FINAL REPORT
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HIGH VALUE PRODUCTS FROM RENDERED FATS, OILS, AND GREASES: PROCESS DESIGN AND ANALYSIS OF PROFITABILITY

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Lay Summary

Much of this project was conducted by 110 Clemson chemical engineering students (50 seniors and 60 sophomores) under the supervision of the Principal Investigator. First the students applied their knowledge of organic chemistry to identify feasible products that can be made from rendered fat and to develop mass balances for the potential applications. The seniors studied published literature to develop details on required reactor operating conditions and separations. They winnowed the list of potential products by analyzing published data on product demand and value, and by evaluating the complexity of each conversion process. Finally four teams of seniors developed more detailed process flow diagrams and stream tables for what they deemed to be the most promising product alternatives and estimated the required capital investment, cost of manufacturing, and projected profitability of their designs.

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

Early in the fall 2010 semester, the senior chemical process design class and the sophomore mass and energy balance class were divided into teams and assigned the task of investigating alternative ways to convert rendered fat into higher value products. The scope of work for the sophomores was limited to basic concepts of process development since they were just beginning the curriculum. The senior teams went much farther. They identified and developed 30 different "initial" concepts while learning how to lay out chemical processes and develop flow sheets. They narrowed those to 15 "most promising" concepts while being taught the techniques of economic evaluation. Table 1 (on the next page) summarizes information on twelve products that the students ultimately recommended for further study.

For their spring semester capstone design project, four teams of five seniors each were assigned to further the work started in the fall. Their task was to develop an integrated approach to maximize the profitability of converting tallow into higher value products. Each team was required to base its design on a feed rate between 10 and 100 million kg/yr of tallow, valued at $0.50/kg, with a composition of 84 % TG, 15% FFA, and 1% water on a mass basis. The specified fatty acid distribution of the feed was:

Mass %	Acid	Common Name
3	C14:0	myristic
26	C16:0	palmitic
3	C16:1	palmitoleic
22	C18:0	stearic
43	C18:1	oleic
3	C18:2	linoleic

Design for a higher feed rate would provide economy of scale and might be appropriate for high demand products and a joint venture involving multiple rendering companies and other participants. A feed rate on the lower end of the specified range could be dictated by a limited product market or might be more appropriate for a single rendering company to consider.

Table 1. Potential products from tallow

Primary product	Value $/kg	Yield kg/kg tallow	Demand metric ton/yr	Byproducts
purified free fatty acids	1.20+	0.9	40,000,000	glycerin
polyol ester biodegradable lubricant	2.00	1	8,000,000	glycerin
plasticizers (epoxilated unsat methyl esters)	1.50	0.5	5,000,000	glycerin, saturated FFAs
C18 di-carboxylic acids	4.00+	0.2	3,000,000	mixed olefins, FFAs
fatty alcohols	1.50+	0.8	2,000,000	propylene glycol
synthetic cocoa butter	6.50	1.2	1,000,000	none
		requires stearic acid addition		
glyceryl monoesters and diesters	2.00+	up to 1	100,000	unused FFAs
calcium salt of stearic, myristic & palmitic acid	2.00	0.5	100,000	glycerin, unsaturated FFAs
methyl ester sulfonate	2.90	1.5	100,000	glycerin
fatty amides (lubricants, slip agents)	5.00+	0.2	100,000	other FFAs
azaleic&nonanoic acids	6.50	0.6	100,000	glycerin, FFAs
ethylene glycol diester	2.00	0.9	25,000	glycerin

The designs developed by the student teams were required to meet certain criteria. No more than 1% of the feed mass could be lost to waste, and a cost of $3/kg had to be used for the disposal of concentrated waste streams. The maximum allowed organic concentration in wastewater was specified to be 1% by mass, and simple dilution to meet this specification was not allowed. The fiscal objective of the project was to maximize the Discounted Cash Flow Rate of Return (DCFROR), assuming a 6- year project life and using the 5-year Modified Accelerated Cost Recovery System (MACRS) for depreciation. The non-discounted return on investment (ROI) and the payback period (PBP) were also determined.

