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High Value Products from Rendered Fat:
Taking the Next Step toward Increased Profitability

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Project Completion Date: June 30, 2012

Lay Summary
The subject of this work was the development and analysis of chemical process flow sheets to convert rendered fat into high value products. The following tasks were completed.

- Examine in more detail the market demand and value of products identified in design studies completed by the PI and Clemson's Class of 2011 chemical engineering students during the 2011-2012 academic year.
- Present results from the spring 2011 capstone design project at the FPRF Emerging Issues and Opportunities Seminar at the October 2011 National Renderers Association meeting. Solicit input and ideas on further development from NRA members.
- Teach fundamentals of chemical process design and economic evaluation to Clemson's Chemical Engineering Class of 2012 in the fall of 2011 using as primary examples the conversion of rendered fat to high value products.
- Select teams from the 2012 senior class and assign as their spring capstone project further development of the most promising process routes to convert rendered fat into high value products with minimal risk and maximum profit potential.
- Make available to the FPRF the final written reports and presentation slides developed by the student teams in the spring 2012 capstone design projects. Evaluate the work of the students and prepare a summary final report.

Objective
The overall goal of this project was to show that a rendering company can convert its fat, oil, and grease into specific, high value products with a substantial return on investment.

Project Overview

In the first year of this project Clemson chemical engineering seniors identified over 30 potential routes to convert rendered fats, oils, and greases into higher value products. Analysis of process complexity and preliminary economics narrowed the product strategies to those listed in Table 1. Closer study of capstone design reports produced by the Class of 2011 indicated that polyol ester biodegradable lubricants might be the most attractive product for several reasons.

- The chemistry of making these lubricants from rendered fat is simple so the estimated fixed capital investment should be relatively low.
- Demand for the lubricants that can be produced from fat is growing as more attention is focused on renewable resources and biodegradability of products.

Table 1. Potential high value products from tallow

Primary product	Value* $/kg	Yield kg/kg	Demand MT/yr	Byproducts	Notes
purified free fatty acids	1.20	0.9	10,000,000	glycerin	difficult separations, limited product flexibility, low margin
plasticizers (epoxilated, unsat'd methyl esters)	2.00	0.5	5,000,000	glycerin, saturated FFAs	must separate sats/unsats, only 50% unsat in feed
di-carboxylic acids	4.00	0.5	3,000,000	mixed olefins, FFAs glycerin	Elevance starting 180,000 MT/yr plant; difficult separations
fatty alcohols	2.00	0.8	2,000,000	glycerin	limited product flexibility, low margin
synthetic cocoa butter	6.00	1.2 requires reaction with stearic acid	1,000,000	replaced FA	food/cosmetic use, expensive process
polyol ester biodegradable lubricant	2.00	0.9	500,000 biolubes	glycerin	industrial lubricant market: 10,000,000 MT/yr global market all lubricants: 40,000,000 MT/yr
glyceryl mono & diesters	3.00	up to 1	100,000	unused FFAs	difficult separation, limited market
calcium salt of stearic, myristic & palmitic acid	2.00	0.5	100,000	glycerin, unsaturated FFAs	difficult separations
methyl ester sulfonate	3.00	1.5	100,000	glycerin	
fatty amides (lubricants, slip agents)	5.00	0.2	100,000	other FFAs	
azaleic&nonanoic acids	6.00	0.6	100,000	glycerin, sat'd FFAs	ozonation, limited market
ethylene glycol diester	2.00	0.9	20,000	glycerin	

* Estimated market value is for product that meets minimum specifications. Higher values are possible for most products if more stringent specs or higher purity are achieved.

- The first step of lubricant production can be the biodiesel process, which some rendering companies have in place already.
- The equipment to convert biodiesel to a polyol ester can be viewed as an add-on that increases profitability or as a hedge against low fuel prices.
- The wide range of lubricant applications and formulations provides opportunities for a single rendering company to develop a niche market.
- The global market for lubricants is huge so bio-lubricants could ultimately be the end use of a substantial fraction of the fats and oils produced by the rendering industry.

