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New Strategies For Converting Waste Lactose From Cheese Production To Biofuels

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Abstract

The coupling of biological experimentation with engineering systems modeling facilitates a realistic economic assessment of the conversion of delcatosed whey permeate (delac), a byproduct from cheese-making, to valuable bioproducts (biofuel & protein) using oleaginous yeast. Results for the upgrading of delac to triglycerides and protein by growth of oleaginous yeast and the development of experimentally validated engineering process models for technoeconomic evaluation are presented. Experimental results are presented and integrated into systems engineering models to perform a technoeconomic assessment of the yeast to biofuels pathway. The primary function of the model is to track mass and energy requirements for each process step at a simulated production level of 25 million gallons of biofuel. Cost data was gathered to account for the capital, installation, and operational expenses of the production plant. Production costs for the proposed process are a $10.97 per gallon of biodiesel with the majority of the costs allocated to the cultivation phase. The total cost reported includes capital, installation, and operational costs with a plant lifetime of 20 years and interest rate of 5%. Results indicate research and development could dramatically impact the total cost of the biofuel through the optimization of the reactor in terms of energy consumptions and productivity. Future work is dedicated to the use of systems models with experimental data feedback to enable an efficient design of experiments focused on assessing the large-scale impact of the proposed processes.

Introduction And Background

- **Delcatosed whey permeate (delac) is a current waste product form cheese making**
  - High lactose content
- **Yeast based biofuels are currently of interest as a third generation feedstock**
  - High productivity potential
  - Use of waste streams
  - Low environmental impact
- **Current experimental data**
  - Limited feedstocks
  - Not representative of large-scale production
  - No optimization of reactor performance or inputs
- **Current economic viability modeling**
  - Does not include scale-relevant data
  - Utilize arbitrary scaling factors
  - Guess and test mentality in terms of optimization
- **Study goals: Evaluation of sustainability, scalability, economic feasibility**
  - Determine the effect of delac on overall productivity
  - Generate a transparent scalable growth data for model validation
  - Optimization and evaluation of yeast to biofuel process
  - Comparison of potential yield to DOE alternative fuel goals

Experimental Methods

Preliminary experimental growth work is divided into three thrusts, i) compositional analysis of delac and comparison to traditional growth media, ii) growth of *Cryptococcus curvatus* and *Rhodococcus opacus* on variable carbon to nitrogen ratio for lipid production evaluation, and iii) growth of *Cryptococcus curvatus* and *Rhodococcus opacus* on varying dilutions of delac for lipid production assessment. Preliminary results validate the feasibility of the concept, but show further experimentation is needed to optimize the growth system.

Media Feasibility

A direct comparison of media composition and the delac obtained from Glanbia foods was performed to verify growth feasibility

Constitute	Media	delac	Constitute	Media	delac	Constitute	Media	delac
Nitrate	**1459**	**14.85**	Fe	0.90	4.17	Se	0	0.05
Ag	0	<0.01	K	0.71	11637	Se	0	0.05
Al	0	0.37	LI	0	0.09	**Si**	**0**	**56.3**
As	0	0.02	Mg	12.15	524.43	Sn	0	<0.01
B	0.01	1.41	Mn	0.08	0.02	Sn	0	<0.01
Ba	0	0.04	Mo	0.04	0.12	Sr	0	0.48
Ca	**4.01**	**1514**	Na	541.8	7188.7	Tl	0	<0.01
Cd	0	<0.01	Ni	<0.01	0.05	V	0	0.02
Co	<0.01	<0.01	P	0.51	2959.5	Zn	0.03	0.15
Cr	0	0.12	Pb	0	<0.01	**Lactose**	**$40*10^3$**	**$170*10^3$**
Cu	<0.01	0.34	Sb	0	<0.001	Galactose	0	3.9

Compositional analysis of delac and standard media, all values presented in mg L^{-1}

Experimental Results

Two sets of *C. curvatus* growth experimentation were performed, 1) evaluation of carbon to nitrogen ratio with results,Table 1 and 2) constant carbon to nitrogen ratio at varying delac concentrations, Table 2.

Table 1. Growth results for the cultivation of *C. curvatus* while, increasing carbon source and nitrogen source proportionately in control (glucose) and delac simulated media

Growth Media		Dry Weight (g L^{-1})	Lipid %	Lipids Productivity (g L^{-1})
Glucose	40 g/L [a]	7.4	38.5	2.85
	80 g/L [a]	7.9	34.1	2.7
	120 g/L [a]	7.2	29.4	2.1
Delac	40 g/L [a]	10.0	38.7	3.9
	80 g/L [a]	10.1	28.4	2.9
	120 g/L [a]	10.2	25.7	2.6

