295°F (115° to 146°C) are used in the rendering process, which are more than sufficient to kill bacteria, viruses and many other microorganisms, to produce an aseptic protein product that is free of potential biohazards and environmental threats. Trout et al. (2001) sampled unprocessed animal by-products at 17 different rendering facilities in each of two seasons.

Clostridium perfringens, Listeria species, and *Salmonella* species were found in more than 70 percent of the samples taken before processing (Table 4). All samples taken after heat processing were negative for these and other pathogens. These data suggest that rendering is an effective tool for use in controlling pathogenic bacteria.

Table 4. Efficacy of the U.S. Rendering System in the Destruction of Pathogenic Bacteria.[a]

Pathogen	Raw Tissue [b]	Post Process [b]
Clostridium perfringens	71.4 %	0 %
Listeria species	76.2 %	0 %
L. monocytogenes	8.3 %	0 %
Campylobacter species	29.8 %	0 %
C. jejuni	20.0 %	0 %
Salmonella species	84.5 %	0 %

[a] Trout et al., 2001. Samples from 17 different facilities taken during the winter and summer.
[b] Percent of positive samples found to be for pathogen out of the total samples collected.

The value of the rendering process as a mechanism to control risks from microbial pathogens as well as other hazards was validated in a United Kingdom Department of Health (2001) study (Table 5). Risks of human exposure to biological hazards were found to be negligible when animal mortalities and by-products were processed by rendering, incineration, or funeral pyre. However, incineration and pyres were reported to cause moderate to high exposure to chemical hazards associated with burning. Only materials that had been rendered yielded negligible exposure to both biological and chemical hazards. The agent causing BSE was the only exception and it was found to pose a negligible risk to humans when the solid products from rendering were subsequently incinerated.

Rendering is Regulated

The rendering industry is closely regulated by state and federal agencies, with each routinely inspecting rendering facilities for compliance to applicable regulations and finished product safety tolerances. Officers of the FDA inspect rendering facilities for compliance to BSE related regulations and chemical residue tolerances. APHIS issues export certificates and inspects rendering facilities for compliance to restrictions imposed by the importing country. State feed control officials inspect and test finished products as they enforce quality, adulteration, and feed safety policies. Other state agencies also regulate the rendering industry through the issuance of air and water quality permits and feed and rendering licenses. This inspection system also helps to assure that dead or diseased animals are not illegally diverted for use in human food.

Internal controls are used by the rendering industry to ensure that biosecurity is maintained and that the finished products are safe and in compliance with all state and federal regulations and tolerances. Two types of control procedures that are common among rendering companies are good manufacturing practices (GMPs) and HACCP-like process control (PC) programs.

GMPs are preventative practices that minimize product safety hazards by instituting basic controls or conditions favorable for producing a safe product. A "raw material GMP" would be one example and would provide validation that raw materials were not exposed to toxic chemicals or metals prior to processing in a rendering facility. GMPs are necessary for development of a PC program.

Table 5. Summary of Potential Health Risks for Various Methods of Handling Animal By- Products. [ab]

Disease/Hazardous Agent	Exposure of Humans to Hazards from Each Option				
	Rendering	Incineration	Landfill	Pyre	Burial
Campylobacter, E. Coli, Listeria, Salmonella, Bacillus anthracis, C. botulinum, Leptospira, Mycobacterium tuberculosis var bovis, Yersinia	Very small	Very small	Moderate	Very small	High
Cryptosporidium, Giardia	Very small	Very small	Moderate	Very small	High
Clostridium tetani	Very small	Very small	Moderate	Very small	High
Prions for BSE, scrapie[c]	Moderate	Very small	Moderate	Moderate	High
Methane, CO_2	Very small	Very small	Moderate	Very small	High
Fuel-specific chemicals, metal salts	Very small	Very small	Very small	High	Very small
Particulates, SO_2, NO_2, nitrous particles	Very small	Moderate	Very small	High	Very small
PAHs, dioxins	Very small	Moderate	Very small	High	Very small
Disinfectants, detergents	Very small	Very small	Moderate	Moderate	High
Hydrogen sulfide	Very small	Very small	Moderate	Very small	High
Radiation	Very small	Moderate	Very small	Moderate	Moderate

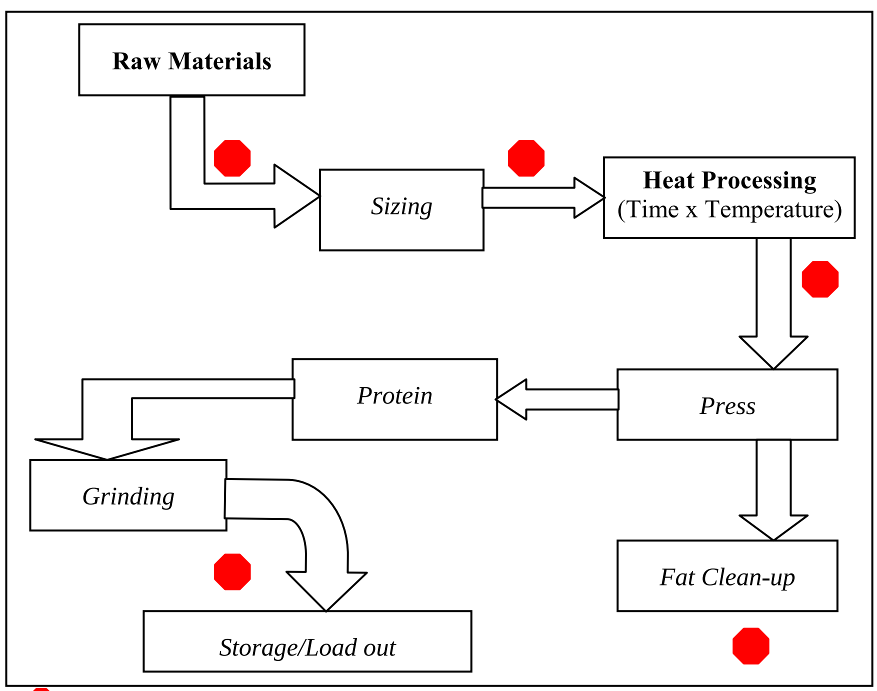
[a] Adapted from the United Kingdom Department of Health (2001).
[b] Legend: Very small—least exposure of humans to hazards.
Moderate—intermediate exposure of humans to hazards.
High—greatest exposure of humans to hazards.
[c] Risk of human exposure to TSEs was rated as very small when solid products of rendering were incinerated.

Rendering companies in the United States have adopted voluntary PC programs as an important component of their biosecurity and food safety programs. PC programs require (1) an evaluation of the entire rendering process; (2) identification of potential biological, physical, or chemical hazards; (3) identification of critical points in the process where the hazard(s) can be controlled; and (4) development of procedures to control these processes and ensure the hazard is eliminated or reduced to acceptable levels.

Processing temperature and particle size of the material are two examples of critical control points associated with the destruction of viral and bacterial pathogens present in unprocessed animal by-products and mortalities. These are critical control points because the transfer of heat through materials at temperatures sufficient to kill biological hazards within a given transit time is dependent on the interaction between processing temperature and particle size. Therefore, settings and condition of sizing equipment must be inspected and documented frequently. Process temperatures are also monitored and recorded. If either of these is out of tolerance, the material must be reprocessed with appropriate documentation.

Additional quality assurance (QA) controls may also be included at various points in the process to assure quality of the finished product(s). A generalized PC/QA program for a typical rendering facility is shown in Figure 2.

Figure 2. Production Flow Chart with Critical and Quality Control Points.



Quality or Hazard Analysis Critical Control Points

The FDA has announced its intention to implement an Animal Feed Safety System by 2007 that will incorporate a risk-based approach to identifying and developing limits for hazardous contaminants within feed, and establish process controls with regulatory oversight to ensure compliance (FDA, 2005). This is consistent with recommendations from the Food and Agriculture Organization (FAO), which called for full traceability and implementation of a code of practice for handling animal by-products and mortalities to ensure safety (FAO, 2002).

Although individual rendering companies have voluntarily implemented their own GMPs and PC programs for years, the industry adopted the APPI Code of Practice in 2004 that formally established minimum industry standards for product safety that include GMPs and PC programs. Participating facilities receive accreditation upon passing an audit conducted by the Facility Certification Institute, a third-party auditing firm.

Rendering Meets APHIS Objectives

The Veterinary Services division of APHIS developed their Strategic and Performance Plan for the 2003 – 2008 fiscal years. Three specific goals were developed. These are presented in Table 6 along with the current impact and benefits contributed by rendering. Processing animal by-products and mortalities through rendering is consistent with each of these goals.

The rendering process provides a means by which the disease cycle can be broken. For typical pathogens, this may be through the rapid destruction of the organism caused by processing at lethal temperatures. For other disease agents, such as the one responsible for causing BSE, the infected animal by-products may first be rendered to reduce infectivity, making the materials safer for handling and storage prior to their disposal. Cohen et al. (2001) reported that batch rendering systems achieved a 3.1 log reduction (1,000-fold) in BSE infectivity, while continuous systems with and without fat recycling reduced infectivity 2.0 log (100-fold) and 1.0 log (10-fold), respectively.

The U.S. government recognized the biosecurity benefits of rendering many years ago. As a result, rendering has been an important component of most animal disease eradication programs in this country. The voluntary pseudorabies virus (PRV) eradication program is the most recent example. PRV cannot survive the rigorous processing steps involved in rendering (Pirtle, 1997). Thus, the depopulation protocol required that euthanized pigs from PRV-infected herds be disposed of through rendering. This was a successful voluntary program, which led to eradication of the disease in the United States by the end of 2004.

Rendering has also become an important component of government surveillance for emerging animal diseases. Renderers provided APHIS nearly one-half of the samples collected during the heightened BSE surveillance initiative from 2004-2006. Recognizing renderers' unique capabilities for collecting farm mortalities and animal by-products, APHIS recently expanded its authority to collect blood and tissue samples at rendering facilities (*Federal Register*: 9 CFR Part 71) in order to enhance their surveillance capabilities.

Table 6. APHIS Goals for FY 2003 – 2008.

Goal	Objective	Rendering's Role
1	Safeguard the health of animals, plants, and ecosystems in the U.S.	Rendering plays a preventative role by containing and killing disease-causing organisms before they can multiply and spread in the environment. Unprocessed animal by-products that are allowed to accumulate will pose a significant new or emerging threat.
2	Facilitate safe agricultural trade.	Marketability is associated with perceived safety. As animal disease spreads in a country, global markets will close, as the U.S. and Canada experienced after their discoveries of BSE. Renderers participate with APHIS in monitoring and eradicating animal disease in the U.S.
3	Ensure the effective and efficient management of programs to achieve APHIS' mission.	Dead animals and other animal tissues are concentrated at rendering facilities, which facilitates access for sampling by government agencies.

Source: USDA, 2003.

Timely processing, processing temperatures, and the concentration of animal mortalities and other animal tissues at a finite number of locations provides APHIS with many of the necessary tools needed to prevent disease outbreaks, eradicate diseases, and monitor the health status of animal herds and flocks in the United States. It will be difficult for APHIS to realize their goals if the rendering industry is not utilized to its fullest potential.

Traceability

Except for incineration, which is cost prohibitive and environmentally unsuitable, the alternatives to rendering for the disposal of animal by-products and mortalities do not provide adequate biosecurity. The origin and ultimate disposition of these materials are not traceable when methods other than rendering are used. This is problematic when attempting to prevent, control, or eradicate disease. Only rendering companies are held accountable and required to document and maintain written records suitable for governmental agencies to trace animal by-products back to their source and the finished products forward to their disposal or use. Once the USDA National Animal Identification System is fully functional, renderers' capabilities will be even more efficient and precise.

Animal by-product traceability was provided for when the FDA implemented the ban on feeding proteins derived from ruminant animals back to cattle and other ruminants (*Federal Register*: 21 CFR § 589.2000; the so called

"FDA feed rule"). This rule required that renderers manufacturing products that contain or may contain protein derived from mammalian tissues intended for use in animal feed take measures to ensure that prohibited materials are not used in feed for ruminants. One of these provisions is to "maintain records sufficient to track the materials throughout their receipt, processing, and distribution and make the copies available for inspection and copying by the FDA." Compliance to this requirement is verified by periodic inspections by FDA compliance officers or state officials under contract to the FDA. Similarly, the Bioterrorism Act of 2002 contains a "records retention" section (Title III, Part 306) that expands those requirements to include all materials received and shipped by renderers. The requirement is for each step in the production chain to keep track of where materials came from and where they were delivered—"one step forward and one step back."

Even firms processing materials that are exempt from the 1997 FDA feed rule, such as those derived exclusively from nonruminant animals, must maintain records sufficient to allow traceability. These firms are also subject to inspection by FDA officers and must be able to demonstrate that their products do not contain materials derived from ruminant animals.

Infrastructure

Full-service rendering companies are capable of efficiently transporting and processing large volumes (one million or more pounds per day) of raw animal by-products and mortalities. Rendering, as we know it, was established in the United States more than 100 years ago. Since then, it has developed as a service orientated industry that continually embraces new technology, science, and sound business decisions to improve process efficiency, product safety, finished product quality, and the environment. Even though the rendering industry has undergone significant consolidation during the past 30 years, most areas of the United States continue to be serviced by one or more renderers.

The equipment used by the rendering industry is specialized and not commonly found in other segments of the agricultural industry. In order to safeguard the food supply and prevent the spread of disease and damage to the environment, many states regulate the collection and transportation of unprocessed animal by-products and mortalities and require that only vehicles equipped with leak-proof vessels be used to transport these materials. This is industry-specific equipment and not commonly found on vehicles used by common carriers or on farm equipment. Renderers must also install air scrubbers, thermal-oxidizers, wastewater treatment facilities, and other equipment necessary to meet state air emissions, odor, and water discharge permits for their facilities. Tens of millions of dollars in equipment, monitoring instrumentation, and analytical testing are invested at rendering facilities in order to meet state and federal standards.

Because the rendering industry is committed to the continual improvement in the safety of its products, it has formed organizations to provide technical support and education in quality assurance and feed safety. The Animal Protein Producers Industry (APPI) administers industry-wide programs for biosecurity, PC training, *Salmonella* reduction, continuing education and third-party certification for compliance to BSE related regulations and APPI Code of Practice accreditation. The Fats and Proteins Research Foundation (FPRF) solicits and funds industry and university research to address pertinent biosecurity and nutrient value issues as well as search for new uses. To focus research on biosecurity issues and develop new uses for rendered products, FPRF entered into an agreement with Clemson University to establish the Animal Co-Products Research and Education Center (ACREC). More about the development and purpose of ACREC is explained in a subsequent chapter of this book.

Volume Reduction

Unprocessed animal by-products contain large amounts of water (Table 7). Heat is used to process these raw materials primarily to remove the moisture and to facilitate fat separation. Removing most of the moisture reduces total volume by more than 60 percent, from 54 billion pounds of raw material to about 11.2 billion pounds of animal proteins and 10.9 billion pounds of rendered fats. Stored properly, these finished products are stable for long periods of time. Dry protein meals provide an unfavorable environment for pathogens to grow because the water activity is below the threshold needed for microbial proliferation.

Table 7. Water, Protein, and Fat Composition of Animal By-Products.

	Protein	Fat	Water
Blood	10	0	90
Fat Trim	5	55	40
Bones	35	10	55
Offal	15	15	70

Timely Processing

Because of the equipment and processing conditions used in modern rendering facilities, bacteria and viruses are rapidly destroyed and not allowed to reproduce and spread. This is critical in order to contain, prevent, or eradicate disease. Alternative methods of disposal do not consistently eliminate pathogens. Incineration does provide for quick pathogen destruction. However, other methods such as burial or composting are based on tissue decomposition, take months to complete the process, and are less effective than rendering.

The U.S. Rendering Industry and BSE

The rendering industry has been actively involved in programs to prevent the spread of BSE in the United States since before 1995, when renderers voluntarily stopped rendering sheep material. This was done to prevent any scrapie-infected material from entering the food chain, especially via feed for ruminant animals.

When the FDA first considered preventative measures in 1996, renderers and cattle producers voluntarily stopped using MBM derived from ruminant animals in cattle feed. This later became official when the FDA published the feed rule (*Federal Register*: 21 CFR § 589.2000), which prohibited the use of these materials in feeds intended for cattle and other ruminant animals. The rendering industry was actively involved in preparing this rule and fully supported it from its introduction in 1997.

The only MBM permitted for use in ruminant animal feed in the United States is material that comes from plants that slaughter or process only non-ruminant materials. If the raw material cannot be verified to be 100 percent nonruminant origin, then the resulting finished material is prohibited from use in feeds for cattle and other ruminant animals. While PC programs target known hazards that can be eliminated or controlled through the rendering process, they also include in-plant enforcement of policies that apply to the acceptance or rejection of raw material. This provides further assurance that material from suspect cattle (such as those being tested for BSE through the APHIS surveillance program), sheep, and goats are not received and processed for feed.

The FDA feed rule includes requirements that finished products are clearly labeled and records of raw material receipts and finished product sales be kept and made available for inspection by the FDA. This allows the FDA to verify the source of raw materials and verify compliance to the feed rule among feed manufacturers, dealers, distributors, and end users. For renderers who process proteins exempt under the feed rule, safeguards to prevent cross-contamination must be demonstrated in practice and in writing.

The APPI Code of Practice for rendering companies introduced in 2004 includes the requirement that facilities be in compliance with the FDA feed rule. An earlier third-party audit (2001) of the industry for compliance to the FDA feed rule showed 100 percent compliance among participating rendering companies which accounted for nearly all of the industry capacity.

Although two cases of indigenous BSE have been identified in the United States as of this writing, it is extremely unlikely to become established because measures taken by agencies of the U.S. government were and continue to be effective at reducing the spread of BSE (Cohen et al., 2001). As a result, the United States is highly resistant to any amplification of BSE or similar disease. Cohen et al. (2001) considered the FDA feed rule to be one of the most important safeguards because it will prevent amplification of the disease. Hueston (2005) concurred that although small doses of contaminated feed are sufficient for BSE transmission, amplification requires significant recycling within the cattle population. The FAO (2002) reflected agreement with these assessments by recommending that the feeding of ruminant MBM to ruminant animals be prohibited worldwide as an additional safeguard against the further spread of BSE.

The U.S. rendering industry fully supports science-based BSE prevention programs and efforts developed by the FDA, APHIS, and other federal and state governmental agencies. The rendering industry is committed to achieving 100 percent compliance to the FDA feed rule as a keystone for its success.

Challenges

Concern about BSE has been the most serious issue affecting the use of rendered products in the past 10 years. Since the FDA promulgated the feed rule, the value of restricted use (prohibited as feed for ruminant animals) MBM has been discounted an average of $18.13 per ton, compared to exempt MBM derived only from nonruminant animals (Sparks, 2001).

Table 8. Annual Production of Animal By-Products (Sparks, 2001).

Protein Meal	Million Pounds/Year
Meat and bone meal (MBM)	
Restricted use (banned in feeds for ruminants)	
Pure ruminant origin	2,734.1
Mixed containing ruminant origin material	2,263.1
Total restricted use MBM	**4,997.1**
Exempt (available for use in ruminant feeds)	
Exempt (pure porcine origin)	1,640.5
Mixed containing only exempt material	14.6
Total exempt MBM	**1,655.1**
Blood products (all exempt from feed rule)	
Ruminant origin	121.9
Porcine origin	54.8
Mixed	49.8
Total blood products	**226.5**
Poultry meals (exempt from feed rule)	
Poultry by-product meal (pure)	3,073.5
Feather meal	1,200.0
Total poultry meals	**4,273.5**

The effects of price discounting and lost markets because of real or perceived consumer concerns have severely impacted the rendering industry. The reason for this impact is best understood by considering the amount of product affected by this regulation (Table 8). Approximately 75 percent (2.5 million tons) of the MBM produced in the United States is totally or partially derived from ruminant animals and cannot be used in feed for cattle or other ruminant animals. Directly, this has had little impact on the rendering industry. Indirectly, compliance issues for feed manufacturers who make both ruminant and nonruminant feeds in the same facility, food safety concerns, media coverage, and marketing campaigns advertising meat from animals fed “animal by-product free” diets have severely impacted the rendering industry. As a result, it has been necessary to pass a portion of the costs associated with rendering on to the generators of animal by-products and mortalities. This has stimulated interest in alternative methods for the disposal of these materials, some of which are legal and some not.

Recent events in North America and proposed rulemaking published by federal agencies within the past two years suggest that additional restrictions on the type and/or specie of raw animal by-products that can be rendered to produce materials for animal feed are likely. Canada and the United States each confirmed their first cases of BSE in 2003. Soon after each confirmation, each country banned specified risk material (SRM) from human food and cosmetics. Canada and the United States identified similar tissues to be SRM, including the skull, brain, trigeminal ganglia, eyes, spinal cord, and dorsal root ganglia from cattle over 30 months of age, and the distal ileum and tonsils from cattle of all ages.

As of this writing, Canada has confirmed eight cases of BSE and the United States three, two in native born cattle and one (the first case) in a cow imported into the State of Washington from Canada. All of the U.S. cases were born before 1997 when the FDA feed rule went into effect. Four of the Canadian cases, however, were born after 1997 when the Canadian government instituted feed restrictions that were similar to the FDA feed rule. As a result, the Canadian Food Inspection Agency announced regulations banning all SRM (skull, brain, trigeminal ganglia, eyes, tonsils, spinal cord, and dorsal rot ganglia of cattle aged 30 months or older and the distal ileum of cattle of all ages) from all animal feed and for use in fertilizers effective July 12, 2007 (CFIA, 2006).

On October 6, 2005, the FDA proposed to amend the FDA feed rule and prohibit certain cattle origin materials in the food or feed of all animals (proposed rule; *Federal Register*, Vol. 70, No. 193, pp58570-58601). Materials proposed to be banned include (1) the brain and spinal cord from cattle 30 months and older that are inspected and passed for human consumption, (2) the brain and spinal cord from cattle of any age not inspected and passed for human consumption ("dead and downer cattle"), and (3) the entire carcass of dead and downer cattle if the brain and spinal cord have not been removed. In addition, the proposed rule provides that tallow containing more than 0.15 percent insoluble impurities also be banned from all animal food and feed if such tallow is derived from the proposed prohibited materials. As of this writing, the FDA was reviewing comments submitted to the proposed rule and had not taken any further action.

The rendering industry estimated that brain and spinal cord can be successfully removed from only about 54 percent of dead and downer cattle, on average (Informa Economics, 2005). Removal of soft tissues such as these is negatively affected by the rate of carcass decomposition, which accelerates with rising ambient temperature. In areas where daytime temperatures exceed 80˚F (27˚C) much of the year, such as in the southern and western areas of the United States, the brain and spinal cord may only be successfully removed 10 percent of the time. Under the proposed rule, failure to remove the brain and spinal cord from dead and downer cattle will prevent their use in feed for any animal and create a significant disposal issue. Other potential unintended consequences of the proposed rule include disruptions in the collection of nonruminant mortalities, compliance issues associated with accepting by-products from non-federally inspected facilities that slaughter cattle over 30 months of age, and a reduction of rendering services in some areas of the country. In the proposed rule, the criteria that the FDA will use to determine compliance for the rendering industry were not clearly stated. As a result, renderers may stop processing prohibited materials rather than risk agency action for non-compliance which would increase the amount of material that must be disposed of by other means.

The United States does not uniformly regulate the disposal of animal by-products and mortalities. Because these materials will have little to no value either in a raw or processed state if they are banned from animal feed, it is unlikely that renderers will be able to collect and process them. As a result, government agencies will lose control over the collection and disposal of SRM as well as any commingled materials. Such a loss of control is in conflict with the intent of BSE safeguards and could contribute to the spread of conventional diseases. While animal fats can be used for fuel or in some industrial applications, animal proteins are currently used almost exclusively as feed ingredients except for a small amount used for fertilizer. Unless large-volume non-feed uses for animal proteins are developed, materials prohibited from animal feed will have no economic value and rendering companies will be unable to collect, transport, process, and dispose of such materials unless their costs can be recovered from the by-product generators.

Figure 3. Improper Dumping of Butchered Deer Remains in a Cornfield.

Rendering is the Optimal Disposal Method

Failure to use the rendering industry for the disposal of animal by-products and mortalities will erode the infrastructure developed to safely handle these materials, resulting in sanitation and environmental challenges in the future (FAO, 2002). These issues may become insurmountable during widespread emergency situations, such as foreign animal disease outbreaks, extended periods of excessive heat, floods, etc. Sparks (2001) estimated that prohibitions against the use of all animal proteins in animal feeds would reduce the market price paid for cattle ($15.49/head), pigs ($3.22/head), broiler chickens ($0.07/bird), and turkeys ($0.33/bird). These costs are based on the complete loss of economic value for animal proteins (not animal fats) and assume that rendering services will continue to be available and utilized. They do not address the potential costs associated with either a major reduction or complete loss of rendering services to the livestock, poultry, and meat industries.

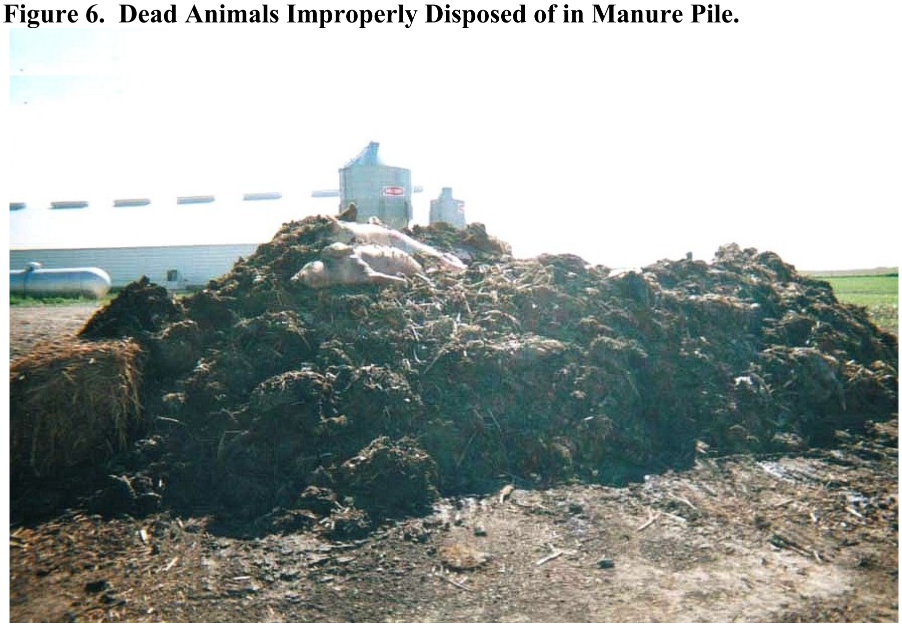
Figure 4. Improper Dumping of Trash Bags Filled with Animal Remains.

Without the rendering industry, it would be necessary to discard or dispose of animal by-products and mortalities in community landfills, compost piles, burial sites, incinerators, or, worse, left in illegal dumping places causing a potential public health hazard. Each of these alternative methods has limitations with respect to animal by-product and mortality disposal, with limited space the most obvious.

When unprocessed animal by-products derived from ruminant animals are disposed of by methods other than rendering, their disposition is not regulated and the potential exists for cattle and other ruminant animals to be exposed to materials prohibited by the FDA feed rule. Domestic and wild ruminant animals may have direct exposure to unprocessed raw materials that have been improperly buried, composted, or placed in landfills. As a result, these non-rendering practices could contribute to the amplification of BSE in the United States. For example, spreading composted animal by-products of ruminant animal origin on land used for grazing and/or hay production is permitted under current regulations.

Figure 5. Improperly Managed Dead Calves.

Figure 6. Dead Animals Improperly Disposed of in Manure Pile.



Landfills

While rendering reduces volume, amendments (such as sawdust) must be added (one part amendment to three parts by-product) to compensate for the high moisture content of animal by-products and mortalities when disposing in a landfill. As a result, the total volume would be increased by approximately 25 percent. When properly prepared, the volume of animal by-products and mortalities generated in one year would take up approximately 25 percent of the landfill space in the United States at an estimated cost of $105 per ton (Sparks, 2001).

Decomposition proceeds slowly and at relatively low temperatures (130° to 150°F) in landfills, which limits pathogen destruction. Landfilling animal by-products contributes to methane gas production and odors, attracts vectors (such as rats, pets, and flies), and creates contact and/or inhalation exposures to humans.

Studies presented in Table 5 indicate that other options are superior to landfills in reducing the risk of exposing humans to potential biological and chemical hazards, including BSE. Further, the potential for increased disease among landfill workers and the transfer of pathogens to off-site locations may be increased when landfills are used for large animal disposal (Gerba, 2002). For these reasons, disposing of cattle carcasses in landfills is prohibited in California and possibly other states.

Composting

Composting is dependent on controlled microbial fermentation to decompose animal by-products and mortalities. Moreover, composting has limited large scale application because large amounts of carbonaceous materials are needed in order to balance the high nitrogen and moisture content in animal by-products and mortalities. Using pork industry guidelines for composting (Glanville, 2001), which consider blending and pile separation issues, approximately one trillion cubic feet of space (800 billion bushels) would be needed to compost the 54 billion pounds of animal by-products that are rendered each year. This is equivalent to the space needed to store all of the corn produced in the United States for the past 100 years. In addition, the spreading of composted animal by-products and mortalities of bovine origin on land used for grazing or feed production is inconsistent with the intent of the FDA feed rule and other federal programs to prevent the spread of BSE in the United States. Widespread composting would dilute the integrity of the FDA feed rule and make all existing risk assessment models (Cohen et al., 2001) invalid. Some states recognize the potential for environmental contamination when cattle carcasses and tissues are composted and prohibit such practices under state statute. California is one such state.

Effective composting is difficult to manage and, depending on the system used, could result in odors and failure to kill pathogens (Franco, 2002). The heat produced during composting (120° to 158°F) will kill most eggs of parasites and vegetative bacteria within four to eight inches of the surface, but are not sufficient to eliminate heat-resistant and spore-forming bacteria such as *Clostridium perfringens*. However, if compost piles are not properly turned, pathogen destruction cannot be assured. Independent renderers are in a unique position to monitor the emergence and operation of alternative disposal methods because of their proximity to areas where livestock are produced. The rendering industry has observed and clearly documented failed and inadequate attempts at composting.

Burial

Burial is not a viable option in many states because of population density and/or the potential for ground and surface water contamination. If not done properly, burial can also create some of the same potential risks from pathogens that landfilling and composting do. Shown in Table 5, human exposure to all biological and some chemical (such as hydrogen sulfide) hazards is high when animal by-products and mortalities are buried (U.K. Department of Health, 2001). Space is also a major limiting factor for the disposal of large quantities of animal by-products and mortalities.

Incineration

Incineration can be cost prohibitive because of the fossil fuel needed to destroy animal by-products and mortalities. Significant amounts of ash residue are left after these materials are incinerated, causing a disposal issue. Incineration is an efficacious means of minimizing human exposure to pathogenic microorganisms. However, incinerators generate potentially hazardous chemicals, such as dioxins and particulates (Table 5). Further, as in the European Union, incineration capacity in the United States is inadequate to dispose of all of the animal by-products and mortalities produced annually (Goldstein and Madtes, 2001). There are also many regulatory challenges to permitting new incinerators.

Abandoned—Dumped

Due to its low cost and low risk of prosecution, the abandonment of animal carcasses or illegal dumping of infectious waste animal tissues is a tempting alternative disposal option (Figures 3-9). The potential to attract scavengers, contaminate ground and surface water supplies, and spread potential animal and human pathogens makes this a particularly harmful practice. Independent renderers are in a unique position to observe and document this growing trend. Employees traveling their daily collection routes observe these materials abandoned in fields or dumped in ravines or waterways. State solid waste regulatory agencies simply do not have the resources to monitor and enforce prohibitions against such activities and admit their awareness is limited to when they receive complaints.

Future Role of Rendering

Further increases in the volume of animal by-products that cannot be used in animal feed because of government regulations or consumer pressures will increase the likelihood of problems due to poor sanitation, spread of disease, and/or damage to the environment. Therefore, a need for a two-tier rendering system is emerging to address these issues and concerns. Under such a system, the risk associated with raw animal by-products and mortalities could be assessed and the materials directed to facilities dedicated to either manufacture products that can be used in feed or products for non-feed applications. Absent any viable non-feed uses, materials that can not be used in feed would be prepared for disposal.

In order for a disposal segment of the industry to evolve, disposal rendering must be sustainable. The lack of regulations requiring all options used to collect, process, and dispose of animal by-products and mortalities to meet uniform standards for biosecurity, traceability, and environmental protection is the only reason that disposal rendering has not already developed as a viable mechanism for handling these materials. Without such standards, the United States will not have the infrastructure to handle a ban on the use of SRM in feed, even if only a portion of SRM is banned as the FDA proposed. Disposal problems that threaten animal health, human health, and the environment will continue to increase as the volumes of raw animal by-products and mortalities that cannot be used in feed increase.

Figure 7. Illegal Dumping Pollutes Water.

Figure 8. Illegal Dumping of Dead Animals in Waterway.

Figure 9. Rotting Swine Carcasses, Improperly Disposed.

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Fat Processing Equipment, 1967.

EDIBLE RENDERING—RENDERED PRODUCTS FOR HUMAN USE

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Summary

This chapter focuses on animal by-products used directly by humans. Information on world and U.S. meat and by-product production is discussed. The main products focused on are fats and oils and their properties, and animal by-products that are harvested from the carcass and cooked by the consumer or incorporated into consumable food items. Also discussed are gelatin extraction, edible tissue separated from bone, and other uses. Where appropriate, references are given where more detailed information is available.

Definitions

Some of the critical definitions important to edible animal by-products are:

Batch cooker – Horizontal, steam-jacketed cylinder with a mechanical agitator.

Centrifuge – Machine using centrifugal force to separate materials of different densities.

Chitlings - Small intestines of pigs.

Continuous cooker – The flow of material through the system is constant.

Cracklings – Solid protein material from screw press after removal of lard.

Dry rendering – Releasing fat by dehydration.

Edible – Products for human consumption that are under the inspection of U.S. Department of Agriculture Food Safety Inspection Service.

Giblets – Consists of the neck, liver, heart, and gizzard of poultry.

Grease – Fats with lower melting points, softer. The titer is less than 40ºC.

Lard (grease) – Fat from pigs (porcine), softer than fat from ruminants.

Rendering – Fatty or oil materials in meat is melted away from the solid portion of the animal tissue.

Tallow – Fat from beef (bovine), mutton (ovine), goat (capra), camel (camelus), llama (lama), deer (cervidae). This fat has a higher melting point than from non-ruminants, increased hardness, and a titer of 40ºC or higher.

Tankage – Cooked material after most of the liquid fat has been removed.

Titer – Determined by melt point (ºC) test which also measures hardness.

Edible Rendered Products

Volumes

In 2004, world meat production was 253.6 million tons, and this increases every year, according to the Food and Agriculture Organization of the United Nations. Approximately 40 percent of a live beef animal weight is processed through a rendering plant. The typical beef fat trimmings from a USDA plant consist of 60 to 64 percent fat, 14 to 16 percent moisture, and 20 to 24 percent proteins solids (Franco and Swanson, 1996). It has been estimated that nearly 54 billion pounds of by-products are generated in the United States each year from processed cattle, pigs, sheep, and poultry. Slaughterhouses, packing plants, supermarkets, butcher shops, and restaurants collectively generate at least one billion pounds of animal by-products each week. Edible rendered by-products utilization in the United States can be found in Table 1.

Table 1. U.S. Production and Consumption of Edible Rendered Products.

	Produced	**Domestic Consumption**	**Exported**
Product, Year	Million Pounds		
Edible Tallow, 1994	1,513	557	295
Edible Tallow, 2005	1,813	402	306
Lard, 1994	559	422	139
Lard, 2005	267	235	94

Source: U.S. Census Bureau, 1995 and 2006. Note: Also, 5.6 million pounds of lard and edible tallow were consumed in margarine for 2004.

Fat Sources

Fat is non-uniformly stored in various areas of the animal and the quantity depends primarily on the nutrition of the animal. The fat cell has a cell membrane and a nucleus located next to the membrane; however, most of the area is composed of triglycerides. Triglycerides from both animal and plant sources are constructed of glycerol, which is an ester linked to three fatty acids. These three fatty acids usually vary for each triglyceride, and triglycerides are usually distinctive for individual locations in the animal. Species have characteristic fats, and ruminant fat is quite different from non-ruminant fat. For non-ruminants, the depot fat can also be influenced by the type of fat consumed. The major difference in the triglycerides is in the fatty acids that are attached and the chain lengths. The saturation level influences chemical reactions.

Rendering Processes for Edible Fats

An edible rendering process is usually continuous and consists of two stages of centrifugal separation. Fresh fat trimmings are usually ground by machine and moved by a belt to a jacket steam-heated melt tank that contains an agitator. The 110ºF (43ºC) melted fat is pumped to a disintegrator to rupture the fat cells. A centrifuge is used next to separate the fat, moisture, and solids. The fat fraction is then heated to 200ºF (93ºC) by steam in a shell-and-tube heat exchanger. A second-stage centrifuge is used to polish the edible fat. The centrifuge discharges the protein fines which go to inedible rendering or into the primary treatment system for wastewater. The edible tallow or lard, determined by the species of raw material, is then pumped into storage. Few cooking vapors are emitted from the two centrifuge methods for rendering edible fat. Since heat contact with the fat is minimal, fresh raw material is used and sanitation and housekeeping have to be approved in a hazard analysis and critical control point (HACCP) program audited by the USDA/FSIS.

In contrast to edible rendering, inedible rendering uses wet and dry rendering systems. The wet system exposes raw material to hot water (180º to 205ºF, 82º to 96ºC) which later has to be evaporated. This technique results in fat, sticky water (containing glue) and wet tankage (protein solids). This system is not very energy efficient, detrimental to fat quality, and no longer used in the United States. However, a continuous variable of this procedure is used to produce edible products. The dry rendering system works by dehydrating raw material at a temperature of 240 to 290ºF (115º to 145ºC) in either a batch or continuous cooker. It is no longer approved for edible grade fats by the USDA. The final temperature in the batch cooker varies from 250º to 275ºF (121º to 135ºC) and usually requires two to three hours of cooking time. After cooking, the product is drained, the solids are pressed (screw press or twin screw press), and the fat content is reduced from 25 percent to approximately 10 percent. The solids are then known as cracklings. The fat from pressing usually contains some fines that are removed by centrifuging or filtration. The continuous rendering system is really continuous cooking with raw material fed into one end of the cooker and cooked material discharged from the other end. The continuous system has higher capacity, occupies less space, and is more energy efficient. Other rendering processes include ring dryers, steam tube rotary dryers, and pressure cooking.

Edible Fats

The animal products consumed as human food that come closest to paralleling the classical definition of rendering are lard and tallow since heat is used to separate these lipids from the muscle and bone tissue. Edible tallow and lard are used in oleomargarine (margarine), shortening, and cooking fats, with the latter two having the greatest market share. Many cooks insist that tallow gives a better flavor to fried foods than vegetable oils. The fast food industry in the 1990s switched from tallow and lard for frying potatoes to vegetable oil, and was led by McDonald’s due to public concern about animal fats, cholesterol, and heart disease.

Lard is defined as fat from pigs that is melted and strained from the cell wall tissues that encase it. The highest grade of lard is leaf lard, which is obtained from the fat around the kidneys. The next grade is from back fat and the poorest is from fat covering the small intestines. Lard is also classified by the method of preparation such as prime steam, rendered in a closed vessel into which steam is injected; neutral, melted at low temperature; kettle-rendered, heated with water added into steam-jacketed kettles; and dry-rendered, which is hashed and then heated in cookers equipped with agitators. Good lard melts quickly and is free from disagreeable odor. Pure lard (99 percent fat) is highly valued as cooking oil because it smokes very little when heated.

Unprocessed lard often has a strong flavor and a soft texture, but lard can be processed in many ways including separating it from the surrounding tissue by heat, filtering, bleaching, and hydrogenation. In general, processed lard is firmer (about the consistency of vegetable shortening), has a milder, more nutlike flavor, and has a longer shelf life than vegetable oil. Lard produces extremely tender, flaky biscuits and pastries. It's also a flavorful fat for frying. When substituting lard for butter or vegetable oils in baking, reduce the amount by 20 to 25 percent. All lard should be tightly wrapped to prevent absorption of other flavors that may be present in the storage area. It may be stored at room temperature or refrigerated depending on how it has been processed. Lard (often with a needle) is also used to insert long, thin strips of fat (usually pork or bacon) into dry cuts of meat. The purpose of larding is to make the cooked meat more succulent, tender, and flavorful. These strips are commonly referred to as lardons.

Table 2. Chemical Composition of Animal Fats.

Carbon Chain Length and Unsaturation	Beef Tallow	Pork Lard	Poultry Fat
^{12}C Lauric			0.5
^{14}C Myristic	3.0	1.5	1.5
^{15}C Pentadecanoic	0.5		
^{16}C Palmitic	24.0	27.0	22.5
^{16}C 1=Palmitoleic	2.5	3.0	8.5
^{17}C Margaric	1.5	0.5	
^{18}C Stearic	20.0	13.5	5.5
^{18}C 1=Oleic	43.0	43.5	40.0
^{18}C 2=Linoleic	4.0	10.5	19.0
^{18}C 3=Linolenic	0.3	0.5	1.0
^{20}C Arachadic	0.5		
Iodine Value[a]	48	65	90
Saponification[b]	200	200	196
Titer C-fatty acid[c] basis	43	36	32

[a] Higher numbers indicate more unsaturated fatty acids.
[b] Higher numbers indicate shorter fatty acid chain lengths.
[c] Higher numbers indicate higher melting points or harder fats.
Modified from Franco and Swanson, 1996; Ockerman, 1996.

Characteristics of Edible Fats

Fats and oils from both animals and plants are composed of triglycerides, which are three fatty acids connected to glycerol by an ester linkage. The only difference in triglycerides is the degree of unsaturation (double bonds in the fatty acids) and the fatty acid chain length. The quality of an edible fat is judged by titer, free fatty acid (FFA), FAC (Fat Analysis Committee of the American Oil Chemists Society) color or Lovibond color, and moisture, impurities (insoluble), and unsaponifiable matter (MIU). The unhydrogenated fatty acid composition of edible fats and oils is listed in Table 2.

Titer determines the hardness or softness of the fat or the temperature at which it will solidify. More unsaturated fats have lower titers as do fatty acids with shorter chain lengths. Titers will vary with species. For example, cattle and sheep fat will have a higher titer and pork fat will have a lower titer. The solidification ranges of fats of three species are:

Beef	108º to 113ºF (42º to 45ºC)
Pork	97º to 104ºF (36º to 40ºC)
Sheep	111º to 118ºF (44º to 48ºC)

The difference in solidification temperature is important when making an emulsified sausage product since the chopping temperature must be modified depending on the species and the titer used.

Within each species the titer will also vary depending on the location of the fat within the carcass. For example, the titer is higher for kidney fat compared to loin fat. For a non-ruminant animal, the diet can also influence the hardness of the fat. Thus, a pig fed on peanuts has a lower solidification point than pigs fed on corn. Well-fed animals will also have a higher titer than fat from emaciated animals.

FFAs are usually expressed as the percentage of oleic acid of total sample weight. FFAs are created by breaking of the ester linkage and liberating the fatty acid from the triglyceride. This is undesirable and an indication of degree of spoilage that has occurred. To keep FFA as low as possible, it is necessary to use clean raw material, clean equipment, control temperature to below 20ºC or above 65ºC (to inactivate bacteria and enzymes), keep raw material whole as long as possible (reduce surface area), handle materials rapidly, and control temperature and pressure during rendering and storage. For acceptable quality, FFA should usually be less than two percent.

Color of fat can be almost white to yellow and often shades of green, brown, or red are observed. The causes of color differences can often be explained by green coming from contact with intestinal content containing chlorophyll, red resulting from rendering overheating, and contamination with blood will often result in a brown color. Color of raw material can also be influenced by breed, feed, age, and condition of the animal. To reduce color problems, raw material should be fresh, clean, and free of contamination. Blood and intestinal content should not be in the cooker, and temperature and pressure must be appropriately controlled.

Moisture is undesirable in fat, since it will encourage bacterial growth and fat-splitting enzymes. Moisture is expressed as parts per hundred and levels of 0.2

percent are usually acceptable. To maintain low moisture levels, drain moisture from raw material (using cool temperature as necessary), avoid ineffective use of water in the settling process, drain water from settling and appropriate storage containers, and avoid condensation.

Impurities (insoluble) are undesirable and may originate from non-fatty material (five to 19 percent) in the trimmed fat. Foreign materials such as protein fines, bone powder, and hair are sometimes found in fat. Some of these can be removed by settling or centrifugation and others may be removed by filtration.

Impurities (fat soluble) are undesirable and often consist of copper, tin (from brass), and zinc. Some of the colloidal fines, or ones that are soluble in the fat, are often difficult to remove. Polyethylene is a problem since it melts during processing, burns on the heater coils, or dissolves in the tallow. It will normally settle out in storage over time. Even in inedible product, a maximum of 50 ppm is the upper acceptable limit. Steps to help reduce this problem include starting with clean raw material, using proper settling and filtration, not using pipes or valves that contain brass or copper or zinc, monitoring raw materials for polyethylene and other contaminants, and filtering aids may also be helpful.

Unsaponifiable matter is the portion of the lipid fraction that will not saponify when an alkali is added. Triglycerides (the major quantity of the fat) will saponify; therefore, the addition of an alkali divides the lipid fraction into two categories. Both fractions are a nonpolar soluble, but the small unsaponifiable fraction is chemically quite different from the saponifiable triglycerides. An example of a natural unsaponifiable material would be cholesterol; however, an example of mineral unsaponifiable material would be lubricating oils and greases from pumps and machinery. Good maintenance can reduce the mineral unsaponifiable from downgrading the fat.

Bleachability is a color test using activated clay and a color measuring instrument. High temperatures will fix color in tallow. Therefore, this test is a good indication of temperature and handling conditions to which the fat has been exposed. Cleaner raw material and lower processing temperatures and pressures will result in a lighter bleach value.

Other indicators of quality of fat include saponification number (the higher the number, the shorter the average fatty acid chain length), iodine value (lower values indicate fewer double bonds or unsaturation), and peroxide value (PV) (a measure of oxidation or rancidity). Fresh fat should have PV values of one to two milliequivalents (me) of peroxide per kilogram. TBA or TBARS are another measure of oxidation or rancidity. Smoke point is correlated to flash and fire point and indicates the temperatures at which these reactions will occur. Smoke points are also directly correlated to the quantity of FFAs. To reduce oxidation and rancidity, pumping and storage should minimize air incorporation and foaming, old and new fat should not be mixed, and antioxidants can be used.

Other Edible By-products

Many other parts of the carcass don't quite fit the high temperature rendering definition but are by-products of the animal industry and are consumed by humans. These vary tremendously by who and how they are used, and their nutritional quality. The quantity available can be found in Table 3. Many cultures outside the United States and Canada utilize a much larger proportion of animal carcasses for human food.

The consumable by-products, characteristic, average weight, quantity per serving, how to store, and use in preparation are categorized in Table 4. A flow diagram of edible by-products, blood collection and processing, percentage of the carcass, percentage of by-products used in various countries, percentage of U.S. packers saving by-products, import and export trade of by-products, nutritional value, chemical composition of enzymatic hydrolysis of by-products, water/protein ratio, collagen and elastin content, amino acid content, cholesterol content, cooking procedures, and detailed descriptions can be found in Chapters 1 and 2 of *Animal By-product Processing and Utilization* (Ockerman and Hansen, 2000).

Table 3. By-Product Yield Based on Live Weight.

	Percentage of live weight			
	Beef	**Pork (Pig)**	**Lamb**	**Chicken 3-5 lb**
Cheeks	0.32			
Blood	2.4 - 6	2 - 6	4 - 9	
Blood, dried	0.7			
Brain	0.08 - 0.1	0.08 - 0.1	0.26	0.2 - 0.3
Chitlings	0.06			
Cracklings	3.0	2.2		
Edible kill fat	1 - 7	1.3 - 3.5	12	
Feet	1.9 - 2.1	1.5 - 2.2	2.0	3.9 - 5.3
Gizzard				1.9 - 2.3
Hanging tender	0.19			
Head				2.5 - 2.9
Head and cheek meat	0.32 - 0.4	0.5 - 0.6		
Heart	0.3 - 0.5	0.2 - 0.35	0.3 - 1.1	0.3 - 0.8
Intestines		1.8	3.3	
Kidney	0.07 - 0.2	0.2 - 0.4	0.6	
Lips	0.1			
Liver	1.0 - 1.5	1.1 - 2.4	0.9 - 2.2	1.6 - 2.3

Lungs	0.4 - 0.8	0.4 - 0.8	0.7 - 2.2	0.7
Pancreas	0.06	0.1	0.2	
Rennet	0.23			
Skirt	0.2 - 0.3	0.4 - 0.5	0.5	
Spinal cord	0.03			
Spleen	0.1 - 0.2	0.1 - 0.12	0.1 - 0.4	0.15
Sweetbread	0.03 - 0.05			
Heart	0.02			
Neck	0.02			
Tail	0.1 - 0.25	0.1		
Tongue	0.25 - 0.5	0.3 - 0.4		
Tripe	0.75 - 2.0	0.6	2.9 - 4.6	
Bible	0.18			
Plain	0.6			
Honeycomb	0.1			
Weasand	0.04 - 0.09	0.05		
Rendered edible fat	2 - 11	12 - 16	9	

Sources: Gerrard and Mallion ,1977; Ockerman, 1983; Romans et al., 1985; and Ockerman and Hansen, 1988 and 2000.

Table 4. By-Products Consumed by Humans.