In their fall 2011 design course Clemson's senior class of chemical engineering students learned how to develop flow sheets and conduct technical and economic evaluations of chemical processes. They did this while conducting a preliminary investigation into producing polyol ester lubricants from rendered fat. In October 2011 the PI presented results from the spring 2011 design studies at the Emerging Issues and Opportunities Seminar, which was held at the annual meeting of the National Renderers Association, and sought industry comments and critique. Subsequently, the spring 2012 capstone project described below was developed and assigned to half of the senior class. Due to the complexity and scope of the assignment the eighteen students were divided into three teams of six members each.

ChE 433 Spring 2012 Capstone Design Project
Polyol Ester Lubricants from Animal Fat

Each team must develop <u>two</u> process designs for the conversion of rendered fat to a polyol lubricant with predictable properties. Start with the base cases outlined below, but consider and evaluate issues, options, and alternatives that might lead to higher profitability.

- *The baseline feed rate of liquid rendered fat from heated storage will be 2500 kg/hr.*
- *On a mass basis the feed will consist of 85% triglycerides (TG) and 15% free fatty acids (FFA). Assume that the fatty acid distribution in the TG and the FFA will be 25% palmitic, 25% stearic, and 50% oleic. Variations in this feed composition should be considered to evaluate the effects of other FFA and variable feed percentages.*
- *The feed must be converted into a polyol ester using a polyalcohol such as neopentyl glycol or trimethylolpropane.*
- *Two process routes must be developed:*
    - *<u>FAME route</u>: Biodiesel (fatty acid methyl esters) will be made from rendered fat. FAME will then be reacted with a polyalcohol to make a polyol ester lubricant.*
    - *<u>FFA route</u>: Triglycerides will first be hydrolyzed to produce free fatty acids and glycerol. The FFA will then be reacted with a polyalcohol.*
- *Preferably, only saleable products will leave your process. If you claim that any stream other than the polyol ester is a saleable product, you must provide composition-specific documentation from a <u>recent</u> reference to support this claim. Otherwise the stream is a waste. The composition of each waste stream must be well defined so that an appropriate treatment or disposal strategy can be specified and appropriate costs can be assigned.*
- *Other process steps will be required. For example, separations and additional reactions will be needed to meet product specifications, to recover unused raw materials and byproducts, or to treat waste streams on site in lieu of assigning per unit costs for treatment outside the process boundaries, etc.*
- *Among the issues, options, and alternatives you should evaluate are:*

- *Structure-property relationships of polyol ester lubricants.*
- *Relationships between physical properties of lubricants and economic value.*
- *Market size for lubricants that meet certain property specifications,*
- *Change in feed composition if advantageous and economically feasible for the rendering industry to achieve.*
- *Change in feed rate and resulting production rate if supported by process economics and market analysis.*
- *Advantages and disadvantages of alternative polyalcohol co-reactants.*
- *Process alternatives, including selection of unit operations and operating conditions.*

During the spring semester, each student team met with the instructor for numerous impromptu discussions and three required oral progress reports. The teams submitted their final written reports on April 12, and these reports were made available to several key individuals affiliated with FPRF. On April 27, 2012 the three student teams presented their results orally before an audience that included J. J. Smith, President of Valley Proteins, and experienced chemical engineers Mike Dobeck of Darling International and Mike Patszi of Rothsay.

Team Vernon, lead by Austin Vernon with team members Jordan Byrd, Charles Grimsley, Cyrus Saharkhiz, Tyler Smith, and Jacob Waters, produced process designs that were judged to be technically superior to those developed by the other two teams. For new plant construction Team Vernon recommended that steam hydrolysis of fats to free fatty acids should be the first step in the process whether FAME is to be produced as an intermediate or not. Steam hydrolysis provides maximum flexibility with respect to feed composition because high FFA content in the feed is of no consequence. Also team hydrolysis requires no catalyst so it produces wet glycerol as a byproduct with no acid, base, or salt content.

For the FAME route the second step is acid-catalyzed reactive distillation to esterify FFA and simultaneously remove water and excess methanol from the reacting mass. Methanol is then separated from water by conventional distillation and recycled. The FAME is then separated into predominantly saturated and unsaturated fractions by hydrophilization (partial crystallization and precipitation of saturated esters). The heavy phase is hydrogenated to produce FAME with little residual unsaturated content. This is transesterified with trimethylolpropane to produce TMP Tri Stearate/Palmitate), a polyol ester valued at about $2.20/kg. The light phase from hydrophilzation is transesterified to produce TMP Trioleate, which is valued at $2.70/kg because it has better cold flow properties thatn TMPTSP despite 25% residual saturate content.