[a]Nitrogen source is kept constant at 0.5 g L^{-1} ammonium sulfate

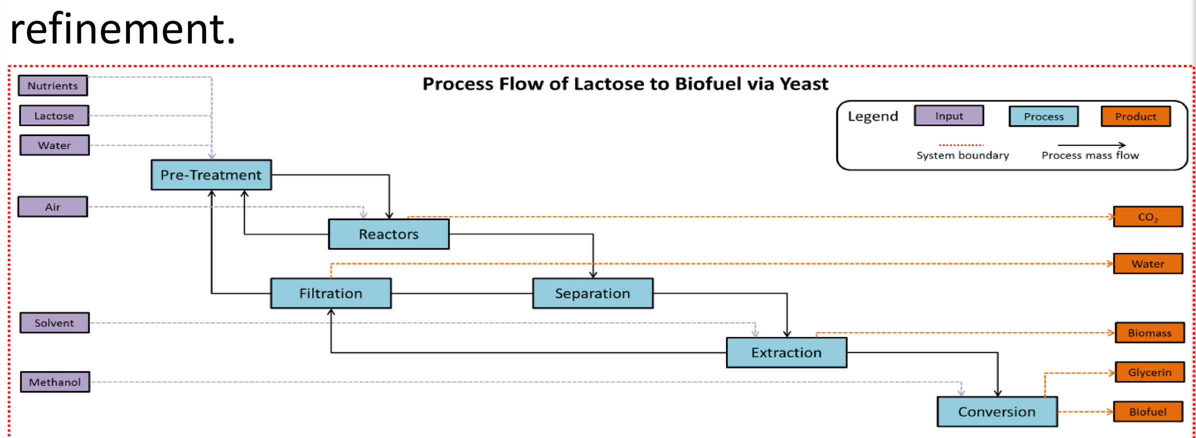
Table 2. Growth results for the cultivation of C. curvatus while, increasing carbon source without increasing nitrogen source in control (glucose) and delac

Growth Media		Dry Weight (g L^{-1})	Lipid %	Lipids Productivity (g L^{-1})
Glucose	40 g/L [a]	13.3	71.7	9.5
	80 g/L [a]	14.1	46.8	6.6
	120 g/L [a]	10.6	21.7	2.3
Delac	40 g/L [a]	13.6	67.5	9.2
	80 g/L [a]	20.3	64.2	13.0
	120 g/L [a]	19.7	51	10.0

[a]Nitrogen source is kept at a constant proportion of 80:1 g L^{-1} ammonium sulfate ranging from 0.5 to 1.5 g L^{-1}.

Technoeconomic Methods

Results from preliminary experimentation were incorporated into an engineering systems model to evaluate the technoeconomic feasibility of the proposed process. The economic evaluation included yeast growth, harvesting, drying, conversion of yeast oil to crude FAMEs, and refinement.



Systems engineering process model for conversion of lactose to biofuel via yeast

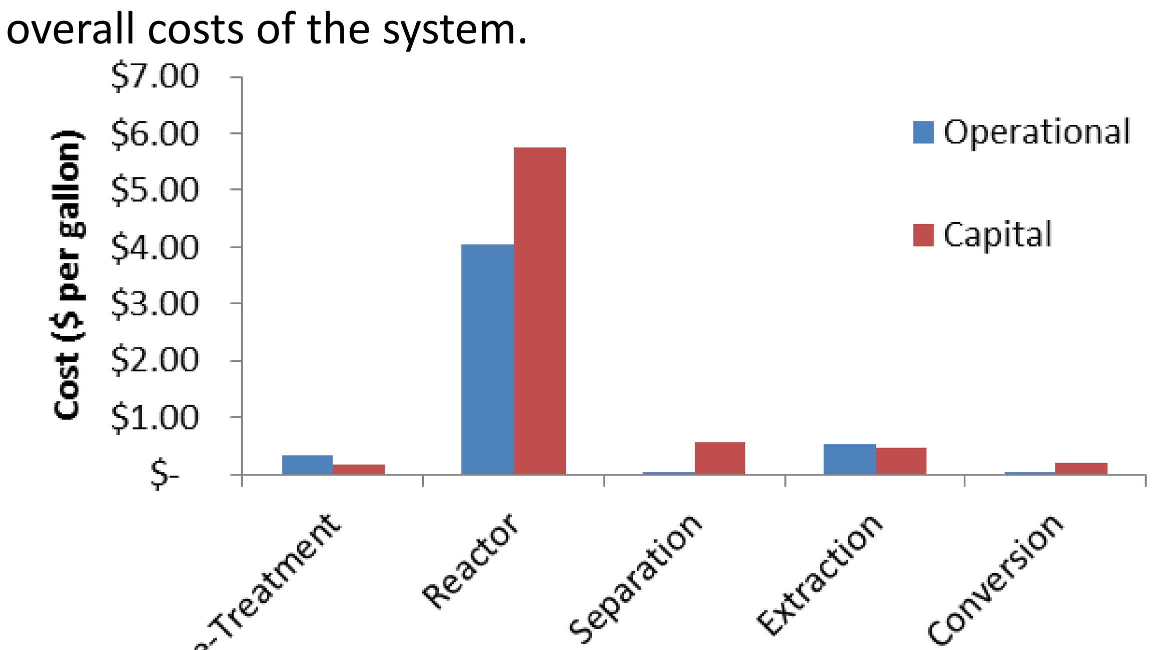
Economics include capital and operational costs with a loan term of 20 years and 5% interest. Protein and biofuel are assumed to be primary products.