By-Product	Charact-eristic	Average Wt., lb	Serving	Storage	Used in preparing
Blood- beef, pork, lamb					Blood food preparation, blood sausage, black pudding, blood and barley loaf, sausage ingredient
Blood plasma- pork, lamb					Sausage ingredient, Black pudding
Bone- pork, lamb, beef					Gelatin, soup, mechanically deboned tissue, rendered for shortening, refining sugar

By-Product	**Charact-eristic**	**Average Wt., lb**	**Serving**	**Storage**	**Used in preparing**
Brains- beef, veal, pork, lamb	Tender, delicate in flavor, veal most popular	Beef - ¾-1 Lamb - ¼ Pork - ¼	¾ -1 lb for four	Frozen, thaw in hot water, fresh, refrigerate use in 24 hr	Used less due to BSE; separated from spinal cord; tender; fried, broiled, sautéed, poached, braised, scrambled, creamed, cooked in liquid; liver sausage
Casings	Cattle, pigs, sheep			Used to contain sausage items	Cleaned, some layers removed and salted; Some do not use ruminant (BSE concern)
Cheek and head trimmings-, beef, pork, lamb					Sausage ingredient; brain (reduced use due to BSE); stew, sauce, liver sausage; boil, poach, fry
Chitlings, chitlins, chitterlings	Small intestines of pigs; beef is also used in some countries			Often frozen	Cleaned, simmered until tender. Served with a sauce, added to soups, battered and fried
Cracklings- pork	Crisp golden brown solid protein material from screw press after removal of lard.			Use quickly since they get rancid quickly	Used in corn bread, biscuits, muffins; added to the surface of sweet potatoes, mashed potatoes, salads, and as a snack
Ears- pork					Stewed with feet
Esophagus					Sausage ingredient
Extract-, pork, lamb, beef					Soup, bouillon
Fat, oleo stock, oleo oil					Oleo-margarine, shortening, drippings, dipping
Oleo stearin					Shortening, sweets, chewing gum
Edible tallow					Shortening, mincemeat, paste, pudding, dripping
Head- pork					Sausage ingredient, jelly, blood and liver sausage, pie, brawn, salt and boil
Lard	Pork				Shortening, lard

By-Product	Charact-eristic	Average Wt., lb	Serving	Storage	Used in preparing
Feet- pork, beef, lamb, chicken	Pig – foreleg shank	Pig, raw – 46% muscle	Pig feet - bone in, semi-boneless, boneless; pork hocks	Chicken eaten in orient; pig feet – fresh, frozen, cured	Jelly, cow heel, foot jelly, pickled pig feet; boil, fry, sausage
Giblets-poultry	Heart, liver, gizzard, and sometime neck	Chicken - 3-4 oz Liver – 2 oz Heart - 0.5 oz Gizzard - 0.1	1 pound for four	Frozen, thaw in refrigera-tor; fresh, refrigerate use in 12 hr	Fry; simmer until tender
Haggis-calves, sheep	Hearts, lungs, livers			Cooked in a sheep's stomach	Combined with oatmeal, heavy seasoning
Heart- beef, veal, pork, lamb, chicken	Beef least tender	1 beef – 4 1 veal – ½ 1 pork – ½ 1 lamb –¼ 10-12 chicken –1	10-12 2-3 2-3 1 3-6 cap-on, aorta, pulmonary trunk, some fat removed	Frozen – thaw in refrigerator; fresh or refrigerated –use in 24 hr	Braise, cook in liquid, stews, fry, baked, broiled, braise, added to other meat; cavities filled with dressing and roasted; sausage, loaf patty
Intestine, large, small- pork, beef, veal, sheep					Sausage casing, pork large intestine – chitlings or chitterlings
Kidney- beef (loabed), veal (loabed), pork (single loabed), lamb (bean shape single loabed)	Veal, lamb and pork more tender and milder than beef; veal and lamb some-times cut with loin chops	1 beef - 1 1 veal - ¾ 1 pork - ¼ 1 lamb -1/8	4-6 3-4 1-2 0.5-1 Blood vessels, ureter, capsule, membrane removed	Refriger-ate use in 24 hr	Casseroles, stews, fry, pies, soup; wrapped in bacon and cooked on skewer, broil, fried, grill, cooked in liquid, braised, patty, loaf

By-Product	Charact-eristic	Average Wt., lb	Serving	Storage	Used in preparing
Liver- beef, veal, pork. Lamb, chicken	Veal, lamb, pork are more tender than beef, veal and lamb milder than pork or beef	1 beef - 10 1 veal -2.5 1 pork - 3 1 lamb - 1 3 chicken-1	¾ - 1 lb for 4 Gall bladder, skirt, arteries, veins, capsule fibrosa are removed	Frozen – thaw in refriger-ator; Fresh, refrigerate, use in 24 hr. Grind for loafs and patties.	Thin sliced braised, broiled, fry, grill, stewed, cook in liquid, fried, soups, loaves, spreads, liver sausages, patty, pate, haggis
Lung- pork, lamb					Europe – blood preparation, haggis, pet food
Meat extract	Meat, bones extracted with boiling water or meat to be canned				Extracted product is condensed
Omentum- pork					Covering for processed meat, pie, pate
Oxtail- beef	Large percentage bone, disjointed, fine meat flavor		1 lb for two	Frozen, thaw in refrigerator; fresh, refrigerate use in 24 hr	Simmer two hours or until tender, soup, stew
Pork jowl	Pork jaw				Often cured like bacon
Processed by-product: souse, pickled pork, headcheese, brawn, scrapple	High collagen meat such as whole pigs head including tongue, trotters, snouts, ears, skin			Some-times stuffed into casings and cold smoked, very perishable	Boil and simmer until tender, season, remove the meat, cool to jell
Skin trimmings, skeens- pork, beef				Pork rinds can be stored for 6 months at room temp.	Rind emulsion for sausage, gelatin, jellied food, pork rinds; extract collagen for extrusion into casings

By-Product	Charact-eristic	Average Wt., lb	Serving	Storage	Used in preparing
Skirt, thick-pork, beef					Stew, sausage ingredients
Spleen-pork, lamb					Blood sausage, pie; fry, flavoring, melt, variety meat
Stock, soup-Beef, veal, lamb, pork	Bones, meat scraps			Refriger-ate or frozen	Roasted with vegetables, simmered, strained, cooled. Used in dishes, soups sauces, gravies
Stomach-pork					Sausage ingredient; sausage container, precook in water, braise, fry, boil
Sweet-breads-beef, veal, lamb	From the heart and throat (thymus)–fat rich, only in young animals, gut (pancreas) bread	Veal, neck and heart pair -1 Beef, neck only – 1/8 Beef heart-bread– 0.15 Beef Gut bread - 3/8 Lamb–2 oz. Lamb gut–3/16 Pig gut–3/16	¾ - 1 lb for four	Frozen, thaw in hot water; fresh, refriger-ate, use in 24 hr	Tender and delicate flavor; membrane, lymph nodes, vessels removed; breaded deep fat fry, coated with butter broil, braise, cook in liquid, stew, poach, scrambled with eggs, cream, variety meat
Tail- lamb				Clean and freeze till needed	Bread and fry
Tail- pork		1.5	4 per serving	Some-times cured and smoked	Hotchpot; barbecued, salt and boil, used with sauerkraut, mustard greens beans
Testicles-lamb, Rocky Mountain oysters, lamb fries; other species are also used			1 per serving		Boil until tender, simmer; bread and fry, grill
Tongue-beef, veal, pork, lamb	Fat rich, types; square cut, short cut, Swiss cut, long cut	1 beef -3-4 1 veal -1-2 1 pork - ¾ 1 lamb - ½	12-16 3-6 2-4 2-3 Amount of trimming varies with type of cut	Fresh, refrigerate use in 24 hr; pickled, soak before cooking	Fresh - thin slice, long term moist heat, broil, stew, smoked, pickled, jellied, potted, canned, blood and liver tongue sausage

By-Product	Charact-eristic	Average Wt., lb	Serving	Storage	Used in preparing
Tripe- beef, sheep, pork stomach	Beef, honeycomb (preferred) plain, bible, hard to clean, not much used, calf – rennet	Beef, honey-comb -1.5, Plain - 7, Sheep -2.2	Plain ¾ - 1 for 4	Fresh, refrigerate use in 24 hr; pickled, soak before use, canned, heat and serve	Often pre-cooked but requires further cooking; sausage ingredient, lamb -container for haggis
Udder					Eaten in Europe; boil, salt, smoke, fry

Sources: Ockerman and Hansen 1988, 2000; Fornias, 1996; McLean and Campbell, 1952; National Livestock and Meat Board, 1974 a,b; Ockerman 1975, 1996.

Gelatin

Another edible by-product is gelatin. Gelatin and glue are both water soluble, hydrophilic, derived colloidal proteins (albuminoids) produced by controlled hydrolysis of water-insoluble collagen (white fibrous connective tissue). Gelatin and glue are physically and chemically similar but gelatin is made from fresh, federally (in the United States) inspected raw material which allows it to remain in the edible category. Since collagen is 30 percent of the body's total organic matter or 60 percent of the body protein, gelatin can be extracted from many raw materials (hides, pig skins, bones, and ossein). This pure protein from collagen, sometimes called isinglass, is used in ice cream, mayonnaise dressing, emulsion flavors, to clarify wine, beer, and vinegar, and is used to make capsules and coating for pills. Collagen (anhydride of gelatin) is constructed of tropocollagen monomers arranged in overlapping fibrils that are configured in three nonidentical, coiled peptide chains with molecular weight ranging from 40,000 to 100,000 (Etherington and Roberts, 1997). The number and type of covalent cross-bonds between chains are altered as the animal ages (more abundant in older animals) and this influences the properties of the extracted gelatin. The conversion of tropocollagen to gelatin requires breaking of hydrogen bonds, which destabilizes the triple-coil helix and converts it into a random coil configuration of gelatin, which is stabilized by the cross-links that remain and the amino terminal and carboxyl terminal groups that have been formed. Since the three original chains were not identical, it results in a single gelatin sample with several molecular weights. The alpha-chain contains one peptide chain, the beta-chain has two connected peptide chains, and the gamma chain is made up of three peptide chains. The distribution of the molecular weights determines the functionality of the gelatin. Larger concentrations of low molecular weight molecules will lower viscosity and gel strengths. This condition is usually caused by high temperatures, high acidic or alkaline conditions, type of raw material, or liming time. Nutritionally, gelatin is a long chain of both acidic and basic amino acids connected by peptide bonds. It is high in glycine and lysine but low in tryptophan and methionine. This makes it a non-complete protein since it does not supply the daily requirement of "essential" (amino acids that cannot be synthesized by the body) amino acids. However, in a "normal diet" with other proteins, it can be quite nutritionally useful. Gelatin has a high content of the amino acids proline and hydroxyproline and the quantities of amino acids are often used as an index of the quantity of gelatin in a protein mix.

The extraction of gelatin is performed in four stages:

1. Selection of appropriate raw materials (can influence gelatin characteristics).
2. Removal of non-collagenous compounds from the raw material with as little change in collagen as possible.
3. Controlled hydrolysis of collagen to gelatin.
4. The recovery and drying of gelatin.

There are also three processes to obtain gelatin from collagen and also various combinations of these procedures.

1. <u>Alkaline procedure (type B gelatin):</u> The most common procedure consists of washing, followed by saturated calcium hydroxide (liming period) which causes the non-collagen material to become more soluble and can be removed by later washing. Liming also causes hydrolytic reactions with limited solubilization. Next, the pH is lowered and the lime is washed with cold water and removed from the stock. This is followed by washing with dilute acid and a final wash with sulfate. The stock is then placed in extraction kettles and extraction takes place in a series of cooks. The liquid extract is pressure filtered followed by evaporation.
2. <u>Acid procedure (type A gelatin):</u> This procedure is often used with pigskins and bones. The raw material is first washed and fat is often pre-extracted (with heat or non-polar chemicals). The raw material is then soaked in inorganic acids, followed by a wash to raise the pH. Next the collagen is given an alkaline treatment. It is then filtered and dried. The product is then subjected to a series of cooks and quickly dried. The acid and alkaline procedures produce two different classes of gelatin and the products produced are not interchangeable.
3. <u>Other Methods:</u> Other methods such as high-pressure steam extraction or enzymatic methods continue to evolve and have succeeded in demineralizing collagen from ossein with improved predictability of quality and yield (Rowlands and Burrows, 1998).

Gelatin is used at fairly low levels (one to 2.5 percent) in gelatin desserts. More details on gelatin extraction, amino acid content, potential raw materials, yield, flow charts, and preservatives can be found in Chapter 5 of the book *Animal By-product Processing and Utilization* (Ockerman and Hansen, 2000).

Edible Tissue from Bone

Bones have long been used to make soup and gelatin. As labor becomes more expensive and as the animal processing industry has attempted to salvage more of adhering meat from bones, new separating techniques have been developed. Specialty items have been developed that utilize non-whole muscle meat products and extracted tissue. In the poultry industry, the trend from marketing whole birds to parts left a number of parts difficult to merchandise and spent layers were also a source of available material. In the beef industry, carcasses are further cut up into boxed beef (wholesale cuts), which concentrates large quantities of bones in a few locations. Central processing makes mechanically de-boning more practical. This process can return major quantities of edible tissue back into the marketplace.

The terms mechanically separated meat and mechanically separated poultry are used in the United States the term mechanically recovered meat is sometimes used in Europe. Minced fish is used for mechanically de-boned fish. Large quantities of mechanically de-boned poultry are currently being used in the United States with smaller quantities of mechanically de-boned red meat utilized. Excellent early reviews by Field (1981, 1988) and Froning (1981) can add considerable insight to this process. History, U.S. regulations, yields, composition, nutrients, protein efficiency ratio, flow charts, and equipment are reported by Ockerman and Hansen (2000).

In general, the bones and tissue are finely ground and the soft tissue is forced through small (0.5 mm) orifices. The resulting structure of the pressed material is finely ground and paste-like in which the myofibrils are heavily fragmented. Post-pressed treatments range from no treatment to washed and dewatered, high temperature, centrifugation, and use of emulsion additives. Selection of the size of the orifices and the amount of pressure applied can affect the yield, the amount of bone marrow, and the size and amount of bone powder in the finished product.

Microbiological quality is determined by quality of raw bones, which is determined by sanitary handling, low temperatures and limited storage, and ratio of external tissue to internal tissue. Temperature rise during de-boning and fine grinding also contributes to an ideal environment for bacterial growth. Rapid lowering of temperature and controlling time after de-boning is also critical. Rancidity can also cause problems in this tissue since bone marrow has more unsaturated fat. Temperature is higher with mechanical de-boning and mixing, so there is more incorporation of air and heme pigments than with hand de-boning. This causes oxidation, and even though it is reduced at low temperature, it can still continue even in frozen de-boned meat.

The additional bright red color is considered a plus for some processed meat items but is a negative if a pale product is desired. Other properties such as emulsifying capacity, water holding capacity, and emulsion stability are comparable to a hand de-boned product.

The addition of bone marrow causes a rise in pH, which aids water holding capacity and emulsion formation. Negatives include elevated calcium (however, the

U.S. diet is usually low in calcium) and magnesium. Uses for this separated product include sausage-type products, stews, sauces, spreads, and even in chunked and formed products. Also, the favorable price compared to hand de-boned tissue makes this a favorite for least-cost products. Other extraction methods include liquid extraction and cold alkaline extraction. Flavor extraction material is obtained by heating in liquid acid or with centrifugal cooking.

Medical and pharmaceutical uses of by-products are other uses for the non-carcass portion of the animal that are directly utilized by humans. These include animal glands, arteries, bezoars, bile, blood, bone, brain, duodenum, eggshell powder, feather, gall bladder, glycosaminoglycans, hair, heart, horns, intestines, liver, lungs, nervous systems, ovaries, oyster shell, pancreas, serum, skin, spinal cord, spleen, stomach, etc. Miniature pigs are also used in medical research since many of their systems are similar to humans. These medical and pharmaceutical uses are discussed in detail in Chapter 7 of *Animal By-product Processing and Utilization* (Ockerman and Hansen, 2000).

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RENDERED PRODUCTS IN RUMINANT NUTRITION

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Summary

The recycling of rendered animal products back into the feed of ruminant livestock species has had a positive impact both on the efficiency of livestock production and the availability of meat and milk for consumers at an affordable price. Rendered animal products are distinguished by a high protein content containing amino acids that resist microbial degradation in the rumen, and for extracted animal fats that supply high energy for meat and milk production.

Historically, the primary rendered animal products used as protein supplements include meat and bone meal, blood meal, fish meal, and feather meal. Regulations by the U.S. Food and Drug Administration (FDA) in response to concerns about bovine spongiform encephalopathy (BSE) will dictate the continued use of some rendered animal products as feed ingredients for ruminant diets. Current restrictions prohibit feeding meat and bone meal from rendered ruminant species back to cattle and sheep, but no restrictions have yet been placed on blood meal or feather meal. Concerns about cattle-based protein supplements have elevated interest in rendered poultry meals, including feather meal and poultry meat by-products for cattle rations.

Rendered animal products with high fat content include tallow and greases. With the majority of lipid material in rendered fats consisting of triglycerides containing 90 percent fatty acid content or higher, energy densities of rendered fats equals or exceeds the energy content of most fat supplements used routinely in cattle rations. The high energy density combined with reasonable pricing makes rendered fats competitive with most other feed fats on a cost per unit of energy basis. The major limitations of fats extracted from animal products include their need for specialized transport and mixing equipment, and their potential to disrupt microbial fermentation in the rumen possibly leading to reduced feed digestibility.

Protein Contributions of Rendered Animal Products

Regulatory Concerns

Rendered animal products have contributed immensely to meeting the protein needs of ruminant livestock species for many decades without health concerns to the animal or to human consumers. The heat treatment applied to rendered animal products to remove moisture was sufficient to kill bacterial and viral infectious agents. The advent of concerns about BSE, commonly referred to as “mad cow disease,” that first occurred in Europe, led to an FDA ban in the United States in 1997 that prevented feeding cattle and sheep any meat and bone meal product rendered from ruminant species. The first case of BSE appeared in the

United States in 2003 (imported from Canada) and a third case was reported in 2006. Concerns remain elevated about the cause and prevention of the disease, which is usually attributed to a prion rather than a bacteria or virus. Prions are pieces of normal cell proteins that can replicate to a disease form, but withstand usual inactivation treatments such as pH extremes, radiation, or formalin exposure.

Clearly, continued use of rendered animal products as protein supplements for cattle and sheep diets hinges on current and future FDA regulations. Although ruminant meat and bone meal was affected by the FDA ban, blood meal, and feather meal were not affected. Also, it is still permissible to feed cattle meat and bone meal originating from pork or poultry products. As a result, interest has grown in feeding more rendered poultry products to cattle, as will be discussed later. Additional FDA restrictions will determine the extent and types of rendered animal products available as protein supplements for cattle and sheep rations. Readers can obtain more information about the impact of FDA regulations on using rendered animal products as livestock feed ingredients at the National Renderers Association Web site (www.renderers.org).

Protein and Amino Acid Composition

Rendered animal products are distinguished by a high protein content containing amino acids that resist microbial degradation in the rumen (Figure 1). The portion of feed protein that escapes microbial breakdown is referred to as rumen undegradable protein (RUP). The RUP fraction carries intact feed amino acids directly to the small intestines of the ruminant animal where they are digested and absorbed. The RUP fraction may favor high meat and milk production if it contains proper proportions of essential amino acids needed for protein synthesis in body tissues. A high RUP fraction may be detrimental if it contains amino acids not needed by body tissues, or its constituent amino acids are not digested well in the small intestines.

The rumen degradable protein (RDP) fraction in feed is subjected to proteolysis by ruminal microorganisms yielding amino acids and peptides. Amino acids are subsequently degraded to ammonia plus organic acids. The ammonia has three possible outcomes: (1) absorption across the ruminal epithelium into blood, (2) passage to the small intestine, and (3) utilization by ruminal microorganisms to synthesize microbial protein which in turn passes to the small intestine for digestion and absorption. Ammonia reaching the blood may be excreted from the animal's body in urine where it has no further opportunity to meet the animal's protein needs.

Although more than 100 rendered animal products are defined by the Association of American Feed Control Officials (AAFCO), the major products used as protein supplements for livestock rations include meat and bone meal, meat meal, poultry and poultry by-product meal, blood meal, feather meal, and fish meal. Those of greatest importance for ruminant diets are shown in Table 1 along with their total protein and RUP contents. Protein contents range from 54 percent for meat and bone meal to 96 percent for blood meal. The majority of protein in rendered products is RUP, which ranges from 55 percent of crude protein (CP) for meat meal to 78 percent of CP for blood meal.

Figure 1. Rumen Nitrogen Metabolism—RUP that Passes Directly to the Small Intestines versus RDP that Either is Converted to Microbial Protein or is Excreted in Urine.

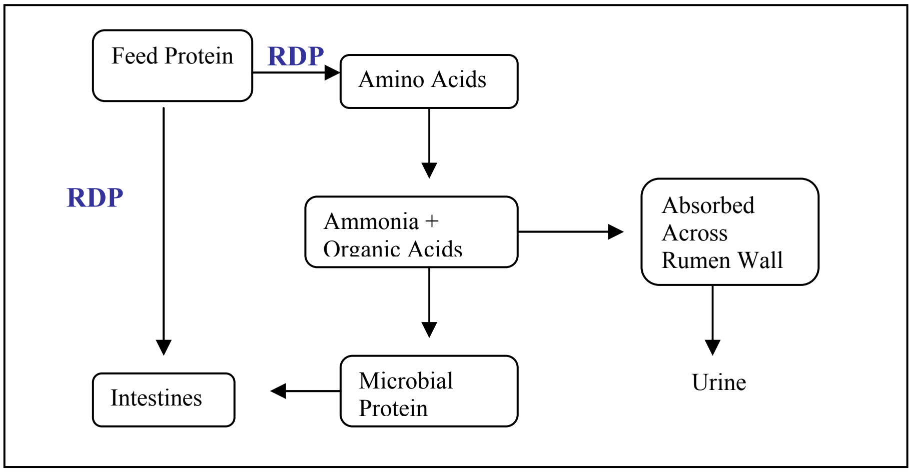


Table 1. Total CP Contents and RUP Fractions of Major Rendered Animal Products Used as Feed Ingredients for Beef and Dairy Feeds.

	CP, as % dry matter		RUP, % CP	
	Beef[a]	Dairy[b]	Beef	Dairy
Blood Meal	93.8	95.5	75.0	77.5
Feather Meal	85.8	92.0	70.0	65.4
Fish Meal[c]	67.9	68.5	60.0	65.8
Meat and Bone Meal		54.2		58.2
Meat Meal	58.2		55.0	

[a] From NRC requirements for Beef Cattle, 1996.
[b] From NRC requirements for Dairy Cattle, 2001. Example RUP data were based on feed intake of 4% body weight and 50% forage.
[c] Menhaden fish as reported in NRC for Dairy Cattle, 2001.

The high RUP concentration is due to heat treatment of the rendered products to remove moisture and facilitate fat extraction. Heating denatures proteins and lowers their water solubility, which substantially reduces their rate of microbial proteolysis. At any given rate of feed particle passage through the rumen, slower proteolytic rates translate into greater escape of feed protein from microbial breakdown. A recent study showed that the RUP value of rendered animal products remains high across a wide range of feeding rates (Legleiter et al., 2005).

Aside from high total crude protein and RUP contents, equally important to the high nutritional value of rendered animal products is the amino acid profile (Table 2). Blood, feather, and fish meals all contained at least five essential amino acids in higher concentrations than are found in soybean meal. Also, the amino acids in these rendered animal products were 58 to 78 percent RUP compared to only 43 percent RUP in soybean meal.

Table 2. Essential Amino Acid Profile (Percent CP) of Major Dried and Ground Meals from Rendered Animal Products Used as Feed Ingredients for Beef and Dairy Feeds versus the Amino Acid Profile of Soybean Meal.[a]

Amino Acid	Blood	Feather	Fish	MBM	Soybean
Arg	4.38	6.93	5.82	6.98	7.32
His	**6.36**[b]	1.15	**2.83**	1.89	2.77
Ile	1.26	**4.85**	4.09	2.76	4.56
Leu	**12.82**	**8.51**	7.22	6.13	7.81
Lys	**8.98**	2.57	**7.65**	5.18	6.29
Met	1.17	0.75	**2.81**	1.40	1.44
Cys	1.28	**5.09**	0.91	1.01	1.50
Phe	**6.85**	4.93	3.99	3.36	5.26
Thr	**4.34**	**4.73**	**4.20**	3.27	3.96
Try	**1.59**	0.73	1.05	0.58	1.26
Val	**8.68**	**7.52**	**4.82**	4.20	4.64

[a] From NRC for Dairy Cattle, 2001.

[b] Amino acid concentrations shown in bold were higher for rendered animal products than for soybean meal.

New Information on Poultry Meals for Ruminant Diets

With the current FDA ban on feeding meat and bone meal (rendered from ruminants) back to cattle and sheep, and the uncertainty surrounding future FDA restrictions on rendered animal products, interest has grown in the nutritional benefits of poultry products in ruminant feeds. One recent effort was a re-evaluation of the nutritional value of feather meal as a feed ingredient for cattle rations (Cotanch et al., 2006). Representative samples of feather meal were taken each day for five days from 15 plants that covered approximately 85 percent of total U.S. feather meal production. Processing information was recorded including heating conditions (time, temperature, and pressure), percentage blood added, and batch versus continuous flow processing.

Among the 15 plants that provided samples for the Cotanch et al. (2006) article, six produced feather meal without blood, and the remaining nine produced feather meal with added blood. Nutrient content of feather meal was consistent among plants within a feather meal category, i.e., the product produced without blood was consistent from plant-to-plant and the product with blood also was consistent in composition from plant-to-plant. The addition of blood, however, influenced nutrient composition of the final product (Table 3). Blood addition to feather meal had no effect on total protein or fat contents, but ash content was higher and the acid detergent insoluble crude protein (ADICP) was lower for product with added blood. The ADICP, or protein bound in the acid detergent fiber fraction, is an estimate of the indigestible protein fraction. Thus, the addition of blood to feather meal increases total tract digestibility of protein. Blood addition had an effect on essential amino acids, but not on individual fatty acids. Methionine and lysine, generally regarded as the most limiting amino acids for meat and milk production, were both higher in the feather meal product containing added blood.

Table 3. Nutrient Composition of Feather Meal with and without Added Blood. [a]

	Feather meal		
	No Blood	**Added Blood**	**SEM** [b]
Dry Matter, %	93.3	93.5	0.9
Crude Protein, %	87.8	87.8	1.1
Ether Extract, %	10.0	9.5	0.9
Total Fatty Acids, %	7.3	6.8	0.7
Ash, %	1.9	2.6	0.2*
NDICP, %CP	49.9	51.2	4.0
ADICP, %CP	26.5	18.9	2.7*
Amino Acids, % of total amino acids			
Arg	6.88	6.73	0.03*
His	0.74	1.28	0.07*
Ile	4.80	4.79	0.03
Leu	8.21	8.54	0.06*
Lys	2.12	2.90	0.11*
Met	0.70	0.77	0.03*
Cys	5.47	5.15	0.33
Phe	4.91	5.10	0.04*
Thr	4.58	4.60	0.03
Try	0.57	0.66	0.04*
Val	7.54	7.56	0.07
Major Fatty Acids, % of total fatty acids			
C14	1.09	1.06	0.05
C16	24.3	25.4	0.3*
C18	8.3	8.9	0.4
C18:1	32.5	32.0	0.6
C18:2	13.2	10.4	0.6
C18:3	0.54	0.34	0.05

* Effect of blood addition ($P < 0.05$)

[a] From Cotanch et al. (2006).

[b] SEM is standard error of measurement.

Another recent effort to utilize rendered poultry nutrients more efficiently for ruminant diets was the development of a new process to reclaim nutrients from the process water of poultry processing plants. The process water from poultry processing plants contains considerable organic nutrients that must be captured, stored, treated, and disposed of in a manner that prevents environmental contamination. As an alternative, nutrients in the process water could be recycled as a feed supplement for ruminants. Because poultry process water has a high fat content containing unsaturated fatty acids, there is concern that it could inhibit ruminal fermentation, causing reduced feed digestibility. A novel process has recently been developed by Simmons Foods, Inc. (Siloam Springs, AR) to reclaim nutrients from the process water by reacting organic matter to yield a dry, free-flowing product called PRO*CAL, which possibly may reduce or eliminate negative effects on fermentation. The final product contains about 47 percent crude protein that is consistently more than 70 percent RUP. Animal studies showed that PRO*CAL could be fed to lactating dairy cows as a poultry-based source of bypass protein and fat without negative effects on feed intake or milk production (Freeman et al., 2005). Also, PRO*CAL had the added advantage over other bypass protein supplements of enhancing milk yield, presumably due to its higher fat and energy values. Additional studies done in continuous cultures of mixed ruminal microorganisms showed that PRO*CAL did not disrupt ruminal fermentation and had lower biohydrogenation of unsaturated fatty acids when compared to an equal amount of soybean oil (Jenkins and Sniffen, 2004). Thus, unlike poultry fats having a higher concentration of unsaturated fatty acids, the PRO*CAL product could be used as a dairy feed supplement without significant negative effects on ruminal fermentation.

Table 4. Uses and Reported Benefits of Additional Fat in Ruminant Rations.

Fat Use	Benefits
Increase diet energy density	Increase meat and milk production
Reduce metabolic heat loss	Elevate feed intake and production in hot, humid climates
Reduce dustiness and particle separation of mixed feeds	Improve feed handling and safety
Alter fatty acid profile of meat and milk	Conform to published nutritional guidelines for humans and enhance consumption of animal food products
Enhance tissue delivery of unsaturated fatty acids	Enhance metabolic and physiological functioning such as improved reproductive performance and immunity

Fat Contributions of Rendered Animal Products

Fat products from animal rendering continue to be used extensively as feed ingredients for a variety of livestock species, including ruminants. Table 4 lists a multitude of investigated uses and benefits of adding fat to cattle and sheep rations.

The core reason for adding fat to ruminant diets has been energy. Over the last 25 years, dairy has received more attention in feeding fat than beef due to higher pressures for maintaining adequate fiber intakes. Increasing energy by replacing forages with cereal grains reached an upper limit in many dairy operations, as low-fiber intakes were associated with increased incidence of several digestive and metabolic diseases. Adding fat to the ration provided an alternative means of increasing diet energy density without appreciably lowering fiber content. Fats are generally chosen for inclusion in cattle diets based on their cost, availability, handling characteristics, and animal performance. Animal performance issues include how the fat source affects feed intake, influence of the fat source on digestion in the rumen, and how the fat supplement itself is digested and absorbed in the intestines of the animal.

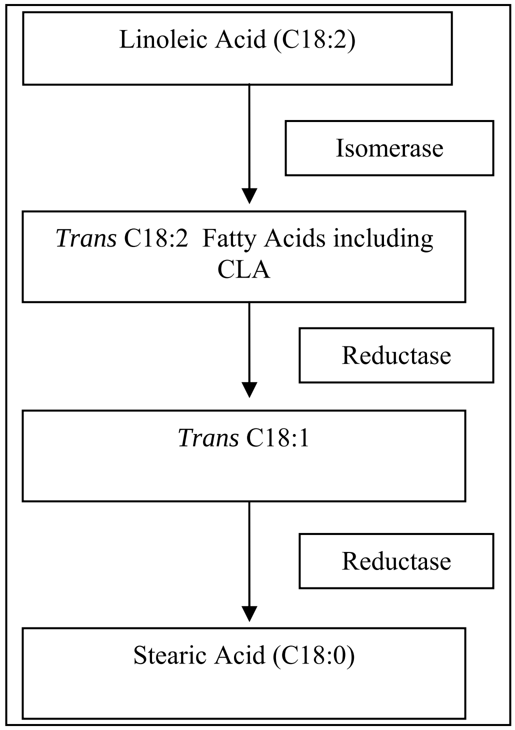
Figure 2. Reported Reproductive Benefits of Feeding Additional Fat to Dairy Cows During Established Lactation (Petit, 2003).

- Increase diameter of the corpus luteum
- Increase progesterone concentration
- Increase synthesis of series 3 prostaglandins from DHA and EPA
- Inhibit cyclooxygenase activity and $PGF_{2\alpha}$ synthesis – prevent regression of corpus luteum and increase fertility rates

As the production virtues of fat supplements in dairy and beef rations were being explored, questions arose about the usefulness of fat to help alleviate heat stress. Metabolism studies in many animal species confirmed that fat yielded lower metabolic heat losses compared to carbohydrate or protein on an equal calorie basis. Thus, it was an attractive idea to replace carbohydrate with fat as a means to elevate energy intakes in hot climates without any additional metabolic heat load. However, because fat levels were limited to relatively low concentrations in the diet, the metabolic heat savings was minimal. Until higher levels of fat are fed to cattle, little merit can be given to its contribution to alleviation of heat stress.

In the last 10 years, more attention has been directed at uses of fat supplements in cattle rations that were not associated with its energy value. These noncaloric functions were focused on increasing the delivery of unsaturated fatty acids to body tissues either to alter the nutritional value of meat and milk, or to meet tissue demands for essential fatty acids. For instance, positive responses in reproductive performance in cattle were reported at several locations when rumen-protected polyunsaturated fatty acids were added to the diet (Figure 2). Fat supplements that compete for these noncaloric functions, such as improved reproductive performance, must satisfy two criteria: (1) they must contain an appreciable quantity of the desired polyunsaturated fatty acid, and (2) the polyunsaturated fatty acids must resist destruction by ruminal microorganisms which occur via the process of biohydrogenation. Biohydrogenation causes rapid and extensive loss of double bonds in dietary unsaturated fatty acids (Figure 3) through an enzymatic reduction process that is carried out by microorganisms in the stomach of cattle, mainly in the rumen compartment.

Figure 3. Major Steps in Biohydrogenation of Linoleic Acid by Ruminal Microorganisms.



Energetic Benefits and Limitations of Rendered Fats for Cattle Rations

With the majority of lipid material in rendered fats consisting of triglycerides containing 90 percent fatty acid content or higher, energy densities of rendered fats equals or exceeds the energy content of most fat supplements used routinely in cattle rations. The high energy density combined with reasonable pricing makes rendered fats competitive with most other feed fats on a cost per unit of energy basis. Further consideration of rendered fats as supplements for ruminant diets are largely based on their convenience and animal performance characteristics. Convenience issues include availability of the product in some geographical locations, but mostly center on the need for specialized equipment for transporting and mixing semi-solid or liquid oils at farm locations. Many competing commercial fat sources have higher cost, but process the fat into a dry, free-flowing powder for easier transport and on-farm mixing.

Energy value of the fat supplement only partially explains reported variation in animal performance. Production is only improved if the added fat increases digestible energy (DE) concentration of the whole diet. All fat sources are grouped together in National Research Council (NRC) recommendations for beef cattle (1996) with an assigned DE value of 7.30 Mcal/kg (Table 5). The NRC recommendations for dairy cattle (2001) divided fat sources into five categories that range in DE value from 7.70 Mcal/kg for vegetable oils to 4.05 Mcal/kg for partially hydrogenated tallow.

Table 5. The Total Digestible Nutrient (TDN) and Digestible Energy (DE) Values for Fats Reported by NRC for Beef and Dairy Cattle.

	TDN, Percent	DE, Mcal/kg
NRC for Beef (1996)	177	7.30
NRC for Dairy (2001)		
Calcium soaps	163.5	6.83
Hydrolyzed tallow	176.3	7.37
Partially hydrogenated tallow	96.6	4.05
Tallow	147.4	6.17
Vegetable oil	184.0	7.70

More important than the fat DE value is the increase in total ration DE resulting from the addition of a fat source. Fat supplements may fail to elevate total ration DE if the fat reduces feed intake, reduces carbohydrate digestibility, or if their constituent fatty acids are poorly digested. The extent of these potential limitations will be discussed briefly for rendered fats.

Animal Fat Effects on Feed Intake

Fat added to dairy rations can reduce feed intake, which can greatly reduce or even eliminate a positive production response. Even as little as 0.5 kg less feed intake can neutralize any energy advantage coming from typical levels of added fat, thus preventing a positive milk production response. Reductions in feed intake have been reported for a wide variety of fat sources, and often the intake depressions are less severe for rendered fats than for vegetable oils or some commercial fat supplements. Across a summary of more than 20 dairy studies feeding tallow or grease, only two studies showed significant depressions in feed intake (Allen, 2000). A more recent summary of the literature by Onetti and Grummer (2004) showed that the intake effects of tallow were dependent on forage source. Tallow added to corn silage diets reduced intake and failed to increase milk production. However, a positive milk production response was seen when tallow was fed in alfalfa-based diets, or in diets with similar alfalfa and corn silage proportions.

Several causes for the depression in feed intake by added fat are under consideration. These include reduced gut motility, reduced acceptability of diets with added fat, release of gut hormones, and oxidation of fat in the liver (Allen, 2000). Refer to Allen (2000) for a description of each factor and a comparison of fat sources. Gut hormones continue to receive considerable attention as regulators of food intake. Depressed feed intake in cows fed fat supplements has been attributed to changes in cholecystokinen (Choi and Palmquist, 1996) and glucagon-like peptide 1 (Benson and Reynolds, 2001). Other peptides of gut origin, such as peptide YY, pancreatic glucagons, glicentin, and oxyntomodulin, have been linked to reduced feed intake patterns in animals fed fat (Holst, 2000). Past work has shown that abomasal infusion of unsaturated fatty acids causes greater feed intake depression than infusion of saturated fatty acids (Drackley et al., 1992; Bremmer et al., 1998). A recent study by Litherland et al. (2005) showed that the intake depression was greater following abomasal infusion of unsaturated free fatty acids than it was following infusion of unsaturated triglycerides. Also, as intake declined in the study by Litherland et al. (2005), the concentration of plasma glucagon-like peptide 1 increased but plasma concentration of cholecystokinen did not change.

Animal Fat Effects on Ruminal Fermentation and Digestion

Fat supplements must be limited to just a few percent in ruminant diets to avoid ruminal digestibility problems resulting from antimicrobial activity of their constituent fatty acids. Fat sources that have the potential to cause ruminal fermentation problems are referred to as rumen-active fats. Antibacterial effects of fatty acids in the rumen are complex and depend on interrelationships among fatty acid structure, fatty acid concentration, the presence of feed particles, and rumen pH (Jenkins, 2002). Fatty acid structural features that enhance antibacterial activity in the rumen include a free acid group on the carbon chain and the presence of one or more double bonds. Therefore, enhancing free fatty acids and fatty acid unsaturation in rendered fat sources generally reduces the amount that can be included in cattle diets. Several commercial fats minimize ruminal fermentation problems by enhancing the concentration of the less antibacterial saturated fatty acids. These are referred to as rumen-inert fats to signify their lower antimicrobial effects in the rumen.

Unsaturated fatty acids typically range from a low of about 48 percent in beef tallow to as much as 70 percent of total fatty acids in poultry fat (Table 6). Lard and pork greases are intermediate in percentage of total unsaturated fatty acids. Oleic acid concentration is similar across animal fat sources, meaning that most of the variation in percentage of unsaturated fatty acids is due to variation in polyunsaturated fatty acids (linoleic and linolenic acids).

Table 6. Fatty Acid Composition of Rendered Animal Fats in Order of Increasing Unsaturation **(Rouse, 2003).**

Fatty Acid	Beef Tallow	Lard	Pork Grease	Poultry Fat
Myristic	3.0	1.5	1.5	1.5
Palmitic	25.0	27.0	23.0	21.0
Palmitoleic	2.5	3.0	3.5	6.5
Stearic	21.5	13.5	11	8.0
Oleic	42.0	43.4	40.0	43.0
Linoleic	3.0	10.5	18.0	19.0
Linolenic		0.5	1.0	1.5
Saturated	49.5	42.0	35.5	30.0
Unsaturated	47.5	57.4	62.5	70.0

A simple equation to estimate the upper limit of rumen-active fat in dairy cattle rations was suggested by Jenkins and Chandler (1998) as Equation 1:

Rumen-Active Fat (percent of ration DM) = 4 x NDF/UFA
Where,
NDF = neutral detergent fiber concentration of total mixed ration
UFA = sum of oleic, linoleic, and linolenic acids in supplemental fat

Table 7. Maximum Amounts of Rendered Animal Fats for Inclusion in Dairy Rations Estimated from Equation 1.

	Beef Tallow	Lard	Pork Grease	Poultry Fat
UFA	45.0	54.4	59.0	63.5
Percent Fat[a]				
NDF=25	2.22	1.84	1.69	1.57
NDF=35	2.93	2.43	2.24	2.08
g Fat/day[b]				
NDF = 25	660	552	507	471
NDF = 35	879	729	672	624

[a] Percent Added fat in ration DM covering the range of NDF concentrations for dairy rations recommended by NRC (2001).
[b] Grams of added fat per day covering the range of NDF concentrations for dairy rations recommended by NRC (2001), assuming DM intake = 30 kg/day.

According to Equation 1, higher concentrations of rendered fats can be fed to dairy cattle by increasing either fat saturation or diet fiber concentration. For instance, recommended levels of rendered fats for dairy cattle consuming diets with 25 percent NDF vary from 2.22 percent for tallow down to 1.57 percent for the more unsaturated poultry fat (Table 7). Increasing diet NDF concentration from 25 to 35 percent increases recommended feeding levels of all rendered fat sources, but increases it the most for the more saturated beef tallow. Because feeding rates of saturated fats are higher in cattle rations, several rumen-inert fat sources have been developed from partial hydrogenation of animal fats to reduce unsaturation and improve handling.

Intestinal Digestibility of Rendered Animal Fats

Low intestinal digestibility of fatty acids in fat supplements can be another factor reducing their DE value for ruminant diets. Differences in DE values among fat sources published in NRC recommendations for dairy cattle (2001) are due mainly to differences in their true digestibilities. True digestibilities assumed by the NRC ranged from a high of 86 percent for vegetable oils and calcium salts to a low of 43 percent for partially-hydrogenated tallow. Tallow was assigned an intermediate digestibility of 68 percent by the NRC.

It was not surprising, based on results from previous studies, that feeding partially hydrogenated tallow reduced fatty acid digestibility. Hydrogenation of yellow grease to reduce its iodine value (IV) from 56 to 18 reduced apparent fatty acid digestibility in the total tract from 67.8 to 47.4 percent (Jenkins and Jenny, 1989). Fatty acid digestibilities pooled from 11 studies were normal (similar to control values) when IV exceeded 40, (Firkins and Eastridge, 1994), but below IV 40 fatty acid digestibility progressively dropped as IV declined.

Lower digestibility of hydrogenated fats may be related to their higher content of saturated fatty acids. The presence of one, two, or three double bonds increased fatty acid digestibility a similar amount. Grummer and Rabelo (1998) also reported similar improvements in apparent fatty acid digestibility from the presence of one or more double bonds. True digestibility of stearic acid was 53 percent and lowest among the 18 carbon fatty acids. Introducing a single double bond improved true digestibility to 78.4 percent. It should be pointed out that some studies did not distinguish between flows of *cis* or *trans* 18:1 to the duodenum. Lower 18:1 digestibilities may result from *trans* 18:1 flows.

Because of the lower true digestibility coefficient and energy value of tallow reported in NRC recommendations for dairy cattle (2001), the Fats and Proteins Research Foundation commissioned an independent review of the literature to examine digestibility of tallow versus other fat supplements for dairy cattle[1]. The final report revealed several discrepancies in the literature. First, several studies reported feeding tallow to dairy cows in digestibility trials, but the reported fatty acid compositions suggested that greases were the more likely fat source. Second, some studies reported examining the digestibility of tallow when in fact a mixture of fat sources was included in the diet.

The final report summarized fatty acid digestibilities from studies that included data only on lactating dairy cows fed a control diet with no high fat ingredients, and fat sources that were not combined with other fats. A total of 32 published studies met all criteria and 45 studies were rejected. The selective criteria limited the number of observations for some fat sources, especially oilseeds and vegetable oils that were usually fed in combination with other fat sources.

Among the fat sources examined, only tallow and calcium salts of palm fatty acids had mean total tract digestibilities that were numerically higher than the control diets (Table 8). The ranking was similar when digestibilities of the fat sources were estimated by difference. Conversely, the hydrogenated fat sources had substantially lower fatty acid digestibilities whether expressed as apparent digestibilities or were calculated by difference. The hydrogenated fat sources also had the highest standard deviations suggesting that wider variation exists in digestibility values of hydrogenated fats compared to other fat sources. Further examination of the data showed that about 80 percent of the hydrogenated fat cases depressed diet fatty acid digestibilities more than five percent. Tallow depressed diet fatty acid digestibilities more than five percent from control fatty acids in only 27 percent of the cases examined.

[1] An independent literature review and opinion of the digestibility of tallow compared to other fat sources was prepared for FPRF by Dr. Tom Jenkins.

Table 8. Fatty Acid Digestibilities of Control Diets or Diets with Added Fat Summarized from 32 Published Studies with Lactating Dairy Cattle.

		Apparent Digestibilities[a]		Fat Digestibilities by Difference[b]	
	n[c]	Mean	SD[d]	Mean	SD
Control	32	72.3	7.7		
Tallow	11	73.9	8.5	72.8	13.2
Hydrogenated Fat	24	62.8	9.0	53.7	17.4
Oilseeds	6	66.4	8.4	54.0	20.8
Vegetable Oils	9	63.5	7.2	61.6	9.4
Calcium Salts	15	74.3	8.9	80.1	12.1

[a] Fatty acids digested across the entire digestive tract as a percentage of fatty acids consumed.
[b] Fatty acids in the basal diet were subtracted from the feed and feces to estimate digestibility of only the added fat source.
[c] Number of studies = n.
[d] Standard deviation.

The Future for Rendered Animal Products as Feed Ingredients for Ruminants

There remains a growing need in both beef and dairy rations for products that can supply RUP containing the essential amino acids needed for growth and milk production. Rendered animal products were positioned well in the past to meet critical amino acid needs with a consistent and affordable product. Regulatory issues surrounding BSE have suddenly emerged in recent years and cast doubt on their future. Undoubtedly, the use of rendered products from ruminant species being fed back to cattle and sheep will be limited. Perhaps interest will grow in utilizing rendered products from non-ruminant species, as is already occurring with poultry-based products.

Fat products derived from rendered animal products appear to be affected less by BSE-driven restrictions. However, tallow and greases from rendered animal products face an increasing competitive market of specialized animal fat sources. In ruminants, fats are looked upon more and more for supplying specific polyunsaturated fatty acids to tissues rather than just as energy sources. While the high energy value of rendered animal fats cannot be overlooked, innovative applications of animal fats for non-energy uses must emerge.

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RENDERED PRODUCTS IN POULTRY NUTRITION

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Summary

The poultry industry in the United States has a long history of using rendered products in its rations. Rendered fats are generally lower in cost than vegetable oils such as soybean oil, which is used substantially in other countries. This allows for higher inclusion rates of fat and thus higher energy diets. These higher energy diets provide faster growth and improved feed conversion, providing a competitive advantage to the U.S. poultry industry. Rendered protein sources are also a boon to the poultry industry. A variety of high quality products are available including meat and bone meal (MBM), poultry by-product meal (PBM), and feather meal (FeM). Each of these is an excellent source of specific nutrients and generally provides a cost-effective source of protein. MBM provides an excellent source of amino acids and phosphorus. PMB provides even higher levels of protein and energy as well as acting as an excellent source of phosphorus. FeM is very high in sulfur amino acids. Combined, these products can be used to provide a substantial cost savings to the poultry industry and use of the products is quite high by the industry. Use of these products is estimated to save the industry as much as $10 for each ton of feed produced in the United States. Strong utilization of these products by the poultry industry is the norm and is expected to continue into the future.

The Poultry Industry

The poultry industry in the United States and worldwide has seen major changes in the past 50 years. While consumption of poultry and poultry products has increased dramatically over this time period, the changes in industry structure are perhaps more dramatic. The industry has gone from a small-scale producer of products for specialty meals to a provider of a major source of animal protein consumed in the United States. Worldwide, there has also been an explosion of poultry production. In developed countries, poultry industries function similarly to the United States. In less developed countries, while smaller in scale, the U.S. model is a goal for their industry development. Chicken production and slaughter in the United States was 8.9 billion birds in 2004 (Watt poultry, 2004) and continues to rise. World slaughter of chickens is also at an all-time high at over 46 billion birds yearly. The evolution of the industry has resulted in advances in diet formulation as new products and technology have become available. As this evolution took place, formulations became more sophisticated, moving from hand to computer formulation, from a total protein basis to a digestible amino acid basis, and incorporating of a variety of micronutrient sources. All of this has led to reduced cost and maximum bird performance for the U.S. poultry industry. The availability of a variety of rendered by-products has been of great benefit to the modern poultry industry.

Use of Rendered Products in Poultry Feeds

There has been a long history of use of animal proteins and a variety of recycled fats in the poultry industry worldwide. Essentially all sources of proteins and fats have been and continue to be used in significant quantities in the United States with the primary issue being relative values compared to other protein sources such as soybean meal. Products currently being utilized include meat meals from ruminant origin, swine origin, and poultry origin as well as the blood products from each of these, fat products from each of these, and FeM. Additionally, there is now some limited production of whole hen meal used as a disposal method for spent laying hens. Each of these products has been used successfully at various levels in the rations of poultry of all types with the higher levels going into broilers and turkeys due to their higher relative protein needs in comparison with layers.

These products of animal origin provide nutrients needed by poultry at reasonable prices relative to competing products, and in fact, prices tend to fluctuate based on prices of competing products. There has also been some interest in replacement of a portion of the soybean meal in poultry rations with animal products to improve performance. The oligosaccharide portion of soybean meal has been shown to produce some detrimental effects to poultry. This is thought to be due to a substance in the undigested portion of the product that irritates the footpad. The addition of animal protein sources may improve performance over standard diets. While these results may be due to high levels of limiting amino acids, it may also be explained by the reduction of poorly digested carbohydrates in the soybean meal. Previous work in the lab has suggested that up to half of the protein source can be provided with mixed by-products if one formulates correctly. While each product has different nutrient contents and potential values, most are excellent sources of energy or high quality protein, highly available phosphorus, and other minerals.

The goal of this chapter is to provide the information needed to utilize these products in ration formulation, methodology for their use, and limitations on their use as well as the economics of their use. Additionally, a review of the pertinent literature will be provided if more in-depth information is needed. Ultimately with this information in hand, proper decisions about the use of these products can be made, and money saved.

Use of Rendered Fats

Use of fats for animal feed has many advantages. Some of the benefits of fat addition:

- Concentrated source of energy and the main method of increasing the energy content of diets
- Increased growth rates

- Increased feed efficiency
- Decreased feed intake
- Source of linoleic acid
- Decreased dustiness of feeds and reduced dust losses
- Lubricant for equipment in feed mills
- Increased palatability of feeds
- Increased rate of gain can decrease age at market and increased throughput of housing systems
- Lower heat increment during heat stress keeps caloric intake up
- May slow gut transit of other feeds, resulting in increased digestibility
- May show an "extra caloric" effect
- May be more cost effective than other energy sources
- Concentrated feeds can decrease transportation costs for feed delivery

Some concerns that should be noted with fat utilization:

- Use of higher levels of fat may negate the effects of pelleting
- Measurement of metabolizable energy (ME) content can be difficult
- Potential for rancidity
- Equipment needs relative to fat additions must be adequate
- Poor digestibility of saturated fats by the young bird

A number of different fat sources are available for poultry from the rendering industry. The primary sources are poultry fat, tallow, yellow grease, lard, and blends. In other countries, there is considerable use of vegetable fats such as sunflower oil, soybean oil, or palm oil. Generally, these fats are relatively expensive when compared to rendered products, resulting in lower fat utilization and thus lower ME diets than in the United States. One of the major concerns relative to fat usage is the actual ME value that should be assigned to each fat source. This number is often difficult to determine in a practical sense and may have little practical value in diet formulation. When analyzing energy content of fat, it is generally done indirectly, by substitution of a portion of the ration fed in the ME determination. Additionally, fat may have an extra caloric effect (Jensen et al., 1970; Horani and Sell, 1977), whereby it affects the nutrient availability of other ingredients. This was noted in the lab where it was found that fat additions resulted in digestibility of MBM being increased (Firman and Remus, 1994). This would explain why some ME values reported are greater than the gross energy values possible for fat as well.

Early work on use of fat in poultry rations generally indicated a higher ME value for unsaturated vegetable oils when compared to animal products or products with high free fatty acid content (Seidler et al., 1955; Young, 1961; Waldroup et al., 1995). However, when fed as a portion of a complete ration, most experiments indicated no difference in performance parameters when different fat sources were fed (Seidler et al., 1955; Young, 1961; Fuller and Rendon, 1979; Fuller and Rendon, 1977; Pesti et al., 2002; Quart et al., 1992). Several reasons may be postulated why the differences seen in energy value in an ME analysis do not translate into differences in actual performance when added to complete diets. One of these is that the improvement in utilization of other dietary components is equally enhanced by different sources regardless of ME content. A more obvious answer may be the relatively small difference in ME content of a total ration at typical fat inclusion levels. In other words, if two fats of 7,000 and 8,000 kcal/kg ME are fed at three percent of the diet, the difference in ME content of the complete ration is only 30 kcal/kg, or less than one percent, of the total dietary energy. This type of difference is very small and would be very difficult to pick up experimentally. In a study by Pesti and coworkers (2002), a variety of fat sources were fed and differences of more than 4,000 kcal/kg were seen. However, when these same fats were fed to birds in a floor pen trial, no differences in gain or feed-to-gain ratio were observed, indicating that the net energy available to the bird was similar (Leeson and Ateh, 1995). Similar results were found in a recent study from the lab and are shown in Tables 1 and 2 (Leigh and Firman, 2005 unpublished).

Table 1. Average Broiler Growth for Birds Fed a Variety of Fat Sources.

