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Advancement of Petroleum Diesel Alternatives Utilizing a Multifaceted and Interdepartmental Approach

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Advancement Of Petroleum Diesel Alternatives

A Multifaceted And Interdepartmental Approach

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Abstract

The advancement of biologically derived alternatives to petroleum diesel fuel requires a multifaceted approach. At Utah State University we use an interdisciplinary team including the Colleges of Engineering, Agriculture & Applied Sciences, and Science in conjunction with industry partners to drive innovation in improving the science behind petroleum diesel alternatives. With increasing petroleum use, depleting reserves, increasing emissions standards, and other factors, there is need for petroleum diesel alternatives that are cost effective, offer improvement, and perform similarly to petroleum diesel. Our team has focused on the use of oleaginous microbes utilizing low value effluent and waste sources including sugars and CO_2 to create biofuels. We have focused on a yeast, *Cryptococcus curvatus*, and a microalgae, *Nannochloropsis salina* which have shown high yields of fuel per cell mass. Using these microbes we have utilized USU's own direct trans-esterification reaction to create sufficient quantities of biodiesel for engine performance and emissions testing, including a subset of ASTM tests characterizing the fuels from each organism. Our initial engine testing used petroleum diesel as a baseline in conjunction with commercial soybean biodiesel to establish the quality of our microbially derived biodiesel. Testing in stationary diesel engines and on the Bonneville Salt Flats has proven our microbial fuels perform similarly to soybean biodiesel and comparably to petroleum diesel. To further improve biological diesel replacements we have begun working to create green diesel, hydrocarbons from a biological source, using a novel method of hydrothermal liquefaction. Preliminary results of those tests are presented here. Through a multifaceted and interdisciplinary approach USU is successfully improving petroleum diesel alternatives from microbial sources including characterization of the properties of these fuels and is working to create the fuels at the scale necessary for exhaustive engine performance and emissions testing including ASTM testing of all important fuel properties.

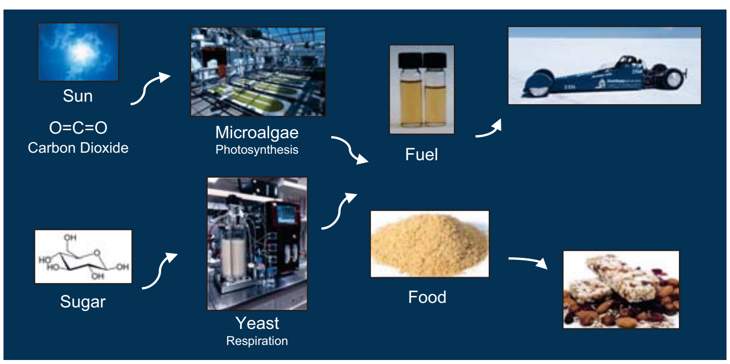
Introduction

Beginning 7 years ago Utah State University began working to utilize CO_2 and sunlight to create biodiesel from microalgae as a team comprising the Colleges of Engineering, and Science. Since then the project has grown to include carbon-rich low value effluent sources to create biodiesel and other high value co-products from oleaginous heterotrophic microorganisms including yeast and bacteria. The team has also grown to include the College of Agriculture and Applied Science. With expertise from the scientists including; professors, graduate students, undergraduate students, and technicians the team has made advances in:

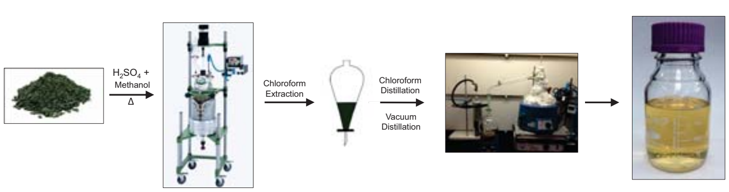
- Strain selection
- Growth optimization
- Nutrient and stress analysis
- Scaling
- Conversion process creation
- Engine and emissions analysis
- Co-product evaluation
- Economic and environmental analysis

Utilizing expertise from the interdepartmental team and industry partners USU is rapidly making advances in many critical areas necessary for process and product optimization to improve the properties and availability of biologically derived petroleum diesel alternatives.

Overview



Microbial Biodiesel Production



USU's patented conversion process converts phospholipids and neutral lipids for a greater total biodiesel yield per biomass conversion.

Fuel Properties

Fuel	Density at 15⁰C (g cm^{-3})	Kinematic Viscosity at 40⁰C (mm^2 s^{-1})	Heating Value (kJ g^{-1})	Volumetric Energy Density (kJ cm^{-3})	Cetane Number (minimum value)	Biodiesel Cetane Index
Petroleum Diesel						
ASTM Standard (D975)		1.9-4.1			40	
#2 (this study)	0.818	2.1 (±0.06)	46.10 (±0.036)	37.7		
Biodiesel						
ASTM Standard (D6751)	0.86-0.90	1.9-6.0	N/A		47	
Soybean *G. max*	0.884	3.9 (±0.1)	39.97 (±0.093)	35.3		54
Microalgae *C. gracilis*	0.885	3.4 (±0.06)	39.51 (±0.006)	35.0		51
Yeast *C. curvatus*	0.876	4.5 (±0.1)	39.33 (±0.289)	34.5		67
Bacteria *R. opacus*	0.895	4.1 (±0.05)	37.31 (±0.252)	33.4		41

Table 1: Properties of fuels

Biodiesel Fuel	Fatty Acid Chain Length (% Of Total Fatty Acids)						Degree of Unsaturation (% Of Total Fatty Acids)		
	C14	C15	C16	C17	C18	C20	Mono	Poly	Mono + Poly
Soybean *G. max*	0	0	11	0	88	<1	24	61	85
Yeast *C. curvatus*	0	0	16	0	83	<1	60	6	66
Bacteria *R. opacus*	2	5	43	22	27	0	51	0	51
Microalgae *C. gracilis*	10	<1	72	0	0	6	34	28	62

Table 2: Fatty acid composition of biodiesel fuels

Each microorganism has its own unique fatty acid profile which affects overall engine performance and emissions profile characteristics.