In the FFA route that does not produce FAME intermediate, Team Vernon again starts with steam hydrolysis. The free fatty acids are then separated into two fractions by hydrophilization, and the light phase is transesterified to produce TMP Trioleate. The heavy phase is hydrogenated to eliminate unsaturates and is then reacted with glycerol to produce Glycerol Mono Stearate/Palmitate, an emulsifying agent valued at about $2.00/kg. In contrast, the FAME route reacted saturated methyl esters with TMP to produce a polyol ester that is valued slightly higher than an equal mass of GMSP. Either of these alternative products can be made in either process. The advantages of making GMSP are (1) low value glycerol from hydrolysis is incorporated into the product, and (2) the amount of TMP that one must purchase for the overall process is halved. Of course, additional market studies will be required to determine which product strategy is superior.

The Vernon team developed economic analyses for three alternatives, each based on a feed rate of 20 million kg of rendered fat per year. Shortcut names for the process routes are:

- with FAME: triglycerides → free fatty acids → FAME → TMP ester (and wet glycerol),
- add-on: addition of TMP ester production to an existing FAME plant,
- w/o FAME: triglycerides → free fatty acids → TMP ester and GMSP products.

Process Attribute	with FAME	add-on	w/o FAME
Fixed capital investment, $ million	5.7	1.5	3.7
Annual revenue, $ million	50	50	50
Annual cost of manufacturing, $ million	33	24	31
Non-discounted payback period, year	< 1	< 1	< 1

Annual revenue estimates above assume that no FAME is sold though the first two alternatives produce FAME as an intermediate. Revenue estimates from the three alternatives are not significantly different because the products all have similar values. The annual cost of manufacturing for each alternative includes specific cost estimates for raw materials, utilities, labor, and waste treatment. In the first and third alternatives, tallow was treated as a raw material with a cost of $0.85/kg. In the "add-on" alternative, FAME was treated as a raw material with a cost of $0.67/kg. Estimates of other direct and indirect costs are also included as factors applied to the four specific costs. Depreciation is not included in the estimates above.

The Vernon report indicates that polyol ester lubricants can be made from rendered fat with considerable profit. The Vernon team estimates of fixed capital investment are probably low, but even doubling them would not change this conclusion. The most important uncertainty in their economic evaluation is the relative values of tallow, FAME, and lubricants because raw material costs contribute about 70% of the total cost of manufacturing.

Complete final reports developed by all three student teams are available in pdf and Powerpoint formats. We will gladly distribute any or all of the written reports and oral presentation sides to additional industry personnel upon the authorization of the Fats and Proteins Research Foundation. (Unfortunately the quality of the written report produced by Team Vernon was not as high as their technical design work. The PI will be glad to assist interested individuals in deciphering unclear details of the work done by this team.)

Impacts and Significance to the Rendering Industry

Economic estimates developed by the Clemson chemical engineering students indicate substantial potential for the rendering industry to increase profits by converting rendered fat into higher valued products, particularly polyol ester lubricants. Before a company could embark on such a venture, laboratory and pilot plant work would be needed to verify required conditions of operation and product compositions and to refine and verify estimates of fixed capital investment and process manufacturing costs. Estimated product values and demand for products need to be verified by market studies.

Converting fat to higher valued products has the potential to increase revenues dramatically and change the dynamic market pressures currently experienced by the rendering industry. While there is always risk in a new venture, the short payback periods indicated by the design teams will reduce these risks if an initial venture is based on sound engineering and market analysis.

Publications, Intellectual Property, Outside Funding

This work was considered to be confidential to the rendering industry so no attempt has been made to publish the work or obtain outside funding. All process development has been based on known science and technology using openly published sources. If this work proceeds to the next phase, it would be prudent to consider the potential of developing intellectual property from the most promising and creative process concepts. This could provide even greater profit potential for the industry.

Future Work

The Principal Investigator has no current plans to continue work in this area, but is available upon request to assist individual rendering companies in the interpretation of the student reports. Initial consultation would be gratis in appreciation for the funding provided by FPRF through ACREC to support the work that has been completed. More extensive consultation will be negotiated on an individual basis.

Acknowledgments

The entire 2011 and 2012 senior classes of Clemson chemical engineering students (86 students in all) deserve recognition for their creative input to this project over the last two years.