Fat Source	0-3 Week (kg/bird/phase)	0-5 Week (kg/bird/phase)	0-7 Week (kg/bird/phase)
Soybean Oil	0.77	1.92	2.85
Yellow Grease	0.76	1.96	2.95
Poultry Fat	0.76	1.93	2.92
Tallow	0.75	1.92	2.99
Ani-veg Blend	0.74	1.89	2.96
Lard	0.75	1.88	2.97
Palm Oil	0.75	1.95	2.94

No statistical differences between treatments.

Table 2. Adjusted Feed-to-Gain Ratios for a Variety of Fat Sources in Broilers.

Fat Source	0-3 Week	0-5 Week	0-7 Week
Soybean Oil	1.38	1.60	1.87
Yellow Grease	1.38	1.56	1.85
Poultry Fat	1.38	1.58	1.85
Tallow	1.40	1.61	1.83
Ani-veg Blend	1.42	1.63	1.86
Lard	1.40	1.52	1.77
Palm Oil	1.42	1.56	1.88

Generally, fats are thought to be more digestible in the older bird relative to the young bird. Renner and Hill (1960) found poor utilization of tallow (highly saturated fat) by the young chick. Carew and coworkers (1972) showed that fat digestibility was compromised in the young chick, but increased rapidly as the chick aged. Similar results were obtained in the turkey as well (Sell et al., 1986). While this period of poor digestion of fats appears to be real, from a practical standpoint, it is less significant since the bird shows improved utilization of fat quite rapidly.

Increasing the level of energy in diets through fat addition may have a beneficial effect on performance (Fuller and Rendon, 1979). Much of the older data on changing energy levels were with diets not fully balanced, making data interpretation difficult. Addition of fats may result in increased body weight in some cases (Sell et al., 1986), although in many cases body weight gain is similar, but with improved feed efficiency (Pesti et al., 2002). Increasing dietary fat improved feed efficiency, but also may result in increased fat deposition (Salmon and O'Neil, 1971; Rivas and Firman, 1994). When turkeys were fed energy from 88 to 112 percent of the National Research Council (NRC) suggested levels, birds showed increased growth rate (25.3 to 29.4 lb) and dramatic changes in feed efficiency (3.41 versus 2.41 feed-to-gain ratio). While birds decreased feed intake in response to the higher energy diets in these studies, energy intake still increased with increased energy intake from fat additions (Firman, 1995).

Additions of fat beyond those required for linoleic acid have had mixed results in layer diets. Careful control of energy consumption in laying hens is required to assure that birds do not become overly finished (high in body fat). Orr and coworkers (1958) found no benefit to 2.5 or 5 percent fat additions in layers. Reid and Weber (1975) found no changes in egg production of caged layers when fed diets as high as 15 percent added fat although feed efficiency was improved. Supplementing fat (one to two percent) early in the laying cycle improved egg size and production (Jensen, 1983), although this was not seen in a trial with two to six percent added fat (Bohnsack et al., 2002).

Fat may also be used in the diet to reduce the heat increment, the heat produced when a diet is digested. The heat increment for protein is highest followed by carbohydrate with fat at the lowest heat increment. Thus it would be logical that if one could increase the proportion of the energy from fat, the animal would be able to handle heat stress more easily. One is cautioned that the total heat load may increase if the energy content of the diet is increased, although generally birds under heat stress will eat less to reduce the heat load from digestion. Broilers presented with a choice of high fat or high carbohydrate diets preferred high fat diets and performed better under high ambient temperatures (Dale and Fuller, 1978). Growth depression due to cycling heat stress was less in broilers fed high fat diets as well (Dale and Fuller, 1980).

Practical Use of Fat in Poultry Rations

The practical use of fat in poultry rations is straightforward, with the effects of fat addition well understood. A minimum level of fat (usually one percent) is generally fixed into the diet. This is for several reasons, but is generally done to assure sufficient quantities of linoleic acid. It also helps reduce dust levels of feed, lubricates equipment, and improves palatability of feed. This one percent addition level is generally done without regard for cost of addition. Levels beyond one percent of the diet are generally used to improve growth rate and feed efficiency and are far more related to cost of the total diet relative to performance gains achieved. In the United States, where relatively speaking, cheap fat is the norm due to the advanced rendering industry, additions of high levels of fat are common. Fat in the United States generally ranges from $200 to 400/ton while in many countries fat can easily be two to five times this price. A typical corn – soybean meal ration with one percent fat will have an energy value of approximately 3,000 kcal/kg ME. Each one percent addition of fat will add approximately 50 kcal of energy. Thus many U.S. rations will include fat at one to three percent in a starter ration and higher levels in the finisher rations of broilers. Higher fat additions generally result in better performance up to the maximum levels that can be physically added to diets (eight to 10 percent is generally considered the maximum in a pelleted or mash poultry ration). In many cases, nutritionists use a calorie-cost calculation to determine the most cost effective energy addition. In many countries corn is less available and soybean meal is quite expensive, leading to use of some lower quality ingredients and subsequently lower energy diets. These lower energy diets (sometimes less than 2,700 kcal/kg ME) result in poor growth rates, high feed-to-gain ratios, and a high cost structure. It is not uncommon to see 20 to 30 percent lower overall performance from the same broiler strain in many cases. Inexpensive fat would substantially improve performance of these birds. Utilization of fat in turkey rations is generally somewhat higher than broiler rations due to the high protein levels fed and the low energy found in soybean meal, which is a substantial component of these diets.

A number of concerns are expressed relative to fat utilization in a practical sense. These primarily revolve around the relative quality of the fat source and include rancidity, free fatty acid levels, and MIU (moisture, insolubles, and unsaponifiables). Many of these concerns can be allayed through the purchasing process where the maximum levels of these can be specified. Rancidity is routinely dealt with through addition of an antioxidant. Free fatty acids below 20 percent are not considered a problem, and MIU is quite low in most cases. The relative number of instances of actual problems from fat is quite small.

Use of Rendered Protein Sources

Use of rendered protein sources for animal feed has many advantages:

- Generally, very cost competitive relative to vegetable protein sources
- Use will reduce total diet costs in most cases
- Source of high quality protein
- In most cases, highly digestible
- May help balance the amino acid needs

- In many cases, will provide slightly faster growth rates than vegetable protein-only diets
- Excellent source of highly available phosphorus and other minerals

Some concerns should be noted with using rendered protein products:

- Poor quality control could result in decreased amino acid digestibility
- Proper formulation methods must be used to make most effective use
- Potential for microbial contamination if improperly handled
- Variation in product due to material mix, processing methodology

Use of rendered protein products has been limited in the past for a variety of reasons. Older research indicated a growth depression if use exceeded certain limits such as 7.5 percent of the diet. This depression in growth occurred primarily due to the reduced digestibility of many products relative to soybean meal. Older data from the lab indicated almost 10 percent less digestible lysine in MBM than in soybean meal (Firman, 1992). Thus, as the levels of MBM increased in the diet, the level of lysine available for use by the bird decreased. While the routine safety factor covered this deficit to a point, an amino acid deficiency eventually developed and growth rate was depressed. Formulation on a digestible basis eliminated this problem, and inclusion rate has become less of an issue. Additionally, more recent product tested has approached soybean meal in terms of amino acid digestibility. The maximum inclusion rate is more likely to be due to the high levels of calcium and phosphorus that occur at higher inclusion rates although cost issues usually dictate levels below this.

Available Products

Meat and Bone Meal

There has been considerable work done with MBM, particularly in the area of protein and amino acids. Firman (1992) found that the amino acid digestibility of meat meal does not differ in turkeys of different age or sex and is similar to the rooster model commonly used. Lysine and methionine are highly available for metabolism, but a significant amount of the cystine is not bioavailable (Wang and Parsons, 1998a). This is of importance because tryptophan and total sulfur amino acids (TSAA) are most limiting in MBM, followed by threonine, isoleucine, phenylalanine + tyrosine, lysine, valine and histidine (Wang et al., 1997). Several reports have found that the protein quality of MBM varies greatly. Parsons and co-workers (1997) found that the ash content is correlated to the protein quality. It is thought to be a caused by the ratio of protein to ash in a ration. As ash increases, protein decreases. The amino acid digestibility is probably not actually decreased (Shirley and Parsons, 2001). The method of determining digestibility can also have an effect, often yielding differing results (Johns et al., 1987). Fat additions to rations have also proved to be a factor as increased digestibility has been shown in the presence of high levels of fat. Increasing the fat component of a diet can slow gut motility, leaving more time for absorption. The micelles themselves may also help transport amino acids to the gut wall (Firman and Remus, 1994). Digestibility can also be affected by the presence of other ingredients, like soybean meal (Angkanaporn et al., 1996). It has been shown that formulating rations based on digestible or bioavailable amino acid levels provides better results than on a total amino acid basis (Wang and Parsons, 1998b).

One of the most important factors determining the nutritional quality of MBM is the processing procedure. With recent concerns over bovine spongiform encephalopathy (BSE), feeding mammalian-derived MBM to ruminants is banned in the United States and the European Union (EU) has banned the feeding of all products of animal origin to livestock. This leaves the poultry and swine industry as the major consumers of ruminant MBM. When a meal is rendered, the time, pressure, and temperature of rendering may vary. The European Union has mandated that animal by-product meals must be processed at 133ºC and 3 atmospheres (43.5 psi) for 20 minutes. Unfortunately, pressure may reduce the availability of nutrients for the bird (Shirley and Parsons, 2000). Temperature also has proven to affect the availability of nutrients. Temperature has the same inverse relationship to nutrient availability as seen with pressure (Johnson et al., 1998), as does the processing time (Karakas et al., 2001). Constant improvement in processing technology has recently resulted in improved nutrient availability, but variation in quality is still an issue for the industry (Elkin, 2002).

Several other studies have estimated the ideal amount of MBM to add to a ration. The level of inclusion of MBM to usual rations has been debated because of variations in metabolizable energy, protein quality, and available phosphorus. It is often included at five percent or less of the ration. However, Sell (1996) found that MBM can be added successfully to diets at up to 10 percent for turkeys.

As given in the name, bone is a component of MBM. This provides an excellent source of calcium and phosphorus. Drewyor and Waldroup (2000) noted that inclusion of MBM must be monitored to ensure phosphorus levels are not so high that environmental issues arise. Others have found that the phosphorus in MBM is highly available to turkey poults (Sell and Jeffrey, 1996). Fortunately, prediction equations for phosphorus content have been developed similar to those used to predict the metabolizable energy of a feedstuff. This rapid determination will aid in the formulation of rations utilizing MBM (Mendez and Dale, 1998).

Of primary concern is the metabolizable energy of MBM. As mentioned previously, the variability of the feedstuff makes it difficult to precisely determine a standard value. Waring (1969) found an ME of 1,988 kcal/kg, lower than many estimates. The National Research Council (1994) uses a value of 2,150 kcal/kg. However, early papers tended to underestimate the ME of MBM, with it probably being between 2,300 and 2,500 kcal/kg (Martosiswoyo and Jensen, 1988a; 1988b; Dolz and de Blas, 1992). Species may also have an effect. Dale (1997) found a ME of 2,449 kcal/kg for beef MBM and 2,847 kcal/kg for pork MBM, while others found no differences in species (Karakas et al., 2001). There has been considerable discussion of the methodologies used in determination of ME of MBM products as well. Robbins and Firman (2005) tested a variety of the common methods currently employed and found few differences due to methodology.

Poultry By-product Meal

This is the by-product of the poultry processing industry and may consist of the offal and other inedible parts of the chicken. Original data on PBM use showed very positive results for the time as a replacement of soybean meal or fish meal, although diet formulations were not very sophisticated (Gerry, 1956; Fuller, 1956; Wiseman et al., 1958). Data also were collected on measures of protein efficiency (Escalona et al., 1986) although this is less useful today given the ability to computer balance amino acid profiles. The main cause for differentiation between PBM and poultry meal is based on the processing source. One plant may include portions of the chicken such as the de-boned carcass from further processing while another may sell primarily whole birds and not render this portion of the bird and thus the meal will have different levels of ash content. This product has become more expensive in some cases as the high quality has led to use by the pet food industry in the United States, with the higher quality product designated as pet food grade. Pet food grade product is generally thought to be more consistent with energy values found in a much narrower range than those of feed grade PBM (Escalona et al., 1986; Dozier and Dale, 2005). More information is provided in the pet food chapter of this book.

Table 3. Percent Digestibility of Poultry By-product Meal.

Amino Acid	Chicken	Turkey
Arg	93.2	91.2
Ser	85.7	85.0
His	80.8	83.4
Ile	90.6	86.6
Leu	91.1	87.3
Lys	90.9	89.3
Met	92.1	89.3
Cys	77.8	78.1
Phe	90.4	86.8
Tyr	93.9	85.5
Thr	86.6	87.3
Trp	95.0	94.8
Val	88.1	85.2
Asp	73.3	82.0
Glu	87.6	87.5
Pro	80.9	85.1
Ala	86.5	87.0
Average	87.3	86.5

Nutrient composition of PBM varies widely depending on sample source (Dozier et al., 2003) with protein contents varying from 49 to 69 percent. Energy content also varies (Pesti et al., 1986) and can be predicted from proximate values using the following equation from Dale et al. (1993): TMEn = (kcal/kg) = 2904 +

65.1(percent fat)- 54.1 (percent ash). Digestibility of PBM also varies, but is generally between 80 to 90 percent. Average digestibilities for a variety of samples can be found through commercial sources, but a representative product for turkeys and chickens is shown in Table 3 (Firman and Remus, 1993).

Feather Meal

FeM is the ground and hydrolyzed feathers from chicken and turkey processing. Generally, FeM is considered to be low in digestibility and to have a poor amino acid balance and is thus not heavily used in the poultry industry. It is generally economically priced, and will normally be used at one to three percent of the ration. Higher levels can be fed when careful formulations are used. FeM usage by poultry was demonstrated to be effective in older trials when amino acid balance was taken into account as long as total inclusion rate was low (Gerry and Smith, 1954; Harms and Goff, 1957; Lillie et al., 1956; McKerns and Rittersporn, 1958; Moran et al., 1968; Sullivan and Stephenson, 1957; Wilder et al., 1955). More recent data indicate FeM is an excellent source of several amino acids most notably cystine and although the overall quality of the protein is low, FeM can often spare the use of synthetic methionine (Wessels, 1972).

Table 4. Digestibilities of Amino Acids in Feather Meal.

Amino Acid	**Chicken**	**Turkey**
Arg	84.2*	89.5
Ser	76.4*	89.3
His	84.2	74.4
Ile	82.3	86.8
Leu	76.8*	85.0
Lys	73.3	76.2
Met	77.5	80.3
Cys	58.8*	86.8
Phe	79.6	85.8
Tyr	79.8	85.9
Thr	72.9*	84.9
Trp	77.0*	87.4
Val	77.5*	85.3
Asp	58.0*	74.0
Glu	71.8*	82.4
Pro	63.1*	88.5
Ala	72.3	80.0
Average	73.6	83.7

[A] Mean digestibility coefficient * Significant differences compared to turkeys.

More recent work has looked at processing methodology and how this contributes to the digestibility of the amino acids in FeM. Morris and Balloun (1971) found a processing time of 60 minutes at 50 psi produced the best results while others (Papadopaulos et al., 1985; Moritz and Latshaw, 2001) found that time and pressure were negatively correlated to produce a high quality FeM. However, Wang and Parsons (1997) found no significant relationships between temperature and processing time. Availability of amino acids (Baker et al., 1981; Han and Parsons, 1991; Bielorai et al., 1983; Firman and Remus, 1993) and energy (Dale, 1992) of FeM have been evaluated. The amino acid digestibilities of an example FeM for chickens and turkeys are shown in Table 4. FeM additions of four to six percent to turkey diets were the maximum inclusion that did not negatively affect performance, especially when in combination with other by-products (Eissler and Firman, 1996). It was noted that a set inclusion rate results in an increasing proportion of the total protein coming from FeM as protein levels are decreased in turkey rations.

Phosphorus Utilization

Phosphorus is one of the most valuable nutrients in the rendered proteins of animal origin. The highly available content of phosphorus in products is, in many cases, what makes the product economically viable when compared to other protein sources. Early work on phosphorus utilization indicated that phosphorus was highly available from animal products (Waldroup et al., 1965). Orban and Roland (1992) found phosphorus from bone meal sources slightly less available than from dicalcium phosphate. However, more recent data indicate no differences in utilization of phosphorus from animal products and dicalcium phosphate (Waldroup and Adams, 1994). Most nutritionists today assume 100 percent availability of phosphorus from rendered by-products.

Use of Animal Proteins in Rations

Products of the rendering industry are heavily used in most rations for broilers and turkeys in the United States. While products may be utilized individually, in most cases the most cost effective additions result from allowing the computer to select from a variety of available sources. MBM of ruminant origin is generally the most cost-effective source, followed by feed grade PBM and FeM. FeM is generally added at very low levels to help offset costs of sulfur amino acids. MBM and PBM are added as protein and phosphorus sources, with the latter generally being higher in energy and thus commanding a higher value. Addition rates of FeM are generally less than two percent while additions of the MBM and PBM can be substantially higher. When formulated on a digestible basis, the upper limit of these additions can easily exceed 10 percent from a growth standpoint, but are generally more based on a cost efficiency standpoint. If not formulating on a digestible amino acid basis, one should still look at digestibility of the product and set a maximum inclusion rate if there are substantial differences in digestibility from soybean meal. Given the quantity of data available, all poultry diets should be formulated on a digestible basis in the future.

The most significant problem in use of rendered products is variation of the product. Formulators are encouraged to maintain a database of product analyses and make every attempt to use the same suppliers to reduce product variation.

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Profile of National Renderers Association and the Industry, Early 1980s.

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FACT SHEET

PROFILE

The National Renderers Association (NRA) is a trade organization representing the rendering industry. Its approximately 500 member companies are producers of animal and poultry by-products and the supplier firms servicing the industry.

The rendering industry produces a wide variety of products, including edible and inedible tallow, lard, grease, partially defatted beef and pork fatty tissue, meat-and-bone meal,poultry by-product meal and feathermeal.

Approximately 57 percent of every beef steer slaughtered in the United States makes it to the consumer's table. What happens to the other 43 percent is the basis of a 2.5 billion dollar a year rendering industry. Over 91 million pounds of fat and bone are discarded daily. An organized network of renderers collects and pays for this "waste" animal material from slaughter houses, packing plants, butcher shops, food and meat markets, hotels, restaurants and locker plants. Fallen animals are also collected from farms, ranches and feedlots. If it were not for the collection efforts of the rendering industry, this mountain of material would create an immense ecological problem and tax burden.

Animal fats and proteins form a substantial part of the world economy. In fact, the annual U.S. production of tallow averages more than seven billion pounds. More than one billion pounds of lard are produced, and about five billion pounds of meat-and-bone meal.

Renderers' products that are designated as edible tallow and lard are used in shortenings for making breads, pastries, and pastas and for cooking compounds for frying chicken, potatoes and other vegetables, fish and meat. Partially defatted beef and pork fatty tissue is used as a meat extender in canned and frozen foods, potted meats and some luncheon meats. Another product, 12 percent beef and pork trimming, is used as an extender in chili, hash, pizza, tamales, egg rolls, soups, meat loaves, franks (hot dogs), baloney, and imitation sausages.

Inedible animal by-products are used in three major sectors of our modern economy. The first, and perhaps the most important one, is animal nutrition where fats and proteins are utilized as high energy and protein supplements in feed rations and in pet food.

The second sector in which animal fats and their by-products are rapidly growing in importance is the industrial area. About 3,000 industrial products contain tallow or its derivatives. Some of the major fields include the chemical industry, paints and plastic materials, pharmaceuticals, cosmetics, the textile industry, lubricants, metallurgy, rubber and the preparation of agricultural pesticides and fertilizers.

The third sector of application is the soap industry where tallow represents the basic material. Traditional tallow-based soap still finds favor with consumers because of its many beneficial qualities. Tallow used in detergents also offers the benefit of utilizing a constantly renewable natural resource.

Renderers successfully recycle 95-100 percent of discarded animal material into useful, saleable products. This represents the most successful and efficient recycling effort in the world today.

RENDERED PRODUCTS IN SWINE NUTRITION

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Summary

Numerous rendered products can be used in swine diets. In general, these by-products of the packing/rendering industry are good sources of amino acids, calcium, phosphorus, and other minerals, as well as B-complex vitamins. The major animal-derived by-products used in swine diets are meat meal, meat and bone meal, fish meal, dried blood products (blood meal, spray-dried plasma, and spray-dried blood cells), steamed bone meal, and rendered animal fats (tallow, grease, and mixtures of animal fats). Small amounts of poultry by-product meal and hydrolyzed feather meal are also use, but to a lesser extent. This chapter gives an overview of the composition of these products and their nutritional value for swine.

Introduction

Pig production represents an important segment of the food animal industry in the United States and throughout the world. Pork is an important source of protein for humans and is the most widely consumed meat in the world today. Today's pork is lean and supplies many essential nutrients to consumers.

Swine are produced in many types of operations from small farms to huge and highly integrated corporations. Today's pork is produced by fewer producers than ever before, and the operations are much larger than they were in the past. Table 1 illustrates that approximately 78 percent of the pork in the United States is produced by only 1.5 percent of pig farms, and these farms are quite large, having an annual production of at least 10,000 market pigs, and for some mega-farms, over 500,000 market pigs annually.

Table 1. Number of Swine Operations in the United States by Size and the Market Share of the Pigs that are Produced on These Farms - 2003[a].

No. of Pigs Marketed Annually	No. of Pig Farms	Percent of All Pig Farms	% Market Share
Less than 1,000	59,950	85.5	1
1,000 to 3,000	6,630	9.5	8
3,000 to 5,000	950	1.4	4
5,000 to 10,000	1,526	2.2	9
10,000 to 50,000	915	1.3	19
50,000 to 500,000	134	0.2	19
More than 500,000	25	0.04	40

[a] National Pork Board, 2006.

Regardless of the size of operations or the types of facilities in which pigs are raised, a sound nutrition and feeding program is necessary for the operation to be profitable. Because feed represents 65 to 75 percent of the total cost of production, swine producers must have a good understanding of the nutrient requirements of pigs, a knowledge of the feedstuffs that can be used in pig feed, and an appreciation for sound feeding management in order for them to produce pigs efficiently and economically.

Pigs are unique in that they have the ability to obtain nutrients from a wide variety of feedstuffs. Swine are omnivorous; that is, they consume both plant and animal food sources. In today's operations, the major feedstuffs are vegetative in nature (predominately cereal grains and oilseed meals) with corn and soybean meal representing 80 percent or more of the total feedstuffs fed to swine. However, feedstuffs from animal sources also are commonly included in commercial swine diets. The majority of these animal-derived feedstuffs are by-products of the meat packing/rendering industry. Many of them by-products have unique properties that enhance the feeding program of pigs.

Overview of Swine Nutrition

An overview of the fundamentals of swine nutrition and feeding will help one to understand and have an appreciation for the use of animal-derived rendered products and other feedstuffs in swine diets.

Pigs require more than 40 individual nutrients in their diet in order to sustain life, grow rapidly, and reproduce and lactate efficiently. Some of these nutrients are present in adequate amounts in normally consumed feedstuffs (cereal grains, oilseed meals, etc.), and those that are deficient can be easily supplemented from concentrated or synthetic sources. The best estimates of the quantitative requirements for all of these nutrients can be found in the publication *Nutrient Requirements of Swine*, published by the National Research Council (NRC, 1998).

Nutrients are traditionally grouped into six classes: water, carbohydrates, fats, protein, minerals, and vitamins. Water is often considered to be the most important nutrient because animals cannot live very long without it. Carbohydrates, fats, and protein provide energy for animals. In addition, protein supplies amino acids that are essential for growth, reproduction, and lactation. Minerals and vitamins have numerous important roles in the body.

Energy

Energy is required for all functions in the life process. For pigs, energy is derived primarily from carbohydrates and fats, and to a certain extent, from protein. Energy is classified as digestible energy (DE), metabolizable energy (ME), or net energy (NE). The DE content of a feed represents the energy that is digested (energy in feed minus energy in feces). The ME content of a feed represents the DE less any energy lost in the urine and in fermentation gasses. The NE of a feed is the ME less the heat expended to digest and utilize the feedstuff. DE and ME are more easily determined than NE, and because of a larger database, DE and ME are more commonly used in the United States.

Pigs are simple-stomached animals, so they must rely on feeds having readily digestible carbohydrates, such as starch and sugars, to meet their energy needs. Ruminant animals depend on microorganisms in their rumen to degrade cellulose, hemicellulose, and other complex carbohydrates found in roughages into fermented products that can be absorbed and utilized. However, pigs cannot do this efficiently. Some fermentation does occur in the hind gut of more mature swine, but the process is much less efficient than in ruminants.

Cereal grains are high in starch and they constitute the major part of modern swine diets. Almost all of the starches in corn and other cereal grains are digested by pigs. The end product of starch digestion is glucose, which is readily absorbed and utilized as an energy source. Sugars, such as lactose in milk and milk products, represent an important energy source for weanling pigs. The sugar, sucrose, in sugar cane and sugar beets also is well utilized by pigs, but these feed sources are not widely used in the United States.

Fats and oils are also highly digestible energy sources for pigs. In addition, the energy in fats and oils is approximately 2.3 times as concentrated as the energy in an equivalent amount of carbohydrates. Thus, supplemental fat represents an efficient way of increasing the energy concentration of the diet. Because pigs tend to eat an amount of feed that will meet their energy requirement, adding fat to the diet will reduce feed intake and substantially improve the feed-to-gain ratio. Supplemental fat also has other beneficial properties (reduced dustiness, etc.), which will be discussed later in the chapter.

Protein in the diet that is in excess of the requirement for the various amino acids can be used as an energy source, but it is too costly to be fed solely for energy. The energy contribution of various rendered animal products is shown in Table 2.

Protein

Body protein consists of 22 amino acids. About one-half of the body protein is in the muscle tissues and the remaining protein is in the organs, viscera, blood, and hair. A small amount is in the enzymes and other digestive secretions as well as the hormones of the body. For protein synthesis (i.e., growth) to occur, the diet must supply sufficient amounts of 10 of the 22 amino acids; these are called "essential" amino acids. The other 12 amino acids, called "non-essential" amino acids, can be synthesized by pigs as long as sufficient nitrogen is present in the diet.

Because pigs are simple-stomached, they must rely on amino acids from dietary sources to meet their essential amino acid requirements. In other words, pigs cannot rely on microbes to synthesize the essential amino acids such as the case with ruminants. Therefore, dietary protein must be in a form that is readily digestible (so as to liberate the amino acids from the protein), and the pattern of liberated amino acids must supply adequate amounts of the 10 essential amino acids. A deficiency of any one of the 10 amino acids will limit pig performance.

The amino acid that is most likely to be deficient in most diets consisting of various combinations of feedstuffs is lysine. This is due to two reasons: first, because lysine is the most abundant of all the amino acids in the body (about 7 percent lysine in whole body protein); and second, because many of the feedstuffs (especially cereal grains) are extremely low in lysine.

Table 2. Dry Matter, Energy, and Fat Composition of Rendered Animal Products and Dehulled Soybean Meal[a].

Feedstuff	Dry Matter %	Digestible Energy kcal/lb	Metabolizable Energy kcal/lb	Net Energy kcal/lb	Fat %
Meat meal	94	1,224	1,178	987	12.0
Meat and bone meal	93	1,108	1,010	615	10.9
Poultry by-product meal	93	1,403	1,298	883	12.6
Feather meal, hydrolyzed	93	1,357	1,128	1,022	4.6
Fish meal, menhaden	92	1,712	1,525	1,060	9.4
Blood meal, ring dried	93	1,530	1,337	940	1.3
Plasma, spray dried	91	--	--	--	2.0
Blood cells, spray dried	92	--	--	--	1.5
Steamed bone meal					
Animal fat					
Beef tallow		3,632	3,487	2,236	
Choice white grease		3,764	3,612	2,313	
Lard		3,761	3,609	2,315	
Poultry fat		3,868	3,714	2,374	
Restaurant grease		3,882	3,725	2,381	
Soybean meal, dehulled	90	1,673	1,535	917	3.0

[a] NRC, 1998.

Protein sources for swine are generally characterized on the basis of their "protein quality," which refers to the amino acids in the protein. Milk proteins have the highest quality protein in that the profile of their amino acids closely matches that of the needs of pigs. The protein in some oilseed meals and rendered animal products is considered intermediate to high in protein quality, but the quality of protein is low in certain other sources. The protein in cereal grains is of very poor quality due to low concentrations of lysine, tryptophan, and threonine. Interestingly, soybean meal by itself is low in methionine, but when combined with cereal grains (which are relatively higher in methionine); the quality of protein is much improved.

The amino acids in feed protein are not totally digested and absorbed by pigs; in other words, the bioavailability of amino acids in intact protein is not 100 percent. However, the availabilities of most of the amino acids are within the range of 70 to 90 percent. The availability of amino acids in individual feedstuffs to the animal is determined by the disappearance of amino acids at the end of the small intestine in ileal-cannulated pigs, and is referred to as "ileal digestibility." The digestibility can be express as "apparent" or a "true" ileal digestibility. The latter corrects for endogenous amino acids (non-feed sources of amino acids such as enzymes, mucus, eroded epithelial cells, etc.). The "digestible amino acid" system is commonly used today in the U.S. feed industry.

Minerals and Vitamins

Pigs require 14 minerals in their diet. Some of these minerals (sulfur, magnesium, potassium, chromium) are provided in sufficient supply by the natural ingredients, but others must be supplemented. Calcium, phosphorus, salt (sodium, chloride), and the trace minerals, copper, iron, manganese, zinc, iodine, and selenium, are commonly added to most grain-soybean meal diets, but significant amounts of some of these minerals can be partially or evenly totally supplied by rendered animal products.

Calcium and phosphorus are required in greater amounts than any other minerals. Pigs require significant amounts of both minerals for bone formation and for many other purposes. Most plant-derived feedstuffs are extremely low in calcium and much of the phosphorus is organically bound in a form called phytic acid (or phytate) that is unavailable to pigs. Because of the low bioavailability of phosphorus in plant-derived feedstuffs (Cromwell and Coffey, 1993), grain-oilseed based diets need rather large amounts of highly available calcium (usually as ground limestone) and phosphorus (as mono- or dicalcium phosphate, defluorinated phosphate, or steamed bone meal) to meet the requirement. Much, or even all, of the calcium and phosphorus requirements can be provided by certain animal-derived protein sources (discussed later in the chapter).

Common salt, added at 0.25 to 0.50 percent, will meet the sodium and chlorine requirements of pigs. The other major minerals – magnesium, potassium, and sulfur – are provided in sufficient amounts by the natural ingredients. The trace minerals are commonly included in diets in the form of a trace mineral premix.

Thirteen vitamins are required by swine. Vitamins A, D, E, K, and B_{12} along with riboflavin, pantothenic acid, and niacin are commonly added to swine diets. Three additional vitamins – biotin, folic acid, and choline – are often added to sow diets. The other two essential vitamins, thiamin and pyridoxine (vitamin B_6), are supplied in sufficient quantities by the natural ingredients and do not have to be supplemented. Additions of the B-complex vitamins is less critical when rendered animal products constitute a portion of the protein supplement because animal protein sources contain much higher levels of these vitamins, as well as trace minerals, than do oilseed meals. In the past, several high-protein feeds were blended with legume products as supplements for cereal grains to meet the vitamin and trace mineral requirements of pigs. Today, synthetically-produced vitamins and inorganic (or organic) trace minerals are commonly included as premixes to supplement these important micronutrients to swine feeds.

Rendered Animal Protein Sources for Swine

In general, animal protein supplements are good sources of lysine and the other amino acids. In addition, they contain higher levels of minerals and B-complex vitamins than plant protein sources. However, animal protein supplements tend to be more variable in nutrient content, and they are subjected to high drying temperatures during processing for dehydration and sterilization. Unless carefully controlled, high temperatures can reduce the bioavailability of certain amino acids.

Typical amino acid composition of the more common animal protein sources for swine is shown in Table 3 and estimates of the apparent and true ileal digestibility of amino acids in these protein sources are given in Tables 4 and 5. The calcium, phosphorus, and bioavailable phosphorus levels in these feedstuffs are shown in Table 6. Nutrient levels in dehulled soybean meal are also given in these tables for comparative purposes. All of the values are from the National Research Council's *Nutrient Requirements of Swine* (NRC, 1998).

Table 3. Protein and Amino Acid Composition of Rendered Animal Products and Dehulled Soybean Meal[a] (Percent).

Feedstuff	Prot.	Lys	Thr	Trp	Met	Cys	Ile	Val
Meat meal	54.0	3.07	1.97	0.35	0.80	0.60	1.60	2.66
Meat and bone meal	51.5	2.51	1.59	0.28	0.68	0.50	1.34	2.04
Poultry by-product meal	64.1	3.32	2.18	0.48	1.11	0.65	2.01	2.51
Feather meal, hydrolyzed	84.5	2.08	3.82	0.54	0.61	4.13	3.86	5.88
Fish meal, menhaden	62.3	4.81	2.64	0.66	1.77	0.57	2.57	3.03
Blood meal, ring dried	88.8	7.45	3.78	1.48	0.99	1.04	1.03	7.03
Plasma, spray dried	78.0	6.84	4.72	1.36	0.75	2.63	2.71	4.94
Blood cells, spray dried	92.0	8.51	3.38	1.37	0.81	0.61	0.49	8.50
Soybean meal, dehulled	47.5	3.02	1.85	0.65	0.67	0.74	2.16	2.27

[a] NRC, 1998.

Table 4. Apparent Ileal Digestibility of Amino Acids in Rendered Animal Products and Dehulled Soybean Meal[a].

Feedstuff	Lys	Thr	Trp	Met	Cys	Ile	Val
Meat meal	83	79	73	85	55	82	79
Meat and bone meal	74	70	60	79	55	74	74
Poultry by-product meal	78	72	74	74	70	77	74
Feather meal, hydrolyzed	54	74	63	65	71	81	80
Fish meal, menhaden	89	85	79	88	73	87	85
Blood meal, ring dried	91	86	88	85	81	71	90
Plasma, spray dried	87	82	92	64	--	85	86
Blood cells, spray dried	--	--	--	--	--	--	--
Soybean meal, dehulled	85	78	81	86	79	84	81

[a] NRC, 1998.

Table 5. True Ileal Digestibility of Amino Acids in Rendered Animal Products and Dehulled Soybean Meal[a].

Feedstuff	Lys	Thr	Trp	Met	Cys	Ile	Val
Meat meal	83	82	79	87	58	84	80
Meat and bone meal	80	80	78	83	63	82	79
Poultry by-product meal	80	77	--	77	72	81	74
Feather meal, hydrolyzed	67	82	86	74	73	88	84
Fish meal, menhaden	95	88	90	94	88	94	93
Blood meal, ring dried	94	94	94	96	91	88	91
Plasma, spray dried	--	--	--	--	--	--	--
Blood cells, spray dried	--	--	--	--	--	--	--
Soybean meal, dehulled	90	87	90	91	87	89	88

[a] NRC, 1998.

Table 6. Calcium, Phosphorus, and Bioavailable Phosphorus Composition of Rendered Animal Products and Dehulled Soybean Meal[a].

Feedstuff	Calcium %	Phosphorus %	Phosphorus Availability[b] %	Available Phosphorus[c] %
Meat meal	7.69	3.88	90[d]	3.49
Meat and bone meal	9.99	4.98	90	4.48
Poultry by-product meal	4.46	2.41	90[d]	2.17
Feather meal, hydrolyzed	0.33	0.50	31	0.16
Fish meal, menhaden	5.21	3.04	94	2.86
Blood meal, ring dried	0.41	0.30	92	0.28
Plasma, spray dried	0.15	1.71	95[d]	1.62
Blood cells, spray dried	0.02	0.37	95[d]	0.35
Steamed bone meal	29.80	12.50	85	10.63
Soybean meal, dehulled	0.34	0.69	23	0.16

[a] NRC, 1998.
[b] Percent of the phosphorus that is bioavailable to pigs.
[c] Total phosphorus times percent of the phosphorus that is bioavailable.
[d] Estimated.

Other reviews of animal protein sources have been written by Cunha (1977), Thacker and Kirkwood (1990), Knabe (1991), Chiba (2001), Cromwell (2002), and McGlone and Pond (2003).

Meat Meal, Meat and Bone Meal

Meat meal and meat and bone meal are the two most common animal protein sources used in swine diets. Both of these by-products have been widely used in swine feeds for many years (Franco and Swanson, 1996). These products are officially described as the rendered product from mammalian tissues including bone, but exclusive of any added blood, hair, hoof, horn, hide trimmings, manure, stomach, and ruminal contents, except such amounts as may occur unavoidably in good processing practices (AAFCO, 2006). The amount of phosphorus is the main criterion for distinguishing the two products. If the phosphorus level is 4.0 percent or greater, the product is designated as meat and bone meal. If the phosphorus level is less than 4.0 percent, the product is designated as meat meal. According to the official definition, the calcium level should not be more than 2.2 times the phosphorus level. Although not included in the official definition, crude protein of meat and bone meal is approximately 50 percent and meat meal is approximately three to five percentage units higher in protein. Meat meal tankage and meat and bone meal tankage are similar to meat meal or meat and bone meal, respectively except that they also contain blood or blood meal.

For most feedstuffs, the percentages of the various amino acids tend to increase as the level of crude protein in the feedstuff increases; however the correlation between the two is often relatively poor. An analysis of 73 samples of meat meal and meat and bone meal (Knabe, 1995), showed that lysine increased by 0.06 percent for each one percent increase in crude protein ($R^2 = 0.47$, Figure 3).

The lysine in meat meal is as high as, and even slightly higher than, the lysine in soybean meal (Table 3). However, the bioavailability of the lysine is slightly less than that in soybean meal (Tables 4 and 5). Both meat meal and meat and bone meal are relatively low in tryptophan and some research has shown that the bioavailability (i.e., ileal digestibility) of tryptophan and some of the other amino acids is a bit low (Knabe, 1987; NRC, 1998). The low tryptophan content is due to the fact that collagen is one of the major proteins in bone, connective tissue, cartilage, and tendons (Eastoe and Eastoe, 1954), and collagen is nearly void of tryptophan (Eastoe and Long, 1960).

Figure 1. Relationship of Calcium and Phosphorus in 426 Samples of Meat Meal and Meat and Bone Meal (Adapted from Knabe, 1995).

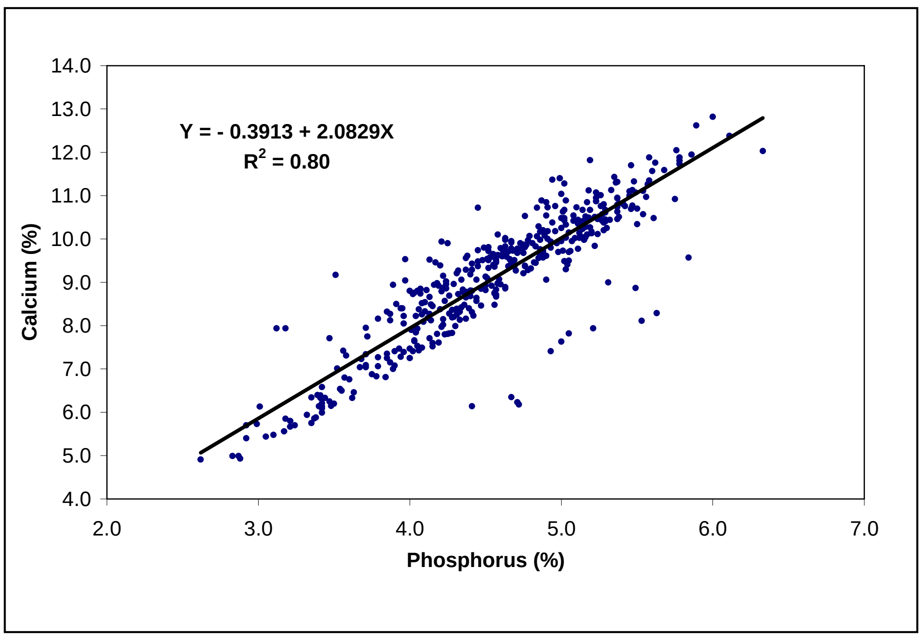


Figure 2. Relationship of Crude Protein and Phosphorus in 426 Samples of Meat Meal and Meat and Bone Meal (Adapted from Knabe, 1995).

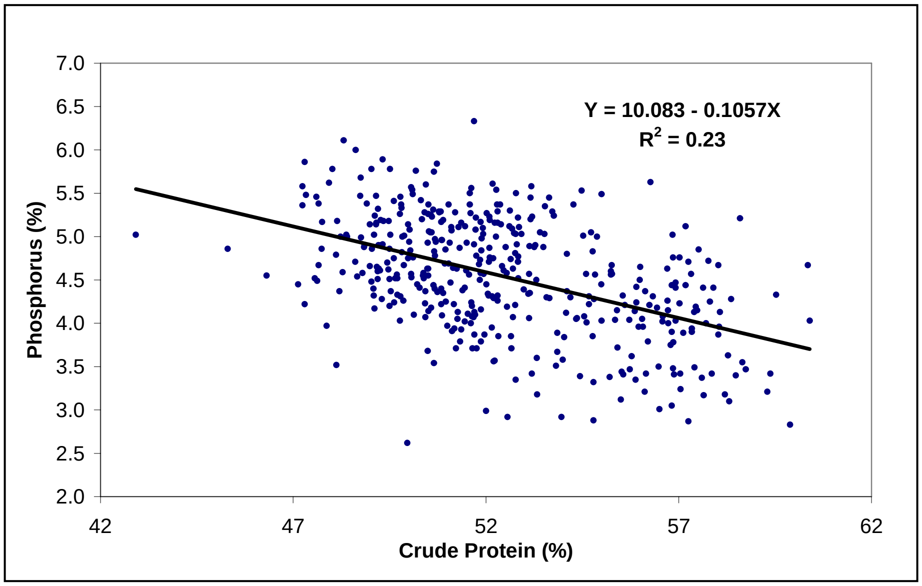
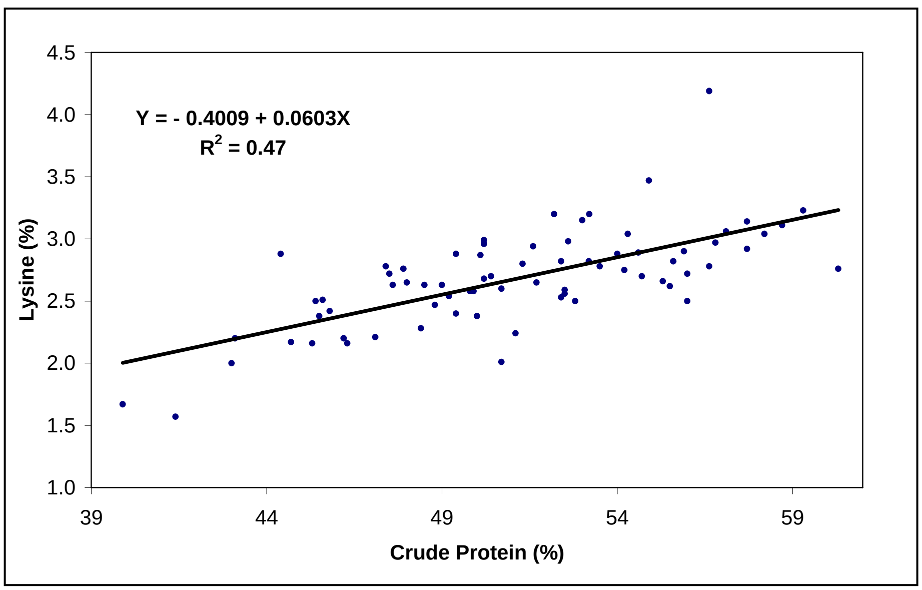


Figure 3. Relationship of Crude Protein and Lysine in 73 Samples of Meat Meal and Meat and Bone Meal (Adapted from Knabe, 1995).



Knabe (1995) summarized the composition of 426 samples of meat meal and meat and bone meal and found that they averaged 52.4 percent protein, 9.07 percent calcium, and 4.54 percent phosphorus (Table 7). The average fat content of 113 samples was 10.68 percent. A regression analysis of the data summarized by Knabe (1995) indicated a very strong linear relationship between calcium and phosphorus in meat meal and meat and bone meal (R^2 = 0.80), with calcium increasing 2.08 percent for every one percent increase in phosphorus (Figure 1). A further analysis of the data summarized by Knabe (1995) indicated that the phosphorus decreased by 0.106 percent for each one percent increase in crude protein (R^2 = 0.23, Figure 2).

Table 7. Composition of Meat Meal and Meat and Bone Meal Analyzed by Three Feed Manufacturers[a].

Feedstuff	No. Samples	Crude Protein %	Calcium %	Phosphorus %	Crude Fat[b] %
Meat meal	171	54.0 ±2.93	7.69 ±1.16	3.88 ±0.41	10.72 ±1.55
MBM	255	51.4 ±2.64	9.99 ±1.01	4.98 ±0.38	10.70 ±1.61
All meals	426	52.4 ±3.04	9.07 ±1.56	4.54 ±0.67	10.68 ±1.58

[a] Knabe, 1995. As fed basis. All samples were sold as meat and bone meal. In this summary, meat meal represents samples having < 4.0% phosphorus.
[b] Crude fat was based on 35 samples of meat meal and 78 samples of meat and bone meal.

Some of the early feeding experiments with meat and bone meal indicated that growth performance was reduced in growing-finishing pigs when increasing levels of meat and bone meal was substituted for soybean meal in corn-based diets (Peo and Hudman, 1962; Evans and Leibholz, 1979). These early studies indicated that the maximum amount of meat meal or meat and bone meal should not exceed two to three percent of the diet. However, more recent studies at the University of Kentucky have shown that higher levels of meat meal or meat and bone meal can be included in growing-finishing diets for swine without reducing performance if tryptophan is also supplemented (Cromwell et al., 1991). The studies showed that when 0.03 percent tryptophan was added for every 10 percent addition of meat and bone meal in the diet, performance was nearly as good as for pigs fed corn-soybean meal diets (Table 8). The studies involved 24 pigs per treatment from 53 to 205 lb body weight in Experiment 1 and 20 pigs per treatment from 99 to 207 lb body weight in Experiment 2. The relatively high levels of calcium and phosphorus in meat meal and meat and bone meal allow diets to be formulated for swine without having to include inorganic calcium and phosphorus supplements. Recent studies at the University of Kentucky indicated that the phosphorus in meat and bone meal was 85 to 91 percent as bioavailable as the phosphorus in mono- or dicalcium phosphate (Traylor et al., 2005ab). Inclusion of sufficient amounts of meat and bone meal to met the calcium and phosphorus requirements of growing-finishing pigs in their study resulted in optimal performance and bone integrity (Table 9).

Table 8. Levels of Meat and Bone Meal in Corn-Soybean Meal Diets on Performance of Growing-Finishing Pigs[a].

	Meat and Bone Meal in Diet, Percent				
	0	5	5	10	10
Item	Added Tryptophan, %				
	-	-	0.015	-	0.030
Experiment 1					
Daily gain, lb	1.51	1.38	1.47	1.05	1.43
Daily feed, lb	4.97	4.80	4.93	3.96	4.93
Feed/gain	3.30	3.50	3.37	3.79	3.45
Experiment 2					
Daily gain, lb	1.89	-	-	1.10	1.80
Daily feed, lb	6.89	-	-	5.10	6.51
Feed/gain	3.65	-	-	4.67	3.60

[a] Cromwell et al., 1991.

Table 9. Performance of Finishing Pigs Fed Diets with the Supplemental Calcium and Phosphorus Supplied by Dicalcium Phosphate or Meat and Bone Meal[a].

	Source of Phosphorus			
	Dicalcium Phosphate		Meat and Bone Meal	
Dietary calcium, %	0.50	0.65	0.55	0.65
Dietary Phosphorus, %	0.45	0.55	0.45	0.55
Daily gain, lb	1.87	1.94	1.96	1.96
Feed/gain	3.10	3.15	3.05	3.03
Lean gain, g/day	330	337	333	332
Bone strength, kg[b]	178	194	182	194
Carcass lean, %	53.1	52.6	52.6	52.4

[a] Traylor et al., 2005a. Study involved 25 pigs per treatment from 99 to 242 lb body weight. These levels of calcium and phosphorus were fed during the first half of the finishing period, then calcium was reduced to 0.45 or 0.55% and phosphorus was reduced to 0.40 or 0.50%, respectively.

[b] Main effect of phosphorus level ($P < 0.05$).

Questions are often asked as to what factors may affect the nutritional value of meat meal and meat and bone meal for pigs. Certainly overheating of the meals during processing has been shown to reduce the bioavailability of several of the amino acids (Batterham et al., 1986; Knabe, 1987). However, excessive heating of meals does not appear to reduce the bioavailability of phosphorus according to the Traylor et al. (2005b) studies. Similarly, particle size of the meal within ranges commonly used in the industry does not affect the bioavailability of phosphorus

(Traylor et al., 2005b). On the other hand, the phosphorus in a high-ash, meat and bone meal of bovine origin was found by these researchers to be more bioavailable than the phosphorus in a low-ash meat meal of porcine origin, a difference of approximately 15 percentage units. The researchers proposed that the difference in phosphorus bioavailability may have been due to a greater proportion of the phosphorus in the high-ash meal being supplied by bone whereas more of the phosphorus in the low-ash meal was supplied by soft tissues.

Poultry By-product Meal

Poultry by-product meal is a rendered product from poultry slaughter and processing plants. It is officially described as the ground, rendered, or clean parts of slaughtered poultry such as head, feet, undeveloped eggs, and intestines, exclusive of feathers except in such amounts as might occur unavoidably in good processing practices (AAFCO, 2006). Because most of the poultry industry is so vertically integrated, this product generally goes back into the companies' own poultry feed, and much less of this product is used in the swine feeds as compared with meat meal or meat and bone meal. The amino acid composition of poultry by-product meal is not greatly different from that of meat meal or meat and bone meal, but it is somewhat lower in calcium and phosphorus than the mammalian products. With respect to feeding studies with swine, very little research has been done with poultry by-product meal.

Hydrolyzed Feather Meal

Feather meal has a similar composition as poultry feathers. This product is very high in protein (85 percent crude protein), but the quality of the protein is poor due to the high content of cystine relative to the other amino acids. Hydrolysis of the feathers is required to break the many sulfur bonds and release the amino acids. Even then, the apparent and true ileal digestibility of lysine and other amino acids is low compared with other rendered products. Much of the feather meal goes back into poultry feeds. Some research has shown that swine can use a limited amount of hydrolyzed feather meal in their diets, but use in the swine industry is relatively uncommon. Chiba (2001) has reviewed several research studies with pigs that involved the feeding of hydrolyzed feather meal.

Fish Meal

Fish meal is officially described as the clean, dried, and ground tissues of undecomposed whole fish or fish cuttings, either or both, with or without the extraction of part of the oil (AAFCO, 2006). Fish meal is an excellent protein source for pigs; however, the high cost of fish meal in the United States limits its use in most diets. The major producers of fish meal are Peru and Chili. Most of the fish meal used in swine feed is used in starter diets for weanling pigs. Fish meals are quite variable in composition, depending on the type of fish used and the type of processing methods. Some meals are made from residues and others are made from the whole fish. Menhaden fish meal is a high-oil fish meal and is the one most commonly used in starter diets. Inclusion of select menhaden fish meal or fish solubles in starter diets has been shown to improve performance of early-weaned pigs in several studies (Stoner et al., 1990; Seerley, 1991). Certain long-chained fatty acids in fish oil can cause a "fishy" flavor in pork, so the level of fish meal should not exceed six to seven percent. In finisher diets, even lower levels can result in an undesirable "fishy" flavor in pork meat products.

Blood Products for Swine

Dried Blood Meal

Dried blood meal is very high in protein (85 to 90 percent) and in lysine (seven to eight percent). Some of the older methods used to dry blood meal destroyed much of lysine and some of the other amino acids and reduced palatability (Chiba, 2001); thus, blood meal was not used to any great extent in swine diets in the past. However, improved methods of drying, including ring drying and flash drying, results in a much improved product with a high level of available lysine and other amino acids (Parsons et al., 1985; Miller, 1990). Blood meal is very low in isoleucine, the first limiting amino acid in a corn-blood meal blend. Because of the high level of hemoglobin in blood meal, the iron content is very high (1,900 to 2,900 ppm; NRC, 1998).