Each design team was required to insure that a market exists for each stream leaving their process. Otherwise they had to treat the stream as waste with an appropriate cost of treatment or disposal. Estimates of chemical price and market demand for products were derived from published sources no more than 2 years old whenever possible. Since this project did not involve experimental work, each chemical process step proposed by the students was required to have a demonstrated, referenced basis.

Each team presented an oral progress report in early February 2011 and submitted an interim written report on March 4. Feedback was provided by the instructor, and the teams completed their work and presented their final written reports on April 15. On April 22, 2011 they presented their final results orally to a design jury of seven experienced engineers, including Mr. Mike Dobeck of Darling International. The work done by the students showed considerable depth of research and application of sound engineering principles and creativity. Three of the four teams focused on the same high value product, azelaic acid, but their work differed in several respects. The fourth team developed a design to produce polyol ester lubricants. A summary of the results generated by each team is given below.

Team Tyson was lead by Leigh Tyson with members Grant Provost, Raymond Smith, Rion Sweet and Will Swoyer. Their recommended plant begins by using the Colgate Emery Process to hydrolyze 10 million kg/yr of tallow and release free fatty acids from the glycerin backbone. Glycerin is separated out, dewatered, converted into propylene glycol and sold. Unsaturated fatty acids (palmitoleic, oleic and linoleic) are ozonated to generate the highest value product, azelaic acid, a dicarboxylic acid used in skin creams and polymer synthesis that sells for $6 to $10/kg, depending on purity. The primary byproduct is nonanoic acid, which has several industrial uses and sells for about $3/kg. The residual mixture of saturated fatty acids (palmitic, myristic and stearic) is separated from the more valuable products and sold as an additional byproduct. Team Tyson also showed that the saturated fatty acids could be converted into calcium salts for slightly higher profitability, depending on the relative market prices of the saturated acid mixture and the calcium salts. The financial analysis of the Tyson team design indicated the following:

Fixed capital investment	$16 million (to process 10 million kg tallow/yr)
Annual revenue	$39 million
Annual cost of manufacturing	$15 million
Non-discounted payback period	1.0 year
Non-discounted return on investment	90%
Discounted cash flow rate of return	50%

Team Ingham was led by Lorcan Ingham with members Kenny O'Connor, William Johnson, Jacob Lindler, and Will Patty. They also focused on producing azelaic and nonanoic acids because of their high value, but the Ingham design differed from that of Team Tyson in several respects. First they designed their process for a feed rate of 50 million kg of tallow/yr. They used the same method of fat splitting, but they converted half of the glycerol into another high value specialty product – dihydroxyacetone. The rest of the glycerol was converted into propylene glycol. Team Ingham recommended conversion of the saturated fatty acids into cetyl stearyl alcohol. The financial analysis of the Ingham team design indicated the following:

Fixed capital investment	$38 million (to process 50 million kg tallow/yr)
Annual revenue	$270 million
Annual cost of manufacturing	$81 million
Non-discounted payback period	0.3 years
Non-discounted return on investment	340%
Discounted cash flow rate of return	140%

Team Muckenhirn consisted of Addison Dill, Petra Kerscher, Jake Morella, Mark Pepin, and team leader Eileen Muckenhirn. They developed a design to produce azelaic and nonanoic acids with a feed rate of 100 million kg of tallow/yr. They recommended that the residual mixture of saturated fatty acids be sold as a low value byproduct, but they also presented information on an alternative biodiesel production process that can be optimized to use only fatty acids as a starting material. They laid out a fermentation process to convert glycerol to lactic acid. The financial analysis of the Muckenhirn team design indicated the following:

Fixed capital investment	$38 million (to process 100 million kg tallow/yr)
Annual revenue	$310 million
Annual cost of manufacturing	$99 million
Non-discounted payback period	0.3 years
Non-discounted return on investment	370%
Discounted cash flow rate of return	140%