Fuel Performance and Emissions

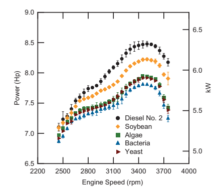


Figure 1: Diesel engine power output

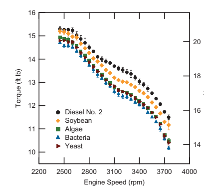


Figure 2: Diesel engine torque output

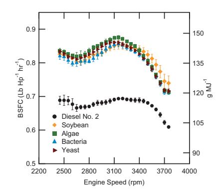


Figure 3: Diesel engine BSFC

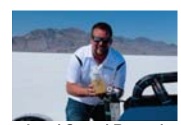
Initial testing of the fuels showed the microbial biodiesel fuels performed similar to soybean biodiesel and comparably to petroleum diesel fuel. The algal biodiesel had lower NO_x emissions than all fuels including petroleum diesel.

Fuel		Emission Parameters				
		CO_2 (%)	CO (%)	HC (ppm)	NO_X (ppm)	O_2 (%)
Petroleum Diesel #2		3.700 (±0.000)	0.109 (±0.006)	28.96 (±1.08)	25.71 (±1.302)	15.3 (±0.000)
Biodiesel						
Soybean	*G. max*	3.881 (±0.000)	0.077 (±0.005)	17.38 (±0.59)	31.67 (±1.433)	15.4 (±0.000)
Yeast	*C. curvatus*	3.800 (±0.000)	0.048 (±0.004)	11.86 (±0.48)	39.67 (±1.394)	15.6 (±0.040)
Bacteria	*R. opacus*	3.891 (±0.032)	0.050 (±0.000)	9.87 (±0.49)	46.76 (±1.283)	15.5 (±0.000)
Microalgae	*C. gracilis*	3.797 (±0.016)	0.090 (±0.006)	19.75 (±0.94)	21.87 (±1.817)	15.6 (±0.000)

Table 3: Emissions for biodiesel fuels and petroleum diesel

Fuel	Top Speed (mph)	
	9-10-12	8-13-13
Petroleum Diesel #2	65.444	72.569
Biodiesel		
Yeast *C. curvatus* (B100)	64.759	n/a
Algae *N. salina* (B50)	n/a	73.977

Table 4: Bonneville Salt Flats performance results



Land Speed Record
I/DS 64.396 mph - Yeast Biodiesel
9/10/12

Hydrothermal Liquefaction of Wet Yeast Biomass

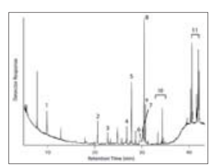


Figure 4: Gas chromatograph of HTL yeast

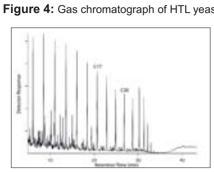


Figure 5: Gas chromatograph of diesel fuel

Peak Number	Retention Time (min)	Compound	% Total
1	9.838	Glycerol (TMSE)	1.54
2	20.616	Heptadecane	1.99
3	23.306	D-arabino-hexanoic acid-3-deoxy-2,5,6-tris-gamma-lactone (TMSE)	0.29
4	26.779	Eicosane	1.22
5	27.801	Palmitic (TMSE)	4.57
6	29.585	Oleic (Non-deriv.)	2.52
7	30.28	Stearic (Non-deriv.)	1.36
8	30.452	Oleic (TMSE)	6.90
9	30.792	Stearic (TMSE)	2.43
10	33.407	Monoglycerides (TMSE)	1.95
11	40.352	Diglycerides (TMSE)	19.63
Not shown	N/A	Triglycerides	55.60

Table 5: Quantitative Analysis of HTL biocrude

The creation of economically viable biologically derived petroleum alternatives are hindered by the energy intensive inputs necessary for conversion such as biomass drying and extensive post processing. Additionally, the resultant biodiesel typically has decreased energy per mass as a result of natural oxygen compounds, such as carboxyl groups, leading to decreased fuel economy etc. The use of wet biomass and a low temperature (240-300⁰ C) hydrothermal liquefaction process removes carboxyl groups from fatty acids to create their associated alkanes such as eicosane and heptadecane as shown here while employing a lower conversion energy input as in traditional transesterification conversion processes.

Conclusions

- All microbial biodiesel fuels were found to generate similar power and torque outputs compared to soybean
- Microbial biodiesels do not show an increase in BSFC relative to soybean
- Hydrocarbon and CO emissions are reduced compared to diesel #2 levels for microbial and soybean biodiesel
- CO_2 levels are increased for the biofuels indicating improved combustion
- NO_x emissions for soybean, yeast, and bacterial biodiesel were higher than the measured levels for diesel #2
- Microalgal biodiesel produced the lowest NO_x emissions of any fuel tested
- Reduced smoke opacity observed with microalgal biodiesel on the Bonneville Salt Flats
- Economic analysis improves experimental design leading to improved petroleum diesel alternatives
- Low temperature hydrothermal liquefaction creates experimentally significant volumes of alkanes

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Utah State University Biorenewable Fuels Project