Fuel For Thought – Biodiesel in the STEM Classroom

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Introduction:

- Biodiesel is a renewable fuel made from triglyceride oils using a transesterification reaction (Figure 1). Biodiesel has lower greenhouse gas emissions as compared to petroleum diesel (Figure 2) and biodiesel can be used in most modern diesel engines and generators without modification to the engine.
- Queens University STEM students designed and engineered a safe and efficient biodiesel reactor system capable of processing 20L (5 gallon) of used cooking oil per batch (Figure 3). The fuel is used in campus equipment (diesel mowers, tractor, generator, vehicles).
- Queens biodiesel process is inherently *safer* than most biodiesel process because it replaces methanol with ethanol as the reactant alcohol (Table 2). However, due to its physical properties (polarity, pKa) ethanol biodiesel production is more challenging, and requires strictly *anhydrous* conditions.
- A successful reaction is qualitatively assessed by observing phase separation (Figure 1).
- Queens' reactor also uses the glycerol "waste product" as catalyst, making the overall process more sustainable.

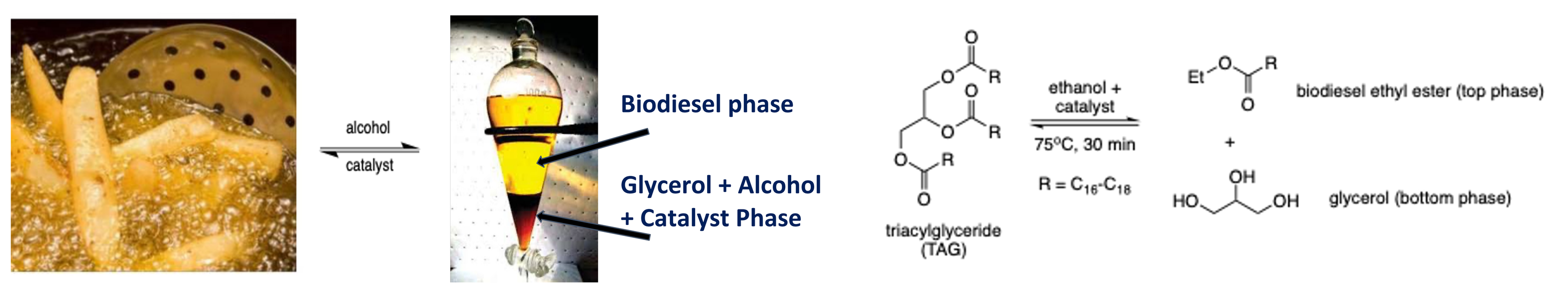


Figure 1: Biodiesel process using cooking oil (triglycerides) with alcohol and catalyst to produce esters and glycerol.

Emission	B100
Carbon Monoxide	-43.2%
Hydrocarbons	-56.3%
Particulates	-55.4%
Nitrogen Oxides	5.8%
Air Toxins	-60 to -90%
Mutagenicity	-80 to -90%
Carbon Dioxide	-78.3%

Reactant alcohol	Flash point (°C)[1]	Dipole moment (20°C)[2]	pKa value (H_2O)[3]	Toxicity (IC_{50} mg/kg, rat)[4]
Methanol (CH_3OH)	12	2.87	15.5	5628
Ethanol (CH_3CH_2OH)	*13*	*1.66*	*15.9*	*10,470*

Figure 2: Biodiesel emissions compared to petroleum diesel (left) and physical property comparison of methanol and ethanol alcohols.