Several studies have shown that properly dried blood meal is a good protein source when used at low levels in pig diets (Miller, 1990; Hansen et al., 1993; Kats et al., 1994). Generally, it is recommended that dried blood meal should be limited to one to four percent of the pig diet (Cunha, 1977; Wahlstrom and Libal, 1977; Miller, 1990), although higher levels (six to eight percent) have also been suggested (Seerley, 1991).

Dried Animal Plasma and Dried Blood Cells

Two relatively new products that are extensively used in prestarter and starter diets for early weaned pigs are made from blood from pig and cattle slaughter plants. The blood is treated with an anticoagulant (sodium citrate), stored under refrigeration, separated into plasma and blood cells, and carefully spray-dried. Spray-dried animal plasma is an excellent protein source for early-weaned pigs. Aside from its superior amino acid profile (Table 3), the high levels of globular proteins (including immunoglobulins) in dried animal plasma stimulate growth and feed intake during the critical postweaning stage. A recent study at the University of Kentucky (Pierce et al., 2005) verified that the immunoglobulins, primarily immunoglobulin G, are the major component in plasma that stimulates growth in early-weaned pigs. Furthermore, plasma from either cattle or swine blood seem to be equally effective in producing this response (Pierce et al., 2005). Spray-dried animal plasma, although relatively expensive, is now commonly used at levels of three to six percent in Phase I pig starters for the first one to two weeks following weaning. A review by Coffey and Cromwell (2001) summarized the value of this product in weanling pig diets.

Dried blood cells, the product that remains after plasma is removed from blood is also an excellent ingredient for pig starter diets. Generally, this product is used at levels of two to five percent in Phase II diets for weanling pigs, following the removal of the more expensive dried plasma from the diet. Blood cells are very high in lysine, but relatively low in isoleucine. In addition, the iron content of dried blood cells is quite high (2,700 ppm; NRC, 1998) due to the high concentration of hemoglobin in the product. A review of feeding studies with dried blood cells was written by Coffey and Cromwell (2001).

Steamed Bone Meal – A Mineral Source for Swine

Steamed bone meal is one of several mineral supplements that are used in the feed industry as sources of calcium and phosphorus. This product is made from bones cooked under steam pressure, then dried and ground. The calcium and phosphorus levels in bone meal are in the same ratio as found in bone (Table 6). Due to its higher cost and slightly lower bioavailability of phosphorus for swine (82 to 85 percent versus 95 to 100 percent for dicalcium phosphate; Cromwell and Coffey, 1993), steamed bone meal is not as commonly used as a phosphorus supplement for swine as mono- or dicalcium phosphate or defluorinated phosphate.

Rendered Animal Fats – An Energy Source for Swine

Animal fats are widely used in swine feeds. Rendered animal fats – inedible tallow, inedible grease, and poultry fat – represent approximately 60 percent of the fats and oils fed to livestock and poultry, whereas restaurant grease, vegetable oils, and fish oils make up the other 40 percent (personal communication, Ray Rouse, 2000, Rouse Marketing, Cincinnati, OH).

As mentioned previously, fats and oils represent a highly concentrated source of energy. As a result, the voluntary intake of feed by pigs is less when fat is included in the diet. This fact, coupled with perhaps a slight increase in growth rate means that feed conversion efficiency (or feed-to-gain ratio) is markedly improved when fat is included in swine diets. On average, every one percent inclusion of fat reduces the amount of feed required per unit of gain by pigs by approximately two percent. This means less feed handling by the producer. Table 10 shows typical responses of growing-finishing pigs to added fat in diets. In some instances, carcass backfat may be increased slightly in pigs fed fat.

The addition of fat to feed improves the physical properties of the feed. When feed is pelleted, added fat makes the feed easier to pellet. It also reduces wear and tear on feed handling equipment. Also, one of the major advantages of using fat in feeds is that it greatly reduces feed dust in mills and buildings housing swine. Since microorganisms tend to travel on dust particles, reduced dust means fewer respiratory problems in pigs raised in confinement buildings as well as handlers who work in the buildings (Curtis et al., 1975). Studies have shown fewer lung lesions in pigs raised in confinement buildings in which the feed contains three to five percent fat (Gordon, 1963).

Fat additions to lactating sow diets have been shown to increase milk yield, increase the fat content of milk, and result in increased survival and weaning weights of pigs (Pettigrew, 1981).

Table 10. Effects of Supplemental Fat on Performance of Growing-Finishing Pigs.

	Study 1[a]		Study 2[b]	
	Added Fat, Percent			
Item	0	5	0	6
--				
Daily gain, lb	1.68	1.77	1.93	1.99
Daily feed intake, lb	5.44	5.22	5.31	5.03
Feed/gain	3.24	2.95	2.75	2.53
Carcass average backfat, in.	1.20	1.31	-	-
Carcass 10th rib backfat, in.	-	-	0.74	0.76
Ham-loin percent	43.40	42.30	-	-

[a] Cromwell, 2002. Summary of five experiments, 88 pigs per treatment from 57 to 208 lb body weight. Research by the University of Kentucky and the University of Nebraska.
[b] Akey research, 2001. Courtesy of Ken Bryant, Akey Inc., Lewisburg, OH.

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INEDIBLE FATS, OILS, GREASE, AND TALLOW

HEARINGS

BEFORE

SUBCOMMITTEE NO. 1 OF THE

SELECT COMMITTEE ON SMALL BUSINESS

HOUSE OF REPRESENTATIVES

EIGHTIETH CONGRESS

SECOND SESSION

ON THE MATTER OF

INEDIBLE FATS AND OILS

Printed for the use of the Select Committee on Small Business

INDEX OF WITNESSES IN THE ORDER OF THEIR APPEARANCE BEFORE THE COMMITTEE

RENDERED PRODUCTS IN PET FOOD

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Summary

Globally, in 2005, pet food and products were a $53 billion industry—and the market is growing. In the United States, dog and cat food sales alone account for $14.5 billion with exports of nearly $1 billion. The global total for pet food and supplies for all pet animals is now approaching $40 billion annually. These rising sales are driven, in part, by increasing ownership of pets with more than 140 million dogs and cats and an estimated 200 million specialty pets, such as fish, pocket pets, and exotic animals. It is also moved by the trend that more people consider their pets as members of the family as demonstrated by everything from birthday and holiday celebrations, family photos, health insurance, burial plots, and preparation of special meals. Pet foods are now more than ever considered packaged goods that are co-mingled with other family food items. The top five pet food companies, over 65 percent of the market, are owned by household names like Mars, Nestle, Proctor & Gamble, Colgate-Palmolive, and Del Monte. Traditional retail outlets such as grocery and farm/feed stores have lost some market share to big-box mass market stores, warehouse clubs, and pet specialty stores, but grocery stores remain the largest outlet.

Pet food choices have become almost limitless with options for different price points, life-stage, shapes and sizes, package type, ingredient preferences, breed, size, and disease condition. Pet foods are also becoming more "humanized" and tracking human food trends. Nutrition research is showing that companion animals have some unique dietary requirements, e.g., arginine in the dog and cat, the aminosulfone taurine, and pre-formed vitamin A for the cat. Emerging nutritional benefits from omega-3 fatty acids, carotenoids, dietary fiber, mineral balance, and how meat proteins and fats are connected to optimal nutrition are actively under investigation. Rendered protein meals such as meat and bone meal, poultry by-product meal, and fish meal are almost universally used in pet foods. Generally, they provide high quality protein with a good balance of amino acids. Nutrient availability and (or) dietary utilization can be hampered by excessive heat treatment, dilution of essential amino acids with connective tissue, high levels of ash, and oxidation. Rendered fats and oils like tallow, lard, poultry fat, and fish oil provide a supplementary source of energy, flavor, texture, and nutrients in pet foods.

Balancing for essential and conditionally essential fatty acids has become a key driver for selection of specific fats in the diet. Application and oxidation issues are the most common challenges faced in their use. Much of the information for pet food ingredients has been gleaned from livestock and human nutrition research. There is a fundamental need to develop these databases specifically for pets in order to address their unique nutritional idiosyncrasies and to support this growing and

continually segmenting industry. Raw, fresh, human edible, and alternative protein sources are competing to supply the protein and fat needs in pet foods. Opportunities for various rendered ingredients especially those that are able to retain their species identity and maintain control over processing conditions while retaining nutrient quality, will be welcome.

The Pet and Pet Food Industry

Size, Growth, and Demographics

Globally, pet food and pet care product sales were nearly $53 billion in 2005 (Kvamme, 2006). In the United States, pet food sales totaled $14.4 billion in 2005 with 54 percent from dog and 32 percent from cat foods (Euromonitor, 2005) with an annual expected growth of three to four percent. Exports were just over $900 million in 2005 (U.S. Bureau of the Census Trade Data, 2006). Pets live in 70 percent of American homes, with 15 percent of those homes owning both a cat and dog (Pet Food Institute, 2003).

Specifically, there were an estimated 81.4 million cats in 37.7 percent of households and 63 million dogs in 43.5 percent of households in the United States in 2005 (Euromonitor, 2005). Other species of pets, defined as specialty pets, such as rodents, reptiles, rabbits, ferrets, exotic birds, and fish account for almost 200 million more household pets. In addition, to many people the horse is considered a pet with the total number of horses in the United States at 9.2 million and with affiliated goods and services accounting for an estimated $39 billion (American Horse Council, 2002).

More people are considering their pets as members of the family by celebrating their birthdays, including them in holiday rituals, providing them with special television programs, including them in family photos, and preparing special meals for them. Many pet owners spend large sums of money for veterinary care, pet health insurance, medications, cremation, and even burial. An increasing number of pet owners are adding pets in their wills and treating them as a second family after children are grown and have left the home, spoiling their pets with special and premium foods, treats, and toys as if they were wayward grandchildren. But all is not frivolous excess; pets are also becoming increasingly valuable as service animals, as therapy aids, and as an emotional and stressful release in an increasingly complex world. There is a bond and interdependence between man and companion animals that will not soon diminish.

Pet Food Companies

The pet food industry in the United States is dominated by five major companies that account for over 65 percent of the market. These big five are owned by multi-national conglomerates that have a primary emphasis in personal care, dry goods, and (or) other consumables (Kvamme, 2006). These companies include: Mars (Pedigree, Whiskas, and Royal Canin), Nestle (Purina, Friskies), Proctor & Gamble (Iams, Eukanuba), Colgate-Palmolive (Hills Science Diet, Hills Prescription Diet), and Del Monte (9-Lives, Gravy Train, Kibbles 'N Bits, Nature's

Recipe, Meow Mix, and Milk Bone). The remaining 35 percent of the market is made up of pet food-exclusive companies, numerous regional brands, and new smaller brands and companies. Some of these latter are supplied by a strong cadre of private-label pet food manufacturers and toll-packers. Consolidation, mergers, and acquisitions continue to play a part in the evolution of the industry; however, unlike other food sectors, this is not the only avenue left for growth. In short, the pet food industry is a very dynamic, growing, and maturing industry where new ideas from non-traditional sectors will continue to emerge and new market opportunities will be available.

Channels to Market

The retail availability of pet foods has expanded across a number of platforms. Big-box mass market stores, warehouse clubs, and pet specialty stores have become market channels in addition to traditional outlets such as grocery and farm/feed stores. Estimated market share of each category in 2002 was grocery (37.4 percent), mass market (16.4 percent), pet specialty (17.2 percent), farm/feed (5.4 percent), vet/kennel (5.0 percent), and other (18.6 percent) (Knudson, 2003). Alternative channels to market via non-traditional retail, direct marketing, catalog, and web-based sales of pet foods are also becoming prominent. Sales through these alternative channels accounted for approximately 12 percent of the total market with annualized growth in 2004 of just over eight percent (Packaged Facts, 2006). The activity in this segment is quite fragmented, generally strong, and expected to continue growing.

Trends in Companion Animal Products and Feeding Practices

There are a number of different factors that motivate consumers to choose certain foods for their pets. Some are driven by cost, some nutrition, some performance, and still others by their pet's preference. The choices seem to be almost limitless. Today there are foods for different life-stages (e.g., maintenance, gestation/lactation, growth; or puppy, kitten, adult, senior), price points (e.g., value, premium, super premium), formats (e.g., kibbles, soft-moist, wet, raw), and packaging styles (e.g., can, retortable pouch, stand-up pouch, paper or plastic bag, re-sealable bag, tray). Pet owners are deciding on foods according to their own ingredient biases (i.e., natural, wheat-free, hypoallergenic), the breed and size of pet they own (e.g., toy breed, large breed, Dalmatian, Persian), nuisance factors (e.g., hairball, multi-cat), and their pet's predisposition to disease (e.g., joint health, senior, struvite, weight loss, renal disease). Pet foods are also becoming more "humanized" (i.e., gourmet, heat and eat, fruits and vegetables) and are tracking human food trends (e.g., raw, organic, holistic, low-carb). While the number of brands and market segments seem almost limitless and the differentiation unstoppable, there are some general principles by which all are judged. These are palatability, digestive and stool consistency, and the influence of the diet on the pet's general appearance (i.e., skin and coat) and behavior (i.e., vigor).

With this much variety, finding raw materials with the right mix of name appeal, nutrition, functional properties, availability, and cost can be a big challenge for the pet food manufacturer, and this challenge will continue to increase. In many cases, the ingredient statement is driving the decision-making process. This is probably best exemplified in the promotion by some pet food companies that their foods are made with "human-grade" ingredients. While no definition exists for such a claim, it is telling about the humanization underway in the pet food market and the lengths that manufacturers will go to meet the pet owner's perception of quality.

Companion Animal Nutrition

Dog and Cat Nutrition

The dog is not a furry pig or an oversized rat, nor is the cat a small dog. While some similarities exist among the species, from a purely nutritional perspective, requirements of the dog and cat take on some unique differences. While these differences are briefly summarized below, the reader is referred to recent texts and literature reviews specifically on dog and cat nutrition and digestive physiology for a more thorough understanding of the topic (Smeets-Peeters et al., 1998; Case et al., 2000; Morris, 2002; Zoran, 2002; NRC 1985, 1986, and 2006).

The dog, while considered to be an omnivore, tends very closely to the carnivorous dietary and nutritional inclinations of the cat. The cat is considered to be an obligate carnivore and has a very substantial requirement for high quality proteins and meat-predominant amino acids. For example, besides the standard array of amino acids, dogs and cats have a dietary requirement for arginine. Cats have an elevated requirement for sulfur amino acids like methionine and a dietary requirement for the aminosulfone taurine. Interestingly, it has recently been discovered that some dogs may require dietary taurine as well (Fascetti et al., 2003). Further, both dog and cat commercial diets are often limiting in tryptophan unless adequate amounts of meat proteins are provided.

In addition to a requirement for linoleic acid, like the dog and many other species, cats also require arachadonic acid. More recently it has been observed that cats and dogs have a conditional requirement for dietary forms of omega-3 fatty acids such as eicosapentaenoic and (or) docosahexaenoic acids. Cats also have a requirement for pre-formed vitamin A as they lack the enzyme systems necessary to cleave β-carotene into vitamin A. Ironically, both cats and dogs have been reported to mount an enhanced immune system response when supplemented with carotenoids such as β-carotene and lutein (Chew and Park, 2004). Cats require dietary biotin, but dogs do not, and neither have a dietary requirement for inositol or vitamin C.

Neither the dog nor the cat has a true requirement for dietary carbohydrates, but both species have a need for metabolic glucose. This need for metabolic glucose can be met through conversion of amino acids in the gluconeogenic pathway. The cat, due to its carnivorous make-up, is in an almost constant state of converting dietary protein to glucose through this pathway.

Though carbohydrates are not absolutely required, they can be utilized in the diet if properly cooked, albeit more efficiently by the dog than the cat. Most of the dietary carbohydrates come from grains and, to a limited degree, tubers. These carbohydrates are also an essential part of making the kibble. While dogs and cats do not require fiber, there is growing evidence that adding moderate levels (three to seven percent) of soluble and (or) fermentable fiber provides benefit to the animal's lower gastrointestinal health, and for the owner this results in more consistent and less odorous stools.

Besides the standard requirement for macro and trace minerals in the diet, mineral nutrition can become an issue for dogs, and especially cats, if the animal is predisposed to renal and (or) urinary tract diseases. Specifically, elimination of excess dietary minerals by the pet can exacerbate conditions such as renal failure and urolithiases. For this reason, low ash, low magnesium, and low phosphate diets have been developed. This area will likely continue to evolve as we better understand the relationship between excess mineral nutrition and disease etiology.

Beyond meeting nutritional deficiencies, research is active in areas such as athletic and working dog nutrition, obesity and diabetes, aging, organ failure (e.g., renal disease), inflammatory diseases like osteoarthritis and dermatitis, and many, many others. Nutrition research for the canine athlete is an area of growing interest. Working dogs in occupations such as search and rescue, bomb sniffing, drug sniffing, guiding, and herding must have nutrition that supports their purpose in order to perform at optimum efficacy. Sporting dogs such as sled dogs, racing greyhounds, upland game hunting dogs, and agility dogs have tremendous nutrient demands at peak activity. This is nutrition well beyond the minimum. From this research it has been learned that the canine athlete has a tremendous oxidative capacity and benefits from a diet that includes animal-based proteins and fatty acids from animal and marine sources (Reynolds, 1996). Besides the benefits to the dog and (or) cat, a great deal of companion animal nutrition research has been beneficial to human nutrition and medicine as well.

Required versus Optimal/Needs versus Wants

The nutrient requirements reported in the 1985 National Research Council *Nutrient Requirements of Dogs*, the 1986 National Research Council Nutrient Requirements of Cats, and the recently released 2006 National Research Council *Nutrient Requirements of Dogs and Cats*, as well as the Association of American Feed Control Officials (AAFCO) 2006 nutrient profiles for dogs and cats are the guidelines to meet when formulating diets. Each is published with overages factored in to account for the wide variability among animals and dietary ingredients. Further, most pet owners are more concerned with issues of longevity and health than with saving a fraction of a cent to meet only the minimum. Thus, pet foods are not formulated to the "minimum" as is customary in livestock feeds; rather, most are "optimized" to some level of nutritional support that meets or exceeds the pet food company's perceived notion of "the best nutrition" for the dog or cat. Vast differences of opinion occur among the companies due to their own research findings, nutritional philosophies, and investment in a certain franchise "position." As just one example, there is a great disparity about whether a senior dog should be fed a low, medium, or high amount of protein. Each company has a strong opinion backed by internal and external research to support their particular position, but little consensus has yet been reached—much like in human foods where brands such as Weight Watchers, Jenny Craig, and the Atkins Diet compete.

Other Companion Animal Species

Horses, rabbits, ferrets, rodents, birds, and numerous other companion animal species are fed commercial foods. Aside from horses and rabbits, these are considered specialty pets. Formulation of diets for these species, if it is fair to lump them into one category, is mostly driven by convenience and ingredient bias rather than lowest cost. While cost of production for performance horses and production rabbits may be a cost of production issue, for those animals considered to be pets it is not as much of an issue. Horse and rabbit feeds are primarily vegetative in nature (i.e. a grain, protein, fat, mineral, and vitamin mix intended to complement a forage diet). The ferret is an exception in this group. Nutritionally it is very much like the cat and has a very high requirement for quality proteins and little to no fiber. Thus, rendered ingredients play a prominent part of its diet. Numerous pocket pets or rodents (e.g., rats, mice, gerbils, hamsters, and guinea pigs) are found in homes today and their commercial foods are most often based on grains and vegetable proteins. Formula considerations for these pets are most often based on nutrient recommendations for laboratory research animals. Only a limited amount of rendered ingredients are used in these rodent diets. Exotic and pet birds, such as the macaw, parrot, finch, etc., are often offered commercial foods. They have nutrient requirements much like those of domesticated fowl (i.e., chicken and turkey), without the need for cost efficiency. The issue, like that for dogs and cats, is on longevity and health. The diet must be visually appealing to the owner and the bird and be nutritionally sound. Pigments (e.g., xanthophylls) are often added to maintain the plumage coloration. Rendered ingredients are not typically part of the ingredient mix for these birds.

General Degree of Research

Compared to funding for livestock or human nutrition research, dog and cat nutrition is a secondary consideration at best. For the most part, there is no direct governmental funding for companion animal nutrition research. Most of the research has been funded either by pet food companies, ingredient suppliers, or special interest groups such as breed associations and foundations. Indirectly, funding has been provided through interest in using the dog and (or) cat as a research model for human nutrition. This has proven beneficial in a limited number of cases. Activist groups have had a negative influence on the level of bureaucracy necessary to initiate research and thus funding for companion animal research has diminished. This has not occurred as a result of financial inability, but rather the "fear" of reprisal from radical groups and how they may distract from public relations and advertising campaigns of today's multi-conglomerate pet food companies. The offset to this has been a general increase in funding from ingredient suppliers and trade groups. While substantial progress has been made in the past several years, there continues to be a need for fundamental research regarding ingredient composition, nutrient availability, and the effects on the two when combined in a processed pet food (Fahey, 2004).

Pet Food Production and Processes

To talk about pet foods without a brief discussion of the processes by which they are made would only give a fraction of the picture regarding pet foods and nutrition. Today, many pet foods are processed not just for the nutrition of the pet, but for their convenience to the pet owner as well. This convenience is the culmination of several factors: (1) foods that are nutritionally balanced by experts for pet owners who may or may not have the knowledge of dog/cat nutrition themselves, (2) foods in a form and format that is easy to use, (3) foods that are virtually waste-free, and (4) foods that minimize the hassles of storage, spoilage, infestation, etc. In many respects, the popularity of modern pet ownership is the product of very successful, wholesome, and convenient commercial pet foods.

There are three basic formats in pet foods and treats: baked, wet canned (including retort packed), and extruded. Except for foods fed to small and exotic pets and companion horses, little to no pelleted or granular meal commercial pet foods are sold. Some of the first pet foods sold commercially (ca. 1860) were produced by a baking process similar to that still used for cracker and biscuit production today (Corbin, 2003). The process involves mixing stiff dough that is based primarily on wheat flour. The dough is pressed into "shape" on a rotary mold. The molded pieces are conveyed through a long tunnel-oven on a chain belt and cooked by direct application of heat. The resulting product at the end of baking is a dry (hot) brittle biscuit, pellet, or wafer. Producing a product that will hold its shape depends on a high amount of grain flour like wheat, which contains gluten protein. The gluten protein acts as the glue that holds the shape of the piece and helps it resist breaking. Through the cooking process, the piece does not expand, but some texture is created by the cross-linking of proteins. The process, relative to other standard pet food production methods, is slow and costly. To the positive, baking does create baked flavors that most dogs appreciate; but, generally speaking, baking does not produce cat-friendly foods. The process can use either fresh/frozen meats or meat protein meals and (or) vegetable protein meals as the protein source.

Canned meats and fish were the route by which several of today's prominent pet food companies got their start. The first canned pet foods were introduced in the 1920s and have been a prominent part of the industry ever since. Hermetically sealed retorted pet food in a can, pouch, or tray provides a convenient, easy to serve, appetizing meal and (or) treat to many dogs and cats, though the term "canned" is not used much currently in marketing. Detractors cite the cost penalty of purchasing high amounts of water, the potential for spoilage, and dental build-up as negatives. Conversely, canned foods are commonly recommended as part of a urolithiasis (urinary tract obstruction) treatment regime in cats in order to get them to consume more water. Canned pet foods rely on fresh/frozen meats and limited amounts of grains. Small amounts of animal fats are used, but only under special circumstances are rendered meals employed.

In the mid 1950s, the first extruded pet foods were produced. This was a technological breakthrough for the pet foods of that day which were loose granular "meals" of inconsistent quality and nutritional content. The extrusion process allowed for the forming of a textured piece that was readily accepted by the dog and simultaneously held the nutrients together so that the full complement of intended nutrients was provided in each bite. It also provided cooking (gelatinization) of the starch in the grains (Riaz, 2003), which improved digestibility and decreased the intermittent diarrhea and flatulence associated with undigested starch in the lower bowel. In addition, the process served to sterilize ingredients that might otherwise be heavily inoculated with pathogenic bacteria. The drawback was the effect that the additional cooking had on proteins, vitamins, and other heat-labile nutrients, especially ingredients like rendered protein meals that had already been heat processed once (Murray et al., 1998). Additionally, these previously heat-processed ingredients lost most of their functional properties and did not contribute to the expansion of the piece upon exit from the extruder. To compensate, specialized starches, vegetable proteins, and (or) spray-dried proteins may be added to achieve the form, texture, and density desired. The other negatives have been resolved by corrective formulation, special protection technologies (e.g., encapsulation), selection of specialized ingredients that resist the effects of extrusion processing (e.g., phosphorylated vitamin C), and more refined processing controls. Rendered protein meals often account for a majority of the protein used in extruded pet foods, whereas fats, oils, flavors, and other heat-labile ingredients may be surface applied post-extrusion and drying.

Most extruded pet foods are sold at a moisture content of less than 12 percent; however, there is a significant market for higher moisture products (20 to 28 percent moisture). These soft-moist and (or) semi-moist foods are cooked as a dough prior to extrusion and simply "formed" by the extruder. They are not dried to control microbial growth, but rather, fungal growth is controlled by managing water activity with humectants and mold-inhibitory preservatives (Rokey, 2003). Humectants like dextrose, propylene glycol, glycerin, and emulsifiers (e.g., lecithin) tie-up water preventing its use by mold spores. Organic acid preservatives like potassium sorbate, sorbic acid, benzoate, and others have been shown to be very safe and inhibit mold growth at very low doses. In addition to fresh/frozen meats, rendered meals and animal fats play a prominent part of these intermediate moisture products.

Utilization of Rendered Ingredients in Pet Foods

Market, Volume, and Trends

No easily obtainable figures are available to provide specifics on the amount of rendered products used in pet foods. However, through some estimates and assumptions it may be possible to determine a reasonable volume. If one were to assume the average cost per pound for all pet food sold was $0.60/lb, then based on total sales of pet food ($14.5 billion in 2005), the total tons produced each year would be in the neighborhood of 12 million. If rendered ingredients were 20 percent of these 12 million tons across all products (protein meals, fats, other), then the pet food industry would consume around 2.4 million tons per year. This represents roughly 25 percent of the total U.S. production of rendered materials during the same period (Swisher, 2005). This indicates substantial reliance and connectedness between the pet food industry and the rendering industry. This dependence for the pet food industry is for a vital supply of animal-based proteins and fats to meet the demands of their customers; for the rendering industry, it is an important outlet for their products with a tremendous value-added upside. Increasing the understanding of opportunities and limitations between the two industries will provide increased value to both, with the pet owner and their pets as the ultimate winners.

Protein Meals

Pet food companies write very specific purchasing requirements for their ingredients, including rendered products. AAFCO definitions are the "starting place" for these specifications.

<u>Meat and Bone Meal and Meat Meal</u>: Meat and bone meal has been a staple protein in pet foods and is still used by a great many today. However, its popularity has declined in recent years due to several issues. Probably the biggest issue is that meat and bone meal is no longer considered "label friendly." What this means, specifically, is that the nomenclature is too generic for today's discerning consumer. Consumers have been taught to distrust something simply called "meat." A strictly beef or strictly pork meat and bone meal would likely be more acceptable to consumers, but these were not commonly available until recently. These meals are now often available for a higher price and are widely used in pet food. Adding to the challenges are its association with livestock feed rather than human food, recurring issues with bovine spongiform encephalopathy (BSE), inspections and record keeping for all ruminant meats, and concerns with disease outbreaks such as foot and mouth disease. These issues continue to place downward pressure on the popularity of meat and bone meal.

Nutritionally, meat and bone meal remains a good source of animal-based protein with a fairly consistent protein level of 50 percent (Parsons et al., 1997; Pearl, 2004). This is an adequate level for traditional pet food diets with protein levels between 18 percent and 26 percent. Like many other animal-based proteins, methionine, cystine, and the total sulfur amino acids are likely the first to become limiting. Fat composition ranges from 10 percent to as high as 25 percent, depending upon supplier. The fatty acid profile can vary some and resembles the composition of the animal from which the meal originates, e.g., beef fatty acids are proportionally more saturated than pork fatty acids. Incidentally, one will often find measurable quantities of omega-3 fatty acids in meat and bone meal of ruminant origin. Due to the more saturated nature of the fatty acids in meat and bone meal it is inherently more resistant to oxidation than many of the other rendered meat meals. The higher level of ash (around 25 percent) in meat and bone meal can be a challenge to formulate with versus some other protein meals. The AAFCO specifications indirectly restrict ash by setting limits on calcium and phosphorus levels and their ratio. Typical levels of calcium and phosphorus in meat and bone meal are 7.5 percent and 5.0 percent, respectively, and they are readily available. However, this level of minerals becomes problematic when formulating higher protein (greater than 30 percent) and low ash foods like those for cats.

Increasing levels of ash in meat and bone meal have not been shown to lower protein digestibility (Johnson et al., 1998; Shirley and Parsons, 2001). However, this may not be directly due to the effect of ash on digestibility (Johnson and Parsons, 1997), but rather due to the amount and quality of connective tissue present. Low quality collagen affects protein quality where a lower proportion of essential amino acids and a higher proportion of nonessential amino acids such as hydroxyproline (Eastoe and Long, 1960) may be to blame for lower digestibility. The requirement (AAFCO) for pepsin indigestible residue of less than 12 percent partially serves to control this. Processing systems and excessive temperatures have also been shown to negatively affect the amino acid digestibility of meat and bone meal (Wang and Parsons, 1998; Batterham et al., 1986). But on the whole, the digestibility of meat and bone meal for companion animals is comparable to that of lamb meal and poultry by-product meal (Johnson et al., 1998). In dog and cat diets, meat and bone meal has not been reported to negatively affect the intestinal flora, stool consistency, or stool volume. However, beef is often blamed for food hypersensitivities so meat and bone meal is one of the first ingredients removed in an “elimination” diet regimen. Regardless of this special circumstance, the palatability, acceptability, and utilization of meat and bone meal-containing diets by both dogs and cats are quite good.

Lamb Meal: Lamb meal has been a popular ingredient in dog and cat diets for the better part of the last 15 years. Initially it was considered a novel ingredient in diets for animals with food-related allergies (hypersensitivity). Lamb meal and rice diets were some of the fastest growing products offered in the pet food aisle—to the point that lamb meal supply was outstripped by the demand. “Lamb meal analogs” made of other protein meals were rumored to have entered the market, but tight controls due to BSE and scrapie issues and new DNA typing technology (Krcmar and Rencova, 2003) have all but made this an issue of the past.

Some domestic lamb meal is available; however, much of the lamb meal used in pet foods is derived from the lamb meat industry in Australia and New Zealand. Most of this lamb meal is rendered in a “low temperature” rendering process. Theoretically, the quality of the meal may be better because heat damage to the proteins is minimized. However, data to support or refute this hypothesis are lacking. Lamb meal is a species-specific category of meat meal, but, very little data are available in the public domain on the ingredient itself. Analytically, lamb meal mirrors the nutrient composition of meat (and bone) meal. Likewise, the protein quality of lamb meal is reported to be roughly comparable to meat and bone meal and about 75 percent of chicken by-product meal (Johnson and Parsons, 1997; Johnson et al., 1998). In the study by Johnson et al. (1998), ileal digestibility of the essential amino acids lysine and threonine and the nonessential sulfur amino acid cystine were quite low in the lamb meal-containing diets. This may be due to contamination of the lamb meal with high levels of wool. Wool is high in sulfur amino acids like cystine, but its nutritional availability is low. This poor availability of cystine, a taurine precursor, may explain the taurine-associated dilated cardiomyopathy in certain breeds of dogs fed an otherwise nutritionally complete diet based on lamb meal and rice (Fascetti et al., 2003).

Effects of lamb meal in dog or cat diets on palatability, shelf-life, or appearance are lacking in the literature. Anecdotally, lamb meal is not considered to be the most palatable of the meat meals due to the "mutton-fat" aroma. Cats prefer other meat meals over lamb meal. Concerns about rancidity and short shelf-life of lamb meal products may result from the long journey that it takes from "down under" and (or) prooxidants inherent to rendered lamb. In addition, high levels of lamb meal in a product can lead to a gray color. If the meal contains appreciable levels of contamination from wool, complaints about "hairs" may be heard from customers, especially in baked products like biscuits and treats.

Poultry (By-product) Protein Meals: Poultry protein meals are a popular, high quality protein source used in pet food. The pet food industry consumes an estimated 23 percent of the rendered poultry proteins produced each year (Pearl, 2003). However, the ability to make one homogenous statement about this ingredient ends there. Due to some inconsistent rules regarding ingredient nomenclature, an evolving pet food customer base, and pressures within the poultry industry, a series of names and classifications of poultry protein meals has emerged. To start, the rendered poultry proteins are defined by AAFCO differently than the meat meals. This has created some controversy in the pet food industry and resulted in a whole layer of confusion and misdirection for the consumer. By definition, poultry by-product meal (Section 9.10) differs from poultry meal (Section 9.71) only by the inclusion of "heads, feet, and entrails" (AAFCO, 2006). Further, they can be labeled specific to their "kind" and many renderers have accommodated. Thus, there are numerous products available in the market under this umbrella: poultry by-product meal, chicken by-product meal, chicken meal, turkey by-product meal, and turkey meal. No duck or goose meal is known to have been developed as of this writing. Adding to this confusion, there are several different grades of rendered poultry products available. "Feed grade" poultry by-product meal is seldom used in pet food because it contains a higher level of ash and lower protein content. Standard pet food grade poultry by-product meal contains less than 14 percent ash and low-ash poultry meal and (or) poultry by-product meal contains less than 11 percent ash. The latter is available in limited quantities at a premium price and typically reserved for low-ash cat formulas. One further split has been the request by certain customers for poultry protein meals that are preserved against oxidation by natural compounds (natural antioxidant systems) rather than the traditional synthetic antioxidants.

Among these various names, grades, and inferences regarding quality or lack thereof, there is very little in the way of direct comparisons between "meal" and "by-product meal" available in the literature. Of studies that are available, the results are mixed. For example, Bednar et al. (2000) reported that protein digestibility was better for poultry meal than for poultry by-product meal. However, protein quality of pet food grade chicken meal did not differ from chicken by-product meal in a chick assay (Aldrich and Daristotle, 1998). From this report, data on individual chicken pieces indicated that the protein quality of feet, bone, and cartilage was poorer than other parts utilized in rendered poultry by-product meal. This appears to be independent of ash level (Johnson et al., 1998; Johnson and Parsons, 1997; Yamka et al., 2003) and would indicate that regardless of whether or not the "by-product" qualifier was present or not, the amount of cartilage and connective tissue had a bigger impact on the quality of the protein. Adding to this, the more extensively the protein meal is processed in rendering, the further the quality can be eroded (Wang, 1997). To make matters worse, there is substantial variation in the nutrient composition of poultry protein meals (Locatelli and Hoehler, 2003). Controlling this variation becomes something that the pet food company must actively manage to assure a consistent finished product. Most manage this by establishing strong relationships with select suppliers.

In general, poultry protein meals are well utilized by dogs and cats and make up the biggest share of proteins in many of the premium pet foods. The fatty acid profile complements dog and cat nutrient requirements very well. Additionally, they contain an enriched level of the essential linoleic acid. Palatability of poultry protein meals is very good in both dogs and cats and in many instances serves as the standard by which other ingredients are measured.

<u>Turkey (By-product) Protein Meals</u>: Turkey protein meal-containing pet foods are becoming more popular, thus the ingredient warrants a separate description. However, nutritional information on rendered turkey is not easily obtained nor is the ingredient constantly available. Most of the turkey to be rendered is lumped in with chicken then processed and labeled as poultry (by-product) meal. There are only a few companies that produce or trade turkey protein meals. Turkey protein meals are a slightly darker golden brown color with a "richer" aroma when compared to chicken protein meals.

The nutrient composition of turkey protein meal is usually considered to be somewhat better than meat and bone meal, which has allowed some pet food companies to use turkey protein meal as a modest upgrade to meat and bone meal as a leading protein source. The nutrient profile of turkey meal is slightly less favorable than that of pet food grade chicken protein meal. For example, turkey protein meal ranges from 62 to 65 percent protein and ash level ranges from 18 to 25 percent, whereas, pet food grade chicken protein meal typically exceeds 65 percent protein with less than 17 percent ash. This may be due to the more efficient removal of meat and other soft materials for the human edible and (or) hot dog markets, i.e. 78 percent of turkey ends up in the grocery meat case versus 72 percent of chicken. Thus, the raw material finding its way to rendering is, in general, lower in protein and fat and higher in bone (i.e., ash). The amino acid and fatty acid profile of turkey meal is very similar to that of chicken meal. Contrary to conventional wisdom, the tryptophan level in turkey meal is not greater than that found in chicken meal so it may not have a sleep inducing or calming effect as is so often rumored. No direct feeding tests of turkey meal to dogs or cats are available in the literature. However, *in vitro* digestibility and amino acid profiles are similar enough to chicken by-product meal to suggest that turkey meal nutritional utilization would be similar. Palatability, acceptability, utilization, and stool quality of turkey protein meal-containing diets is very good when fed to either cats or dogs. However, the ingredient does not appear to have any unique nutritional features from that of chicken or poultry protein meals aside from its name in marketing campaigns.

Fish Meal: Fish meal is an increasingly common ingredient in pet foods. While there are a few exclusionary diets in which fish meal is the feature protein ingredient, by and large, fish meal is added only secondarily as a protein source. Fish meal, relative to most other protein meals, has a high level of protein with a correspondingly high protein digestibility. Typical fish meals contain upwards of 19 percent ash which can be problematic for cat, puppy, large breed, or therapeutic diets. Besides being a source of high quality protein, fish meal also contains about eight to 12 percent fat which is rich in omega-3 fatty acids including eicosapentaenoic acid (EPA; 20:5n3) and docosahexanoic acid (DHA; 22:6n3). Thus, in most diets its primary purpose is to serve as a vehicle to deliver fatty acids. There are indications that these longer chain omega-3s may be needed. While the more direct method for the inclusion of these fatty acids would be through fish oils, the use of fish meal serves an additional purpose. Stabilizing the more highly unsaturated oils, like fish oil, can be quite difficult, especially when surface applied to pet foods. However, for reasons not fully understood, the volatile omega-3 fatty acids found in fish meal seem to be easier to stabilize in a pet food application than those in the surface applied oil. This is doubly true for those companies attempting to utilize marine oils simultaneous to claiming to be naturally preserved. For insurance and to comply with maritime laws, antioxidant preservatives may be used when the situation warrants.

The predominant fish meals available and used by the pet food industry in the United States are Gulf and Atlantic menhaden meals, capelin and herring meals from the North Atlantic, and mackerel meal from Chile. Freshwater fish meals, such as catfish from the Mississippi delta region, are also found in some pet foods. There can be substantial compositional differences in the fatty acid profile, stability, and ash levels among the many fish species (Palstinen et al., 1985; Pike and Miller, 2000). Further, the different fish meals are not necessarily interchangeable as they can dramatically affect palatability. The cat seems to be more sensitive than the dog to changes in the origin of the meal. There are very little data in the literature on the nutrient utilization of fish meal by dogs and cats. This is one case where utilizing nutrient availability data from aquaculture and swine is probably appropriate and applicable. Results from these species would suggest that fish meal is a very high quality protein source for cats and dogs with few negatives aside from compositional considerations like ash and stability.

Fats and Oils

In the diet, fat provides a concentrated source of energy, essential fatty acids, a route for fat soluble vitamin absorption, texture, aroma, and flavor. Fat, in and of itself, will increase the palatability of a diet up to a certain point in cats, and without limit in dogs. Addition of fat to the diet to meet label guarantees will often reach 10 percent of the formula. While energy and essential fatty acids are a concern nutritionally, maintaining food stability is a primary issue. Dietary oxidized fat has been associated with lower metabolizable energy values (Pesti, 2002), slower puppy growth, suppressed immunity, and lower dietary and serum linoleic acid concentrations (Turek et al., 2003). Choosing the right fat source and method to retain freshness are important.

Tallow: Tallow was one of the original fats applied to early commercial pet foods and there are several companies that still use it today. Most of the animal fat sold as tallow comes from federally inspected animals and facilities and has regulated quality and composition, something many other fats and oils cannot claim. Although other animal fats can be found in tallow, it is, practically speaking, derived from beef because it is a dominant meat in North America and Europe. Because of the saturated nature of the fatty acids (i.e., saturated fats are solid at higher temperatures) in fat from beef animals, it most often meets the definition of tallow—a titer of 40, or a melting point of 40ºC.

For many, the "harder" fats like tallow carry a poor nutritional connotation due to the negative association of saturated fats with transport lipoproteins, cholesterol, and coronary heart disease. This is really a human nutritional issue as coronary heart disease is not a prevalent health concern for dogs or cats. Dogs and cats are considered to be "HDL species" meaning they have a preponderance of the "good" HDL in their circulation. The fatty acids in beef tallow are about 50 percent saturated, with a small amount of linoleic acid (LA; 3.0 percent) and linolenic acid (ALA; 0.6 percent) and none of the longer chain omega-3 fatty acids (EPA or DHA). Mutton tallow has a similar level of saturation (47 percent), but with a slightly higher level of LA (5.5 percent) and ALA (2.3 percent). Since beef tallow is considered a "saturated" fat and is a common fat source encountered by dogs and cats, it often serves as the baseline or "control" treatment in fatty acid research.

Tallow digestibility is high (i.e., apparent fat digestibility of 97 percent or better) and comparable to other fat sources like chicken fat and lard. Among the different fat sources, beef tallow is well known for being one of the more palatable. Mutton or lamb tallow is not quite as palatable, possibly due to the aroma. Animal fat from tallow has even been shown to benefit "olfactory acuity scores" (Altom et al., 2003), which may translate to beneficial effects during hunting. Tallow is also considered to be more shelf-stable than less saturated fats and requires less antioxidant addition to achieve shelf-life goals. Tallow also contains a small level of conjugated linoleic acid that is now showing promise as a potent natural element in the fight against cancer. Tallow is a good "platform" to provide energy and flavor, but a balanced diet may require a complementary oil enriched with linoleic acid and (or) omega-3 fatty acids.

Lard/Choice White Grease: Lard and choice white grease are also common animal fats used in pet foods. They are derived primarily from pork and are most often labeled generically as animal fat. Like tallow, most of the lard used in pet food comes from federally inspected facilities and a portion of the available supply is human edible. Thus, pet food companies may partially compete in the human edible market for this ingredient. Due to its abundance, the cost is not typically beyond that of other fat sources.

The proportion of essential fatty acids such as linoleic acid can range between 3 percent and 16 percent (Firestone, 1999). To some degree, this can be influenced by the diets the pigs were fed prior to slaughter. Lard is relatively easy to stabilize due to a preponderance of palmitic and oleic acids. Lard and choice white grease are semi-solid to viscous liquid at room temperature. It can solidify during colder weather so transportation and handling can be an issue. Further, it must be coated on foods when they are hot in order to get adequate penetration. Digestibility of lard is high and comparable to other fats. Palatability is good in both cats and dogs.

Poultry Fat: Poultry and, more specifically chicken fat, has become a very popular fat source in pet foods. Poultry fat use in pet foods is probably more than 10 percent to 20 percent of the 888 million pounds of poultry fat that was produced in 2003 (U.S. Census Bureau).

There are several different sources by which poultry fat is obtained: rendered, rendered-refined, and low-temperature blanched. They differ with regard to quality, consistency, and cost, and they may differ ever so slightly in minor nutrients (e.g., carotenoids), palatability, and stability. Stabilizing chicken fat in bulk storage is not a big challenge; however, when added to pet food, stability can become an issue. The potency of preservative application must consider the food and its handling and packaging. Further, the condition of the fat at the time preservatives are added is critical, i.e., the lower the moisture content, peroxide value, free fatty acid level, and impurities, the better. The trade-off is cost, availability, flavor, and aroma.

Chicken fat is a good source of the essential linoleic acid (19.5 percent; USDA-ARS, 2006) and about double that of lard. Chicken fat fits very well in dog and cat diets because it is well accepted by both, having a flavor that is preferred over many other fats. Chicken fat is comparable to other fat sources such as tallow or pork fat in digestibility and overall contribution of metabolizable energy to the diet.

Fish Oil: The majority of omega-3 fatty acid research in dogs and cats was conducted with the longer chain omega-3s from fish oil (e.g., EPA and DHA). These oils are derived primarily from pelagic fish like menhaden, anchovy, herring, and mackerel. This family of fish is typically found in the lower-latitude temperate to sub-tropical coastlines. They are known to have a strong oily taste and aroma not appreciated by most people; but while this doesn't appear to be a big problem for dogs, some cats may show a preference for one fish oil over another. Most fish oils are added to the surface of the pet food post-extrusion and drying. The application of fish oil to meet the desired omega-3 fatty acid level is typically less than one to two percent of the formula. This small amount can be challenging to accurately meter without properly designed equipment. Surface application can also lead to palatability concerns.

The fatty acid profile of the different fish oils can vary substantially. Most of the fish oil used in the pet food industry is cold pressed and (or) refined. While the more processed oils add to the cost, the trade-off is improved handling, animal acceptability, and shelf life. Stabilizing bulk fish oil against oxidation requires very little to no preservative; the same goes for oil in canned pet foods. However, application onto the surface of a dry extruded kibble can become an oxidation issue. The most effective antioxidant preservative is ethoxyquin; however, natural antioxidant systems based on tocopherols can be effective.

Once ingested, the utilization of fish oil is similar to other fat sources. The omega-3 fatty acids appear in the circulation within hours of ingestion and pass along their benefits for weeks.

Other Rendered Ingredients

There have been numerous attempts to bring spent hen meal into pet food. However, no "label friendly" name has been developed. Until a suitable approach can be found, it is unlikely that a rendered spent hen meal will be used. Feather meal, while rich in desirable amino acids like methionine and cystine, is seldom, if ever, found in pet foods. This is likely due to issues with labeling and translation to the pet owner. Further, digestibility and utilization of the sulfur amino acids is not adequate to justify its use. Recent research would indicate that while blood meal is a good protein source, from a protein quality perspective, there are issues with its palatability in dogs (Dust et al., 2005). This may limit its use for anything other than a very specialized application like enteral or parenteral prescription diets. Joint cartilage and bone typically represent materials that are not desirable due to the high degree of connective tissue and low level of essential amino acids. However, there are a couple of applications in the pet food industry that may benefit from these fractions. Specifically, there has been an effort to introduce more "natural" sources of chondroprotectives like glucosamine and chondroitin sulfate into the diet. These have been traditionally sourced from China as extracts from bovine trachea (chondroitin sulfate) and crustacean shells (glucosamine). Naturally occurring and measurable levels can be found in bone cartilage and has been marketed by at least one company. Additionally, there is a move, albeit small, to develop foods which rely upon more holistic ingredients—for this purpose steamed bone meal provides calcium, phosphorus, and a host of other trace minerals.

There are likely more opportunities to extract specific nutrients from rendered materials. The dependence will be upon the creativity of the product developers and the economic incentives these opportunities present.

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History of National Renderers Association from Early 1980s.

HISTORY AND PURPOSE

The NRA was organized in 1933 by a small group of renderers who believed there was a need for a cooperative effort to deal with the current problems of the industry. In 1955, NRA moved its headquarters from Washington, D.C. to the Chicago area. Today, NRA has member companies in all continents and celebrated its 50th anniversary as an association in 1983.

NRA's purpose is to collectively deal with current industry problems and to promote a larger consumption of rendered products, both domestically and overseas. It sponsors research in order to discover new and better applications and disseminates information resulting from this research, thus developing new markets for animal fats and proteins.

ORGANIZATION

The management of the National Renderers Association is conducted by its professional staff reporting to an elected board of directors who decide the organization's policies and direction. Services for the betterment of the rendering industry are proposed by members through the standing committees to the board of directors. Recommendations for action are brought about by a combination of the efforts of volunteer industry representatives and a professional staff, all committed to implementing association programs.

NRA is made up of nine regional areas which elect their own officers and directors and function as individual entities. One of the nine regional areas is based on a non-geographical area designated for packer-renderer members. The NRA board of directors consists of representatives from these regional areas.

ACTIVITIES

Activities dealing in current industry problems, domestic and overseas marketing, research and education play major roles in NRA's day-to-day programs.

The broad spectrum of NRA marketing activities includes organizing of industry teams and consultants who travel overseas frequently on market development trips.In conjunction with the USDA's Foreign Agricultural Service, NRA develops, plans and implements these programs to increase demand for rendered products.

NRA also serves its members by providing important technical findings affecting the rendering industry; by producing an industry and a marketing newsletter for its membership; and by publishing a trade magazine, RENDER, as a public service to the entire industry. Close liaison is maintained with state and federal regulatory agencies to assist in developing reasonable and practical standards for the industry.

Area meetings, regional workshops, two meetings of the board of directors and an annual national convention are held during the year to conduct association business, discuss common problems and gain new information from others in the industry.

LOCATION

Headquarters of the National Renderers Association are located in Des Plaines, Illinois, a suburb of Chicago just a short distance from O'Hare International Airport.

Overseas regional offices operated with the support of the Foreign Agricultural Service are located in London, Singapore and Seoul. Their marketing, research and educational activities are carried out with the support of overseas poultry and livestock associations, feed manufacturers, soap makers, bakers, universities and laboratories in roughly 35 countries world-wide. In addition to these offices and their respective directors and staff, NRA has 11 contract representatives working to promote renderers' products in countries throughout the world.

NRA facilitates and encourages contacts between its members and individuals interested in exchanging information on the use of animal by-products.

RENDERED PRODUCTS IN FISH AQUACULTURE FEEDS

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Summary

Aquaculture is an extremely diverse industry expanding rapidly. An ever growing segment of this industry utilizes high quality, but expensive, compounded feeds. Most fish culture operations are confronted with the challenges of improving their profitability and economical sustainability. Studies have also clearly shown that fish feeds can be formulated with very low levels of fish meal and fish oil through the use of more economical protein and lipid sources.

Rendered animal proteins and fats have been used in aquaculture feeds for several decades. Early research studies had suggested that rendered animal proteins and lipids were of relatively poor quality and poorly digestible to fish. However, the large number of studies published in recent years has shown that rendered animal by-products available today are of much higher quality than those produced 20 or 30 years ago. Most rendered products are a cost-effective source of digestible protein and digestible energy, bio-available essential amino acids, fatty acids, and minerals for most aquaculture species. Rendered proteins and fats are especially valuable for the formulation of aquaculture feeds since these feeds are formulated with much higher protein and lipid levels than feeds for other livestock species. Feeds formulated with high levels of rendered proteins, alone or in combination, support high performance and excellent feed conversion ratio. Studies have shown that blood meal is an excellent source of highly bio-available lysine which compares advantageously with synthetic lysine. Significant amount of rendered fats (tallow, lard, poultry fat) can also be used in fish feeds provided the feed is formulated to contain sufficient amounts of mono or polyunsaturated fatty acids to promote the digestibility of saturated fatty acids, and contain adequate levels of essential fatty acids to meet the requirement of the animals.

The Aquaculture Industry

Aquaculture is one of the fastest growing food producing sectors in the world. The United Nations' Food and Agriculture Organization estimated the total production of cultured finfish, shellfish, and aquatic plants at 51 million metric tons (112 billion pounds) valued at $60 billion in 2003. Asia accounted for more than 80 percent of the world production. China, the leading producer, contributed for more than 50 percent of world production. Today, about one-third of the fish consumed by humans is the product of aquaculture and this proportion is growing yearly. Products of aquaculture, such as shrimp, salmon, trout, catfish, tilapia, mussels, and oysters are nowadays "main stream" products in North American supermarkets.