Team Alton took a different approach. Rafael Alton and teammates Kristin Cook, Donald Harter, Jonathan McKinley, and Stephen Vance developed a process design to make polyol ester lubricants. One of the potential advantages of this scheme is that the first step of the process can be the production of fatty acid methyl esters (FAME), also known as biodiesel fuel. An alternative is to begin with the Colgate Emery process that frees fatty acids from the glycerol backbone, but Team Alton chose the biodiesel route. They designed their process for a tallow feed rate of 100 million kg/yr. In the second step of the process FAME is reacted with purchased neopentyl glycol to produce the polyol ester. The financial analysis conducted by the Alton team design indicated the following:

Fixed capital investment	$7 million (to process 100 million kg tallow/yr)
Annual revenue	$300 million
Annual cost of manufacturing	$150 million
Non-discounted payback period	0.1 years
Non-discounted return on investment	2300%
Discounted cash flow rate of return	120%

The results obtained by the four teams certainly indicate that the conversion of rendered fat into higher value products can be profitable. Some caveats and considerations are noted below.

- As shown in Table 1, the current best estimate of demand for azelaic and nonanoic acids together is about 100 million kg/yr. Team Tyson took this into account more directly than the other two teams that focused on these products. Running 7700 hours per year, Team Tyson's relatively small plant would produce about 3.2 million kg/yr of azelaic acid and 2.4 million kg/yr of nonanoic acid, roughly 5% of the current combined market for these products. The addition of even 5% capacity might be enough to affect market price. The additional of 50% capacity with respect to total market demand by the Team Muckenhirn plant would most certainly have a dramatic affect on price. The smaller plant designed by Team Tyson gives up some economy of scale in fixed capital investment, which is one reason that the designs developed by Teams Ingham and Muckenhirn have more impressive profitability numbers, but Team Tyson's projections are more realistic with respect to market value of product.

- Another uncertainty in the production of azelaic acid is the cost of ozone, which must be generated on site due to its tendency to decompose. All three teams investigated this issue extensively and found considerable variation is the estimated capital investment and operating cost of large ozone generators.

- The price of polyol ester lubricants varies from about $2/kg to over ten times this value, depending on the performance specifications they can meet. Hundreds of formulations exist, and all of them compete with petroleum based lubricants. The total lubricant market is huge, and demand is growing for biodegradable lubricants made from renewable materials. The report produced by Team Alton had a number of deficiencies that call into question the accuracy of their profitability estimates, but their overall strategy is appealing. The estimated fixed capital investment is much lower than an azelaic acid process even if it includes the first step of biodiesel production. The equipment to convert FAME to a polyol ester can be viewed as an add-on to a biodiesel plant 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 size of the total market indicates that lubricants could ultimately be the end use of a substantial fraction of the fats and oils produced by the rendering industry.

- The value of tallow rose to roughly $1.00/kg during the year in which this study was conducted. If this feed value is charged to each project instead of the lower value of $0.50/kg, the annual cost of manufacturing before depreciation (COMd) rises about 40%. Projected annual revenues are still much higher than the COMd in each case, and the profitability estimates are still high though not quite as impressive.

Complete final reports developed by the four student teams are available in pdf form. We will be glad to distribute any or all of them to industry personnel upon the authorization of the ACREC research committee or the Fats and Proteins Research Foundation.

Impacts and Significance to the Rendering Industry

The economic estimates developed by the four teams in the spring semester indicate substantial potential for the industry to increase profits by converting rendered fat into higher valued products. Further work is needed to refine and verify estimates of process costs, product values, and market demand for products, but the potential is obvious. Converting fat to higher valued products can increase revenues dramatically and change the dynamic market pressures currently experienced by the 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 is considered to be confidential to the rendering industry so no attempt has been made to publish the work or obtain outside funding. To date process development has been based on known science and technology using openly published sources. As the work proceeds into 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

Continuation of the work described above has been authorized and funded by the Fats and Proteins Research Foundation through ACREC. The ongoing work will be described further in the September progress report and in a presentation at the Emerging Issues seminar at the 2011 annual meeting of the National Renderers Association in Tucson.

Acknowledgments

The entire 2011 senior class of Clemson chemical engineering students deserves recognition for their creative input to this project. In particular the twenty senior students named above did much of the work described.