Input	Value	Unit
Whey	3785	L/day
Feedstock lactose	170	g/L
Yeast production	40	g/L
Media lactose	80	g/L
Lipid	70	%
Protein	20	%
Lactose to nitrogen ratio	80:1	

Primary baseline inputs for economic feasibility study

Technoeconomic Results

73% of the operational costs and 72% of the capital costs are associated with the reactor system. There is an opportunity to optimize the reactor production system and decrease the overall costs of the system.



Preliminary economic results for the production of 25 million gallons of fuel separated into operational and capital costs[1]

Preliminary results show the systems should be optimized for protein production, protein valued at \$7 lb^{-1}, biofuel at \$4 gal^{-1}

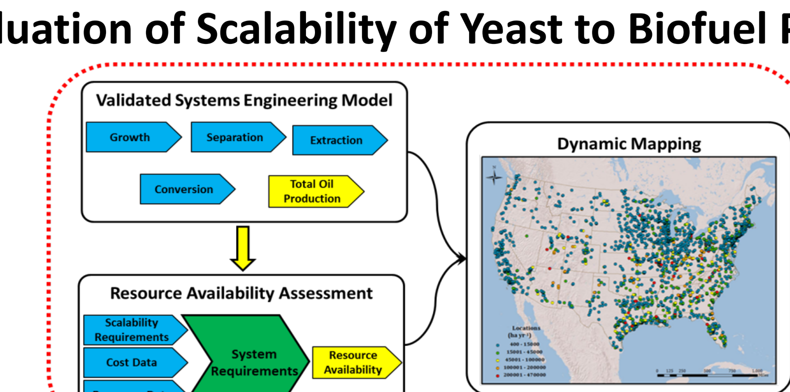
Costs (daily)	
Capital	$ 64,361.69
Opperational	$ 745,012.12
Revenue (daily)	
Biofuel	$ 267,628.32
Protein	$ 737,343.34
Total	$ 195,597.85

Daily costs associated with the processing of 1 million gallons of delac per day

Future Work

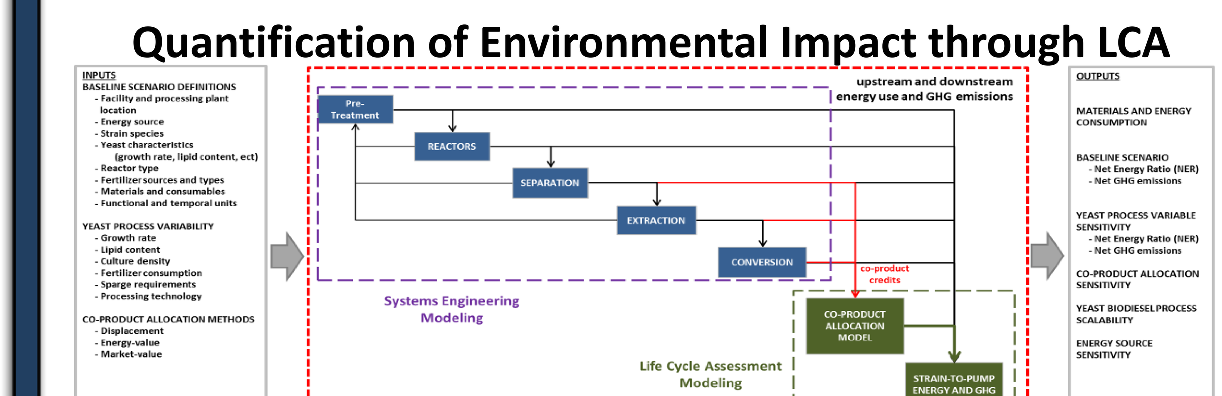
Three specific objectives have been outlined for future development: 1) Upgrading of whey permeate or delac to triglycerides by growth of oleaginous yeast (*Cryptococcus curvatus, Rhodosporidium toruloides,* and *Yarrowia lipolytica*), 2) Engineering process evaluation and optimization of harvest, lipid extraction, and biofuel conversion, and 3) Development of experimentally validated engineering process models for the assessment of scalability, sustainability, and economic feasibility.

Evaluation of Scalability of Yeast to Biofuel Process



Modeling architecture incorporating systems engineering model and GIS resource data for scalability assessment

Quantification of Environmental Impact through LCA



Process integration diagram of engineering process model and lifecycle modeling

[1]Lactose to Yeast to Biofuel Plant Life Cycle Cost, Redd Engineering & Construction Inc.