Aquaculture is an extremely diverse industry, both in terms of species cultivated and production systems used. It is estimated that more than 200 species of fish, crustaceans, and molluscs are cultivated around the world. The bulk of world production, especially in Asia, consists of lower value species (carp, milkfish, catfish, and mullet) produced semi-intensively. In this type of production system, growth is based on food items naturally present in the rearing environment (pond). The production of natural food is generally stimulated through fertilization (fodders, manure, inorganic fertilizer), and low value supplemental feeds (such as, grain by-products, oilseed cakes, tubers, poultry offals, and kitchen wastes) are also used to improve fish production. The aquaculture industry is, nonetheless, in rapid evolution and the production of fish and other aquatic animals is done using increasingly intensive practices (higher stocking densities, lower contribution of natural food items to nutrition of the cultivated organisms). Very substantial increases in the use of formulated feeds have been observed over the past three decades, both as a result of and the progressive intensification of the culture of lower value species and the increasingly widespread culture of higher value fish species (such as, shrimp, eel, sea bass, sea bream, grouper, croaker, salmon, and turtle).

Formulated Aquaculture Feeds

It is estimated that the use of compound feeds in aquaculture is close to 20 million tons (Tacon, 2004). Aquaculture feeds are generally significantly more costly than feeds for other livestock species. Typical cost of aquaculture feeds varies from $300 to $1,500 per metric ton. Aquaculture feeds are also characterized by the widely ranging nutritional composition to which they are formulated. The protein, lipid, and starch contents of feeds vary very significantly, not only as a function of species and life stages for which they are formulated (trout versus tilapia versus shrimp feed, larval versus starter versus grower feed), but also as a function of a myriad of other factors such as production and environmental constraints, market or manufacturers' preference, and economic climate (such as, fish price and access to financing). The composition of feeds used for some species has also dramatically changed over the past two or three decades. The most striking example of this is the dramatic increase in the fat content of feeds used for Atlantic salmon production over the past 30 years. Atlantic salmon feeds were routinely formulated to eight to 10 percent lipids in the 1970s and are currently formulated to contain 35 to 40 percent lipids.

Part of the high cost of formulated aquaculture feeds is due to the fact that the feeds are, in general, of high nutrient density and manufactured using costly processes (extrusion, steam-pelleting). Their high cost is also largely attributable to the use of high levels of expensive ingredients (fish meal, fish oil, pigments, krill, squid meal, cholesterol, and lecithin.). Fish meal and fish oil are still considered key ingredients in the formulation of feeds for aquaculture species. Fish meal and fish oil, combined, currently account for 30 to 80 percent of the weight of most of the salmon, trout, marine fish, and shrimp feeds sold worldwide. Most fish culture operations are confronted with the challenges of improving their profitability and economical sustainability. Studies have also clearly shown that fish feeds can be formulated with very low levels of fish meal and fish oil through the use of more economical protein and lipid sources.

Progressive fish feeds are formulated to contain lower levels of fishery by-products, and higher levels of more economical agricultural commodities. However, most economical protein and lipid sources (soybean meal, corn gluten meal, canola meal, meat and bone meal, feather meal, and animal fats) have been shown to have significant limitations and these cannot be used at extremely high levels in the diet of most fish species. Formulating successful cost-effective feeds, relying less on fish meal and fish oil, requires access to a variety of economical ingredients. It also requires an understanding of the nutrient requirement of the animal but also several other, less well-defined, factors (tolerance to anti-nutritional factors, interactions between nutrients, and palatability of the finished feed).

Rendered Products

Terrestrial animal products have been used in aquaculture feeds for several decades. From the 1930s to the mid-1970s, salmon and trout species raised in hatcheries in the United States and Canada were mainly fed with semi-moist "meat meal mixtures" that were made of slaughter house by-products (beef, pork, or horse liver and spleen), fresh or frozen fishery products, and dry "meals" (mix of cottonseed meal, soybean meal, skim milk, wheat, salt, vitamin and mineral premixes). The first nutritionally complete dry fish feeds were developed in the 1960s and rendered proteins and fats have found wide use in dry fish feeds from their inception.

The use of rendered animal proteins was limited in the 1970s and 1980s because a small number of studies indicated that some of these ingredients had poor digestibility for fish or were of highly variable quality (e.g., Cho and Slinger, 1979; Cho et al., 1982; NRC, 1993). Studies conducted more recently have shown these quality issues are a problem of the past (Bureau et al., 1999; Bureau et al., 2000, 2002). Ingredients produced today appear to be of much higher quality than those produced 20 to 30 years ago. More than 200 studies on the nutritive value of rendered animal proteins for aquaculture species have been published in the scientific literature over the past three decades. The results from a large majority of these studies suggest that rendered products are cost-effective sources of highly available amino acids, fatty acids, and several other nutrients.

Rendered proteins and fats are economical commodities that are very valuable for the formulation of cost-effective aquaculture feeds. Their high protein and lipid content make them especially well-suited for use in the high protein and lipid aquaculture feeds. These ingredients are also effective sources of several key nutrients (lysine, sulphur amino acids, histidine, arginine, and phosphorus) and they complement very well certain plant protein ingredients (e.g., corn gluten meal and soybean meal). In addition, most animal by-products are highly palatable to most fish species. Rendered animal proteins and fats are key components of cost-effective aquaculture feeds in many countries, including the United States and Canada. Table 1 presents an example of the composition of rainbow trout feed used in North America.

Protypical perceived food safety issues (the main one being bovine spongiform encephalopathy (BSE)) are currently the main road block hindering the use of all rendered products in aquaculture feeds. This is largely due to the fact that Europe is a significant export market for several aquaculture products (shrimp, salmon, sea bass, and sea bream). European Union requirements or guidelines have profound influence on feed manufacturing practices, even in countries where the European Union is only a minor export market. Despite this conjecture, rendered animal proteins and fats, such as poultry by-product meal, feather meal, blood meal, and poultry fat have, for example, found widespread use in very high quality fish feeds used in salmon and trout production in Canada, the United States, and Chile. In many countries, ingredients of avian origins are subject to less significant import and export restrictions, and, consequently, are more widely used. Mixed species or ruminant by-products have also been shown to be of high nutritive value but their use is generally more limited. However, significant growth in some markets can be foreseen.

Table 1. Composition of a Prototypical Rainbow Trout Feed.

Ingredients	**Percent**
Fish meal	25
Corn gluten meal	12
Poultry by-product meal	12
Soybean meal	8
Blood meal, spray-dried	5
Feather meal	5
Wheat	12
Vitamins and minerals	2
Dicalcium phosphate	1
DL-Methionine	0.5
Lysine HCL	0.5
Fish oil	17
Total	100

Nutritive Value of Rendered Animal Protein Ingredients in Fish Feeds

Digestibility of Animal Proteins

A relatively large number of studies have examined the digestibility of rendered animal protein ingredients. Estimates of apparent digestibility of crude protein among studies appear quite variable for most ingredients. This variation may be due to the quality of the ingredients investigated but may also be due to differences in the methodology used. Overall, recent studies indicate that most rendered animal proteins produced using modern manufacturing practices are quite highly digestible for fish.

Poultry By-product Meal

One of the first studies examining the digestibility of animal proteins was that of Cho and Slinger (1979). These investigators observed that the digestibility of protein in poultry by-product meal (PBM) was relatively low (approximately 70 percent). In a more recent digestibility trial, high digestibility of crude protein (87 to 91 percent) were observed for two batches of regular PBM fed to rainbow trout (Bureau et al., 1999; Table 2). These results were obtained using the same equipment, fish strain, and methodology as that of Cho and Slinger (1979). Comparison of the results of Cho and Slinger (1979), Dong et al. (1993), Hajen et al. (1993), Sugiura et al. (1998), and Bureau et al. (1999) suggests progressive improvements in the digestibility of protein in regular PBM for rainbow trout over the past three decades. High digestibility of protein for PBM appears to be observable in other fish species. For example, Lupatsch et al. (1997) observed a digestibility of crude protein of about 80 percent for PBM fed to gilthead seabream (*Sparus aurata*), a marine fish species widely cultured in the Mediterranean region.

Blood meal

The digestibility of crude protein of blood meal (BM) manufactured using different techniques has been shown to differ significantly (Cho et al., 1982; Bureau et al., 1999). Blood proteins appear to be especially sensitive to heat damage, and the drying technique used can have a very significant effect on digestibility of BM. Cho et al. (1982) observed that a flame-dried BM had crude protein digestibility of only about 12 percent, whereas the protein in spray-dried BM was almost completely digestible. Bureau et al. (1999) observed that the digestibility of crude protein in spray-dried blood products was significantly higher than that of rotoplate-dried, steam-tube dried, and ring-dried BMs (Table 2).

A recent study with rainbow trout suggested that the bioavailability of lysine in spray-dried or flash-dried BMs was slightly higher than that of L-lysine HCL (Table 3) (El-Haroun and Bureau, 2004). These results suggest that BM can be a very good source of bio-available amino acids. However, some differences between BMs exist. For example, disc-dried BM appears to be an inferior source of available lysine to spray-dried or flash-dried BMs (Table 3).

Feather Meal

In the late 1970s, the digestibility of crude protein of feather meal (FeM) for rainbow trout had been estimated to be between 58 percent and 62 percent (Cho and Slinger, 1979). Digestibility trials conducted in more recent years suggested significant improvements. Bureau et al. (1999), for example, estimated the digestibility of crude protein of four FeMs to be between 77 percent and 86 percent (Table 2). A very comparable apparent digestibility coefficient (ADC) value was reported by Sugiura et al. (1998) for a FeM fed to rainbow trout. It also appears to be relatively well digested by other fish species. For example, Lee et al. (2002) estimated that the digestibility of crude protein of FeM was about 79 percent for rockfish (*Sebastes schlegeli*).

Table 2. Manufacturing Characteristics, Crude Protein (CP) Content, and Apparent Digestibility Coefficients (ADC) of Dry Matter (DM), CP, and Gross Energy (GE) of Rendered Animal Protein Ingredients from Various Origins.

Ingredients	**Processing Conditions**	**CP**	**ADC**		
		as is	**DM**	**CP**	**GE**
Feather meals		**%**	**%**	**%**	**%**
1	Steam hydrolysis, 30 min at 276 kPa, disc dryer	75	82	81	80
2	Steam hydrolysis, 5 min at 448 kPa, disc dryer	82	80	81	78
3	Steam hydrolysis, 40 min at 276 kPa, ring dryer	76	79	81	76
4	Steam hydrolysis, 40 min at 276 kPa, steam-tube dryer	75	84	87	80
Meat and bone meals					
1	125º-135ºC, 20-30 min, 17-34 kPa	57	61	83	68
2	same as above but air classification of final product to reduce ash content	55	72	87	73
3	133ºC, 30-40 min, 54 kPa	50	72	88	82
4	128ºC, 20-30 min, 17-34 kPa	48	66	87	76
5	132º-138ºC, 60 min	50	70	88	82
6	127º-132ºC, 25 min	54	70	89	83
Poultry by-product meals					
1	138ºC, 30 min	65	76	87	77
2	127º-132ºC, 30-40 min, 54 kPa	63	77	91	87
Blood meals					
1	Steam-coagulated blood, rotoplate dryer	83	82	82	82
2	Steam-coagulated blood, ring dryer	84	87	88	88
3	Whole blood, spray dryer	83	92	96	92
4	Blood cells, spray dryer	86	92	96	93
5	Blood plasma, spray dryer	71	99	99	99
6	Steam-coagulated blood, steam-tube dryer	91	79	84	79
7	Whole blood, spray dryer	82	94	97	94
8	Steam-coagulated blood, ring dryer	86	87	85	86

Source: Bureau et al., 1999. (Processing conditions provided by manufacturers).

Meat and Bone Meal

The digestibility of protein in meat and bone meal (MBM) appears to be somewhat variable. Bureau et al. (1999) observed digestibility of protein of six MBMs to be between 83 percent and 89 percent for rainbow trout (Table 2). McGoogan and Reigh (1996) and Gaylord and Gatlin (1996) observed protein digestibility of about 74 to 79 percent for MBM fed to red drum (*Sciaenops ocellatus*). Lower digestibility values were reported by Allan et al. (2000) for Australian lamb and beef MBM fed to Silver perch (*Bidyanus bidyanus*). A series of studies carried out in Japan and Portugal indicated that meat meal (i.e., high protein, low ash MBM) were very highly digestible for several freshwater and marine fish species (Gomes et al., 1995; Watanabe et al., 1996; da Silva and Oliva-Teles, 1998). Results from a number of trials (e.g., Bureau et al., 2000) suggest that the ADC of crude protein tends to overestimate the digestible amino acids of MBM, and that relatively "conservative" estimates of digestibility of protein should be assumed for MBM when formulating fish feeds on a digestible protein basis.

Table 3. Relative Bioavailability of Lysine in Blood Meals of Different Origins, Relative to Lysine-HCL (Assumed to be 100 percent Bio-Available) and Based on Different Parameters: Weight Gain, Feed Efficiency, and Retained Nitrogen in Rainbow Trout.

Parameters	Lysine HCL	Spray-dried blood meal	Flash-dried blood meal	Disc-dried blood meal
Weight gain, g/fish	100	138	150	84
Feed efficiency, gain-to-feed	100	139	132	85
Retained N, g/fish	100	129	143	86

Source: El-Haroun and Bureau, 2004.

Rendered Animal Proteins as Source of Digestible Phosphorus

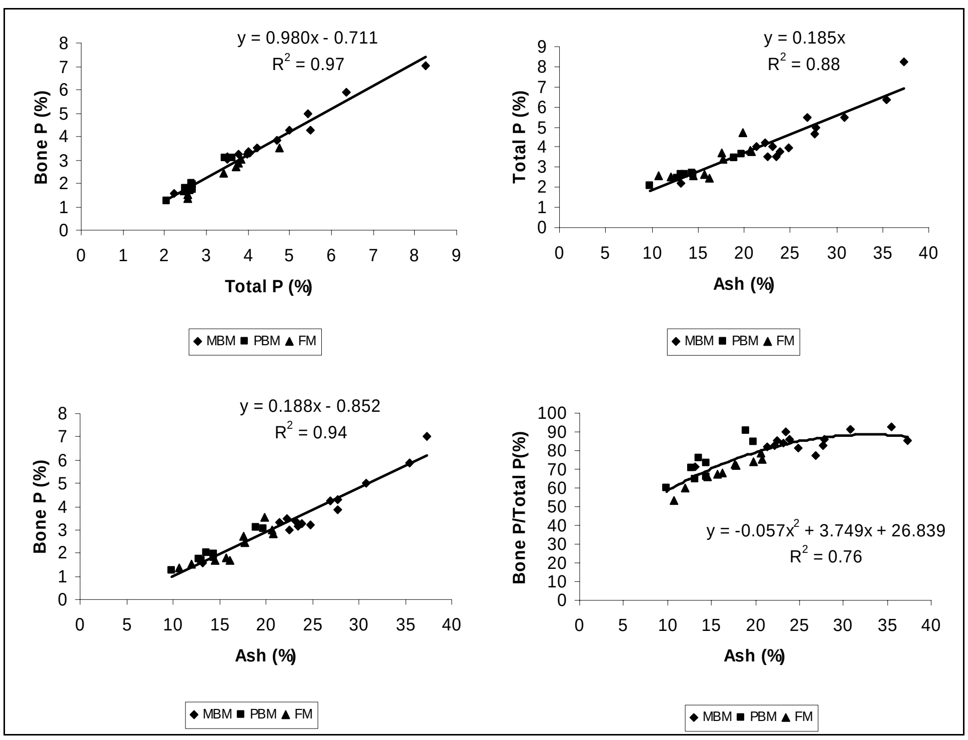
Animal protein ingredients generally have high, but variable, phosphorus (P) content (Table 4). In these ingredients, P is primarily bound with calcium in what is commonly referred to as "bone P." This bone P generally represents a large proportion of the total P of animal protein ingredients (Figure 1). Some of the P is also found as part of several other compounds, such as nucleic acids, amino acids, lipids, and carbohydrates, and is often referred to as "organic P."

The estimates of digestibility of P of animal by-products reported in the literature are highly variable. For salmonid fish, digestibility of P ranges from 17 percent to 81 percent for fish meal, 22 percent to 45 percent for meat and bone meal, and 15 percent to 64 percent for poultry by-product meal. This high variability in the estimate of P digestibility of animal protein ingredients is probably the results of difference in bone P content of the ingredients and the level of different chemical forms of P in the finished feeds. Hua and Bureau (2006) developed a model to estimate digestible P content of salmonid fish feeds based on levels of different P types. Phosphorus types present in feed ingredients were classified into broad chemical categories: bone P, phytate P, organic P, Ca monobasic/Na/K Phosphate (Pi) supplements, and Ca dibasic Phosphate (Pi) supplements (Figure 2). The relationship between digestible P content of feeds and various P chemical compound contents was examined through a multiple regression approach. Multiple regression analysis on data from 22 studies yielded the following model:

Digestible P = 0.68 bone P + 0 phytate P + 0.84 organic P + 0.89 Ca monobasic/Na/K Pi supplement + 0.64 Ca dibasic Pi supplement + 0.51 phytase/phytate – 0.02 (phytase/phytate)^2 - 0.03 (bone P)^2 - 0.14 bone P * Ca monobasic/Na/K Pi supplement ($P < 0.0001$, $R^2 = 0.96$).

The results from this model suggest that the digestibility of different P types differ significantly and the apparent digestibility of bone P is not additive, as suspected. The model predicts that animal protein ingredients, such as MBM and PBM, are highly effective sources of digestible P in feeds formulated with high levels of plant protein ingredients.

Figure 1. Bone P Content as a Function of Total P and Ash Contents of Animal Protein Ingredients.

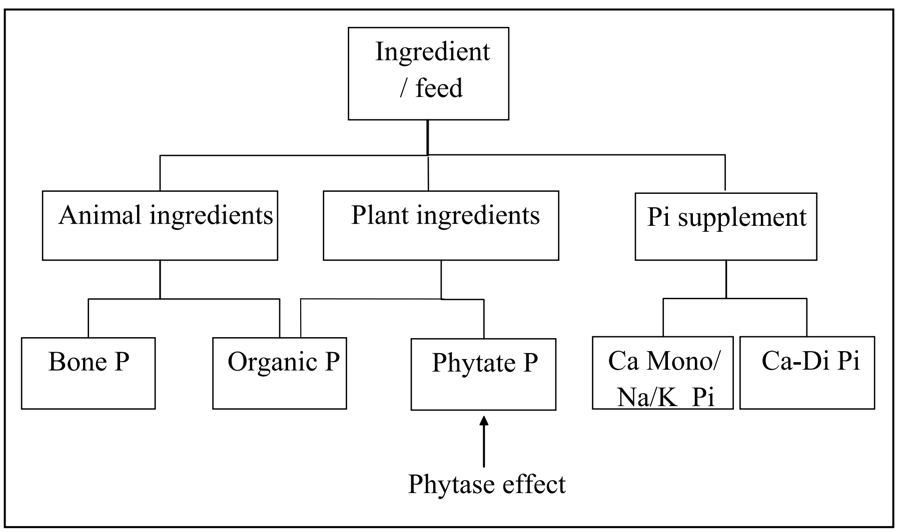


Source: Hua et al., 2005.

Table 4. Phosphorus Content of Common Fish Feed Ingredients (Dry Matter (DM) Basis).

Ingredient	Phosphorus content (g/kg DM)
Fish meal	10.8 - 41.9
Meat and bone meal	24.9 - 70.8
Poultry by-product meal	16.5 - 34.5
Blood meal	0.8 - 17.1
Feather meal	5.4 - 12.6

Figure 2. Schematic Representation of a Model Estimating the Digestible P Content of Fish Feed Based on the Levels of Different P Chemical Forms in Feeds.



Source: Hua and Bureau, 2006.

Use of Animal Proteins in Feeds

Blood Meal

Spray- and ring-dried BMs are widely used in salmonid feeds due to their very high digestibility and consistent quality. Good performance of fish have been observed for fish fed diets containing approximately eight to 20 percent BM in conjunction with high (more than 20 percent) fish meal levels (Luzier et al., 1995; Abery et al., 2002). A study carried out at the University of Guelph also demonstrated that spray-dried BM was of high nutritive value for rainbow trout (Table 5, Trial #1).

Poultry By-product Meal

The use of PBM in fish diets has been studied quite intensively (e.g., Higgs et al., 1979; Alexis et al., 1985; Steffens, 1987; Fowler, 1991; Steffens, 1994). The general conclusion from earlier studies was that approximately 20 to 25 percent PBM can be included in salmonid diet without effect on growth and feed conversion of the animal. More recent studies have indicated that feeds formulated to contain up to 30 percent PBM supported excellent growth performance in rainbow trout (Table 5, Trial #1). PBM is very similar to fish meal in terms of nutritional value for rainbow trout, and this ingredient can effectively replace all the fish meal in the diet of rainbow trout without negative impact on performance (Bureau et al., unpublished).

Feather Meal

Fowler (1990) observed that 15 percent FeM (90 percent CP, four percent lipid) replacing herring meal could be included in the diet of Chinook salmon without effect on growth and feed efficiency of the fish. Henrichfreise (1989, cited by Steffens, 1994) observed that 20 to 25 percent FeM could be included in the diet of rainbow trout without effect on growth and feed efficiency. A more recent study suggested that about 15 percent feather meal (providing 20 percent of total digestible protein) could be incorporated in the diet of rainbow trout without effect on growth and feed efficiency of the fish (Bureau et al., 2000). FeM is quite commonly used in fish feeds at significantly lower levels (five to 10 percent).

Meat and Bone Meal

Shimeno et al. (1993) observed that 10 percent meat meal (68 percent CP, 16 percent lipid, 11 percent ash) along with 20 percent soybean meal could replace 23 percent brown fish meal in diets for yellowtail, a highly carnivorous fish species. Bureau et al. (2000) observed that the incorporation of up to 24 percent MBM (providing about 25 percent of total digestible protein) was possible in feeds for rainbow trout. The results of the study of Bureau et al. (2000) are in agreement with the results of Tacon and Jackson (1985), Davies et al. (1989), and Robaina et al. (1997) who observed that significant amounts of MBM could be included in the diets of rainbow trout, Mozambique tilapia, and gilthead seabream without effect on performance (e.g., Table 5, Trial #2).

Table 5. Performance of Rainbow Trout Fed Practical Diets with Different Rendered Animal Protein Ingredients Alone or in Combination.

	Trial #1				Trial #2			
	Diets				Diets			
	1	2	3	4	1	2	3	4
Protein Sources								
Fish meal, herring	28	24.5	24	20	40	20	20	20
Corn gluten meal	28	24.5	24	20	11	11	11	11
Soybean meal	-	-	-	-	13	-	-	-
Blood meal, spray dried	6	12	-	-	4.5	5	5	5.5
Feather meal	-	-	-	-	-	17	17	-
Meat and bone meal	-	-	-	-	-	25	-	25
Poultry by-product meal	-	-	20	30	-	-	16	16
Composition								
Digestible protein, percent	43.3	43.7	44.5	44.6	42	42	42	42
Digestible energy, MJ/kg	21.3	21.3	21.5	21.6	19	19	19	19
Performance								
Initial weight, g/fish	17	17	16	18	35	35	35	35
Final weight, g/fish	209	215	202	209	278	247*	264	245*
Feed efficiency, gain:feed	1.18	1.26	1.19	1.18	1.26	1.11*	1.20	1.09*
Thermal-unit growth coefficient	0.200	0.205	0.199	0.199	0.261	0.241*	0.252	0.239*

* Significantly different from control diet (Diet 1).
Source: El Haroun et al., unpublished.

Combinations of Animal Proteins

A number of studies have shown that a mixture of high quality rendered animal protein ingredients could replace most of the fish meal in a practical rainbow trout diet sustaining high growth. Dabrowski et al. (1995) observed good performance of rainbow trout fed a diet containing 20 to 30 percent of a fish meal analogue, formulated using BM, MBM, PBM, and FeM. The potential of different combinations of rendered animal protein ingredients was recently examined in a 16-week feeding trial (Table 5, Trial #2). Diets were formulated with combinations of PBM, FeM, and MBM providing about two-thirds of the digestible protein. Growth rates of fish fed diets containing a combination of PBM and FeM was not statistically significantly different than the growth rate of fish fed the control diet. Growth rates of the fish fed diets containing combinations of MBM and FeM or MBM and PBM were slightly lower than that of the fish fed the control diet.

Amino acid supplementation (L-Methionine or L-Lysine), the two amino acids predicted to be the most limiting, had no effect on performance of the fish. It is worth noting that growth rates of fish fed all the experimental diets was superior to what was observed in all previous trials conducted at the University of Guelph. The results clearly indicate that most rendered animal protein ingredients have a high nutritive value and can be very valuable protein sources for fish feed formulation. However, feeds should be formulated on a digestible basis, and relatively conservative estimates of apparent digestibility or safety margins should be used. This is especially critical in the case of FeMs and MBMs.

Use and Nutritive Value of Rendered Animal Fat

Formulated aquaculture feeds are often high in lipids, the bulk of which is generally provided by fish oil. Because of its cost, foreseeable long-term supply problems, and more recently, concerns over contaminant levels, it is widely acknowledged that fish oil should be used more sparingly in aquaculture feeds. Fish oil availability is increasingly problematic since the demand has grown considerably with the expansion of the aquaculture industry. Various projections suggest that within a decade, the demand for fish oil will be well above the available supply. Along with this increase in demand, the price of fish oil has also risen considerably. The market price for fish oil has varied between \$0.20 and \$0.80/kg over the past decade. Prices in recent years have consistently remained high.

Rendered animal fats, because of their low costs and wide availability, could be interesting alternative for part of the fish oil in fish feeds. Opposite to fish oil prices, the price of inedible animal fats has decreased in the last 10 years by 40 to 50 percent to a current price of about \$0.30/kg for good quality choice white grease and tallow. Prices for rendered fats are unlikely to move dramatically over the next few years. Substantial savings could be made immediately by substituting some of the fish oil in feed formulae with these more economical lipid sources. The cost of aquafeed could be reduced by about \$3/ton for every percentage point (one percent) of fish oil replaced by rendered fats. There are very few other dietary modifications (e.g., fish meal replacement) to current salmonid feed formulae that could result in such substantial savings.

Animal Fats: Digestibility and Use in Feeds

The ability of fish to use rendered animal fats as an energy source is dependent mainly upon the digestibility of these ingredients. Studies have suggested differences in the digestibility and nutritive value of lipid sources with different fatty acid profiles at different water temperatures. Cho and Kaushik (1990) presented the results from an experiment indicating that the digestibility of fish oil and plant oils (rapeseed, soybean, and linseed) remained high over a wide range of water temperatures (5^{o}C to 15^{o}C). However, the digestibility of lard and tallow were clearly poorer at lower water temperatures, in contrast with the lack of effect of water temperatures on the lower melting point oils. Other observations suggest, however, that the digestibility of tallow is high for rainbow trout provided the diet contains a certain amount of fish oil (and/or other lipid sources rich in mono and polyunsaturated fatty acids). Bureau et al. (2002) found that there was no difference in the digestibility of lipid (94 percent) of a feed with 16 percent fish oil and that of a feed with eight percent fish oil and eight percent tallow at a low water temperature (7.5°C). At 15°C, the digestibility of lipid of the diet comprised of eight percent fish oil and eight percent tallow was only slightly lower than that of the feed comprised of 16 percent fish oil (95 versus 98 percent) (Table 6).

Table 6. Lipid Digestibility and Growth Performance of Rainbow Trout (Initial Weight = 7 g/fish) Fed Practical Diets Containing Fish Oil or Fish Oil and Tallow Combination Reared at 7.5°C or 15°C for 12 Weeks.

	Water Temperature			
	7.5°C		15°C	
Ingredients	**Diet 1**	**Diet 2**	**Diet 1**	**Diet 2**
Fish meal, herring, 68% CP	50	50	50	50
Corn gluten meal, 60% CP	20	20	20	20
Fish oil, herring	16	8	16	8
Beef tallow, fancy, bleachable	-	8	-	8
Composition				
Digestible Protein (DP), %	44.0	43.5	44.9	44.4
Digestible Energy (DE), MJ/kg	19.5	19.9	20.9	20.8
DP/DE, g/MJ	22.6	21.9	21.5	21.3
Performance				
Lipid digestibility, %	93	94	98	95*
Weight gain, g/fish	13.7	13.1	38.1	39.2
Feed efficiency, gain:feed (as is)	1.32	1.27	1.22	1.15
Retained energy, % digestible intake	47	47	50	48

* Significantly different from control diet (Diet 1).
Source: Bureau et al., 1997.

The difference in estimates of lipid digestibility between studies is likely due to the synergetic effect of polyunsaturated fatty acids on the digestibility of saturated fatty acids, a well-described phenomenon in poultry. The low digestibility values reported in Cho and Kaushik (1990) for highly saturated lipid sources is probably only the result of the methodology used. Cho and Kaushik (1990) used a reference diet with very low levels of lipids (less than three percent) (Cho, personal communication). This reference diet was then supplemented with significant amounts of the test lipid sources (fish oil, soy oil, lard, tallow) producing test diets in which more than 80 percent of the lipids were provided by the test lipids. It has been demonstrated, more than 40 years ago, that highly saturated lipids, when used alone in the diet, are poorly digested by poultry and other animals. Supplementation of tallow-containing diets with limited amounts of polyunsaturated fatty acids (e.g., from soy oil) resulted in significant improvements in the digestibility of lipids in poultry (Sibbald et al., 1962; Sibbald, 1978). The results presented in Table 6 are consistent with these observations and indicate that saturated fatty acids are effectively utilized by rainbow trout at low water temperature when the diet contains some fish oil. It is suggested that saturated fatty acids levels of the diet should perhaps not exceed 40 percent of total fatty acids of the diet of rainbow trout since digestibility of lipids can possibly decrease quite significantly when more is used.

Several studies have examined the use of poultry fat, tallow, and lard in the diet of various fish species (reviewed by Bureau et al., 2002). Evidence presented in these studies indicate that animal fat incorporation levels corresponding to 30 to 40 percent of total lipids of the diet have no adverse effects on growth performance, feed efficiency, and product quality of most fish species studied. It is transparent from these studies that diets containing animal fats must contain significant amounts of n-3 and/or n-6 polyunsaturated fatty acids to meet the essential fatty acid requirements of the fish and to allow for proper digestibility of the lipids.

Conclusion

Formulated aquaculture feeds are often high in protein and fat, and the bulk of those generally provided by fish meal and fish oil. Because of their high cost and foreseeable long-term supply problems, progressive increase in the use of economical protein and lipid sources in aquaculture feeds is inevitable. Feed manufacturers consequently require information on the nutritive value of various economical protein and lipid sources.

Rendered animal proteins and fats produced today in North America are relatively highly digestible and meet high quality criteria required for use in high nutrient density aquaculture feeds. Rendered proteins and fats are cost-effective sources of key nutrients and can also be used to improve the nutritive value of more economical feeds. Sufficient information is available on the nutritive value of rendered products to allow feed manufacturers to judiciously use these products in their fish feeds.

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RENDERED PRODUCTS IN SHRIMP AQUACULTURE FEEDS

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Summary

Fish meal (FM) has become expensive for commercial feed applications. Poultry by-product meal (PBM) and meat and bone meal (MBM) may be used as replacement for FM. This chapter describes research in which PBM and MBM have been evaluated for their impact on feed intake, digestibility, weight gain, carcass sensory characteristics, immune response, and survival rate when used as dietary FM replacements. Nutrient digestibility, maximum FM replacement rate, and digestible essential amino acid (EAA) profile are important least cost formulation criteria for selection of protein ingredients and minimizing the variability in growth performance of aquatic animals. Protein, essential amino acids (EAA), and energy in PBM have been shown to be digested more than 84 percent and 73 percent by *Litopenaeus vannamei* (white shrimp) and *Penaeus monodon* (black tiger shrimp), respectively. Limited meat and bone meal data indicate that protein and EAA digestibility of MBM is similar to that of PBM in *L. vannamei*, but no reliable EAA digestibility data for MBM have been reported for *P. monodon*. Energy digestibility MBM is about 14 percent lower than that of PBM due to the high content of ash and saturated fatty acids.

When used alone, PBM appears to be adequate in meeting digestible EAA requirements of shrimp with a minor deficiency in sulfur amino acids (AAs), whereas MBM needs to be supplemented with histidine and sulfur AAs (methionine and cystine). However, under zero-water exchange (eutrophic) rearing conditions, white shrimp growth was not significantly different between FM and PBM or MBM (100 percent replacement of FM). Supplementation of microencapsulated EAAs may broaden and increase the use of rendered protein meals in shrimp feeds. Feeding PBM or MBM at high rates (up to 80 percent replacement of FM) does not affect shrimp conformation, carcass composition and sensory characteristics, survival rate, or immune response.

Under clean water rearing conditions, and without effective supplementation of EAAs, the maximum FM protein replacement rate by PBM is 80 percent for both *P. monodon* and *L. vannamei* feeds, while the maximum FM protein replacement rate by MBM is 80 percent and 60 percent for *P. monodon* and *L. vannamei,* respectively. With the adequate supplementation of EAAs and essential fatty acids (EFAs), the FM protein replacement rate could be increased to 100 percent by MBM and PBM.

Replacement value of hydrolyzed feather meal (FeM) for FM in shrimp feeds has not been widely researched. The maximum FM protein replacement by FeM is 33 percent (steam-pressure hydrolyzed, SPH), 66 percent (SPH plus crystalline lysine and methionine), and 43 percent (enzyme treated FeM). Greater

use of FeM in shrimp feeds requires supplementation of EAAs, EFAs, and perhaps also, palatability enhancers.

The main advantage of using rendered products in shrimp feeds as FM replacements is the reduction in cost of feed and weight gain. The typical savings at 60 to 80 percent FM replacement by MBM and PBM is a 15 to 25 percent cost reduction. Research supports the use and value of PBM, MBM, and FeM as FM replacement in feeds for carnivorous and omnivorous shrimp species.

Introduction

Animal proteins are considered essential dietary components for carnivorous aquatic animals, and are desirable protein sources for omnivorous species. FM has been the prime choice among all animal proteins in aquaculture feeds for its protein quality and palatability. However, for various reasons, the supply of FM will be insufficient to meet the demand for feeding of both aquatic and terrestrial species. PBM, MBM, and FeM are potentially suitable replacements for FM in aquafeeds due to their resemblance to FM in nutritional composition, but are much lower in cost. Recent studies funded by the National Renderers Association (NRA) and others (Davis, 2000; Kureshy et al., 2000; Kureshy and Davis, 2002; Samocha et al., 2004; Allan and Rowland, 2005; Davis et al., 2005; Tan et al., 2005; Tidwell et al., 2005; Yu, 2006) have demonstrated that a large portion of FM can be replaced by PBM and MBM without impairing the growth of fish and shrimp.

For effective use of PBM and MBM as FM replacements, aquafeed nutritionists need to know the digestibility coefficients of key nutrients preferably measured in the same species for which the diets are being formulated. This improved precision in formulation will not only result in more consistent and predictable growth of the aquatic animal but will also give a more accurate estimate of feed cost of production. Reliable knowledge about the maximum rate of FM substitution by PBM and MBM without causing a negative effect on weight gain is important to avoid erratic growth performance while reducing the dependence on FM. This chapter presents recent findings on digestibility and growth response of shrimp when fed diets with PBM and MBM as FM replacements.

Composition of Poultry By-product Meal, Meat and Bone Meal, and Hydrolyzed Feather Meal

Nutrient and amino acid composition of PBM, MBM, FeM, and FM used in several digestibility and growth trials in China (Xue and Yu, 2005) are listed in Table 1. The FM samples were taken from a leading aquafeed mill in South China, and were identified to be of Peruvian origin. U.S. renderers supplied the PBM, MBM, and FeM which were considered of high quality as evident when compared with compositions listed in *Nutrient Requirements of Fish* published by the National Research Council (1993).

Requirements: Energy, Protein, and Amino Acids

Requirements of energy, protein, and EAA of most aquatic species are interrelated and should be evaluated simultaneously for one particular species. Estimates of requirements for protein and amino acids are given in Table 2 (Bureau, 2000). Gross requirements for EAA can be estimated from the EAA profile of the carcass. For feed mills to meet the requirements of one particular species, it is important to know total protein, EAA as percent of feed, and EAA requirements for the species. Formulation precision can be improved by using digestible protein and EAA for shrimp requirements and ingredient contributions. Utilization of crystalline amino acids may be lower in shrimp feeds as compared with fish or poultry feeds. Coated EAA for slow rate of release may be desirable for shrimp.

Table 1. Nutrient Composition (percent) of Meat and Bone Meal, Poultry By-product Meal, Hydrolyzed Feather Meal, and Fish Meal Used in Shrimp Digestibility and Growth Trials.

	MBM[1]	PBM[2]	FeM[3]	FM[4]
Dry matter	96.6	97.5	97.2	92.6
Crude protein	54.0	65.6	80.0	62.9
Crude fat	12.7	12.5	6.0	11.1
Essential Amino Acids (EAA)				
Arginine	3.33	4.01	5.73	3.20
Histidine	1.43	1.72	0.69	1.61
Isoleucine	1.93	2.69	3.84	2.40
Leucine	3.66	4.85	6.80	4.41
Lysine	3.27	4.42	2.04	4.41
Methionine	1.29	1.59	0.67	1.60
Phenylalanine	2.07	2.70	4.30	2.43
Threonine	2.10	2.71	3.8	2.50
Valine	2.44	3.13	5.87	2.63
Cystine	0.61	0.74	4.16	0.59
Tyrosine	1.39	1.92	2.73	1.91

[1]Meal and bone meal (U.S.). [2]Poultry by-product meal (U.S.).
[3]Hydrolyzed feather meal (U.S.). [4]Fish meal (Peruvian).

Table 2. Protein and Amino Acid Requirements of Shrimp.

	P. monodon	***L. vannamei***
Protein % (Juvenile)	40	35
Arginine		
% Protein	5.8	5.8
% Feed [1]	2.32	2.03
Histidine		
% Protein	2.1	2.1
% Feed	0.84	0.73
Isoleucine		
% Protein	3.4	3.4
% Feed	1.36	1.19
Leucine		
% Protein	5.4	5.4
% Feed	2.16	1.89
Lysine		
% Protein	5.3	5.3
% Feed	2.12	1.86
Methionine + Cystine		
% Protein	3.6	3.6
% Feed	1.44	1.26
Phenylalanine + Tyrosine		
% Protein	7.1	7.1
% Feed	2.84	2.48
Threonine		
% Protein	3.6	3.6
% Feed	1.44	1.26
Tryptophan		
% Protein	0.8	0.8
% Feed	0.32	0.28
Valine		
% Protein	4.0	4.0
% Feed	1.6	1.4

[1] On a 90% dry basis.

Digestibility Trials

Nutrients and EAA digestibilities of PBM, MBM, and FM have been measured in *P. monodon* and *L. vannamei* (Table 3). Test protein was typically mixed with a base mix (FM being the only protein source) at a ratio of 3 to 7. A typical base mix analysis used for shrimp trials in China (Xue and Yu, 2005) is given in Table 4. Under similar experimental conditions, protein, and EAAs of all three protein meals were well digested (83 to 88 percent) by *L. vannamei*, suggesting the suitability of PBM and MBM as FM replacement in *L. vannamei* diets.

Limited digestibility data with *P. monodon* suggest that FM's protein, energy, and EAAs were highly digestible (89 to 93 percent, Table 3), and the protein and EAAs in PBM and MBM were 20 percent less digestible than FM. No apparent reasons can be given for the higher digestibility of EAAs noted in *L. vannamei* compared to *P. monodon* when fed the same test protein from the same source. Energy in MBM was least digestible among the three protein meals and was likely related to the high content of ash and saturated fatty acids.

Table 3. Nutrient Digestibilities of Rendered Non-Marine Animal Protein Meals in Shrimp.

	MBM[1]		**PBM[2]**		**FM[3]**	
	V[4]	**M[5]**	**V[6]**	**M[7]**	**V[8]**	**M[9]**
Protein	82 - 85	77	84 - 90	77	81	93
Energy	69	61	76 - 84	73	85	89
Essential Amino Acids (EAA)						
Arginine	85		86	90	90	93
Histidine	86		89	91	91	93
Isoleucine	86		91	89	89	90
Leucine	86		89	70	70	91
Lysine	93		93	85	85	95
Methionine	86		95	81	81	93
Cystine	76		76	79	79	85
Phenylalanine	86		89	77	77	90
Tyrosine	85		88	89	89	100
Threonine	82		85	79	79	91
Valine	84		81	82	82	91
Avg.	85		88	83	83	92

[1] Meat and bone meal.
[2] Poultry by-product meal.
[3] Hydrolyzed feather meal.
[4] *L. vannamei* (Forster et al., 2003).
[5] *P. monodon* (Smith, D.M., 1995).
[6] *L. vannamei* (Xue et al., 2006).
[7] *P. monodon* (Xue et al., 2006).
[8] *L. vannamei* (Xue et al., 2006).
[9] *P. monodon* (Smith, D.M., 1995).

No reliable digestibility data for EAAs in MBM have been reported for *P. monodon,* but one could assume an average value close to that of protein (77 percent), which is similar to the digestibility of PBM (Table 3).

Data in Table 1 and Table 3 suggest that PBM should be considered one of the best substitutes for FM in shrimp feeds, while the limiting factor for MBM is the relatively low content of EAAs rather than the digestibility of EAAs. More measurements of digestibilities of EAAs are needed for MBM and FeM in order to predict the weight gain response of shrimp to FM substitution by these two proteins.

Table 4. Ingredient Percentages of Base Mix Used in Shrimp Digestibility Trials.

Ingredient	**Percent**
Fish meal	33.0
Soybean meal	8.0
Peanut bran	20.0
Squid meal	3.0
Blood meal	3.0
Fish oil	1.0
Soy oil	1.0
Soy lecithin	1.5
Wheat flour	25.0
Zeolite	2.0
Premix	2.5
Analysis	
Dry matter	89.9
Crude protein	43.7
Fat	8.0
Gross energy (MJ/kg)	18.2
Ash	11.8
Total phosphorus	1.7

Digestible Amino Acids Profile

Digestible EAA specifications in shrimp feeds are important for nutritionists in predicting or ensuring growth performance and protein utilization. When digestible EAAs are expressed as percent of digestible protein of MBM and PBM, and are compared with the established requirements (Table 5), PBM meets all the EAA requirements, with only the exception of sulfur-containing amino acids (methionine + cystine). In clear water rearing systems and with PBM as the only source of dietary protein, the weight gain of shrimp is likely to be reduced by about eight percent compared with the ideal protein feeding condition (i.e. meeting 100 percent of the requirements). A similar comparison for MBM shows the slight deficiency in sulfur-containing amino acids and histidine, which could limit the weight gain by about 40 percent, should MBM be the sole protein source in shrimp diets in clean water conditions. Therefore, in practical shrimp feed formulation, total replacement of FM protein by MBM is not recommended (see details in the section on Growth Trials).

Supplementation of crystalline EAAs in shrimp diets has not produced consistently positive growth response (Cheng et al., 2002; Tan and Yu, 2003; Xue and Yu, 2005) and the critical factor is the effectiveness of the release rate control treatment (e.g., microencapsulation) applied to the EAAs. The success of this technology would allow a greater and broader use of many animal by-product protein meals in shrimp diets.

Under zero water exchange conditions (eutrophic water), Forster et al. (2003) showed that MBM and PBM can replace 100 percent of the FM protein in shrimp diets without causing significant adverse effects on weight gain or feed efficiency. This apparent contradiction to the EAA profile comparison (Table 5) was explained by the nutrients contributed by the microflora flourishing in the water under the minimum water exchange condition. This practice has been gaining acceptance by modern shrimp producing farms worldwide for disease prevention purposes. Therefore, in green water (fertilized pond conditions) shrimp maintain normal weight gains when fed a diet in which FM protein has been 100 percent replaced with either PBM or MBM.

Table 5. Comparison of Digestible Amino Acid Requirements of Shrimp and Amino Acid Profiles in Meat and Bone Meal and Poultry By-Product Meal.

Essential Amino Acids	Requirements [1] (% Protein)	Digestible amino acids profile in	
		MBM[2]	PBM[3]
Arginine	5.3 - 5.8	6.6	3.7
Histidine	2.0	1.7	2.2
Isoleucine	2.5 - 4.2	3.2	3.5
Leucine	4.3 - 8.2	6.2	6.9
Lysine	5.2 - 6.1	5.7	6.1
Methionine + Cystine	3.5	2.1	3.2
Phenylalanine + Tyrosine	4 - 7.2	6.1	6.7
Threonine	3.5 - 4.4	3.5	3.6
Valine	3.4 - 4.0	4.4	3.9

[1] Akiyama et al., 1992; Chen et al., 1992; Millamena et al., 1997; Millanena et al., 1996a; Millamena et al., 1996b; Millamena et al., 1998; Millamena et al., 1999; Dietary protein is 40%.

[2] Meat and bone meal. Total amino acids (Table 1) x AA digestibility coefficient (Table 3) ÷ digestible protein content x 100.

[3] Poultry by-product meal. Total amino acids (Table 1) x AAs digestibility coefficients (Table 3) ÷ digestible protein content x 100.

Protein Efficiency Ratio

Since the main function of MBM and PBM in shrimp diets is to provide protein for its conversion biologically to shrimp body mass, various researchers have measured the protein efficiency ratio (PER) of shrimp fed FM, MBM, or PBM diets (Tan and Yu, 2002a; Tan et al., 2003; Tan and Yu, 2003; Tan and Yu, 2002b; Cruz-Suarez et al., 2004). Substitution of FM protein by MBM or PBM did not cause significant reduction of PER (average 1.75) until high rates (greater or equal to 80 percent) of substitution were reached. The results are in agreement with the comparison of EAA profile versus requirements (Table 5). The main reason for the deterioration of PER at high rates of substitution under clean water conditions is most likely due to deficiency in some EAAs.

Immune Response

Only Chinese workers (Yang et al., 2002; Yang et al., 2003) have evaluated the immune response of shrimp (fresh water shrimp, *Macrobrachiun nipponense*) when fed FM substituted diets with MBM (up to 50 percent replacement) or PBM (up to 100 percent replacement). As shrimp lack true antibodies and have to rely on innate mechanisms, three immune parameters (total haemocyte count, phenoloxidase activity, and respiratory burst or superoxide anion production) were compared between the FM control and FM replacement groups. After a 70-day growth trial, no significant differences in immunological parameters were observed for all groups. It was concluded that MBM or PBM could replace FM up to 50 percent and 80 percent, respectively in diets for shrimp without significant negative effect on the growth, survival, and immune parameters.

Sensory Evaluation

Meat and Bone Meal

Reports on sensory evaluation of shrimp fed MBM diets have been scarce. Australian workers (Smith, 1996) compared *P. monodon* fed either control (FM) or MBM diets (20, 40, 60 percent inclusion rates) for nine flavor characteristics (metallic, meaty, sweet, seafoody, muddy/earthy, fresh, salty, weedy, and other) and found only “meaty” flavor being significantly different. However, this was not correlated with the inclusion level of the MBM. There was also no significant difference in the overall acceptability of the taste of the shrimp. Similar findings, although by a less sophisticated evaluation method, were reported by Chinese workers (Tan and Yu, 2002b) with graded inclusion rates of MBM (up to 40 percent) in diets fed to *L. vannamei*.

Poultry By-product Meal

Only one trial evaluated the flavor of shrimp fed diets with multiple inclusion rates (up to 38 percent) of PBM (Tan et al., 2003). Taste score was reduced only when PBM replaced 100 percent of FM in the diet (3.5 versus 4.1; 5 =

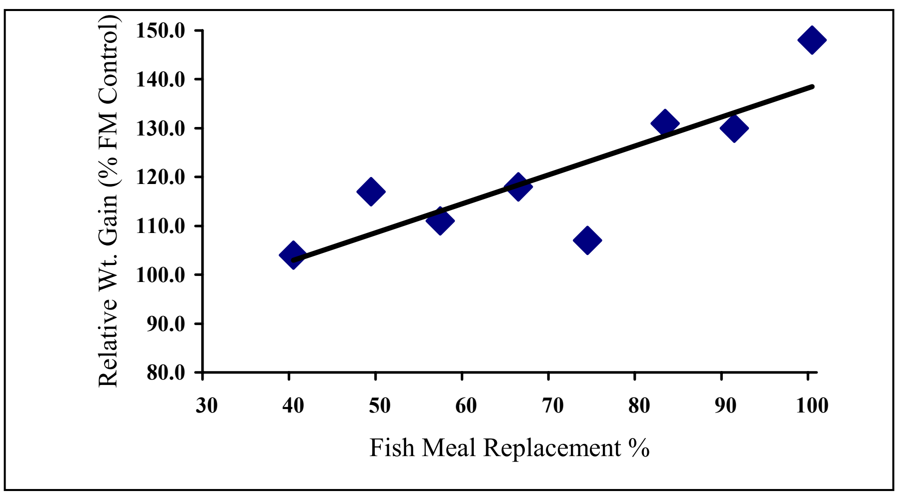
best). These studies indicate that the inclusion of high levels (up to 80 percent) of MBM or PBM in the diet is unlikely to have an adverse effect on shrimp sensory characteristics.

Growth Trials

Poultry By-product Meal

Shrimp growth response to feeding of PBM depends on (1) the inclusion rate, (2) the grade as defined by the manufacturing processes, (3) the complexity of dietary formulation (i.e., single or multi-protein ingredients), (4) total protein content in the diet, (5) stocking density of the shrimp, and (6) nutrients (natural foods) availability from the water. For true comparisons of protein quality, shrimp should be fed a single protein feed in clean (filtered) water rearing conditions. Results of a typical trial in clean water conditions comparing PBM with FM is depicted in Figure 1. Fresh water shrimp (*macrobrachium nipponense*) grew at a faster rate when fed PBM replacing up to 100 percent of FM in diets. Possible reasons for the growth rate difference are that the EAA profile in PBM fits requirements of this particular shrimp species closer than that of FM, and the quality variation (composition and digestibility) of the FM may have been greater than that of the PBM used in this trial.

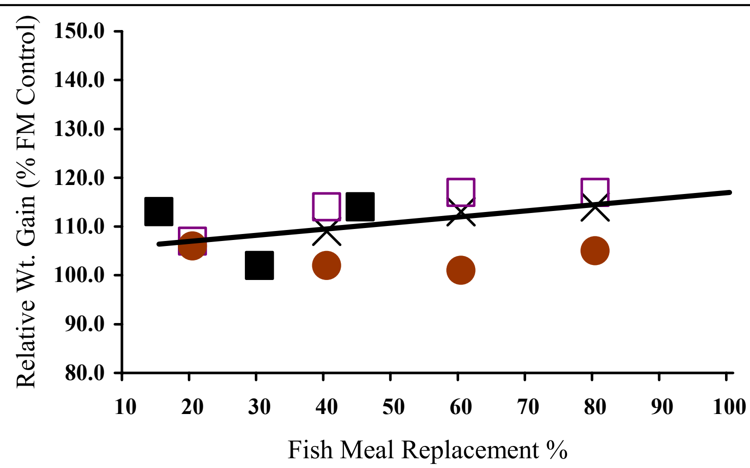
Figure 1. Weight Gain Response of Fresh Water Shrimp (*M. nipponense*) FM Substituted Diets with Graded Levels of PBM (China, 2003).



When formulations with multi-protein ingredients (practical diets) were tested, high grades of PBM (e.g., flash dry, pet food grade, low ash, etc.) all have supported a weight gain equal or superior to FM at high replacement rates (up to 80 percent, Figure 2 for *L. vannamei* and Figure 3 for *P. monodon*).

Details of a recent shrimp growth trial with *P. monodon* are provided in Table 6. Survival rate is not listed because no significant relationship was seen when PBM was substituted in the diets for FM. Since PBM and FM contain comparable levels of crude protein, dietary substitution of FM by PBM has been frequently done on equal weight basis for growth trials as illustrated in the formula for a typical substitution trial with *P. monodon* in China (Table 7; Xue and Yu, 2005). This practice is strongly discouraged as it ignores the possible variability in EAA content and their digestibilities as illustrated in this chapter. Test diets for FM substitution growth trials should be formulated on a digestible nutrients basis (Allan and Rowland, 2005). FM substitution rates ranged from 25 to 100 percent. Among all growth response variables, weight gain is considered to be the most important economic variable for aquaculture producers, and it therefore was selected for analysis of response trend to FM substitution. Maximum replacement rate is defined as the point when weight gain begins to decline sharply.

Figure 2. Weight Gain Response of White Shrimp when Fed FM Substituted Diets with Graded Levels of PBM (Texas, 1998X, 1998□; Hawaii, 2002■; Quigdao, China, 2002●).



P. monodon shrimp fed PBM substituted diets gained more weight (up to six percent) until the replacement reached 75 percent. At 100 percent FM replacement, weight gain was identical to that FM control, and supplementation of crystalline methionine resulted in no further improvement in weight gain. Body composition of shrimp was not affected by PBM replacement up to 100 percent (Table 6).

Figure 3. Weight Gain Response of Shrimp (*P. monodon*) when Fed FM Substituted Diets with Graded Levels of PBM (China, 2005).

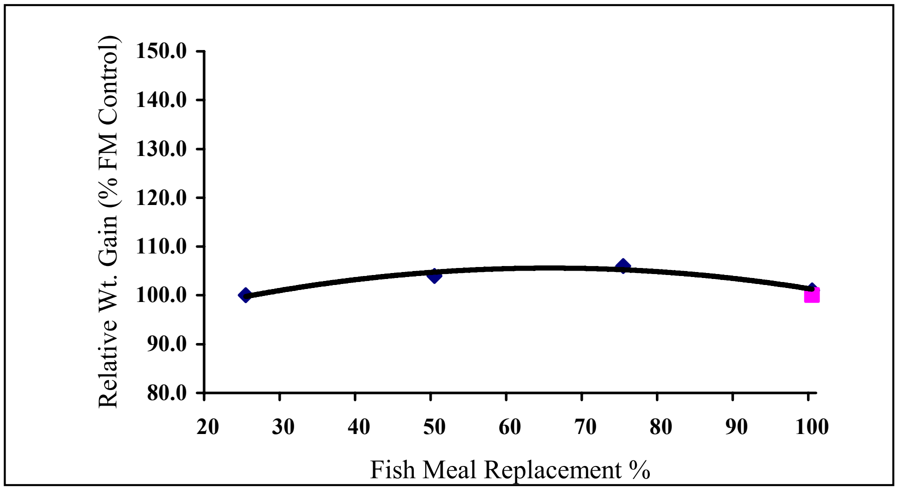


Table 6. Response of *Penaeus monodon* Shrimp to Fish Meal Substitution with Poultry By-product Meal in Growth and Body Composition.

FM Replacement rate (%)	IW[1] (g)	Growth		FI[4] (g)	FCR[5]	Body composition (%)[6]			
		SGR[2]	Gain[3]			Water	CP	Lipid	Ash
0[8]	0.2	4.25	2.28	7.8	3.42	76.0	17.2	.5	4.2
25	0.2	4.23	2.38	8.0	3.37	78.3	15.7	.6	3.7
50	0.2	4.41	2.51	7.9	3.13	78.6	15.4	.5	3.9
75	0.2	4.51	2.70	7.8	2.88	79.2	15.2	.5	3.8
100	0.2	4.28	2.60	8.4	3.22	77.9	16.0	.7	3.6
100+Met.[7] (0.16%)	0.2	4.23	2.44	8.8	3.59	81.3	13.7	.3	3.3

56-day trial by Xue and Yu, 2005.
[1] IW = Initial weight.
[2] SGR = Specific growth rate.
[3] WG = Weight gain.
[4] FI = Feed intake.
[5] FCR = Feed conversion (feed/gain) ratio.
[6] On wet basis.
[7] Met = Crystalline methionine.

Table 7. Nutrient Composition (Percent) of Control and Experimental Diets Used in *Penaeus monodon* Shrimp Growth Trials.

	Percent FM replaced by PBM					
	0	**25**	**50**	**75**	**100**	**100+AA[1]**
Ingredient						
Fish meal	37	28	19	9	0	0
Poultry by-product meal	0	9	18	27	36	35
Soybean meal	12	12	12	12	12	12
Peanut bran	16	16	16	16	16	16
Squid meal	3	3	3	3	3	3
Zeolite	2	2	2	2	2	2
Soy lecithin	1.5	1.5	1.5	1.5	1.5	1.5
Fish oil	1	1	1	1	1	1
Soy oil	1	0.9	0.8	0.7	0.6	0.6
Wheat flour	24	25	25	26	26	26
Na_2HPO_4	1.6	1.6	1.6	1.6	1.6	1.6
Methionine	0	0	0	0	0	0.16
Other	1	1	1	1	1	1
Analysis						
Dry matter	89.0	90.0	90.0	89.0	89.0	90.0
Crude protein	44.2	44.1	43.7	43.6	43.0	43.0
Crude fat	8.0	8.3	8.6	8.6	8.7	8.3
Ash	10.5	10.2	9.7	9.4	8.9	8.9
Total phosphorus	1.5	1.5	1.6	1.5	1.5	1.5
Gross energy (MJ/kg)	18.1	18.5	18.6	18.7	19.1	19.1

[1] Amino acid (methionine). Source: Xue and Yu, 2005.

The growth response of *P. monodon* to PBM substitution for FM is not in full agreement with digestibility data in Table 3, even though the source of PBM was the same for both the digestibility and growth trials. According to Allan et al. (2000), protein and EAA digestibilities of FM by *P. monodon* were in the range of 80 to 90 percent, which are much higher than 59 to 78 percent of PBM reported by Xue and Yu (2005) (Table 3). One possible reason for better weight gain of shrimp fed PBM was the difference in actual EAA content in PBM and FM. This may also explain the zero response in weight gain to methionine supplementation. High quality PBM could meet EAA requirements of *P. monodon* adequately. Another possible explanation could be the increased feed intake resulting from PBM substitution for FM. These results imply the maximum FM protein replacement rate with PBM in shrimp feeds in clean water culturing systems is about 80 percent.

Digestible EAA profile analysis agrees well with weight gain response of *L. vannamei* to FM substitution with PBM but to a less extent with *P. monodon.*

Meat and Bone Meal

Tan et al. (2005) measured growth response of *L. vannamei* to MBM substitution for FM (Table 8). Weight gain was not affected up to 60 percent of replacement, but there was a seven percent reduction in weight gain at 80 percent replacement. Feed conversion ratios also deteriorated by nine percent at the high level of replacement (Table 8). However, data in the literature on weight gain response of *P. monodon* to feeding diets in which FM was replaced by MBM show a slight positive trend (Figure 4; Yu, 2006). This disagrees with the analysis of EAA profiles listed in Table 5. Possible explanations are: (1) EAA digestibilities of MBM by *P. monodon* were under-estimated, (2) some provision of EAAs from natural foods in the water, and (3) increased feed intake with greater levels of substitution. The maximum FM protein replacement rate by MBM under practical culturing conditions is 80 percent for *P. monodon* and 60 percent for *L. vannamei*. However, in a minimum water exchange system, MBM can replace 100 percent FM without significant effect on weight gain and feed utilization (Forster et al., 2003).

Table 8. Response of *Litopenaeus vannamei* Shrimp to Fish Meal Substitution with Meat and Bone Meal.

FM replacement rate (%)	IW[2] (g)	WG[3]	FI[4] (g)	FCR[6]
0	0.9	5.86	8.0	1.37
20	0.9	6.03	8.6	1.42
30	0.9	5.82	4.4	1.39
40	0.9	6.16	8.1	1.32
50	0.9	5.78	8.2	1.41
60	0.9	5.82	8.4	1.44
80	0.9	5.46	8.1	1.49

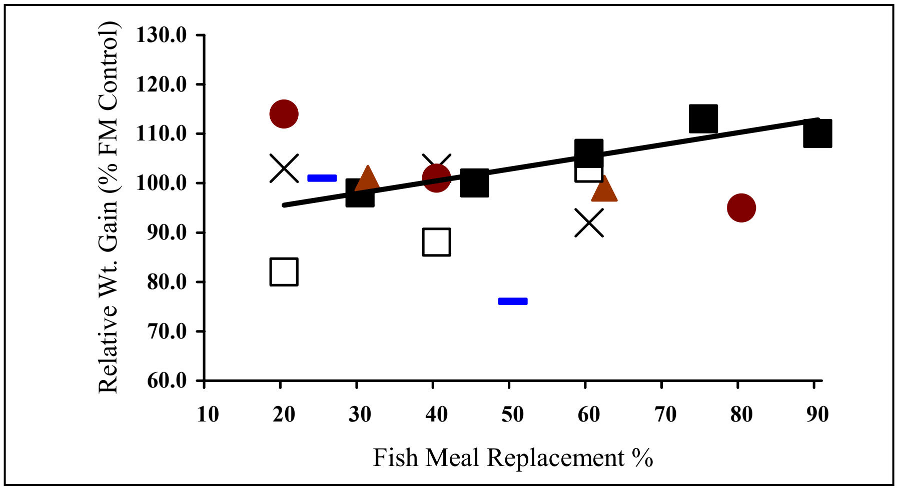
56 day trial by Tan et al., 2005.
[1] 40% protein anchovy FM.
[2] IW = Initial weight.
[3] WG = Weight gain.
[4] FI = Feed intake.
[5] FCR = Feed conversion ratio.

Hydrolyzed Feather Meal

Only a limited number of feeding trials have been conducted with FeM as a FM replacement in shrimp feeds. A Hawaiian study indicated that without the supplementation of crystalline lysine and methionine, steam-pressure-hydrolyzed FeM could replace 33 percent of FM in white shrimp feeds without losing performance (Cheng et al. 2003). Substitution rate could be increased to 66 percent by supplementing lysine and methionine.

When FeM was treated with an enzyme specifically developed for hydrolyzing FeM, Mexican workers have shown that up to 43 percent of FM in white shrimp feed could be replaced by treated FeM (Mendoza et al., 2001). With proper supplementation of microencapsulated EAAs and other nutrients (e.g., essential fatty acids), FeM (steam or enzyme hydrolyzed) may be used to replace FM protein to levels greater than 60 percent in shrimp feeds.

Figure 4. Weight Gain Response of Black Tiger Shrimp when Fed FM Substituted Diets with Graded Levels of MBM (Australia, 1995■, 1996X, 1999▬; Thailand, 2002 (28 days)●, 2002 (60 days)□; Vietnam, 2003▲).



Recommendations for Application of PBM and MBM

The recommended digestion coefficients of protein, energy, and EAA, and the maximum FM replacement rate for *L. vannamei* shrimp are given in Table 9 for MBM and Table 10 for PBM. These values are useful in formulating diets utilizing PBM and MBM as FM replacements while guarding the normal growth performance of shrimp. All digestion coefficients were discounted by five percent as a safety margin.

Table 9. Formulation Recommendation for Meat and Bone Meal in *L. vannamei* Shrimp Feeds.

	Digestibility (Percent)[1]
Protein	78
Energy	66
Maximum fish meal replacement rate (%)	60 - 70

[1] Digestibility coefficient x 0.95 (discount). Source: Tan et al., 2005.

Table 10. Formulation Recommendation for Poultry By-product Meal in *Litopenaeus vannamei* Shrimp Feeds.

	Digestibility (Percent)[1]
Protein	80
Energy	80
Essential Amino acids	
Arginine	81
Histidine	85
Isoleucine	86
Leucine	85
Lysine	88
Methionine	90
Phenylalanine	85
Threonine	81
Valine	77
Cystine	72
Tyrosine	84
Maximum fish meal replacement rate (%)	80

[1] Digestibility coefficient x 0.95 (discount). Source: Xue and Yu, 2005.

Feed nutritionists should use the analyzed nutrients and EAA values of all ingredients available for feed formulation. While digestibilities and the maximum FM replacement rates are higher for PBM than MBM, nutrient requirement specifications of the feed will determine the optimum use rate of the two protein meals. Generally, diets with relatively high digestible protein requirements (20 percent and above) are more likely to use PBM and MBM, while low digestible protein requirement diets will more likely select plant source ingredients.

Conclusion

PBM, MBM, and FeM are high protein source dietary ingredients for carnivorous and omnivorous aquatic animals. Recent research has indicated that PBM resembles FM in nutritive value and could replace most of FM (up to 80 percent) in shrimp and several other economically important fish diets without causing a reduction in weight gain. MBM should be mainly considered for its cost advantage over FM as its nutritive value is slightly lower than FM and PBM. The maximum FM protein replacement rate by MBM is 60 percent for *L. vannamei* and 80 percent for *P. monodon*. Under limited water exchange culturing systems, the FM protein replacement rate could be increased to 100 percent by PBM and MBM. The maximum FM protein replacement rate by FeM should be about 40 percent.

Greater use of FeM requires blending with other quality protein meals to improve palatability and amino acid balance or supplementation with coated crystalline EAAs. Decisions on selection of ingredients and their inclusion rates when formulating aqua diets should be largely based on an accurate nutrient composition, digestibility, palatability, and the risk of anti-nutritional factors.

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First Meeting of the Association of American Producers of Domestic Inedible Fats in Chicago, 1933. (It Became the National Renderers Association in 1942.)

Early 7th Regional Renderers Convention in Minneapolis, MN, 1939.

THE GLOBAL MARKET FOR RENDERED PRODUCTS

Kent Jay Swisher
Vice President, International Programs
National Renderers Association

Summary

Modern efficient renderers are mainly concentrated in North America, where they process nearly 25 million tons of raw materials per year, in the European Union (EU), about 15 million tons per year, and in the leading livestock and meat processing countries of Argentina, Australia, Brazil, Uruguay, and New Zealand, roughly 10 million tons per year. The value of the products sold by the worldwide rendering industry is estimated to be in the range of \$6 to \$8 billion per year. The global rendering industry provides products that are critical to other industries around the world, and they are developing new products such as biofuels and enzymes to meet changing demands worldwide. Rendered products include edible and inedible tallow, lard and greases, feed fats (yellow grease and poultry fat), animal protein meals, hides and skins, and gel bone. High-quality fats and proteins improve the nutrition of farm animals, poultry, and companion animals. Renderers also contribute essential ingredients for industrial products like fatty acids, lubricants, plastics, printing inks, and explosives; and consumer products such as soap, cosmetics, shaving cream, deodorants, perfumes, polishes, cleaners, paints, candles, and caulking compounds.

In the United States, exports have traditionally represented one-quarter of U.S. product annual disappearance. However, in 2004, that number dropped to one-fifth due to trade distortions created by the discovery of bovine spongiform encephalopathy (BSE) in North America. Trade and use of animal fats and grease have been relatively unaffected by BSE trade restrictions because the World Organization for Animal Health or OIE lists tallow as a product that can be safely traded if it has a maximum insoluble impurity of 0.15 percent. (The OIE is an intergovernmental organization that is involved in recommending standards in regards to the control of animal disease.) At the time of this writing, China is the only known country to ban the importation of animal fats from North America. However, animal proteins are facing much more scrutiny. At the time of this writing, ruminant animal proteins are banned by all U.S. major importers, whereas porcine and poultry meals have faired better. It must be noted that production and trade of meat and bone meal (MBM) includes ruminant MBM, porcine meal, and poultry meal. Non-ruminant protein meals should be unaffected by BSE concerns. Even though the trade and production statistics lump all of these products under one term, MBM, the author tries to distinguish between these products where appropriate.

The outlook for rendered products, especially animal proteins, is quite favorable. Even with many global trade impediments to rendered products, there is

a huge growing demand and this demand will become a catalyst for the resumption of trade.

History of Global Trade of Rendered Products– the Early Years (1800s-1945)

The early years of rendering and trade in rendered products were dominated by fat recovery and trade of potential tallow, soap, glue, and candle-making materials. The value of these products cannot be overlooked. For example, in the book *The Cattle on a Thousand Hills*, the author, Robert Glass Cleland, reported correspondence between two Western pioneers that translated to the sale of a single steer equating to $16 per head for fat and only $6 per head for meat. The tallow was worth approximately $0.20 per pound, which is similar to today's price in nominal terms. However, this $0.20 per pound in 1880 is equivalent to $3.67 per pound if converted to 2004 value by using the Consumer Price Index, yet the actual price in 2004 was approximately $0.19 per pound. This shows the relative importance of animal fats in the early years of the industry.

Prior to the depression, the United States was importing a fair amount of competing oils such as coconut oil, palm oil, and whale oil, while it exported much smaller amounts of tallow and lard. The nation was clearly a net importer of fats and oils. By 1932, the price of imported copra (coconut) oil, mainly from the Philippines, was driving down the price of rendered fats. The price of copra was nearly $0.02 per pound and it drove the price of animal fats down to similar levels. This price was an all-time low, and was a decrease of 75 percent from the normal average prices. In recent years, trade experts have learned to talk about fair trade instead of just free trade. This global trade problem threatened the very existence of renderers in the early 1930s and became the rallying call for the industry to organize and form the American Producers of Domestic Inedible Fats in 1933. This organization later became the National Renderers Association (NRA). The first act of the organization was to successfully lobby the U.S. government to impose the so-called fats and oils excise tax, which became part of the Revenue Bill of 1934. The intention of the organization was not to stop imports, but to provide some price support for the commodities, hence creating a "fair" market environment. The organization was successful and this legislation helped to strengthen and stabilize prices while still keeping the market open for imports. Focus on keeping this policy in place continued until World War II began. The World War II years found a controlled economy along with fixed prices for rendered products. In other parts of the world the same scenario transpired along with a basic collapse of commercial infrastructures in some countries. After World War II, the market for rendered products changed quickly and dramatically.

The Global Market for Animal Fats and Greases

Before and shortly after World War II, the U.S. rendering industry was mostly dedicated to the domestic market. Animal protein production went to the local feed industry and the majority of tallow went to domestic soap manufacturers to produce flakes, powders, and granules. A major turning point for the industry came in the early 1950s when the U.S. soap industry turned to detergents that were made from petrochemicals. Tallow producers lost 40 percent of their market in a couple of years and fat prices dropped to less than three cents per pound. This was a 50 to 75 percent price drop for tallow. At this time the rendering industry decided to work on promoting its products to the global marketplace and by 1953, between one-third and one-half of all tallow produced was exported, and by 1956, at least half of tallow and grease production was exported, indeed making up for the lost market domestically. It was this same year that the NRA entered into a cooperative agreement with the U.S. Department of Agriculture Foreign Agricultural Service (FAS) to jointly fund international marketing activities for animal fats and greases. This important cooperative relationship remains to this day. The initial marketing efforts of the FAS/NRA cooperation from the 1950s through 1980 were aimed at promoting industrial demand for beef tallow from soap companies and the fatty acid chemical industry through technical and marketing seminars and the production of technical and promotional literature. In addition, highly successful national soap and hygiene promotion programs were undertaken in Japan, Turkey, Taiwan, Korea, and elsewhere in collaboration with domestic soap producers and government ministries of education and health to encourage soap usage, and thus demand for high quality tallow.

Figure 1. NRA Booth Promoting Soap Use at a Trade Show in Asia. Early Promotional Efforts Included Billboards in Subways, Magazines, Newspapers, and Education Hand Washing Campaigns at Grade Schools.

Figure 2. NRA President Ralph Van Hoven Participates in a Soap Exhibit in Osaka, Japan, in the Late 1950s.

Figure 3. Tallow-Based Laundry Soap from the 1950s Produced and Packaged by Nihon Detergent Manufacturing Co., Ltd., Toho Fats & Oils Co., and Nippon Fats and Oils Co.

Over the period of 1960 to 2004, the global market for fats and oils became saturated. Rendered animal fats, the traditional choice for soaps, began receiving great pressure from detergents and competing vegetable oils (Table 1).

Table 1. Global Exports of Fats and Oils, 1960 - 2004.

	1960	1996	2004
	Million Metric Tons		
Soybean	0.67	5.69	9.06
Palm Oil	0.62	10.80	25.06
Rapeseed Oil	0.05	1.75	1.15
Sunflowerseed Oil	0.22	2.71	2.52
Coconut Oil	0.27	1.40	1.73
Palm Kernel Oil	0.06	0.91	1.85
Fish	0.36	0.77	0.71
Tallow	1.08	2.12	2.25

Source: Oil World (1960 – 1996); USDA/FAS for 2004 vegetable oil data; FAO for fish oil and tallow 2004 data.

Tallow went from being the largest exported fat in 1960, to the fourth largest traded in 2004, and from a commodity that set the oil and fat prices to one of a price taker. The dramatic increases in the production of competing vegetable oils that resulted in large supplies during this time had the affect of depressing prices for animal fats. The trade in palm oil, the major competitor to tallow for industrial uses, went from 0.62 million metric tons (mmt) in 1960 to approximately 25 mmt in 2004, or a 40-fold increase in exports versus a two-fold increase in tallow exports in the same period. Global soybean oil exports also grew 14-fold over the same period. This was the result of the large growth in the production of these products. For example, palm oil production grew from 1.32 mmt in 1960 to 33.24 mmt in 2004, and soybean oil production grew from 3.36 mmt to 32.43 mmt during the same period. Malaysia and Indonesia have historically been the largest producers of palm oil. Together, these two countries have traditionally accounted for well over 80 percent of total global production in palm oil. In regards to soybean production, traditionally the United States has been the largest producer followed by Brazil, China, and Argentina.

As stated earlier in this chapter, the rendering industry output is bound by livestock production. Hence, the industry cannot increase or decrease output in changes to market conditions, and has become a price taker in the global market. The large increases in production of competing vegetable oils have been partly fueled by government support and intervention in the production of these products, giving them an unfair advantage against rendered fats and greases in the world marketplace. These same government policies have also had the effect of artificially changing the global fats and oils prices and, hence, unfairly affected the price that renderers receive in the global marketplace for their products. The major suppliers of tallow in the world are as follows (Table 2).

Table 2. Tallow Exports by Major Suppliers, 2000 – 2005.

	2000	2001	2002	2003	2004	2005	% change last 2 yr
	Metric Tons						
United States	915,879	781,383	1,034,398	904,673	853,015	790,204	-7.36%
Australia	384,099	414,962	340,901	384,758	396,129	376,064	-5.07%
Canada	227,099	252,480	245,243	173,433	289,432	227,654	-21.34%
New Zealand	117,421	125,045	114,180	136,337	143,760	142,493	-0.88%
Brazil	146	22,974	13,352	4,259	46,347	44,491	-4.00%
World Total	1,687,718	1,611,027	1,814,947	1,653,582	1,807,845	1,658,928	-8.24%

Source: Global Trade Atlas for national exports; world total excludes intra EU trade.

Tallow production is tied to the cyclical nature of the beef industries in the producing nations. Exports from the major suppliers have been fairly static over the last five years. However, it is interesting to see a very large increase in exports from Brazil. Brazil's rendering industry is fairly new and will probably continue to increase its exports in the near future. The majority of tallow exports from these countries are utilized for industrial purposes with the remaining used in livestock feed as an energy source. The major importers for tallow are listed in Table 3.

Table 3. Tallow Imports by Major Markets, 2000 – 2005.

	2000	2001	2002	2003	2004	2005	% change last 2 yr
	Metric Tons						
Mexico	261,458	283,464	377,441	370,966	454,512	430,619	-5.26%
China	332,914	299,265	320,865	296,478	318,520	306,575	-3.75%
Cent. Am & Carib	139,852	136,832	161,852	150,460	169,214	98,389	-41.86%
Turkey	123,656	88,436	136,430	116,640	130,993	133,891	2.21%
Pakistan	99,838	71,324	84,324	113,483	70,189	83,126	18.43%
Nigeria	47,615	57,215	51,585	62,705	57,834	105,440	
World Total	1,687,718	1,611,027	1,814,947	1,653,582	1,807,845	1,658,928	-8.24%

Source: Global Trade Atlas; world total excludes intra EU trade.

As would be expected, Mexico, the largest importer of tallow, imports nearly all of their tallow from the United States, and China imports from Australia and New Zealand. Before BSE was found in North America, China was importing increasingly large quantities of tallow from North America. However, after BSE was found, China closed the market and as of this writing they have not re-opened to tallow from North America, despite all scientific evidence that shows tallow with a maximum insoluble impurity level of less then 0.15 percent is safe.

Post World War II Protein Meals

Research at Purdue University by Professor Plumb in the early 1900s showed that pigs fed protein residue or tankage along with corn grew much better then those fed corn alone. So began the feeding of rendered animal proteins to livestock because of the rich nutrient content and amino acid complex of these proteins. Prior to World War II, very little, if any, animal proteins were traded. Most were fed back to the livestock industry in the countries where they were produced. After World War II, there continued to be little trade in animal proteins because they were valuable and thus utilized in the countries where they were produced. Hence, it is extremely difficult to find trade data for animal proteins prior to the late 1980s. It appears that entering the late 1980s, exports of animal proteins meals started to increase dramatically. Many countries in the world are protein deficient and as their livestock industries have developed, the need for imported protein feed ingredients has grown. High quality animal proteins offer a good source of nutrition along with a desirable amino acid complex, and are a very good complement to plant-based protein meals in a ration.

Animal protein meal exports have become increasingly more important to the American rendering industry. During the period 1992 to 2002, U.S. exports went from 160,000 metric tons to over 550,000 metric tons, a near four-fold increase. However, in 2004 and 2005, due to BSE concerns by importing nations, exports of animal proteins decreased substantially. On the domestic side, according to the U.S. Census Bureau's monthly surveys and NRA estimates, U.S. production of animal protein meals is somewhat static to down slightly (Table 4).

Table 4. U.S. Production and Consumption of Animal Protein Meals.

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**% change last 2 yr**
	Thousand Metric Tons						
Production	4,215.5	4,120.1	4,525.1	3,845.1	4,020.5	3,881.1	-3.5%
Consumption							
Domestic	3,729.6	3,619.1	3,916.7	3,296.8	3,841.5	3,644.9	-5.1%
Exports	485.8	501.0	608.4	548.3	179.0	236.2	32.0%
Total	4,215.5	4,120.1	4,525.1	3,845.1	4,020.5	3,881.1	-3.5%

Sources: U.S. Census Bureau. Global Trade Atlas for exports. Domestic consumption is derived.

The livestock industry must comply with a 1997 Food and Drug Administration (FDA) BSE safeguard measure that prohibits the feeding of ruminant-derived (mainly cattle and sheep) materials back to ruminant animals. This has resulted in market differentiation whereby porcine materials and poultry meals command a price premium. As a consequence, prior to December 2003, renderers successfully marketed ruminant-derived and/or mixed-species materials into the export market. However, since the United States announced a case of BSE from an imported cow toward the end of 2003, all export markets for ruminant or mixed materials have disappeared. The exports of 236,000 metric tons in 2005 was attributed mostly to poultry by-product meal, porcine meal, feather meal, and a brief period of exports of ruminant MBM to Indonesia before two additional cases of BSE were reported. Amazingly enough, after BSE was reported, most international markets even closed the doors to North American porcine and poultry meals. However, government-to-government negotiations soon resulted in most of these markets reopening. This has led to price premiums in the domestic market for these proteins as opposed to ruminant MBM. There also continues to be a shift in consumption whereby ruminant or mixed material is being fed domestically to poultry and pigs, and the single species, non-ruminant material is commanding a premium in the export market, opposite the case prior to December 2003.

World exports of animal proteins were relatively stable in the time period 2000 to 2005 (Table 5). The European Union issued a ban on the exports of MBM due to BSE in 2000 that caused a 29 percent decrease in global exports of MBM between 2000 and 2001. Soybean acreage in the major producing countries continues to grow, pushing exports of soybean meal from approximately 36 mmt in 2000 to about 48 mmt in 2005.

Table 5. World Meal Trade, 2000 – 2005.

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**% change last 2 yr**
	Million Metric Tons						
Total veg. & fish meal	48.79	52.79	53.72	58.49	59.91	62.27	3.9%
Soy	36.11	41.53	42.67	45.41	46.15	47.89	3.8%
Fish	3.46	3.19	2.88	3.13	3.55	3.60	1.4%
Other	9.22	8.07	8.17	9.95	10.21	10.78	5.6%
Animal Prot.	1.37	0.97	1.23	1.12	1.26	1.27	0.8%

Sources: USDA/FAS Oilseeds: World Markets and Trade Circular, February 2006.
NRA estimates and forecast for animal proteins.

The world trade in protein meals increased by approximately four percent in 2005, continuing a trend of increases in trade for all protein meals. Soybean meal trade increased by four percent to total 48 mmt versus trade in animal proteins of a little over one million tons.

In 2005, U.S. exports of MBM increased by about 42 percent over 2004 levels mainly due to a substantial increase in exports of non-ruminant protein meals to Mexico and to the brief period in which ruminant MBM was exported to Indonesia (Table 6). Australian exports increased, as did exports from Argentina. Both countries were filling the demand that was left open due to the United States and Canada being out of the ruminant MBM market. Of interest to note among the group of exporters is that the EU-25 continues to increase exports of MBM. As they re-enter the export market they will be strong competition to U.S. exports. Brazil is one of the world's largest producers of poultry and beef, so, as their rendering industry develops, they could become a major competitor as well.

Table 6. Meat and Bone Meal Exports by Major Suppliers, 2000 – 2005.

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**% change last 2 yr**
	Metric Tons						
U.S.	460,824	458,641	569,435	505,671	136,932	193,857	41.6%
Australia	192,903	204,747	222,424	282,486	201,869	205,821	2.0%
N. Zealand	133,169	140,384	132,540	131,390	233,018	132,049	-43.3%
EU-25	365,628	21,773	32,638	46,007	111,434	117,559	5.5%
Canada	53,005	65,634	110,011	77,393	60,891	57,811	-5.1%
Brazil	2,243	3,493	16,448	31,847	44,505	40,296	-9.5%
Argentina	62,952	32,302	39,864	41,813	75,058	75,887	1.1%
World Tot.	1,050,745	884,311	1,180,683	1,197,084	872,504	915,890	5.0%

Source: Global Trade Atlas for national exports; does not include intra EU trade.

Regarding global importers of MBM, Indonesia continues to be the largest importer (Table 7). However, in 2005, imports declined by 15 percent—a continued decline since 2004. This decrease is mostly due to the presence of avian influenza in that country and the liquidation of poultry flocks. In 2005, imports of MBM by Egypt also declined by 34 percent, again due to the concerns of avian influenza and the impact on the poultry industry and consequently the feed industry. In 2005 the major suppliers of MBM to Egypt were Argentina and Uruguay. In 2004, imports of MBM into China were down 79 percent due to banning MBM from the United States and Canada, its two major suppliers. However, in 2005, Australia filled this demand and exports grew by 78 percent.

Table 7. Meat and Bone Meal Imports by Major Markets, 2000 – 2005.

	2000	2001	2002	2003	2004	2005	% change last 2 yr
	Metric Tons						
Indonesia	283,816	250,021	310,301	394,379	212,056	180,469	-14.9%
Egypt	65,112	74,610	111,465	106,920	110,651	73,518	-33.6%
Mexico	92,755	79,868	62,634	61,711	59,750	113,267	89.6%
Bangladesh	10,971	24,746	30,373	30,667	110,187	46,032	-58.2%
China	135,972	75,314	130,932	73,561	21,097	37,323	76.9%
Taiwan	35,023	31,142	56,169	88,020	36,420	44,044	20.9%
World Tot.	1,050,745	884,311	1,180,683	1,197,084	872,504	915,890	5.0%

Source: Global Trade Atlas for national exports; does not include intra EU trade.

Traditionally, exports of protein meals went to countries with larger poultry sectors because they have provided nutrients needed by poultry at reasonable prices. MBM is unique as compared to other feedstuffs in that it provides for a highly digestible source of protein, fat, calcium, and phosphorous—all in one source. Poultry producers understand the importance of MBM in the ration because of its nutritional and economic benefits. This is important for poultry companies competing as low-cost producers in the global marketplace. Using animal proteins as opposed to a corn and soybean meal-only diet, has shown a five percent savings in feed cost, with some showing a savings as high as 10 percent (*Render*, August 2004). According to researchers in Brazil, when their poultry industry stopped using animal proteins to meet European Union requirements, the following observations were noted (Penz, Brazil, 2004):

- $10/ton increased feed cost
- Poorer feed conversion
- Compromised pellet quality
- Increased harmful oligosaccharides and antigens
- Increased feet and leg problems
- Increased water intake and wet litter
- Lower metabolizable energy
- Variability of SBM protein, digestibility not accounted for in research

Hence, there is good reason why animal proteins are so highly demanded around the world from poultry producers. Demand for animal proteins is starting to increase in the aquaculture sector as well. As the production of fish meal, a main ingredient in aquaculture feed, is not keeping up with the demand, prices are rising to extreme levels and aquaculture producers are searching for alternatives to fish meal. Animal proteins are an excellent source to partially replace and complement fish meal in an aquaculture ration, at a fraction of the cost of fish meal.

Production Outlook for Rendered Products

Extrapolating data from the Economic Research Service (ERS) meat production forecasts, U.S. production of protein meals should remain steady in the near-term and rise to over 2.9 mmt by 2013 (Table 8), a 19 percent increase over 2003. Production of animal fats and greases is predicted to rise by 15 percent between 2003 and 2013, reaching approximately 4.9 mmt in 2013 (Table 9).

Table 8. U.S. Animal Protein Meal Production Forecast, 2003 – 2013.

Year	Metric Tons
2003	2,432,603
2004	2,392,234
2005	2,565,505
2006 (Forecast)	2,601,388
2007 (Forecast)	2,655,684
2008 (Forecast)	2,709,603
2009 (Forecast)	2,767,493
2010 (Forecast)	2,800,743
2011 (Forecast)	2,833,385
2012 (Forecast)	2,867,069
2013 (Forecast)	2,900,551

Table 9. U.S. Production Outlook for Fats and Greases, 2003 – 2013.

Year	Metric Tons
2003	4,243,334
2004	4,302,755
2005	4,185,366
2006 (Forecast)	4,367,026
2007 (Forecast)	4,458,174
2008 (Forecast)	4,548,690
2009 (Forecast)	4,645,872
2010 (Forecast)	4,701,690
2011 (Forecast)	4,756,486
2012 (Forecast)	4,813,033
2013 (Forecast)	4,869,241

Unknown variables within the United States could change the production forecasts dramatically. Of specific concern is the long awaited follow-up to FDA's July 14, 2004, advance notice of proposed rulemaking (ANPR) that was officially published in the *Federal Register* on October 5, 2005. There was a 75-day public comment period that closed on December 20, 2005. Currently, the FDA is reviewing all comments and will make a determination regarding a final rule. The FDA has the ability to implement the rule as written, alter the rule due to comments, or decide not to issue a final rule. Due to the process involved in issuing a final rule, and the extremely low level of risk, it may likely be towards the end of 2006 before it is known what FDA's final decision will be regarding a final rule. This ANPR proposes, among other things, the elimination of specified risk material (SRM) from cattle over 30 months and dead stock from the feed chain. An NRA funded study by Informa Economics predicts that these restrictions, if enacted, would decrease production of MBM by over 35,800 metric tons, valued at over $7.1 million dollars. The same restrictions would decrease tallow production by 21,772 metric tons at a value of over $8.6 million. Hence, total rendered product production could fall by over 57,572 metric tons. This is equal to approximately four percent of U.S. exports by volume (2005 data). As stated earlier, the comment period for this rule ended on December 20, 2005. As of September 2006, FDA had taken no action on this rule. Due to the relatively high cost and disruption to the market, for a relatively miniscule risk level, and the already proven effectiveness of existing regulations, it would be hard to justify such a rule on pure scientific terms. Another unknown variable in the production of fats and greases is energy prices. Production of fats and greases in 2005 was down approximately three percent compared to 2004 production, while at the same time the cattle slaughter by weight was higher, along with MBM production. It appears, due to high energy costs, producers of fats and greases relied upon their own production to fuel their plants, hence leading to a decrease in the reported production of fats and greases. If this trend continues, the production forecast would need to be adjusted downward.

Outlook for Rendered Products

The demand outlook for rendered products is quite favorable. Aside from the continued demand for rendered products in traditional markets, the future holds great promise for new demand patterns to form. Demand for fats and greases is expected to increase dramatically as biodiesel production continues to absorb more raw materials, including both vegetable oils and animal fats and greases. The demand for animal proteins should continue to grow in the long term; however, in the short term, the stigma of BSE still acts as a catalyst for importing nations to raise regulatory barriers blocking the imports of some products. As time passes, and the relative low risk of BSE in North America is understood, and as demand for protein meals grows, markets will open slowly to the imports of MBM. The rendering industry is quite unique in that it takes waste material from the slaughter of animals and converts this waste into high quality, high value products that are in turn the solution to providing safe alternative ingredients to the livestock, aquaculture, and industrial sectors.

Problem—Shortage of Fish Meal
Solution—Animal Proteins as a Substitute

The outlook for increased demand for animal proteins is being fueled by demand for fish meal, for which animal proteins make a good substitute. Fish meal is a major feed ingredient in poultry rations, but more so in aquaculture rations. According to Dr. Albert Tacon, University of Hawaii, the average annual growth in the aquaculture sector has been approximately nine percent per year since 1970. In contrast, the average annual growth rate in the non-food catch of fish has only been 0.8 percent per year between 1970 and 2002 (Tacon, 2004). This contrast shows the dramatic increase in demand for fish meal and the lack of increased supplies while prices of fish meal have increased to unheard-of levels. In May 2006, it was reported that fish meal prices reached nearly $1,000 per metric ton as opposed to average traditional price levels of $400 to $600 per metric ton. This is compared to rendered protein meals that range from $120 to $300 per metric ton. As this shortage of fish meal continues and the prices increase, feed millers will have no choice but to find alternative proteins, and rendered protein meals are a good fit. Feed trials that have been conducted by NRA further prove the positive effect of substituting rendered protein meals for fish meal (Yu, 2006). Furthermore, the reduced fish meal supply could have catastrophic effects on the aquaculture sector in China. Since fish is considered to be the food of choice in China, much like beef is in the United States; disruption in the aquaculture sector is a serious concern. The substitution of animal proteins for fish meal in poultry and aquaculture rations is a viable solution to the ever-growing crises created by the shortage of fish meal, and feeding trials have proven the replacement to cause no ill effects.

Problem –High Energy Costs and Reliance on Unstable Foreign Oil
Solution—Animal Fats and Greases as a Feedstock for Biodiesel

In regards to fats and greases, the outlook for use in biodiesel is the largest variable on the demand side of the equation. The drastic rise in oil prices and the uncertainty of day-to-day supplies of oil from unstable regions of the world have led many nations to look to renewable energy sources and biodiesel as a solution. According to the U.S. Department of Energy, “Biodiesel is made by transforming animal fat or vegetable oil with alcohol and can be directly substituted for diesel either as neat fuel (B100) or as an oxygenate additive (typically 20 percent-B20).”

The European Union is the world’s largest producer of biodiesel and the United States is the second largest producer. The growth in biodiesel production is astonishing. According to the European Biodiesel Board, European Union production of biodiesel between 2002 and 2004 increased by about 35 percent per year, and increased by 65 percent in 2005 versus 2004 (Table 10).

Table 10. Estimated EU Biodiesel Production.

Year	Million Gallons
2001	278
2002	319
2003	430
2004	580
2005	955

Source: European Biodiesel Board.

In the United States, biodiesel production went from a relatively small production of two million gallons in 2000 to 75 million gallons in 2005. The growth tripled between 2004 and 2005 (Table 11). Extremely high energy prices starting in 2005 and continuing through 2006, along with government incentives to develop renewable fuels have sparked massive growth in biodiesel production. Since animal fats and greases are a good raw material for biodiesel, demand for these products will increase as biodiesel production continues to increase. On a global level, the International Energy Agency (IEA) predicts global production of biodiesel to increase from below 0.8 billion gallons in 2003 to approximately 6.2 billion gallons by 2020 (Table 12). Hence, a whole new market for fats and oils is emerging in which both vegetable and animal fats will compete.

Table 11. Estimated U.S. Biodiesel Production.

Year	Million Gallons
1999	0.5
2000	2.0
2001	5.0
2002	15.0
2003	20.0
2004	25.0
2005	75.0

Source: National Biodiesel Board.

Table 12. Global Biodiesel Production Projections to 2020.

Year	Million Gallons
1990	0
1995	211
2000	309
2005	991
2010	2,906
2015	4,438
2020	6,208

Source: International Energy Agency/Organization for Economic Cooperation and Development (IEA/OECD), 2004, p 169.

Conclusion

In conclusion, there continues to be a very large demand for animal proteins globally from countries that are protein deficient. Animal proteins are best positioned for use in the poultry and aquaculture industries, as well as in pet food and swine rations. As fish meal prices continue to climb, demand for high quality animal protein meals continue to rise as well. However, one obstacle for North American proteins is the food and feed safety barrier related to BSE. Unfortunately, the situation in the EU, where close to 200,000 cases of BSE have been reported, drove the global regulatory structure to stop trade of ruminant MBM from any country that had a case of BSE. Obviously, North America, with fewer than 12 cases total through August 2006, should not be treated similarly to the European Union in regard to risk level and import standards.

There is also a growing demand for animal fats and greases as a renewable energy source. Their use for energy is two-fold. First, they can be used directly in industrial burners. As energy prices rise, there is more direct burning occurring, especially within renderers' own plants. Second, the growing biodiesel industry will also demand more. Currently, in the United States, most of the biodiesel facilities utilize soybean oil, and in the EU, they use canola oil. However, there are a growing number of plants that can use multiple sources of feedstock, and some that utilize animal fats and greases alone. Since this industry is at the beginning of major expansion, it is hard to predict the ultimate impact. However, the expansion will result in increased demand for animal fats and greases. Rendered products are the solution to two major problems being faced today and in the foreseeable future—the growing cost of energy and the growing cost of fish meal.

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

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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.

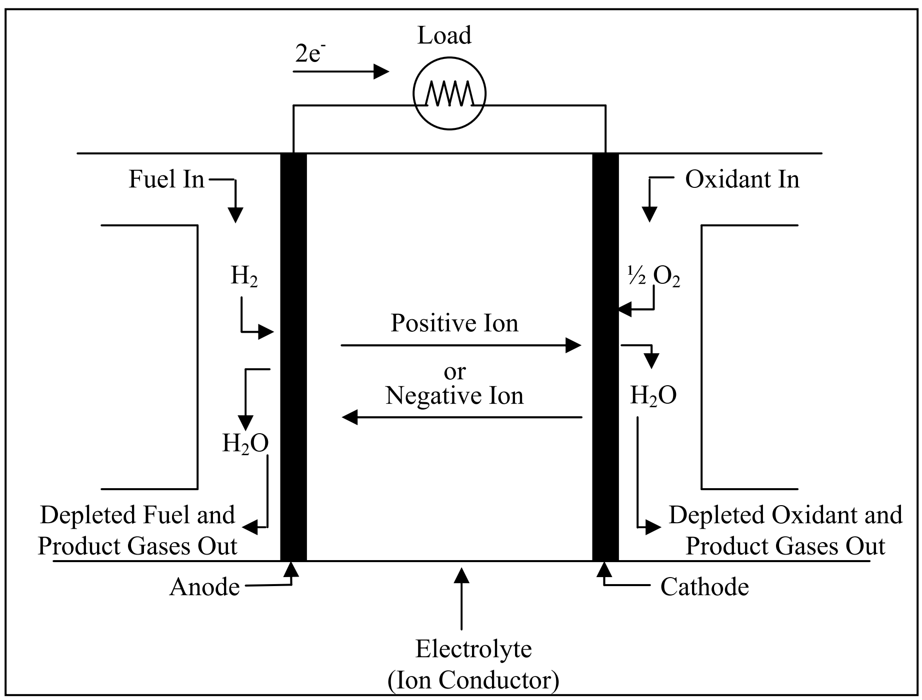

Figure 1 shows the basic cell configuration. The electrochemical reactions occurring within the cell are:

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.

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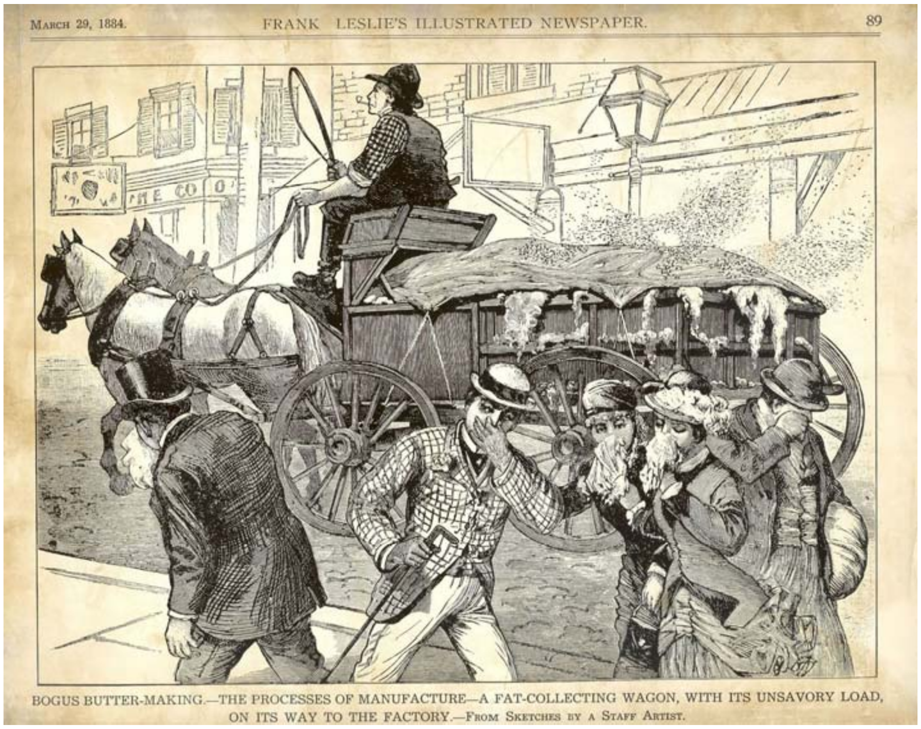

Early Rendering Route Equipment and Driver.

ENVIRONMENTAL ISSUES IN THE RENDERING INDUSTRY

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Summary

The rendering industry has a significant positive impact on environmental quality. The processing of low economic value organic matter from the livestock production, meat processing, food processing, and food service industries by the rendering industry reduces the amount of wastes deposited in landfills and discharged to municipal wastewater treatment facilities. The rendering of dead stock from livestock production reduces the risk of groundwater pollution and public health problems associated with improper disposal of livestock mortalities.

The rendering industry also has the potential for producing negative impacts on environmental quality. Even though most rendering facilities do not produce hazardous wastes, the handling and processing of organic raw materials produce significant amounts of undesirable biodegradable by-products that can have significant impacts on water and air quality. Modern rendering facilities have sophisticated treatment processes and control equipment for maintaining acceptable water and air emissions. Water and air emission control systems require significant capital and plant operating costs.

The rendering industry operates under several sets of environmental regulations. In addition to governmental control under federal, state, and local regulations, the rendering industry is also subject to pressures from environmental interest groups and individual citizens. It is becoming increasingly difficult to site new facilities and to ensure compliance with all environmental regulations as the number and complexity of rules and regulations as well as environmental legal issues continue to increase.

Many members of the rendering industry rely on industry and trade organizations such as the National Renderers Association (NRA) and the American Meat Institute (AMI) and their environmental committees for monitoring the development of environmental policy and regulations.

The developing environmental management system (EMS) concept is a step toward self-regulation and environmental quality improvement implemented on a plant scale. EMS programs are encouraged by environmental regulatory agencies including the U.S. Environmental Protection Agency (EPA).

Environmental regulation will become more stringent and compliance will become more complex and expensive as more water and air contaminants are regulated in the future. The regulation of greenhouse gases and ammonia air emissions and total nitrogen, phosphorus, and dissolved solids wastewater discharges will be challenges in the near future. Regulation of other contaminants unknown at this time will undoubtedly develop in response to environmental research and real or perceived environmental problems.

The rendering industry has voluntarily participated in EPA research and industry survey projects. This type of cooperative work, rather than the traditional confrontational relationship with regulators, is leading to the development of federal rules, regulations, and policies that are based on the application of reliable and economically feasible control technology to provide adequate environmental protection.

Wastewater Issues

Rendering plants generate significant volumes of wastewater. The wastewater contains contaminants that are relatively low in long-term environmental risk, but cannot be released directly to the rivers, streams, or lakes without proper treatment. Wastewater discharges are regulated by federal, state, and local laws and rules.

Environmental Concerns

There are four basic categories of environmental concerns regarding wastewater generated and discharged by rendering plants: protection of aquatic life, protection of human and animal health, protection of receiving stream aesthetics, and protection of water supply quality. Protection of aquatic life requires the most significant attention and expense in wastewater treatment.

Limiting the discharge of organic matter attains protection of aquatic life from low dissolved oxygen in streams downstream of wastewater discharges. Organic matter is used as a food source by bacteria in streams. As bacteria consume the organic matter, they consume oxygen. If the rate of oxygen consumption by the bacteria exceeds the rate that oxygen dissolves into the stream, the dissolved oxygen concentration will decrease and fish will die due to lack of dissolved oxygen. Fish kills due to inadequate dissolved oxygen downstream of inadequately treated municipal and industrial discharges were common prior to the large scale construction of biological wastewater treatment facilities in the United States in the 1970s and 1980s.

Carbonaceous biochemical oxygen demand (CBOD) and biochemical oxygen demand (BOD) are methods of measuring the organic matter concentration. CBOD and BOD are the amounts of oxygen consumed by microorganisms as they utilize the contaminants as a food source during a five-day laboratory test. The results are expressed in terms of milligrams per liter (mg/l), or parts per million, of oxygen consumed during the five-day test.

BOD has been used for several decades as the measure of organic concentration. CBOD is similar to BOD, but the reaction of organic nitrogen is blocked in the CBOD test. The amount of nitrogen reaction is assumed to be insignificant in the BOD test when testing low strength wastewater. The BOD and CBOD concentrations are similar in wastewaters that have low nitrogen concentrations. Reaction of nitrogenous compounds during the BOD test can be significant in wastewater with high organic nitrogen and ammonia concentrations such as rendering plant wastewater. Therefore, the use of CBOD rather than BOD is preferred for these wastewaters. The CBOD concentration is always less than the BOD concentration. Raw rendering plant wastewater has CBOD concentrations in the range of 4,000 to 10,000 mg/l. Typical CBOD limitations for discharge to streams are 10 to 25 mg/l.

Ammonia is produced from the biological degradation of proteins. Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen and ammonia. Ammonia is very toxic to aquatic life. Free ammonia (NH_3) and ammonium (NH_4^+) coexist in equilibrium in water. Ammonia is toxic whereas ammonium is not toxic. Ammonium is converted to free ammonia as the pH increases. Ammonia is also more toxic at higher stream temperatures. Therefore, pH and temperature are important considerations in evaluating ammonia toxicity to aquatic life. Ammonia toxicity increases with increasing pH and temperature. Raw rendering plant wastewater has TKN concentrations in the range of 500 to 1,000 mg/l. Typical ammonia limitations for water quality in streams are less than two mg/l expressed as nitrogen.

Aquatic life is sensitive to pH. The typical range of allowable pH for discharge to streams is six to nine.

Some dissolved salts such as chloride and sulfate can be toxic to aquatic life. Rendering plant wastewater can contain high concentrations of dissolved salts due to salt discharge from hide operations and salts contained in raw materials such as blood serum water. Total dissolved solids (TDS) are the concentration of solids that pass through a filter paper. It is a measure of the dissolved organic matter and salts. The concentrations of specific components of the TDS such as chloride, sulfate, and other constituents are of greater concern rather than the TDS concentration. Therefore, the use of TDS as an aquatic life protection parameter is not as technically sound as the use of specific contaminant concentrations such as chloride and sulfate. Although several states have had water quality standards for dissolved solids, chloride, sulfate, and other dissolved constituents for several years, in many cases they have not applied the standards for these parameters to discharge permit limitations until recently. The development of regulatory standards for constituents that make up dissolved solids will be important in the future as states develop revised water quality standards.

Wastewater from rendering facilities contains the liquid that drains from uncooked raw material, including potentially pathogenic microorganisms. Fecal coliform is used as an indicator of the potential for pathogenic organisms. The concentration of fecal coliform is expressed in terms of “most probable number” per 100 milliliters (MPN/100 ml). The typical limitation for fecal coliform discharge to streams and lakes is 200 to 400 MPN/100 ml.

Total suspended solids (TSS) are a measure of the amount of material that can be removed from the wastewater by passing a sample of wastewater through a filter paper. TSS is an important aesthetic water quality parameter. Typical suspended solids limitations for discharge to streams are 10 to 30 mg/l.

Phosphorus and nitrogen compounds are sources of nutrients for plant growth in lakes and streams. Rendering process wastewater can have relatively high concentrations of nitrogen compounds as a result of protein degradation.

Nutrients stimulate excessive growth of algae in lakes and streams and thereby impact the aquatic life and water aesthetics. Limitations on phosphorus discharge to the Great Lakes drainage basin have been in effect for several years. The 2004 EPA rules require that discharges from rendering facilities to streams and lakes contain no more than 134 mg/l of total nitrogen. Local limitations based on state water quality standards may be more stringent. Typical phosphorus discharge limitations in regions with phosphorus water quality standards are 1.0 mg/l of total phosphorus. Phosphorus and total nitrogen limits may become significantly more stringent as states adopt more stringent nutrient water quality standards.

Oil and grease is an aesthetic water quality parameter. Oil and grease is defined as any material that can be recovered with an organic solvent such as hexane. Oil and grease is more correctly defined as hexane extractable material (HEM) as all compounds recovered by the test method may not actually be true oil or grease. Excessive oil and grease discharge can result in floating solids accumulation in streams and lakes. Excessive oil and grease discharge to city sewers forms grease coatings in sewers and leads to sewer maintenance problems. Typical oil and grease limitations for discharge to city sewers are 100 to 200 mg/l.

Regulation of Wastewater Discharges

Limitations on wastewater discharge to streams and lakes are based on two considerations: minimum quality based on the use of treatment technology (technology-based limits), and quality required for protection of the stream or lake water quality (water quality-based limits). The EPA establishes the minimum water quality based on the application of treatment technology for specific industries, commonly referred to as categorical industry discharge limitations or effluent limitation guidelines (ELGs). The rendering industry is subject to the ELGs for the renderer subcategory of the Meat and Poultry Products Point Source Category as published in the *Code of Federal Regulations* (40 CFR Part 432, Subpart J). The EPA established ELGs for independent renderers in 1975 and periodically reviews them. The EPA revised the ELGs for the renderer subcategory in 2004, which includes standards for new and existing point source dischargers to streams and lakes. The standards for ammonia, BOD, oil and grease, and TSS are based on raw material volume and are expressed in terms of pounds of contaminant per 1,000 pounds of raw material. The fecal coliform standard is 400 MPN/100 ml, and the total nitrogen standard is 134 mg/l as per the rules promulgated in 2004.

Water quality-based discharge limits are based on the water quality standards for the receiving stream. State regulatory agencies develop standards for protection of aquatic life and other uses of streams and lakes. Limits for discharges to streams are calculated by allocating the stream capacity for receiving and assimilating wastewater constituents from all sources without violating the stream water quality standards.

Direct discharges to streams and lakes are authorized with National Pollutant Discharge Elimination System (NPDES) permits issued by state regulatory agencies under authorization of the EPA and the Clean Water Act.

EPA may also impose standards for categorical industry discharge to municipal treatment facilities referred to as pretreatment standards. EPA did not include pretreatment standards for the renderer point source subcategory in the 2004 rules.

Limitations on discharge to publicly owned treatment works (POTW), or municipal sanitary sewers, are based on state rules, local city ordinances, and the POTW treatment facility capacity. In general, the wastewater characteristics from rendering facilities are compatible with conventional POTW treatment processes, if the POTW has adequate treatment capacity.

Discharges to POTWs are commonly authorized by local municipal ordinances and agreements between industrial users and the POTWs. In some regions, state permits or state approval of treatment agreements are required.

Storm water discharges are authorized with NPDES permits issued by state agencies under authorization of the EPA.

Wastewater Sources

Contaminants in rendering plant wastewater represent lost product. For example, the oil and grease discharge is grease that could have been recovered as finished grease in the rendering operations. The protein loss to wastewater can be estimated by multiplying the TKN concentration by 6.25. Ammonia discharge is indicative of the amount of protein that has been degraded. The organic nitrogen (TKN minus ammonia nitrogen) discharge is indicative of actual protein loss to the wastewater system. Packing plants routinely use the wastewater oil and grease and TKN monitoring data to determine product loss and indicators of production plant performance.

Rendering facility wastewater generation rates and characteristics are quite variable and are functions of raw material types and condition, type of rendering processes, and general housekeeping practices. Wastewater problems are often the result of relatively low volume but very high concentration wastewater sources. A typical dead stock rendering plant with three to seven million pounds of raw material per week production capacity generates about 100,000 gallons of wastewater per day with 5,000 lb CBOD and 900 lb TKN per million pounds of raw material.

A typical rendering plant generates wastewater from the following sources:

- Raw material liquids
- Cooking condensate
- Restaurant grease processing
- Blood processing
- Plant wash down and sanitation
- Hide operations
- Air pollution control equipment
- Non-contact cooling water
- Storm water

Even though raw material liquids are only a small fraction of the total wastewater volume, these liquids can be a significant source of CBOD, organic nitrogen, and ammonia. For example, the CBOD concentration of whole blood is in the range of 150,000 to 200,000 mg/l. Liquids that drain from raw materials increase in volume and strength as the raw material quality degrades during long holding periods in hot weather.

In conventional rendering facilities, cooking vapors are cooled and vapor condensate is discharged with the wastewater. The cooking vapor condensate contains condensable organic compounds, ammonium, and aerosol grease and solids carryover from the cooking process. Some rendering processes experience foaming problems and the foaming results in periodic very high concentrations of grease and solids in the vapor condensate. The amount of cooking condensate is easily estimated from rendering process yields. Cooking condensate quality is a function of raw material type and quality. Cooking condensate from feather processing and from degraded raw material can have very high ammonia concentrations. Typical cooking condensate has 2,000 to 5,000 mg/l CBOD and 500 to 1,000 mg/l TKN.

Some rendering facilities use short term, high temperature treatment of cooking vapors to destroy odorous organic compounds and discharge the thermally treated vapors to the atmosphere rather than condense the water vapor. These plants do not generate cooking condensate liquid waste.

The free water removed from restaurant grease is very high strength due to free fatty acids and protein degradation products. Typical restaurant grease process wastewater has 50,000 to 100,000 mg/l CBOD, 100 to 800 mg/l phosphorus, and 1,000 to 3,000 mg/l TKN.

Steam coagulation and centrifugal separation of whole blood generates serum water that has very high CBOD and TKN concentrations. Typical blood serum water has 7,000 mg/l CBOD, 150 mg/l phosphorus, and 1,800 mg/l TKN.

Hide salt brine raceways generate wastewater that has very high TDS, sodium, and chloride concentrations. Typical chloride concentrations in salt brine hide operations are 100,000 to 150,000 mg/l.

Packed bed air scrubbers produce wastewater with relatively low organic strength but high TDS concentration due to the addition of chemicals such as bleach and caustic soda.

Primary Pretreatment

Conventional wastewater pretreatment prior to discharge to municipal sanitary sewers involves removal of oil and grease and suspended solids. The removal of suspended solids also removes the CBOD fraction that is associated with the suspended solids.

Conventional wastewater pretreatment includes the following unit operations:

- Screening
- Gravity separation
- Flow equalization

- Chemical pretreatment
- Dissolved air flotation

Rotary drum screens with opening sizes of about 0.030 inches are used for removal of large diameter solids.

Gravity separation is the removal of particles and free floatable grease by gravity. The solids and grease are removed in circular or rectangular tanks with scraper mechanisms for continuous grease and solids removal.

Flow equalization is used to provide a more consistent flow rate and wastewater characteristics for downstream pretreatment operations. Flow equalization tanks also act as grease traps for partial protection of downstream operations from slug grease discharges.

Chemical pretreatment is the addition of chemicals to enhance the removal of oil and grease and small solids. Solids and grease remain in suspension due to surface charge characteristics. Most solids in suspension have net negative surface charges. Reduction of the pH with acid addition reduces the negative surface charge. Addition of metal coagulants such as aluminum sulfate (alum) further reduces the net negative particle surface charges and forms metal precipitates that trap the small solids inside larger agglomerates of solids called floc. Organic polymers with high surface charges further assist with coagulation of solids and floc formation.

The destabilized solids from the chemical pretreatment step are typically removed with dissolved air flotation (DAF). Conventional DAF involves introduction of water that is saturated with air at high pressure along with the chemically pretreated wastewater into a circular or rectangular open-top tank. As the pressure is reduced, the air comes out of the solution, small bubbles form on the particles, and the particles float to the tank surface. The solids are scraped from the surface and removed. A portion of the treated wastewater is re-circulated to the dissolved air pressurization system.

Pretreatment with chemicals and DAF typically produces wastewater with less than 100 mg/l oil and grease and TSS. Solids and grease recovered from pretreatment operations are commonly rendered along with the raw material.

Conventional pretreatment does not remove soluble CBOD or soluble TKN. Soluble proteins can be removed with aggressive chemical pretreatment for denaturing proteins followed by DAF. Proteins can be denatured with acid addition to very low pH and/or addition of a strong oxidizing agent such as chlorine. Aggressive chemical pretreatment for soluble protein removal is usually not cost-effective as compared with biological secondary wastewater treatment.

Secondary Treatment

Secondary treatment refers to the removal of organic contaminants using biological treatment processes. Secondary treatment processes involve the same basic natural biodegradation of the organic matter that occurs in streams and lakes. The biodegradation occurs in tanks with very high concentrations of microorganisms so that the organic matter can be removed from the wastewater in a much shorter time period than in the natural aquatic environment.

Anaerobic secondary treatment is the biological removal of organic contaminants in the absence of oxygen. Most of the organic matter is converted by bacteria into methane and carbon dioxide gas referred to as biogas. Some of the organic matter is incorporated into biomass or sludge. Organic nitrogen is converted into ammonia. The biogas is about 70 percent methane, or natural gas with a heating value of about 700 BTU per cubic foot. The biogas can be recovered for use as a boiler fuel for heating the anaerobic process and for use in production plant boilers. Anaerobic processes produce about eight to ten cubic feet of natural gas equivalent per pound of CBOD removed.

Anaerobic lagoons and covered anaerobic reactor tanks are typically used in the rendering industry for anaerobic biological secondary treatment. The tanks are covered for control of air emissions and biogas recovery. Many newer anaerobic lagoons are covered with plastic membranes for biogas recovery. Anaerobic processes perform best at about 100ºF. Anaerobic lagoons are typically not heated. Anaerobic reactor tanks are usually heated to maintain the 100ºF optimum operating temperature. Anaerobic pretreatment removes about 80 to 90 percent of the CBOD. Most of the organic nitrogen is converted to ammonia. Therefore, there is no significant reduction in TKN with anaerobic secondary treatment.

Aerobic secondary treatment is the biological removal of organic contaminants in the presence of oxygen. Organic matter is converted by bacteria and other microorganisms into carbon dioxide, water, and biomass or sludge. The activated sludge process is commonly used for aerobic biological treatment. The activated sludge process includes aeration tanks in which oxygen is supplied to the microorganisms using compressed air and air diffusers. The microorganisms, referred to as activated sludge, are removed from the treated liquid by gravity in a separate clarifier tank and returned to the aeration basin.

Batch treatment processes, or sequencing batch reactors (SBR) are also used as secondary treatment processes. A separate clarifier tank is not used in the SBR process. The SBR process is operated as a batch process. Solids are separated in the aeration tank by turning off the aeration air, allowing the solids to settle, and decanting the liquid.

The activated sludge solids are retained in the aeration basin system for several days even though the liquid retention time may be less than two days. The long solids retention time provides for very rapid removal of organic contaminants. The activated sludge process generates about four to five times the mass of biological solids per pound of CBOD removed than anaerobic processes. The disposal of the activated sludge biosolids can be a significant operating cost. Waste activated sludge is typically land-applied as a plant nutrient and soil amendment.

Aerobic and facultative lagoons have been used for biological secondary treatment, but the use of lagoon treatment for direct discharge to streams is becoming less common as the discharge limitations become more stringent. Lagoon treatment produces discharge with significant TSS concentration due to algae growth in the lagoons. Lagoon treatment requires very long retention times to achieve ammonia removal in cold climates.

Disinfection

Disinfection refers to the removal of pathogenic organisms. Use of a strong oxidizing agent such as chlorine or ultraviolet light is commonly used for disinfection of rendering plant wastewater. Chlorine gas and sodium hypochlorite or bleach are common sources of chlorine. Chlorine contact basins are designed with adequate volume and flow control baffles to ensure that the liquid is retained for at least 15 minutes prior to discharge. Chlorine is toxic to aquatic life. Unreacted chlorine is removed prior to discharge with a reducing agent chemical such as sulfur dioxide or sodium metabisulfite.

Tertiary Treatment

Tertiary treatment refers to processes that remove contaminants beyond conventional CBOD and TSS removal in secondary treatment processes. This includes ammonia, total nitrogen, phosphorus, and enhanced TSS removal. Tertiary treatment is frequently required to meet nutrient and ammonia discharge limits. Suspended solids removal may be required for meeting stringent CBOD or BOD discharge limits because biodegradable, organic suspended solids contribute to CBOD.

Organic nitrogen is converted to ammonia in anaerobic and aerobic biological treatment processes. Ammonia can be biologically converted to nitrate in the activated sludge process under the proper operating conditions. This process is called nitrification. Nitrification is accomplished in the activated sludge secondary treatment process by providing proper operating conditions. In general, nitrification requires longer solids retention times than conventional activated sludge process operation because the nitrification bacteria have slower growth rates than other organisms. The nitrification process requires adequate aeration to provide oxygen for the biological conversion of ammonia (NH_3) to nitrate (NO_3^{2-}). Nitrification also produces acid so pH control and alkalinity addition is usually required.

Nitrification processes usually achieve ammonia nitrogen concentrations of less than two mg/l. Nitrate removal is required for meeting nutrient, or total nitrogen, discharge limits. Nitrate is removed by the biological conversion of nitrate to nitrogen gas in the absence of dissolved oxygen. This process is called denitrification. Bacteria in the presence of nitrate, no dissolved oxygen, and a food source utilize nitrate in a manner similar to oxygen and convert the nitrate to nitrogen gas. This is called anoxic biological treatment. Anoxic treatment is a separate stage of biological treatment. Ammonia is converted to nitrate in aeration basins as part of the secondary treatment process. The sludge removed in the clarifier following the aeration basin and the aeration basin effluent contain nitrate and bacteria, but very little organic carbon food source. Dentrification is accomplished by bringing the clarifier return sludge and re-circulated aeration basin effluent in contact with raw wastewater in a mixed, but non-aerated basin. The bacteria use the nitrate as they metabolize the organic matter in the raw wastewater.

Denitrification is accomplished in SBR batch processes by operating with extended periods of no aeration after raw wastewater is introduced at the start of each batch. The denitrification process provides some benefits to the operation of the nitrification process. The use of CBOD in the raw wastewater as a food source in the anoxic process reduces the CBOD load and aeration requirements in the activated sludge process. The denitrification process produces alkalinity and raises the pH. This reduces the alkalinity chemical addition required in the activated sludge process for neutralization of acid produced by nitrification. The effluent nitrate concentration achieved with denitrification processes is dependent on the relative concentrations of TKN and CBOD in the raw wastewater and the sludge recirculation rate. There must be adequate CBOD available as a food source in the anoxic process for nitrate removal.

Phosphorus is removed by chemical precipitation. Phosphate is precipitated with aluminum using aluminum sulfate (alum) and with iron using ferric chloride or ferric sulfate. The chemicals are commonly added ahead of the clarifiers in an activated sludge secondary treatment process. The precipitated phosphate solids become part of the activated sludge. Separate stage phosphorus precipitation following the activated sludge clarifiers can be used to produce a phosphorus rich sludge and reduce the solids loading on the activated sludge process.

Phosphorus can be removed biologically in the activated sludge process under the proper operating conditions. The bacteria can concentrate the phosphorus in the biomass. The use of long solids retention times required for nitrification and denitrification at rendering facilities usually do not provide the operating conditions conducive for biological phosphorus removal. Chemical phosphorus removal can consistently achieve one mg/l total phosphorus discharge quality.

Additional suspended solids removal is usually required if the suspended solids and CBOD discharge limits are less than about 15 mg/l. Enhanced suspended solids removal is commonly accomplished with filtration using granular media filters. The suspended solids are captured within the pores of deep bed filters. Deep bed filters are single media sand or dual media sand and anthracite coal. The solids are removed from the filters by backwashing with water and air. Shallow bed filters remove solids by capturing the solids on the upper surface of the very small diameter granular filter media. In moving bridge filter equipment, the filter is divided into narrow segments. The solids are cleaned from the media surface by water backwash using a traveling backwash mechanism that isolates and backwashes each filter segment. Tertiary filtration can consistently achieve five mg/l TSS discharge water quality.

Land Application

Wastewater from rendering operations can be applied to agricultural land for beneficial use of the water as an irrigation water supply. The nitrogen and phosphorus contained in the wastewater is used beneficially as a supplement or replacement for commercial fertilizers. The organic carbon in the wastewater stimulates the growth of beneficial soil bacteria.

Wastewater application rates are usually limited by the nitrogen or phosphorus uptake rate of the crop, or agronomic rate. Wastewater is usually pretreated for reduction of CBOD prior to storage and land application for minimization of odor emissions. Extensive pretreatment is not required because the ammonia, phosphorus, and organic matter in CBOD are beneficial for soil fertility. Therefore, land application can have a significant capital and operating cost advantage over secondary and tertiary treatment and discharge to a stream.

Wastewater is land-applied using conventional irrigation equipment such as center pivots and traveling guns. Highly concentrated wastes with potential for odor emission can be land-applied with direct injection to the root zone with knife or field cultivator injection.

Use of sodium and other dissolved salts are limitations to the use of land application disposal. Excessive sodium application can cause clay soils to expand and lose the porous soil structure. This leads to inability to percolate water through the soil profile and development of a hard soil crust and loss of fertility. Dissolved salt application is a particular concern in arid climates where the salts accumulate in the upper soil profile due to high evaporation and low precipitation rates.

Air Quality Issues

Odor emissions have historically been the most significant air emission issue in the rendering industry. Regulation of odor emissions has been challenging due to the difficulty in quantifying odor concentrations. Odor emissions are often regulated at the local governmental level and regulations are often based on nuisance concepts rather than on analytical concepts.

The use of citizen or expert odor panels in qualitative evaluation and characterization of odors is frequently used in the evaluation of odor emissions. The odor unit concept has been developed as a method of quantifying odor intensity. The odor unit is a measure of the dilution required to reduce the odor to a concentration that is not detected by a panel of odor experts.

Other air emissions from rendering facilities are regulated by the EPA under the Clean Air Act and by states. In general, ammonia, particulates, nitrogen and sulfur oxides from boiler operations, and hydrogen sulfide or reduced sulfur are the emissions of most concern at rendering facilities. Greenhouse gases from boiler operations may become significant issues in the future.

Air Emission Controls

Rendering facilities have extensive controls for odor and particulate emissions. Most facilities do not have significant emissions of other constituents that require operation of emission control equipment. Particulate emissions from production operations that generate dust are commonly controlled with bag houses. Bag houses are fabric filters that capture particles as the air is passed through the filters. The filters are cleaned by periodic air purging and/or vibration.

Rendering plants are designed for capture and treatment of potentially odorous air and vapors. The room air ventilation systems are designed for maintaining negative pressures in the rooms, thereby preventing air escape from the rooms. Production operations that generate high intensity odors are designed with vapor and air collection systems that isolate the odor sources from the lower intensity room air.

Odor control methods include the following processes:

- Chemical oxidation
- Combustion
- Thermal destruction
- Biological odor reduction

Chemical oxidation involves absorbing the odorous compounds into water and then oxidizing the odorous compounds with a strong oxidizing agent such as chlorine or chlorine dioxide. Odorous compounds can also be oxidized directly in the vapor phase with ozone. The air from room air ventilation systems is usually scrubbed in a chemical oxidation system using packed bed scrubbers with chlorine, bleach, or chlorine dioxide.

Cooking vapors have high odor intensity. Cooking vapors are often treated in a two-stage process. The vapors are cooled and particulate is partially removed in venturi scrubbers. The vapors are passed through a venturi pipe restriction at a high velocity. Water is sprayed upstream of venturi. The cooking vapors are cooled and portions of the particulate and aerosol grease entrained in the vapors are removed in the venturi. The vapors from the venturi can be further treated in a chemical packed bed scrubber.

Cooking vapors can also be condensed with an air-cooled condenser or a shell and tube condenser using non-contact cooling water. The non-condensable vapors can be treated chemically or incinerated in a boiler. The high intensity odors from rendering processes and non-condensable cooking vapors are often used blended with combustion air at the plant boilers. The odorous compounds are incinerated in the boilers.

Odorous compounds can be removed by thermal destruction. Thermal destruction involves heating the odorous vapors to very high temperatures that result in destruction of the odorous compounds. This technique is applied to treatment of cooking vapors and other very high intensity odors. The advantage of thermal destruction of cooking vapors is that it does not generate cooking vapor condensate. The water evaporated from the cooking process leaves via the air emissions rather than as a wastewater emission.

Odorous compounds are organic compounds that can be used as a food source by bacteria. Biofilters are used for biological removal of odor. A biofilter consists of a packed bed that serves as a support structure for bacterial growth. The odorous air is passed through the packed bed. The odorous compounds are absorbed into the moist bed and bacteria consume the compounds as a food source.

Other Environmental Issues

Compliance with all environmental regulatory requirements can be very challenging, particularly for small, independent renderers that do not maintain full-time environmental staff. The following is a partial list of environmental regulations and requirements for operation of rendering facilities:

- Wastewater NPDES permitting for process wastewater discharges to streams
- Local wastewater pretreatment and discharge permitting
- Storm water NDPES permitting and reporting
- Spill Prevention Control and Countermeasures plans and implementation
- Land application permitting and reporting
- Air emission permits and inventory reporting for Clean Air Act Title V regulations
- Toxic chemical release reporting
- Underground and above ground storage tank registration and reporting
- Hazardous chemical inventory reporting
- Emergency Planning and Community Right-to-Know regulations
- Solid and hazardous waste disposal requirements

It is becoming increasingly difficult to manage environmental compliance and track environmental issues as the federal and state regulations grow at seemingly exponential rates. Many renderers rely on industry and trade organizations such as the NRA and the AMI and their environmental committees for monitoring the development of environmental policies and regulations. These industry and trade organizations pool the resources of its members to maintain close watch on developing environmental issues and policies. These trade organizations retain legal and technical consultants for monitoring regulatory agency and legal developments, and for developing the trade organization policies on environmental issues. While the trade organizations have been quite effective in providing professional and scientific input into the development of federal rules and policies, it has been quite difficult to monitor the state and local regulatory developments.

Environmental Management Systems

The development of the EMS concept in recent years is a step toward self-regulation and environmental quality improvement implemented on a plant scale. The EMS approach to environmental management in meat packing, food processing, and rendering industries has been developed in a cooperative effort between federal and state regulatory staff and industry organizations including the AMI's Environmental Committee.

An EMS is a systematic, iterative approach to achieve individualized, facility specific environmental and other organizational goals through continuous improvement. It is based on the objective of identifying environmental or process weaknesses that can adversely impact the operations. The EMS approach ranks the weaknesses and develops a prioritized schedule for resolving the problems. Progress is evaluated annually and the plan is modified for continuous improvement. The results improve financial performance and reduce environmental noncompliance risks. The EMS system energizes the employees to become part of the improvement team.

The International Organization for Standardization (ISO) has developed a standard for EMS systems. The ISO standard 14001 defines EMS as "the part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes, and resources for developing, implementing, achieving, reviewing, and maintaining the environmental policy."

An EMS accomplishes the following:

- Identifies environmental risks and impacts
- Prioritizes risks and impacts
- Applies management control to risks and impacts
- Builds a business case for continuous improvement

An EMS includes evaluation of regulatory compliance, pollution prevention, waste reduction, and utility management. Facilities that have implemented EMS programs have documented significant improvements in environmental compliance records and reductions in operating costs that have greatly exceeded the costs of EMS program development.

Regulatory agencies, including the EPA, are encouraging the development and implementation of EMS programs. EPA has indicated that it may reduce the frequency and scope of regulatory compliance inspections and relax enforcement action penalties for facilities with EMS programs.

A formal ISO 14001 EMS is a very structured approach that requires periodic outside audits by ISO certified auditors. Full implementation of the ISO 14001 EMS program is a big task and experience has demonstrated that the ISO 14001 EMS is not suited for all facilities. An EMS program can be developed in phases, or tiers, that address the facility's immediate needs and then expanded in the future. The AMI Environmental Committee has developed a four-tier EMS program and model EMS that leads to ISO 14001 certification.

Cooperative Development of Environmental Protection Standards

The rendering industry has voluntarily participated in EPA research and industry survey projects. Renderers have assisted regulators with technical input and review of proposed environmental regulations. This type of cooperative work, rather than the traditional confrontational relationship with regulators, is leading to the development of federal rules, regulations, and policies that are based on the application of reliable and economically feasible control technology to provide adequate environmental protection.

As environmental protection and regulation expand to address future environmental quality concerns, cooperation between regulators and the regulated community will become more important. This cooperative effort is required for development of environmental policies and regulations that are reasonably and economically achievable.

Research and the Rendering Industry

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Introduction

The rendering industry is one of the longest existing industries as described by Frank Burnham in *The Original Recyclers* (Franco and Swanson, 1996). Its research role can similarly be traced well into the eighteenth century. Though historically the crude process of extracting fat from animal tissue or carcasses via open flames could be characterized as a form of rendering, rendering evolved during the 1900s as a process. Its predecessors comprehended the value of collecting the fat drippings from the open fire cooking that accompanied their successful hunts. As the industrialized evolution progressed, the value of these traditional customs was modified into cooking vat systems that utilized the three basic principles of rendering: removal of water, fat extraction from the protein fraction, and sterilization. The process continued to provide products that could subsequently be stored and used for both life sustaining and life enhancing benefits. The progression that brought the rendering industry from open fire process to its modern, electronically controlled and monitored systems of today's facilities was assisted by a number of factors, but research has proven to be a consistent significant influence.

As animal agriculture evolved into animal production units that replaced hunting at-large for meat, milk, eggs, and hides, the evolution of how to be more productive and more efficient has been a primary motive to bring modern agriculture to the present. Research has influenced nearly every aspect of animal agriculture in its progress to modern day standards. Historical accounting of the symbiotic relationship of the rendering industry with all segments of animal agriculture is most evident in the quest to keep meat, milk, eggs, fiber, and now bioenergy at the top of the agriculture production chain. Research has made significant contributions in guiding the production and processing of rendered animal products and assisting in the production of the safest, most economical, most wholesome animal-derived food in the world. Research will continue to be a proactive component in guiding the rendering industry into its future role as being a vital, integral part of sustainable animal agriculture.

Research

Research is described as the diligent search, inquiry, scientific investigation, and study to discover new facts. Thus, "If you only look at what is, you might never attain what could be" (Anonymous). In actuality, research has progressed from a basic trial-and-error process. An idea was successful if one could demonstrate that a theory or even an idea worked. Science and the process of research have become a rather precise process. The requirements are now well articulated and for a referenced journal publication, a research report must undergo a stringent peer review process. Although the research process varies substantially, to be effective, it must contain basic components. An objective must be established in concert with a hypothesis. A plan or protocol to solve the identified problem or hypothesis is developed. The plan is implemented to develop data to scientifically and statistically be evaluated. Duplication or replication of the exact treatment parameters must be sufficient to assess a statistical interpretation of the resultant data. Thus, the principles of good experimental design for animal science research are based on standard textbooks that outline design and analysis of experiments. The American Society of Animal Science (ASAS) has published *Techniques and Procedures in Animal Science Research* as an assist to guide the process (ASAS, 1969-1998). This rather simplistic review of the highly scientific process of establishing research conclusions provides opportunities for questions of interpretation or application. There are many examples of such pertaining to animal research that will be addressed later in this chapter. However, it is a fact that research results and their interpretation and implementation create obsolescence and change our lives daily. It is important to note that in composite, over 80 percent of the increased efficiency and overall productivity advancements in American agriculture can be directly attributed to research and its application.

Historical Perspective

The formality of animal research has not always been as clearly articulated as the modern scientific approaches of 2006. Nutrient requirement development has been a perpetual process subject to interpretation, safety factor inclusion, and substantial personal bias. It has been a similar evolution for all species. Matching nutrient specifications to the established or believed-to-be requirements has been likewise a process requiring multiple interpretations.

The actual "scientific" approach to early animal nutrition projects can be described as astute observation and demonstration when compared to today's research standards. As a historic perspective, Dr. George Fordyce of England in 1791 was the first to use a control group experiment to document the need for calcium supplementation in laying hens to produce eggs with shells that did not break easily in the nest. A hundred years later, Professor C.S. Plumb at Purdue University reported the first experiment to demonstrate the accelerated growth that occurred when animal proteins were used to supplement ear corn rations that heretofore had been the standard diet for growing-finishing pigs in the Midwest. It was a historic event that opened the research arena to protein nutrition. The early studies utilized animal protein to a great extent, which consisted of both meat and milk sources. Plant-sourced supplements were comprised of high fiber legumes which preceded the advent of the oil seed evolution that now predominates today's protein ingredient market. Demonstrations of the benefits of animal proteins were common. Morrison's *Feeds and Feeding* was first published in 1898 and was received with widespread favor by practical stockmen and professors and students of animal husbandry (Morrison, 1957). The first edition was written by Dean

William Arnon Henry of the University of Wisconsin. Annual or biannual editions have provided volumes with updated scientific data. Numerous veterinary journals of the early 1900s reference the preventative qualities of animal protein and meat for many diseases and conditions in animals such as cannibalism in cooped chickens. Despite the current protests against closed housing systems used today, it was necessary to coop poultry as a protection from predators, even in those days. Feather picking and other cannibalistic conditions were reported that could be prevented via providing chunks of meat suspended on wires for the poultry to peck on. *The Practical Stock Doctor*, copyrighted in 1904, references the use of lard, tankage, and skimmed milk in many of the remedies for many of the described diseases (Waterman, 1904).

Today there are innumerable journals, both animal science and veterinary science, which have continued to relate to refining the nutritive requirements of animals. The journals have been historically prolific in adding science with each new volume. Combined, there are undoubtedly more volumes published on animal nutrition than nearly any other subject. The American Dairy Science Association was founded in 1906, followed by the formation of the American Society of Animal Science and the Poultry Science Associations in 1908. These associations/societies were brought together as the Federation of Animal Science Societies to represent the member societies as a scientific liaison in 1998. The journals, section, and national meetings provided by these organizations have been the primary sources for the establishment of animal nutrient requirements. The National Research Council of the National Academy of Sciences has routinely published species reports that summarize the knowledge of the nutrient requirements and the nutritional characteristics of nutrient sources (NRC, 2006).

Thus, research based on scientific principles has guided the animal industries through a rather archaic period to today's standards in which the United States is now producing an even greater number of animals for meat, milk, eggs, fiber, and bioenergy with less than one percent of its population compared to more than 80 percent when the country was founded.

The Formative Years of FPRF

The Fats and Proteins Research Foundation, Inc. (FPRF), is now in its 44th year of research and technical services to the rendering industry. Formally chartered as a foundation on June 20, 1962, FPRF has completed over 570 individual research projects and innumerable scientific and technical manuscripts in support of rendering and rendered animal products. FPRF is perhaps as well known by its acronym as by its official name. It is a recognition acquired through its close collaboration with the scientific community and for its funding support of quality projects.

Rendered animal product research was previously sponsored under the direction of the National Renderers Association (NRA) Research Committee. This committee was inspired by Robert J. Fleming in 1959 for the development of a foundation concept for directing the industry's research initiatives. The formation and initial funding of the foundation can be credited to the vision of Bob Fleming, National By-Products, Inc., and Charles L. Haussermann Jr., Darling Delaware Company, Inc. It is indicative of change and ironic that these two companies became one in 2006.

The vision that research commands a different business model as compared to other organizational functions inspired the foundation's formation. FPRF was founded with a specific research and education mission and a non-lobbying reference in its bylaws. The success of the action of the founders of FPRF is evident as one reviews the scientific criteria and understands the requirements of research to be accepted by peer reviewed journals and by end users. A research committee was formed on October 23, 1962. Dr. Fred D. Bisplinghoff, Faber Industries, Inc., was a charter member of that committee. Dr. Bisplinghoff is a current life member of the FPRF Research Committee and served as its president and director of technical services from 1988 to 1993.

It is not possible to review each of the research arenas that the foundation has pursued during its tenure, nor is it possible to credit all of the contributors to the research committee or the multitude of scientists and researchers that have been a part of the foundation's history. However, during the early 1960s, animal fats commanded significant attention. Exploration as herbicide sprays, attempts to modify saturated fatty acids and tallow, dehydration of saturated fats, and the use of animal fats as waterproofing agents for concrete commanded research project approvals. Odor abatement studies were high priority projects. A pilot plant operation was available at Theobald Industries and was used by the Battelle Institute for odor abatement research. The foundation later acquired a patent for an olfactometer to measure odor components and intensity (FPRF, 1965).

In the late 1960s, projects addressing odor and alternative uses for tallow were still priorities. It is interesting to note that a project proposal to study the use of "Ozone for Odor Control" was rejected early on, but an FPRF project by Dr. Annel Greene at Clemson University was completed in 2002 addressing the same objective. The late 1960s brought attention to potential *Salmonella* and pesticide contamination of rendered animal products and research was stimulated in these areas. Research continues to improve our understanding and control over biological and chemical product safety hazards today.

The 1970s, with the increased usage of animal fats as feed ingredients, as well as the advancement of amino acid (AA) nutrition brought new opportunities for research. Calf milk replacer, catfish, and digestible AA studies were conducted. The competition from the advent of the corn-soy concept compromised the use of animal by-products in swine rations in favor of the simplicity of on-farm blending of local corn, commodity soybean meal and a small package of vitamins and minerals for the "Mix Mill" era. Enhanced attention to swine nutrition studies was initiated as animal protein ingredient suppliers are now frequently asked about amino acid content and digestibility. Targeted research projects with basic animal nutrition studies are, and will continue to be necessary to command a marketplace position in all species' diets. Under the FPRF research committee's guidance, a number of multi-species projects are currently in progress to address these objectives.

The 1970s also brought interest in the enhancement of the energy content for the diets of most animal species. Animal fats contribute 2.6 to 3.8 times the metabolizable caloric value as compared to corn, and this attribute commanded research that were directed to these usages. The dairy cow, the lactating sow, laying hen, broilers, and both feedlot and range cattle were targets for research projects for the utilization of animal fats. The benefits of feeding fats were later expanded into the equine, companion animal, and aquaculture species.

The rendering industry responded by supplying on-farm fat storage with systems to deliver directly to farm prepared diets. The development of "dried fats" brought numerous new products to the marketplace. By the 1980s, research projects were highly oriented towards nutritional subjects. The foundation was organized with four subcommittees: fats, protein, special projects, and nutrition. As will be noted in the ruminant nutrition chapter of this book, the research that demonstrated the benefits of "by-pass" protein to the ruminant animal provided new uses and innovative products for animal protein ingredients. The foundation was extremely involved in supporting research that brought major advances in understanding the mysteries of many of the digestive processes in the ruminant animal. Projects funded by FPRF for numerous research leaders in ruminant nutrition have assisted in bringing a "by-pass" protein concept to those that now incorporate mathematical models for predicting undegradable and degradable fractions of protein and amino components and their digestible availabilities. Unfortunately, many of these benefits in ruminant nutrition provided by animal co-products were eliminated or critically compromised via the 1997 Food and Drug Administration (FDA) feed rule restricting ruminant protein use and subsequent regulatory and consumer reaction.

Research and the Last Decade

The 1990s brought new challenges, but also, as always, new opportunities to animal agriculture and the rendering industry. It was a period in which the intensity of food safety concerns was exacerbated. The bovine spongiform encephalopathy (BSE) epidemic in the United Kingdom fueled reactions of fear, perceptions, myths, regulatory processes, opportunistic marketing programs, and enhanced animal rightist activities that are unprecedented heretofore. Several forces have been proactive in countering these intensified influences. It is very evident that research and science have provided positive roles; however, it is very difficult to counter fear and perceptions. Nevertheless, these influences have affected FPRF's focus.

The reality of the influences that all of these issues have on a research program must be recognized. FPRF has completed, initiated, or collaborated in approximately 200 research projects in the past decade. Nearly all of these projects have resulted in peer-reviewed publications and significant contributions to the numerous nutrition and scientific conferences held each year. Project objectives and priorities have been altered in the past decade. In the mid-1990s, the foundation established a policy to direct 75 percent of its resources to projects with non-feed/non-food objectives, but reserve 25 percent for focused multi-species nutrition studies. This research agenda brought special attention to biosecurity issues, new use applications, aquaculture, and bioenergy.

FPRF became involved in cooperating with the National Soydiesel Development Board in 1992, which was later renamed the National Biodiesel Board. The biodiesel industry is dramatically expanding, not only in the United States, but also internationally. Additionally, the demand for alternative fuels and the economic drivers for energy prompted the need for biofuel research. With a project at the University of Georgia, FPRF provided animal fats and recycled restaurant grease/used cooking oils to heat the campus during the winter of 2002, and provided important data for the emissions and energy comparisons to the fossil fuels. FPRF has become the clearinghouse for the resultant final report and its interpretation (Adams, 2002). A significant volume of the rendering industry's total fat production is now being used as a biofuel.

Biodiesel, as it relates to the rendering industry, actually deserves a book of its own. The number of biodiesel producing facilities is expanding rapidly, and also expanding biodiesel availability. Though most of the current facilities are structured to use plant oils, numerous rendering companies in both the United States and Canada have, or are strongly considering investments in biodiesel production facilities. Griffin Industries, Inc. was the first North American rendering company to construct a facility and produce biodiesel at their Butler, Kentucky, location in 1998. The American Soybean Association (ASA) can be credited for dedicating the primary resources for biodiesel initiatives. FPRF and the rendering industry's goals have been to support a neutral feedstock specification, regulation, and legislative agendas. Legislative actions to retain parity among the feedstocks have been a constant issue and have not always resulted in the equality that rendered animal fats/oils deserve. Technical processes and analytical data provide assurances that the lipid feedstocks of the rendering industry can result in the production of quality biodiesel that meets the current requirements of the American Society for Testing and Materials (ASTM) Standard D6751. The biofuels derived from animal fats have not been immune from similar biosecurity issues so common to rendered products. However, the questions regarding any influence that BSE, other transmissible spongiform encephalopathies (TSEs), and toxicants have on the safety of biodiesel/biofuel have been addressed. FPRF Directors Digest No. 329 provides a summary to those queries (Pearl, 2004). In addition, an extensive literature review conducted by Clemson University draws conclusions of extremely low biosecurity risk in total (Greene and Dawson, 2005).

The rendering industry's production of lipid feedstock sources approximates nearly one-third of all fats and oils currently produced in the United States and Canada. Alternative fuels and energy sources will continue to be not only a domestic opportunity, but one the entire world must address more aggressively. Rendered animal co-products are positioned to remain a major contributor to the alternative energy needs of the United States.

Research addressing the microbial security of rendered products has been evident throughout FPRF's history. More recently, a study at the University of Illinois conducted by Dr. Fred Troutt validated the effectiveness of the sterilization process of proper rendering. Seventeen rendering facilities cooperated with Dr. Troutt, his associates, and FPRF in conducting the trial (Troutt et al., 2001). Research continues at the Animal Co-Products Research and Education Center (ACREC) to address this subject. It is hoped that the construction of a pilot rendering facility can be planned in the near future.

In keeping with FPRF's revised research priorities, it continued in the 1990s with the traditional nutrition studies but with a more focused priority. Its funded aquaculture work expanded into an international program. Projects were completed or are in progress in China, Vietnam, Canada, United Kingdom, and numerous research facilities in the United States in a variety of fish and shellfish species. Aquaculture has been projected to be a major opportunity for animal derived feed ingredients. However, the growth of aquaculture in North America has not kept pace with the rest of the world. Seafood and shellfish imports into the United States now rank third in balance of trade, behind petroleum and automobiles. Thus, the current market and short range market projections for aquaculture production must be directed at the international segment while not ignoring the slower growing industry in North America.

The diversity of projects can be seen by reviewing the list of completed projects and those in progress on the FPRF Web site, www.fprf.org. The projects have served the industry well in meeting current market, new market development, regulatory, and legislative needs. It is probable that continued diversity will be necessary in the future. However, the development of ACREC as an adjunct and complimentary research asset, with its focused mission supplemented with focused animal nutrition studies, will position FPRF well into the future in meeting the wants and needs of the rendering industry.

BSE Research and Surveillance

In events leading up to and the promulgation of the 1997 feed rule, FDA recognized that numerous needed scientific facts were, and still are not available concerning the TSEs, including BSE. Dr. Stephen Sundlof, Director, Center for Veterinary Medicine (CVM), said, "Research from independently validated studies in the etiology, pathogens, and transmission of TSEs would be helpful to FDA as well as to other governments as each of us pursue efforts to reduce the risk of TSE diseases in man and animals. More importantly from the perspective of effective regulatory and enforcement measures, there is great need for more scientific knowledge about the assay of the agent(s) in food or feed, a reliable assay for specific protein in meat and bone meal, manufacturing processes that destroy or otherwise denature the disease agent(s), and tests for the diagnosis of TSE disease in live animals" (Sundlof, 1997). Though a strong endorsement for research in all of the aforementioned areas, few answers have become available in the decade that has passed. However, in response to the need, FPRF established an international team to develop a protocol for inactivation research in 1997. A study was designed and widely endorsed by several agencies and organizations. It would have been a valuable investment for all of animal agriculture but was not funded—another example of missed opportunities in research.

The rendering industry has been a primary contributor to the enhanced Animal and Plant Health Inspection Service (APHIS) BSE surveillance program. It has cooperated to the fullest in acquiring surveillance data, especially for the high risk non-ambulatory and dead animals on farms. The number of cattle brains examined has been impressive over the past two years. However, the need for the enhanced program required several years of encouragement. In 1996, FPRF developed a diagnostic laboratory survey to assemble data on central nervous system (CNS) diseases. There were 23 state laboratories that participated in the survey in coordination with state veterinarians. The results were provided to APHIS and FDA. Data were collected on the numbers of bovine specimens submitted to their laboratories with histories of CNS symptoms. In addition, data were obtained on those specimens submitted to the National Veterinary Services Laboratories (NVSL) for BSE confirmation. Specimens with a positive diagnosis of other CNS diseases such as listeriosis, rabies, polio, or chemical toxicities were not submitted to NVSL. The Dx Monitor Summer 1996 Issue reported the surveillance of BSE in the United States totaled 3,425 brains during the period of 1986 through July 31, 1996. The FPRF survey of accredited state diagnostic laboratories reported through their state veterinarians that they had examined and provided a diagnosis of another CNS causative agent or a negative BSE examination on 8,383 animals during the period of 1991 through June 1996. These data provided a much greater assurance that BSE was not present or of very low incidence in the U.S. cattle herd at that time.

In 1997, a TSE Surveillance Sub-Committee was again developed to assist in a program to assure the proper disposal of cattle carcasses condemned for CNS disorders at packinghouses while awaiting a confirmatory test for BSE. The sub-committee was headed by Dr. Fred Bisplinghoff and comprised of Dr. Gary Pearl, Doug Anderson, Edward Murakami, Mike Gilbert, and Greg Van Hoven. The rendering industry cooperated fully in refraining from rendering carcasses that exhibited neurological disease until which time a confirmed negative BSE diagnosis had been established. This cooperative program again supplemented the strength of the surveillance of BSE in the United States. The rendering industry was again primary in the intensified testing program initiated following the first case of BSE in the United States in 2003. A very high percentage of the 785,638 currently tested animals have been sourced by renderers since the June 2004 enhanced testing was initiated. The industry's infrastructure and support in animal disease surveillance is just another important function it contributes to animal agriculture.

Regulatory action by FDA to prohibit certain ruminant derived protein from feeds used for ruminant animals, numerous demands from countries of export, the recent concerns regarding chronic wasting disease in cervids, and pending regulations for specified risk material (SRM) have created a need for rapid analytical procedures. Assays for detecting and identifying tissues derived from specific animal species are still needed. The SRM issues now also create the need to identify specific tissues within the same species. These capabilities are not available with the specificity and speciation accuracy required consistent with the cost and timely results required. FPRF has been collaborating with Florida State University and Neogen in sponsoring research to develop this technology. It is hopeful that these ongoing research efforts will be fruitful in bringing forth procedures to assist in these voids.

The Animal Co-Products Research and Education Center

The rendering industry has entered a new era of commitment in securing a scientific basis for the utilization of animal co-product tissues. The FPRF and Clemson University have consummated a collaborative agreement for the formation of a research center directed at animal co-products. ACREC was officially approved in October 2005, and dedicated at a conference held on the campus of Clemson University, Clemson, South Carolina, on March 27, 2006. ACREC is an international co-product research center to concentrating on the inedible tissues of food animal production and processing. Its focus will be new or enhanced and safe utilization of animal co-product resources. Its establishment will allow a network of scientists, in concert with all segments of animal production, to concentrate on the safe utilization of nearly 50 percent of all food animal live weight production. This volume of raw animal material in the United States approaches 54 billion pounds annually and in and of itself justifies the development of ACREC by the rendering industry.

A Historical Brief of ACREC

The industry and its products have moved into another level of scrutiny. Though there are no scientific reasons to deter the continued use of animal by-products as sources of nutrients in feed, challenges to this notion have become more frequent and have increased in intensity. It is imperative that research directed at new non-feed/non-food use objectives receive greater priority. Additionally, ensuring microbial safety of rendered products must become a higher research priority. These realities and numerous strategic planning inputs led to the conception of a center or institute that could focus on these objectives. The concept was first discussed by the FPRF president with the executive committee in the spring of 2002. The president was given the authority to pursue the interest and mutual opportunities with several public and private research institutions. One could have been discouraged by the numerous negative reactions received during these initial presentations. Reactions were very typical of the perception of rendering and its products. The multimillion dollar commitment required to partner with private institutions meant that alternative was not economically feasible. The industry and its allies compete with numerous industries that have research funding available via commodity check-off programs and government subsidies.

However, during a project consulting review with Dr. Annel Greene, Department of Animal and Veterinary Science at Clemson University, a center concept was discussed. Immediately, Dr. Paul Dawson of the Department of Food Science was consulted, and this pair of researchers and professors at Clemson University became champions in pursuing the establishment of ACREC.

Clemson University, located in Clemson, South Carolina, is one of the land-grant institutions established to foster a symbiotic relationship among research, teaching, and extension. It has a student enrollment of 17,000 in five academic colleges with over 70 fields of study. Of particular importance is its superb record of establishing an intra-curriculum atmosphere. This interaction of interests and expertise has lead to the development of research centers for specific industries. Most notable are the National Brick Research Center established in 1987, and a newly established International Center for Automotive Research in Greenville, South Carolina. Virtually all research pertaining to the compounding, manufacture, and quality assurance for brick and ceramic is conducted at the National Brick Research Center and it has now grown into a multimillion dollar program and is housed in a newly constructed facility. The interdisciplinary culture among Clemson faculty has placed it among the top 25 universities nationally in income earned from patents and intellectual properties.

Following the conceptual discussion of a center, Drs. Greene and Dawson championed the integration of scientists and educators from diverse academic fields. A discussion forum was held February 21, 2003, at which a quorum of supporters representing expertise from numerous departments and executive officers filled room F-145 Poole Agricultural Center to standing-room-only capacity. The concept and a basic plan were discussed at the 2003 FPRF Spring meetings. Don Davis, then chairman of FPRF Board of Directors, established a steering committee to pursue the development of an Animal Co-Products Research Institute:

Don Davis, Central Bi-Products
John Dupps Jr., The Dupps Company
Barry Glotman, West Coast Reduction
Ross Hamilton, Darling International
Kevin Kuhni, John Kuhni Sons
Mark Myers, National By-Products
J.J. Smith, Valley Proteins
Dr. Gary Pearl, FPRF president (chairman)

This committee met on the Clemson campus August 17-19, 2003, for in-depth discussions with university executive officers, deans, department heads, faculty, and researchers, and visited laboratories and the brick center. The committee's report to the FPRF Board of Directors resulted in the approval for the development of an agreement, by-laws, and the initiation of an inaugural group of research projects to be approved at the April 2004 FPRF Research Committee meeting. The official name approved by the board of directors was the Animal Co-Products Research and Education Center. The name was finalized only after considerable deliberation. The majority expressed the need to include the education component as being very important to the ultimate objectives provided by ACREC. Education continues to be an important missing link in portraying the importance of rendering and its products to the food animal industries, regulators, and consumers. The arduous task of articulating an agreement and operating by-laws was initiated and the following nine inaugural projects were initiated and completed:

04C-1 Enumeration of Thermally Resistant Bacteria in Raw Rendering Materials – Dr. Annel Greene
04C-2 Determination of Z and F Values of Thermally Resistant Bacteria Isolated from Raw Rendered Materials – Dr. Paul Dawson
04C-3 Microbiological Evaluation of Antibiotic Resistant Bacteria in Rendered Animal Products – Dr. Xiuping Jiang
04C-4 Analyses of Separable Fractions of Proteins from Selected Raw Animal By-Product Materials – Dr. Jim Acton and Dr. Ashby Bodine
04C-5 Determination of Protein Content and Potential Uses of Bovine and Swine Mammary Gland Tissue Homogenate Supernatants – Dr. Tom Scott
04C-6 Screening Bioactive Peptides from Animal By-Product Proteins – Dr. Feng Chen
04C-7 Biodiesel Synthesis from Animal Derived Fats Using Heterogenous Catalysis – Dr. James Goodwin Jr.
04C-8 Extrusion and Molding of Proteins Fractions and Fats Derived from Animal By-Products for Packaging and Structural Applications – Dr. Amod Ogale
04C-9 A Study of Economically Feasible Technologies to Remove Dioxin and Dioxin-Like Toxicants from Animal Co-Products – Dr. John Coates

Several of FPRF members' legal staff assisted in the agreement and by-law development process. The Provost office at Clemson provided the assistance of Renee Roux, thus, legal expenditures were minimized. The organizational structure of ACREC is unique, functional, and provides for the integration of scientists and educators from diverse fields in academic, industrial, and governmental institutions to meet specific research and education priorities dealing with animal co-products. FPRF is identified as the sole founding sponsor. However, participation is open to both FPRF members and non-members. There are distinct benefits in acquiring memberships in both FPRF and ACREC to maximize the benefits from animal co-products research. There is a demonstrated benefit and productivity provided by research coalitions comprised of universities, industry research foundations, and representative industry members in acquiring and utilizing project funding. The ACREC agreement and by-laws are available to FPRF members and applicants at any time. Membership support from all allied industries is paramount in the future success of the ACREC.

ACREC's Mission Statement

The center will advance the science and technology of animal co-products, augment the education of university students and the public, and educate and serve the rendering industry, the commercial users of animal co-products, and the center members with priority research for improved and new uses for animal co-products and rendering processes.

The mission of the center is compatible with the educational mission of the University and with the intent and purposes of its members to foster and support research, education and public service in matters related to the rendering industry.

Guiding Principles for ACREC

- Support the educational process by educating undergraduate and graduate students and industrial interns in research and service activities.
- Provide timely research services and research results that have a significant impact on the operations of its members and allied animal industries.
- Be managed by the governing board in compliance with university regulations and defined within its by-laws.
- Be proactive in providing timely information to members.
- Aggressively seek external funding from federal, state and local sources.
- Follow university, state, and federal laws, rules, and regulations.
- Establish global recognition as an institution of excellence.
- Consider emerging and traditional issues within the rendering industry.
- Serve as a technical resource and scientific advisor.

The FPRF Board of Directors and Clemson University Board of Trustees approved the governing agreement documents that became effective October 1, 2005. These Governing Board and Officers were elected at the first meeting:

Dr. Calvin L. Schoulties (chair), Clemson University Dean College of Agriculture, Forestry, and Life Sciences
Dr. Gary G. Pearl (vice chair), Past FPRF President
Gerald "J.J." Smith – Valley Proteins
Dr. Annel K. Greene (center director), Clemson University
Dr. Paul L. Dawson (associate center director), Clemson University
Dr. Doris Helms (secretary/treasurer), Clemson University Provost and vice president for Academic Affairs
Dr. Ross Hamilton – Darling International, Inc.
Dr. John Kelly – Clemson University vice president for Public Service and Agriculture
Kevin Kuhni – John Kuhni Sons Inc.

The ACREC Research Committee first met in December of 2005 at the Valley Proteins, Ward, South Carolina rendering facility. The members of the first committee were J.J. Smith; Fred Wellons, Baker Commodities; David Kirstein, National By-Products; Dr. Gary Pearl; Dr. Annel Greene; and Dr. Paul Dawson.

FPRF has invested heavily to bring the center to reality. On March 27, 2006, ACREC was formally dedicated at a dedication conference at the Madren Center on the Clemson University campus. The attendance and enthusiasm from an international audience of media, government officials, political leaders, students, researchers, scientists, industry, and academic executives underscored the opportunities for co-product research. The conference presentations certainly brought forth the need to support rendering as the safest most economical means to utilize animal co-products as "the gatekeeper for animal agriculture."

The USDA/ARS

Another important research resource to our industry has been the U.S. Department of Agriculture (USDA). The USDA Agriculture Research Service (ARS) is a network of research facilities positioned specific ARS research locations or in cooperation at university sites. Though the units are multi-disciplined, each has a specialty. As an example, the Eastern Regional Research Center (ERRC) in Wyndmoor, Pennsylvania has been extremely beneficial and supportive to the research efforts of FPRF and animal co-products. ERRC is directed by Dr. John P. Cherry and the ERRC has served as the facility in which wool, hides, and leather research has traditionally been conducted. The facility and its staff have conducted routine training schools directed at these co-products for several years. Currently, Dr. Bill Marmer is research unit leader of the newly named Fats, Oils, and Animal Co-products Unit. The name change reflects the research concentration this facility is directing to animal co-product resources. It is essentially the only group in ARS devoting exploratory research directed at adding value to animal co-products, meat and bone meal, tallow, fats, hides, and wool. The work collaborates with those research priorities established for ACREC. Dr. Marmer has served on the FPRF Research Committee since 1998 and has consulted with numerous FPRF grantees on their individual research projects. Dr. Raphael Garcia, a member of the unit, is currently conducting a project titled "Non-Nutritional Engineering Properties of Meat and Bone Meal." Also, Dr. Thomas Foglia and Dr. Michael Haas are involved in numerous biodiesel and bioenergy projects that utilize both animal fats and animal rendered protein products. These initiatives are complimentary to the research agenda outlined in the FPRF strategic plans. The synergic research efforts of FPRF, ACREC, USDA/ARS, and the allied industries is of major significance to all meat producers and processors, oleochemical industries, and their consumers. The United States' continued dependence on foreign oil places an even higher significance on exploratory research. Animal agriculture has numerous co-product resources to contribute to this end. Cooperative research targeted to these priority objectives provides the opportunity to bring them to reality.

Summary

FPRF has been synonymous with research for the rendering industry. The importance of research to any industry cannot be overemphasized, but it is a necessity to rendering and rendered animal products. FPRF has been an integral research resource to all of animal industries and is now poised to be even more important and more productive as it moves to the future. A new president, Dr. Sergio Nates, is anxious and poised to keep rendering as the "gatekeeper of animal agriculture." Research by FPRF will continue to direct the rendering industry and support the integrity of its processes and policies.

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FUTURE RESEARCH FOR THE RENDERING INDUSTRY

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Summary

For thousands of years, humans have been using animals for food, fiber, and power, and rendering has been carried out for many centuries. However, over the last two decades, the versatility of rendered by-products has led to their increased use in many applications. Also, there have been numerous technological advances and regulatory changes in the last few years that directly impact the recycling of agricultural wastes into value added products. Many of these changes have forced reevaluation of how to deal with the spent animal populations, and have directed the approach and research goals among the rendering scientific community.

Research in the Rendering Industry

In the late 1950s, as part of an overall research program funded by the National Renderers Association (NRA), a substantial number of projects were routed towards the field of polymers and plastics from fats. Moreover, letters were sent to over 100 laboratories requesting proposals on the use of tallow and protein products. Tallow has always been considered a valued product of the rendering industry, and with the drop in value after the bovine spongiform encephalopathy (BSE) scare, it became a good candidate for conversion to fuel.

Nutrition

The earliest recommendation on the use of meat by-products in animal feeds was made by Liebig in 1865. Working with Belgian engineer George Giebert, Liebig devised an efficient method of producing beef extract from carcasses, and the same year they founded the Liebig Extract of Meat Company (Lemco), marketing the extract as a cheap, nutritious alternative to real meat. Today, Lemco is part of the Unilever group, which owns many of the world's consumer product brands in foods including Slim-Fast and Ragu.

The results of studies examining the utilization and digestibility of a relatively large variety of rendered animal protein ingredients have been summarized in numerous studies since the early 1950s. During the 1960s and early 1970s, a variety of references were quoted in literature relating to the use of rendered meat in dairy, calf, and beef feeds. In response to the emergence of BSE, epidemiological studies were started in the late 1980s and the role of meat and bone meal (MBM) as a feed ingredient has been amply studied. Likewise, a surplus of MBM has encouraged research to find new applications for it. Many of these applications include the use of MBM as fertilizer and as a plastic material base. Similarly, studies have been conducted to evaluate the value of feather and meat meals as a source of protein supplement for multiple species (swine, beef and dairy cattle, poultry, cats, dogs, fish, and shrimp). As with most feed ingredients used by the animal industry, nutrient levels and true metabolizable energy values have been also calculated for both feather and meat meals. Palatability problems with meat and feather meals have been also addressed, and more recent studies have focused on the biochemical, physiological, and molecular characteristics of rendered by-products. The effects of manipulation of pH, hydrolysis of poultry feathers by enzymes, and bacteria species present in rendered by-products are also being studied.

Among the most recent exploratory areas of research for the use of rendered by-products is aquaculture. However, due to a number of constraints, aquaculture research is frequently conducted at laboratory scale, and it is always uncertain whether results from these studies are valid at a commercial scale. On the other hand, with the growth that has taken place in aquaculture over the last decade and given the dramatic increase in the proportion of fish meal and fish oil consumption by the aquaculture feed sector, most research within the industry has focused on the use of alternate protein sources. Among the alternatives, meat and feather meal have been studied and the potential as a major component in aquaculture diets for fish and shrimps to replace or partially replace fish meal has been established (Smith et al., 2001; Kureshy et al., 2000; Abdel-Warith et al., 2001). Though a significant concern remained due to the relatively low digestibility of both meals and the effect this would have on increasing nitrogen and phosphorous loads in ponds and discharge waters, the enhancements in the nutritional quality of by-product meals achieved in recent years should allay those fears. Improvements are probably attributable to better manufacturing practices, better sorting of the raw material, and the optimization of the processing conditions. In conclusion, the most marked response noted in experiments has been the difference in digestibilities of nutrients among rendered by-products, suggesting that digestibility is influenced by the components of the mix or by the rendering process.

Research at FPRF

The purpose of the Fats and Proteins Research Foundation (FPRF) is to direct and manage a research process that results in an enhanced current usage and the development of new uses for rendered animal products. FPRF has carried out extensive evaluation and assessment studies for the renderers and animal feed industry since 1962.

The scientific process is fundamental to scientific investigation and to the acquisition of new knowledge based upon physical evidence by the scientific community. However, scientific research, like other cooperative endeavors, requires trust to flourish. Cooperation and trust in the rendering industry are reflected by the fact that since establishing the foundation, FPRF has completed over 550 projects. One of the priority areas of FPRF has been to support research on the utilization of animal by-products/co-products processed by the rendering industry, such as blood meal, MBM, tallow, hydrolyzed hair, and feather meals.

During the past 40 years, FPRF research has documented the continued improvement in the rendering industry products as measured by bioavailability, biosecurity, and consistency. Likewise, analytical technology has provided specific nutrient data for formulation purposes. FPRF has also presented an extensive literature base to contest issues such as the presence of biogenic amines in animal proteins and polyethylene in animal fats as being nutritionally detrimental. Other projects have been related to the ecological aspects of the rendering processes. Many past projects were nutritional studies, with others directed at modifications to increase their value and applications (Pearl, 1996).

Biodiesel research has been a part of FPRF's research goals since the early 1990s. The rendering industry has experienced significant success in using rendered animal fats as burner fuel. An accumulation of burning characteristics and emission testing by FPRF has allowed for the permitting of substituting animal fats for No. 2 or No. 6 fuel oil or natural gas for the production of steam.

Almost certainly the most remarkable and recent of all the FPRF research achievements have been the official opening of the Animal Co-Products Research and Education Center (ACREC) at Clemson University, Clemson, South Carolina. As a result, an initial base of nine specific interdisciplinary alternative use and biosecurity projects were initiated in April 2004. Current research projects at ACREC include chemical analysis of tallow, investigation of growth factors, peptides and pesticides residues in by-product meals, odor remediation, and identification of bacteria isolated from rendering products.

The Future

A note from Dr. C. Wayne Smith, an associate professor of Anthropology at Texas A&M, reads, "It's a world of the paradoxical and, at times, macabre. A leather shoe from the seventeenth century feels as soft and supple as ever despite resting at the bottom of the ocean for hundreds of years." One of his major research goals is to develop new processes that can be used to conserve relics, and currently being employed in the preservation of organs for medical studies. A neat thing in research—you can do something that is beneficial within one discipline and then go further to put it into other industries.

The U.S. Department of Agriculture calls "rendering" a process of heat-treating fat, bone, offal, and related material derived from the carcasses of livestock, poultry, and fish, and used cooking fats and oils. The processes and techniques developed by the rendering industry were initially intended to convert dead animals and animal by-products into ingredients for a wide range of industrial and consumer goods. However, they have been so effective that they're already playing significant roles in other areas such as medicine and biotechnology.

The rendering industry continues to benefit from improvements in the agro-food industry as its by-products are being engineered to meet a variety of needs. Ironically, about half of every butchered cow and a third of every pig is not consumed by humans, and by 2020 developing countries will consume 100 million metric tons more meat than they did in 1993. Thus, many of the innovations in the industry will probably focus on the use of environmentally sound technologies; for the most part, to provide the food processing industry with more efficient tools with regards to resource usage and to diminish the volume of effluents. Likewise, further innovative research will be needed in order to provide the rendering industry with competitive tools that are compatible with environmental considerations. On the other hand, the application of genetic engineering to agriculture, including a broad variety of purposes to a host of animals traditionally used as food sources, including cows, pigs, and fish, will trigger debates among scientists, public health officials, business leaders, and regulators over a range of issues—including the safety of by-products from the rendering industry.

Because the U.S. seafood and fisheries trade deficit is the largest of any food and agriculture commodity, the United States has a major opportunity to further develop a sustainable and profitable domestic aquaculture industry. However, achieving this goal will not be easy and research will keep looking for alternative sources of protein to feed farm-raised aquaculture species. It is a must that the industry keeps demonstrating and discovering safe and more efficient ways to convert by-products of the rendering industry into nutritious components of aquaculture feed.

Without any doubt, through the use of modern technologies and quality control methods and with the continued emphasis on biosecurity, one may look back before too many years have passed and realize how much progress has been made in expanding the quality, value, and safety of rendered by-products.

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WHAT WOULD A WORLD WITHOUT RENDERING LOOK LIKE?

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Summary

A world without rendering is envisaged, even though the industry has existed globally for many years. In trying to consider what a world without rendering would look like, the rendering industry has itself been defined and the boundaries drawn for evaluating the scope of the chapter. A variety of scenarios have been considered, including controlled alternatives to rendering and the uncontrolled disposal of animal by-products as waste. Using information available in the literature, a hierarchy of options other than rendering has been proposed. In the light of current knowledge, using animal by-products as fuels to produce energy appears to be the best of the non-rendering options. Research, and indeed full scale application of these technologies appear to indicate their promise, particularly in a world without rendering.

Other controlled options considered all have some merits in terms of processing of animal by-products, but also have de-merit including lack of manufactured products, lack of capacity, and negative environmental impacts. Perhaps not surprisingly, indiscriminate tipping and controlled landfill would be the worst options leading to very negative environmental impacts with potentially severe implications for animal and human health. It is concluded that in the event of rendering not being available as a process technology, then very significant efforts to "invent" rendering would be underway.

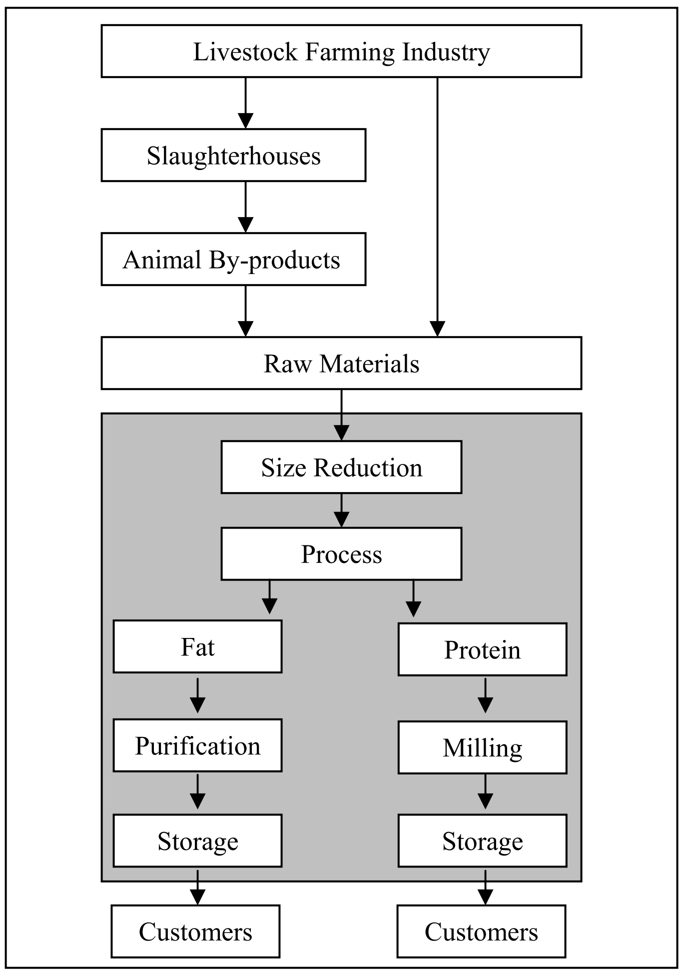
Introduction: What is Rendering?

Rendering is one of the oldest activities practiced by human civilization (Woodgate and Van der Veen, 2004) even if it was not developed into the industry we are familiar with until relatively recently. Furthermore, Woodgate (2005) concluded that rendering was "the essential industry." Therefore, a world without rendering is somewhat difficult to contemplate and describe. Nonetheless, that is the challenge faced in this chapter.

In order to put the world without rendering into the proper context, it is firstly necessary to define rendering as we know it and to set out the boundaries beyond which this chapter will describe. Essentially the rendering process deals with high moisture, highly microbiologically active animal materials to which it applies heat to evaporate water, reduce microbiological "loading," and separate "cellular" fat (if present) from the other components. If high levels of fat are present in the raw materials, the molten fat is removed from the mass by physical means such as centrifugation or expeller pressing. The two possible products of rendering are a high protein "solid" residue known as processed animal protein or meat and bone meal (MBM), and a lipid material known as rendered fat (tallow). In the classic sense of rendering, the protein rich products have been used in animal feeds and the tallow has been used in animal feed, oleochemicals, and the soap production industries.

Rendering is described in generic terms in Figure 1. This schematic applies to the processing of animals and by-products which contain significant levels of fat or fatty tissues. However, for the sake of completeness, the term rendering will also include those processes that deal with low fat raw materials such as blood and feathers. From this simplistic and general description of rendering and uses of rendered products, it is now possible to consider other processes or treatment methods or uses which may not be described as rendering.

Figure 1. Rendering Industry Flowchart in Context of the Livestock Industry.



Rendering and Alternative Processes

There have always been many alternatives to rendering and some of these approved methods available and used in the European Union (EU) are shown in Table 1.

Table 1. Summary of Controlled Options for Processing Animal By-Products in the EU.

Rendering
Raw materials preparation for pet food
Approved "alternatives"
Anaerobic digestion- biogas
Composting
Incineration
Co-incineration

Taking all animal by-products not intended for human consumption into account, there are a range of processing opportunities which can be considered according to the status of the raw material and demand for the products produced. A range of uses for products produced by either conventional rendering or by "alternative" processes following rendering, are shown in Table 2.

Table 2. What Can Be Done with Rendered Products?

Processed Animal Proteins		**Rendered Fats**	
Conventional	**Alternative**	**Conventional**	**Alternative**
Animal feeds	Fuel	Animal feeds	Fuel
Pet Food	Aggregates	Soap	Biodiesel
Fertilizer	Apatite (calcium hydroxyphosphate)	Oleochemical	Plastics

It therefore follows that if rendering had not been invented or was suddenly not available anymore, then alternatives currently available to process some of the arising raw materials would be required to process it all, or material would be disposed of by illegal dumping.

Alternatives to Rendering

This section will consider only the standalone technical aspects of each alternative. Other essential factors such as capacity, animal or human health implications, and environmental impact will be considered in a later section. The alternatives may be broadly split into four groups, of which three are processing technologies and one is a disposal option (Table 3). The three processing technologies are described in terms of energy (in or out).

- Low energy: Those methods which use only raw materials and do not apply any external heating to the material.
- Medium energy: Those methods that apply heat in some form or other but not for the purpose of dehydration, microbiological stability, or splitting into products.
- High energy: Those methods that apply heat to generate energy from the raw materials which may be subsequently captured and used as heat and/or power.
- Uncontrolled discarding/dumping/fly tipping.

Table 3. Alternative Controlled Processing Options.

Energy Group	Brief description of option
Low	Burial/Landfill Composting Anaerobic digestion Liquefaction – digestion – ensiling
Medium	Pet food preparation (Chill/freeze) EU "alternative" processes Materials production, for example, feather fiber Extraction of components such as amino acids
High	Incineration Energy production by combustion

Low Energy

Burial: For most farmers whose animals die on the farm, this option is a natural process which has been carried on for several hundred years. In the EU, the practice of burial (and depositing in approved landfills) of dead animals and all raw animal by-products has been prohibited by the advent of the Animal By-products Regulations (ABPR) 1774.

The justification of the EU legislation has been based upon the high risk of the spread of animal diseases resulting from burial, although no detailed studies have been published which provide details of risk assessment. From a transmissible spongiform encephalopathy (TSE) perspective, residual infectivity after burial of infective carcases has been reported. However, in global terms burial is still used as a means of safely dealing with dead animals either as individuals or when mass disease outbreaks occur, such as avian influenza in Asia in 2004, although OIE (Office of International Epizootics, now known as the World Organization for Animal Health, 2002) indicated that rendering was the preferred bio-secure option.

Composting: This option has been refined in Europe to a point where detailed conditions are laid down by ABPR 1774. These conditions include the prohibition for composting Category 1 (Table 4) raw materials and requiring pressure processing of any Category 2 materials before composting. Category 3 raw materials may be composted without pre-treatment. The resulting compost (organic soil improver) can in principle be returned to the soil, but the application of these materials to certain types of agricultural land, such as pasture, have restrictions such as "withdrawal" periods for grazing animals. Not withstanding the fact that it is theoretically possible to compost certain animal by-products, it is in practice impossible to compost purely animal by-product because of the adverse chemical composition and physical nature. In practice, these problems of high protein and fat levels limit the use of animal by-products to a composting mixture that contains high levels of carbon rich components, such as cereal straws.

Table 4. Categories of Animal By-products in ABPR 1774.

Category	Brief Description	Requirements
Category 1 Very high risk	Bovine spongiform encephalopathy (BSE) carcasses and suspects Specified risk material Catering waste from international transport	Must be destroyed, not for use in composting or biogas plants.
Category 2 High risk	Condemned meat Manure and gut contents	Can be used in composting and biogas plants after rendering (133ºC, three bar pressure). Manure and gut contents only can be used without pretreatment.
Category 3 Low risk	Catering waste from households, restaurants Former foodstuffs Much slaughter house waste e.g., waste blood and feathers	Can be used in composting and biogas plants without pretreatment.

Anaerobic Digestion-Biogas: The chemical composition concerns regarding animal by-products alluded to in relation to composting also apply to anaerobic digestion. Here the carbon/nitrogen ratio is vitally important to provide the optimum anaerobic digestion conditions to give the maximum output of methane (biogas). Again, this leads to the practical situation whereby animal by-products cannot be processed on their own but rather in mixtures of other high carbon materials. In the EU, anaerobic digestion of different categories of raw material is restricted in a similar way to the composting controls, and specific process conditions are laid down. The methane biogas produced is required to be cleaned of acid gases (for engine reasons) before combustion in a gas engine which in turn produces electricity. The sludge residue is applied to land with similar restrictions as apply to compost.

Liquefaction – Digestion: This method of processing animal by-products has been used for many years to make liquid or digest products from specific raw materials. In principle, this method uses hydrolytic bacterial action to autolyze the protein into a liquid form. Once in this state, the digested liquor can be stabilized indefinitely by adjusting the pH to less than 3.0. Traditionally this method has been used to prepare liquid digests as palatability attractants for use in pet foods. This manufacturing process requires that the starting raw materials are of a very high quality standard, although in principle the method can be applied to any raw materials that can be hydrolyzed by endogenous or exogenous enzymes.

Medium Energy

Production of fresh, chilled, frozen animal by-products for pet food: In principle, the pet food industry can utilize a considerable quantity of raw materials, but there is a very heavy emphasis on quality, which severely restricts certain materials from being used in practice. Nevertheless, this route is a viable alternative method to utilize raw materials although the amount of moist/canned pet food that can use raw material is reducing globally. Interestingly, sales of dried pet food product, which uses rendered materials as ingredients are increasing.

Alternative Processes in the EU: European Commission regulation 92/2005 sets out approval conditions for four methods of processing raw materials. A short summary of all four processes is given below. It is assumed the majority of these technologies are designed to inactivate TSE agents in the EU ABPR Category 1 raw materials, although in principle they could be used for any category of material worldwide. Many of these technologies have been based upon the review of methods able to inactivate prions (Taylor and Woodgate, 2003)

- Alkaline Hydrolysis

This method of processing raw materials employs a combination of physics and chemistry to reduce whole carcases (if required) to a soup-like consistency. The hydrolysis units are engineered to facilitate very alkaline conditions (pH above 12), high pressures (higher than three atmospheres), and mixing by a pumping circulation system. In principle, the concept includes the ability to inactivate animal tissues that may contain infective agents such as bovine spongiform encephalopathy (BSE). However, the capital cost per ton processed is very high (partly due to low/batch throughputs) and any subsequent disposal cost of the liquid soup would also be considerable due to the polluting load.

- High Pressure Biogas

This process is essentially one of a pre-treatment procedure that is a prelude to anaerobic digestion. The focus, as in alkaline hydrolysis, is to be able to process raw material that may contain an infective agent, but here the concept is to convert the nutrients present into methane biogas using methanogenic bacteria in an anaerobic digestion system. This system is approved in the European Union in regulation 92/2005, but as in alkaline hydrolysis, suffers from practical disadvantages of high engineering specification, high cost, and low throughput. Although there is a theoretical yield of product (methane) which can be converted into energy or electricity, it is not expected to be a viable process in terms of replacing rendering.

- High Pressure and Temperature Hydrolysis

This method is approved to operate at a temperature of at least 80°C (at the center of any raw material) with an absolute pressure of 12 atmospheres, for at least 40 minutes. The process is effectively a batch system and the resulting hydrolysate may or may not be dehydrated. It is not clear what the intended use of the materials produced might be.

- Brooks Gasification

This is a batch process that effectively volatilizes the chemical constituents of animal by-products into complex hydrocarbons and gases over a period of 24 hours. The products of the process described are secondary gases, which are subsequently combusted in a secondary chamber to produce heat and an inorganic ash which is disposed of.

Materials (Feather Fiber): Globally, poultry feathers are used in two different ways. A small amount is used for producing high quality feather down for pillows, duvets, and furnishings. The processing requirements are rigorous and the essential criteria include cleanliness and odor. The market for these products is rather limited and therefore the vast majority of feathers are converted into an animal feed grade hydrolyzed protein. As mentioned in the introduction, and although this method is not strictly rendering, it would not be considered as an alternative to rendering. A possible viable solution which is an alternative to rendering may not be too far away.

An EU project, high performance industrial protein matrices through bioprocessing (HIPERMAX), is researching a range of technologies that might be viable methods of converting animal proteins such as wool, silk, feather, or leather (hides/skins) into nano-matrices. These materials may be used in a wide variety of applications once the biotechnology aspects of each process have been optimized. Considering only the feathers segment of the project, significant advances have been made in the last 18 months. Developing an effective but environmentally acceptable method of cleaning feathers from the slaughter industry has been a vital preliminary step. This has now been achieved, ensuring that "clean" feather is able to enter the second phase of the process. Here, entire feathers are converted into fiber which is usable in a wide variety of applications. The research program will be completed in 2007 and more details of the possibilities will be publicly available thereafter.

Extraction and Purification of Components: Animal by-products are made up of essential chemical components the same as any life form. The major constituents, apart from water, are proteins, lipids, and minerals. Proteins are of course mainly constituted from amino acids, while the lipid content is made up of mainly triglyceride fatty acids. The mineral constituents comprise the two major constituents of bone, i.e., calcium and phosphorus. From time to time proposals have been made to extract interesting or potentially valuable components from raw materials.

Most commonly, amino acids have been proposed for extraction from materials such as bone or feathers. Although these ideas may have been based upon sound biochemistry and chemical engineering principles, no such methods have reached successful launch. Many of the commercial problems have centered upon high costs for engineering and labor, with subsequent high production costs. The uncertain or low value of the products has led to many processes failing to fulfill their potential.

High Energy

Incineration: The term incineration, as applied by the EU ABPR 1774, is limited to the disposal of materials without any recovery of heat or other residues such as ash. Most designs of incinerator result in a high temperature aerobic combustion for sufficient time to achieve the conversion of all organic materials back to constituent molecules such as CO, $C0_2$, and H_20. This option is the one that probably provides maximum security in terms of organic matter disposal, but with the major disadvantage that no products result.

Co-incineration: Co-incineration means "to combust or incinerate, with the recovery of energy" either in the form of heat, electricity, or both. This technology may also include the process of cement manufacture, whereby cement is also a product, along with recovered heat. Several systems have been developed in the EU, following the BSE crisis in 1996, where the majority of processed animal protein (PAP) and rendered fats have been required to be disposed of as part of the BSE precautionary policies. These systems, such as combustion of rendered fat in steam raising boilers and PAP in bubbling fluid bed reactors, have achieved excellent reduction of organic matter, alongside the production of combined heat and power, which has in many cases been used to power the rendering process itself. However, if PAP and tallow do not exist because rendering is not available, then the direct use of raw materials has to be considered. Here there have been some significant advances over the last three years.

The Biomal concept in Sweden may be the best example to illustrate the opportunities for this approach. The Biomal process is less complicated while the energy demanding processing of the raw material into fat and MBM is removed. The comparison of a conventional rendering system commonly seen in Europe (Figure 2) and the Biomal system (Figure 3) shows a clear difference in approach. In the Biomal system, the raw material is crushed and ground and then pumped to a fluidized bed boiler where it is co-combusted together with a base fuel such as wood chips, peat, or municipal waste.

Figure 2. Process Outline for Animal By-products Showing Energy Inputs and Outputs.

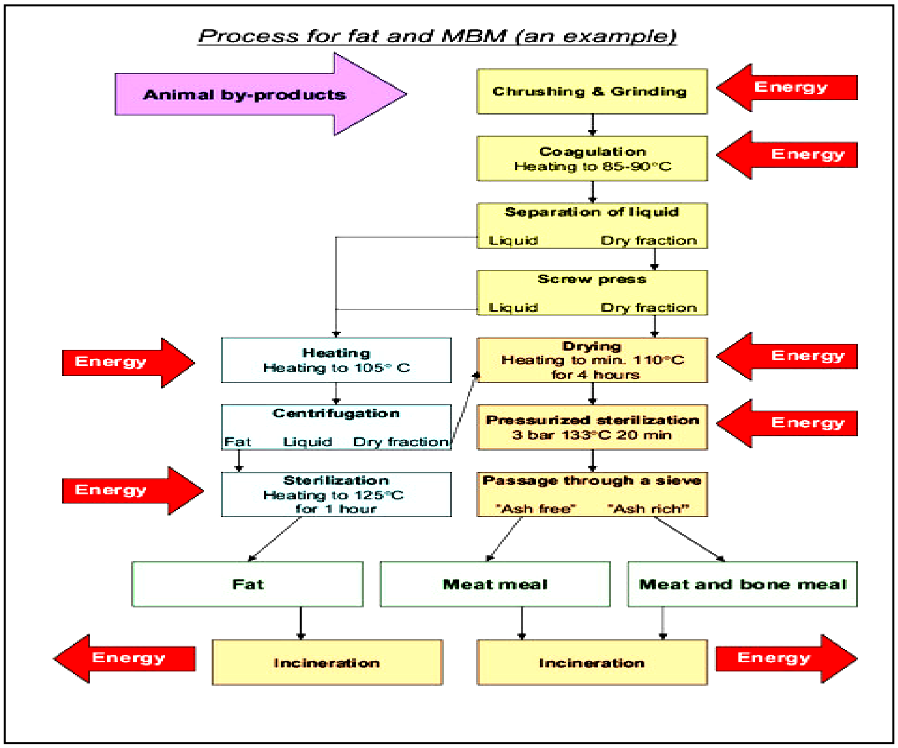
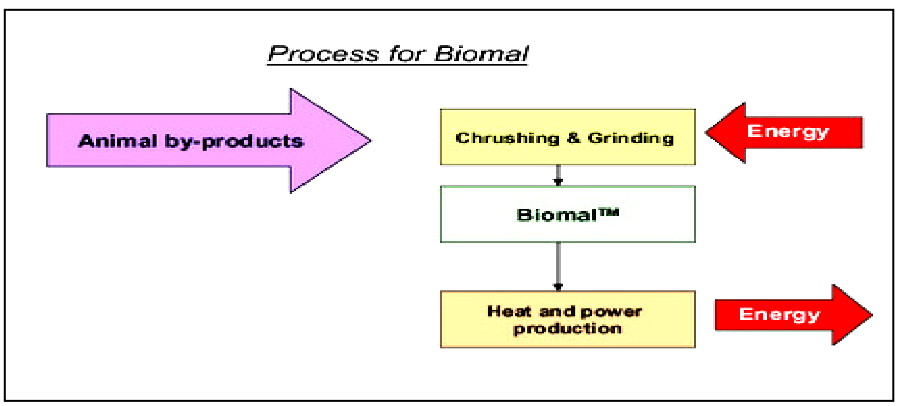
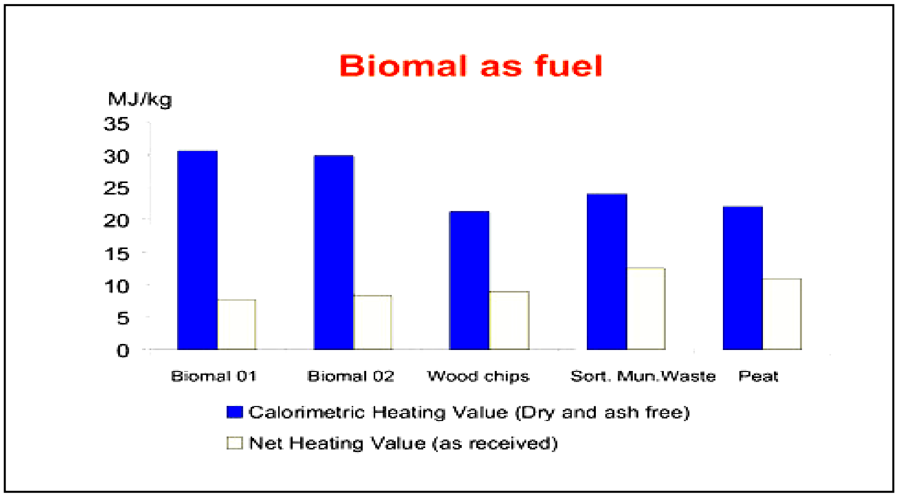


Figure 3. Process Outline for Biomal Process Showing Energy Inputs and Outputs.



Energy is recovered from the animal by-products by producing renewable heat and electricity, and the net outcome of energy is considerably increased. Since animal by-products contain fat, this offsets the high content of ash and moisture (which contains no energy); the net heating value is very acceptable at approximately eight megajoules per kg fuel (Figure 4). This corresponds to the net heating value of other biofuels containing moisture content of 50 percent.

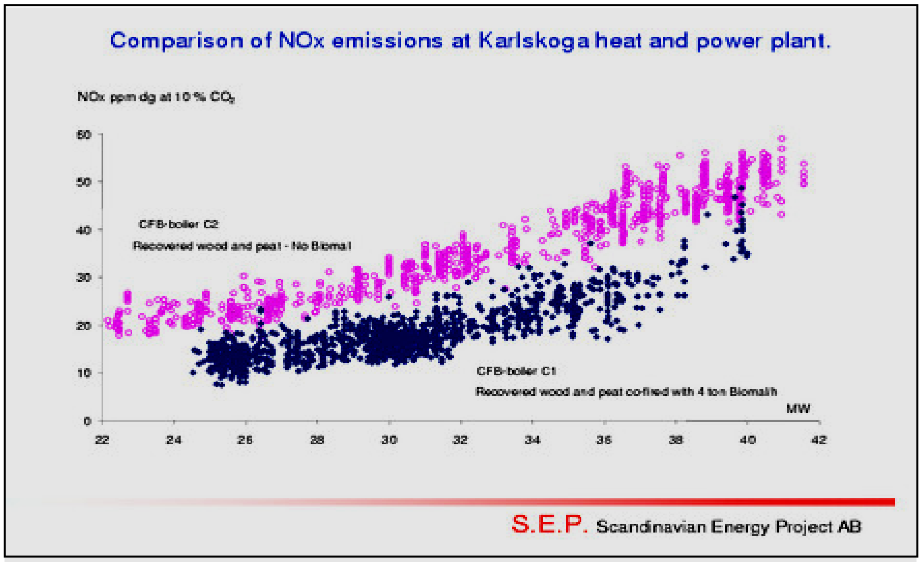
Figure 4. Comparison of Energy Contents in Biomal and Other Types of Biomass Fuels.



The Biomal concept has some advantages as a complete system, including the ability to reduce or eliminate the risk for BSE-infection or other diseases. It is also an energy effective method compared with the more complicated conventional method. The water usage and the discharge of biological oxygen demanding substances are reduced. In the EU, Biomal is a renewable biofuel, which does not contribute to the global warming and can replace fossil fuels for production of heat and power.

Figure 5 indicates the effect of Biomal on nitrogen oxides (NOx) where the nitrogen compounds in Biomal appear to reduce NOx emissions in the same manner as ammonia or urea. In separate emission studies, no elevated levels of dioxin emissions due to co-firing with Biomal have been measured.

Figure 5. Comparison of Biomal and Wood-Peat as Fuels on Emissions of NOx.



Uncontrolled Disposal

Using landfill to dispose of animal by-products would introduce a significant risk to biosecurity, and pose a serious potential hazard to animal and human health. The less controlled the disposal the greater the risk, the highest risk being the uncontrolled dumping of the by-products.

Biosecurity will be diminished in a number of different ways. The risk of transmission of pathogens to both humans and animals will be increased, either directly or indirectly. In addition, the lack of traceability implicit in landfill and/or dumping will hinder the prevention, control, and eradication of disease once identified. These issues may become insurmountable during widespread emergency situations, such as the outbreak of new animal diseases, or environmental crises such as floods.

In addition to a reduction in biosecurity, if animal by-products were disposed of by landfill the pressure on space and disposal facilities would increase, at a time when the legislative drive is to reduce the amount of general waste from human activities that are disposed of in this way. Environmental concerns about the transport of waste, and operation of landfill sites, are already forcing society to re-examine the way in which even non-hazardous waste is disposed.

Thus, even without any increased threat to biosecurity, the disposal of animal by-products by landfill and/or dumping would be seen as environmentally undesirable. The volumes involved are significant. Gerba (2002) estimates that the quantity of livestock, poultry, and wastes from food processing in the United States is equivalent to 21 percent of the waste going to landfills. Steps to reduce and eliminate landfill or dumping would be a high priority even if the additional implications of risk to health were not present.

Traceability

The need for traceability to prevent, control, and eradicate disease in animals has been dramatically demonstrated in recent years with the global impact of diseases such as BSE, foot and mouth, and avian influenza. One of the main weapons used by the authorities in addressing these diseases has been the stringent control of not only the infected animals, but also in the control of the disposal of the by-products from slaughtered animals.

The introduction of unprecedented levels of traceability of animals and birds has led the attack on these diseases, through the whole animal chain from origin to disposal. Traceability has become one of the key components in the global fight to ensure biosecurity. Disposal involving landfill and/or dumping makes this method of protecting society impossible, and unacceptable.

Control of Pathogens

Unprocessed animal by-products and mortalities contain large numbers of microorganisms, including pathogenic bacteria and viruses. Unless properly processed in a timely manner, these materials provide an excellent environment for disease-causing organisms to grow and potentially threaten animal health, human health, and the environment.

If allowed to accumulate and decompose without restraint, these tissues would become a substantial biohazard, promoting disease, attracting and harbouring rodents, insects, scavengers, and other recognized disease vectors, and attracting predatory animals into densely populated areas. Livestock and poultry are commonly infected with pathogens, even though they may be causing no apparent illness in the animals. Many pathogens of large animals can be transmitted to humans (Enriquez et al., 2001). These include *Escherichia coli* 0157:H7, *Salmonella* species, *Campylobacter jejuni, Yersina enterocolitica, Clostridium perfringens, Cryptosporidium parvum*, and *Giardia*.

There is much evidence that pathogens are present in animals. For example, recent studies in the United States have shown that 23 percent of cattle were shedding *E. coli* 0157:H7 (Smith et al., 2001); 55 percent of the dairy cattle were excreting *Salmonella* species. (Troutt et al., 2001); the incidence of *Salmonella* in chickens can be as great as 100 percent in some flocks (Council of Agricultural Science and Technology, 1994); *Salmonella* has been found in 46 percent of the pigs going to slaughterhouses (Swanenburg et al., 2001); *Yersina enterocolitica* has been reported in 2.5 percent to 49 percent of the pork (Council of Agricultural Science and Technology, 1994); and 39 percent of calves and 22 percent of adult animals on dairy farms shed *Cryptosporidium parvum* (Huetink, 2001). Hepatitis E virus, which causes a serious life threatening liver disease (as many as 30 percent of the infected pregnant women die) is endemic in swine (Yoo et al., 2001; Meng et al., 2002; Haas et al., 1996). Evidence also suggests that people who work with swine, and veterinarians, are at risk of infection in the United States (Meng et al., 2002).

It is clear that a significant number of animal materials after slaughter will contain pathogens that can be transmitted to humans. It is estimated that more than half of the animals would contain one or more human pathogens making rendering of offals and by-products essential.

Risks from Pathogens

Gerba (2002) stated that a conservative estimate of only 10 percent of animals being infected with a human pathogen would represent over 99 percent of all infectious waste received by landfills. Any increase in animals being disposed in landfills would dramatically increase the quantity of human pathogens which they receive.

Workers involved in the transportation to, and operation of, landfill sites, and the environment of landfills, will be exposed to a large increase in the concentration of microorganisms. New microbial agents will also be present, e.g., the hepatitis E virus (Enriquez et al., 2001).

These agents will be more likely transmitted by the aerosol route and to animals that frequent landfills. Currently, human and animal pathogens in fecal material are the largest source of infectious agents in solid waste received by landfills (Haas et al., 1996). Most of these microorganisms are transmitted by direct contact and not by aerosols. In contrast, aerosols transmit many of the animal pathogens, both by inhalation and dermal contact with the aerosols (Hirsh and Zee, 1999).

The exposure risk to animals such as birds, insects, and rodents would also be expected to increase. This increases the risk of exposure to pathogens and microbial toxins being transmitted off-site. Many insects are attracted to feces, but birds and rodents would be more likely attracted to the dead animals. Depending upon the time of year, birds are abundant at landfills (Belant et al., 1995) and they may act as vectors in transmission of pathogenic microorganisms and/or their toxins (Galey, 2001).

The considerable mortality of seagulls in the United Kingdom has been linked to landfill sites, which the birds visit (Ortiz and Smith, 1994). The organism, *Clostridium botulinum*, was found in 63 percent of the landfills examined. Rotting animal carcasses will serve to further attract birds to landfills, increasing their exposure and risk of disease.

Hamilton and Kirstein (2002) also show the value of the rendering process as a mechanism to control risks from microbial pathogens, as well as other hazards, by quoting data given in a U.K. Department of Health study (U.K. Department of Health, 2001; Table 5). Risks of human exposure to biological hazards were found to be negligible when animal mortalities and by-products were processed by rendering, incineration, or funeral pyre. However, incineration and pyres were reported to cause moderate to high exposure to chemical hazards associated with burning. Only materials that had been rendered had negligible exposure to both biological and chemical hazards. The agent causing BSE was the only exception and it was found to pose a negligible risk to humans when the solid products from rendering were subsequently incinerated.

Table 5. Summary of Potential Health Risks for Various Methods of Handling Animal By-products.

Disease/Hazardous Agent	Rendering	Inciner-ation	Landfill	Pyre	Burial
Campylobacter, E. Coli, Listeria, Salmonella, Bacillus anthracis, C. botulinum, Leptospira, Mycobacterium tuberculosis var bovis, Yersinia	Very small	Very small	Moderate	Very small	High
Cryptosporidium, Giardia	Very small	Very small	Moderate	Very small	High
Clostridium tetani	Very small	Very small	Moderate	Very small	High
Prions for BSE, scrapie	Moderate	Very small	Moderate	Moderate	High
Methane, CO2	Very small	Very small	Moderate	Very small	High
Fuel-specific chemicals, Metal salts	Very small	Very small	Very small	High	Very small
Particulates, SO_2, NO_2,	Very small	Moderate	Very small	High	Very small
PAHs, dioxins	Very small	Moderate	Very small	High	Very small
Disinfectants, detergents	Very small	Very small	Moderate	Moderate	High
Hydrogen sulfide	Very small	Very small		Very small	High
Radiation	Very small	Moderate	Very small	Moderate	Moderate

Adapted from the U.K. Department of Health, 2001.

Legend: Very small - least exposure of humans to hazards
Moderate - intermediate exposure of humans to hazards
High - greatest exposure of humans to hazards

Risk of human exposure to TSEs was rated as very small when solid products of rendering were incinerated.

Impact of No Rendering Industry

This is a particularly difficult area to quantify as most of the alternatives have not been quantified in the same way as rendering. However, a report commissioned by the U.K. Renderers Association (conducted by Det Norske Veritas in 2001) is able to give an indication of some of the effects of operating a range of different options (Table 6).

Table 6. Summary of Options for Utilization or Disposal.

Rendering Plus		Incineration♣ / Co-Incineration♥		Landfill	
A	Fat - Animal feed MBM - Animal feed	G	No energy recovery - Large♣	M	Anaerobic digestion & energy recovery
B	Fat - Animal feed MBM - Fertilizer	H	No energy recovery - Medium♣	N	Landfill No energy recovery
C	Fat – Animal feed MBM - Landfill	I	No energy recovery - Small♣		
D	Fat - Fuel MBM - Landfill	J	Energy recovery - Large♥		
E	Fat - Fuel MBM - Fuel on-site	K	Energy recovery - Medium♥		
F	Fat - Fuel MBM - Fuel off-site	L	Energy recovery - Small♥		

Each of the options was ranked according the criteria shown in Table 7. Some of the determinations were made on the basis of quantified data, where available, according to the individual process option, and other information was taken from the literature.

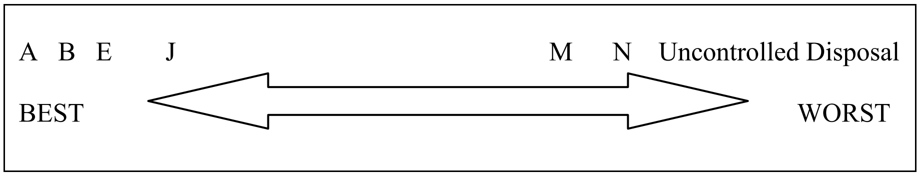
Table 7. Criteria for Evaluating Disposal Hierarchy.

Environment	Sustainability
Emissions - Air	Waste hierarchy
Emissions - Water	Legislation
Emissions - Land	Capacity
Energy Resources	Nuisance
Carbon balance	Societal

As a result of the data compilation, the report indicated a hierarchy of options based upon environmental and sustainability criteria. In summary, the top four options include three of the rendering options, and large scale co-incineration (Figure 6).

The fact that rendering with products used as feeds, and rendering with products used as energy resources are at the top of the hierarchy is very reassuring.

Figure 6. Results of Overall Environmental Impact Assessment.



However, the presence of (controlled) biogas and landfill at the bottom of the hierarchy is an equally powerful indication that these two options, if used to dispose of significant amounts of animal by-products, would lead to major adverse environmental impacts. Although not specifically included in the Det Norske Vertitas study, the uncontrolled dumping of animal by-products has also been included in the summary in Figure 6 to illustrate the expected position in any such study.

In addition to the environmental impact criteria illustrated there would of course be no products of rendering to use. In other words, the uses for rendered products described in Table 2 would not exist. From the 66 million metric tons of animal by-products each year, about 12.5 million metric tons of processed animal protein and six million metric tons of rendered animal fat are produced. To put this into a global perspective, this equates to approximately eight percent of the world supply of proteins (as protein) used in animal feed and six percent of the world supply of oils and fats.

If these materials were not available for their traditional uses, then substitution with alternative sources would need to be made. If these alternatives were indeed vegetable proteins and oilseeds, the growing of these crops could lead to negative environmental consequences. These may include deforestation, excessive use of fertilizers, pollution of water courses, and even an increase in the amount of genetically modified material in the environment. Although these impacts might appear to be impossible to quantify and be somewhat speculative, some or all of these may be severe enough to disrupt the environmental balance seen under the current rendering regime.

Animal and or human health impacts, particularly zoonotic diseases, are dealt with professionally by the rendering industry from time to time. Without this processing option, the risk of further spread of such diseases would probably increase.

Conclusion

The challenge faced in this chapter is to envisage a world without rendering. Within this challenge, several assumptions are made which may or may not be true in the event of no rendering industry being present. Firstly, it is assumed that livestock are still bred, produced, and slaughtered to produce food for human consumption in approximately the same level as currently. This level of animal production would in all probability grow in accordance with expectations of greater demand for meat, milk, and eggs by an ever increasing world population.

If rendering did not exist, the approximately 66 million metric tons (145.2 billion pounds) of animal by-products, high in water content and susceptible to rapid degradation, would still be produced globally every year. If not stabilized quickly, the material would degrade and pollute rapidly by releasing a wide variety compounds, elements, or energy into the environment in a totally uncontrolled way. Without rendering and use of rendered products, there would be no real capture or sequestration of elements as seen with rendering operating as it does currently.

From the review of options made, it appears that the majority of non-rendering processing options are niche concepts when considering the annual amounts of materials produced around the world. Uncontrolled dumping, tipping, or disposal might result, but assuming that some legislative framework was in place, one cannot imagine this happening across the wide spectrum for any length of time. Of those controlled options discussed, only three are currently available that might be able to deal with the amounts of animal by-products produced. In practical terms, these three options are landfill, incineration, and co-incineration.

It is clear from the DNV study that use of the former at significant levels may lead to the possibility of environmental and human health impacts. Incineration could alleviate direct human health concerns, but energy present in the materials would be lost forever and therefore could not be considered a sustainable option. The highest ranking environmental and human health option apart from rendering appears to be co-incineration. The Biomal project in Sweden has helped to place this technology at the top of non-rendering options.

However, as is clear from the process described earlier, there is no recovery of protein for potential use as an animal feed ingredient, or as a supplier of energy or minerals in other applications. In addition, there is no recovery of rendered fat which might be used in feed, soap, oleochemicals, or biofuels. Without these products, it is unclear what the economic return to the animal livestock industry would be. Energy values may be relatively high, but would they be high enough to ensure a sustainable industry?

Therefore, if a world without rendering did exist, it would be almost certain that someone, someday, would be calling out for a new technology to be invented that would be environmentally neutral, sustainable, and economical for the total animal livestock industry. Perhaps the new technology would be called rendering.

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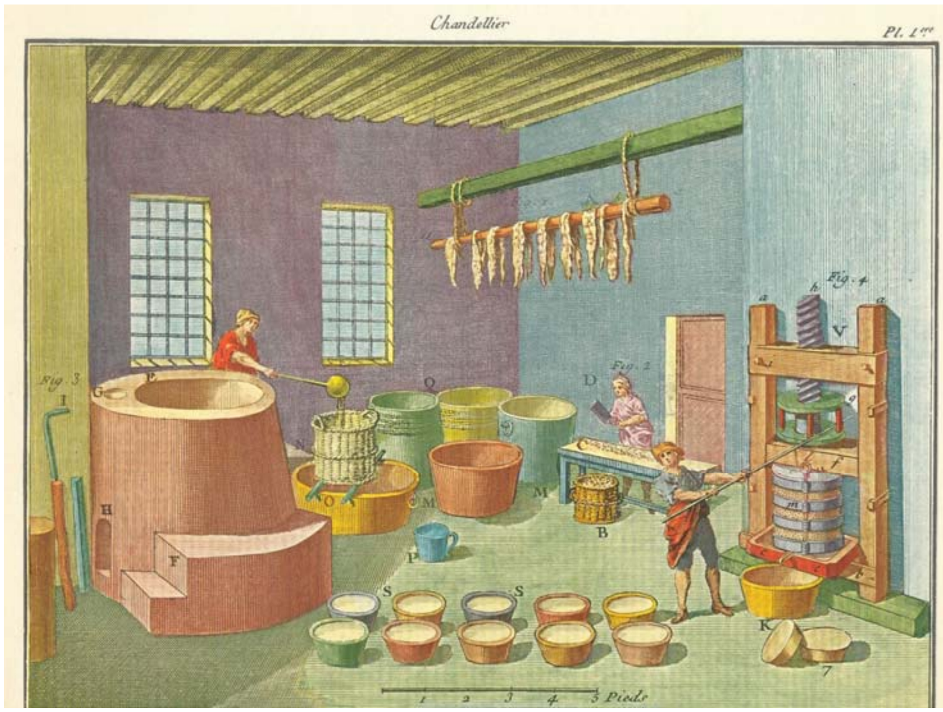

A reproduction of "Rendering in the 18th Century" originally hand colored by the artist. The print of the engraving shows the rendering operation of a French chandler in the late 1700s. Workmen are shown chopping fat, smelting, and extracting it in a press.

Published by:
The National Renderers Association
The Fats and Proteins Research Foundation
The Animal Protein Producers Industry
ISBN: 0-9654660-3-5