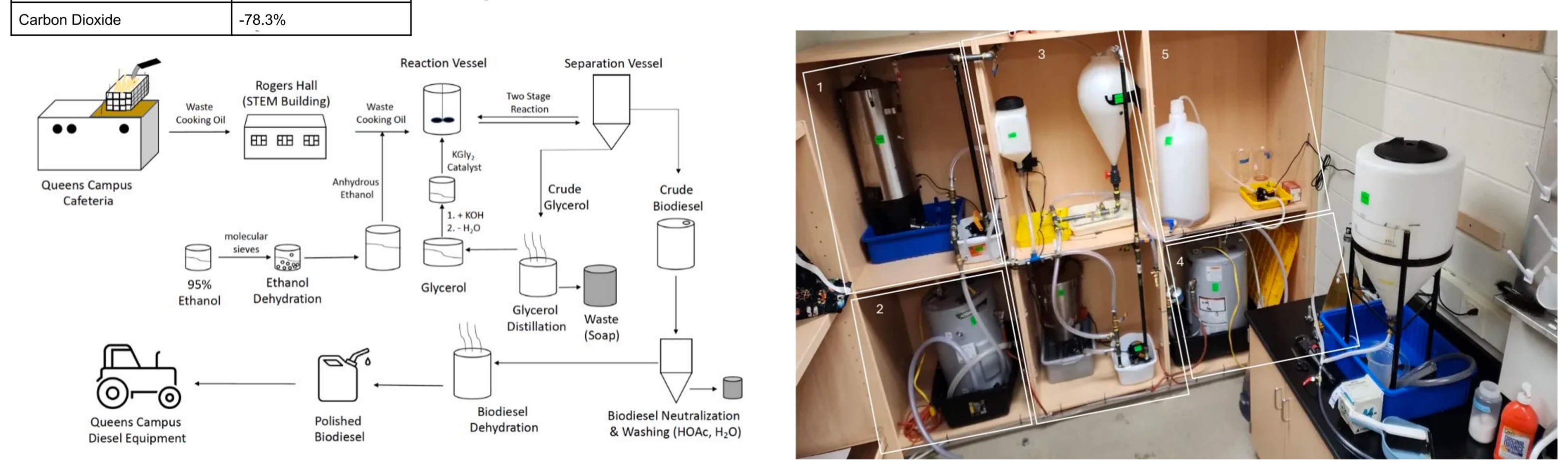


Figure 3: Campus biodiesel schematic (left) and 20L reactor system in Rogers Hall Room 114 (right)

Summer SRET Project Plan

Learn basic biodiesel theory for incorporation into elementary and middle school curricula

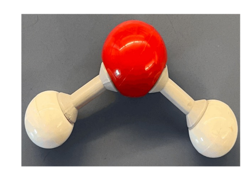
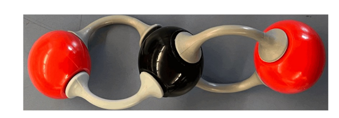
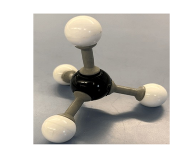
Group photo taken 6-17-24

Biodiesel lab lessons and experiments:	***NC Science Standards***
Experiment 1: *Use molecular models to explain biodiesel reaction*	**3.P.2** Understand the structure and properties of matter before and after they undergo a change.
Anticipated Results for Experiment 1: ChemDraw Software will be able to predict molecule name, molecular weight, and boiling point	**8.P.1.1** Construct an explanation to classify matter as elements, compounds, or mixtures based on how the atoms are arranged in various substances.
Experiment 2: Synthesize 10g of biodiesel using ethanol and glyceroxide catalyst	**3.P.2** Understand the structure and properties of matter before and after they undergo a change.
Anticipated Results for Experiment 2: - Thin layer chromatography (TLC) will show different Rf values for triglyceride reactant and biodiesel product - use infrared (IR) spectroscopy to analyze biodiesel product and triglyceride reactant • Measure reaction rate using IR. • Develop a lesson plan to explain IR spectroscopy and consider a field trip in Fall 2024.	**5.P.2** Understand the interactions of matter and energy and the changes that occur. **8.P.1.2** Use models to illustrate the structure of atoms in terms of the protons, electrons, and neutrons (using the location, charges and comparative size of these subatomic particles), without consideration of isotopes, ions, and energy levels.
Experiment 3: Design and perform viscosity "race" using transesterification reactants and products.	**8.P.1.3** Analyze and interpret data to explain how the physical properties of elements and their reactivity have been used to produce the current model of the Periodic Table of Elements.

Experimental:

Experiment 1: Building molecular models

A lesson plan describing atomic structure was devised, and models were built, using an organic chemistry model kit. Molecular models were built for simple compounds (H_2O, CO_2) and reagents used to make biodiesel (ethanol, triglyceride, glycerol). Model structure accuracy was verified using ChemDraw software.

 Hydrogen (H)	 Carbon (C)	 Nitrogen (N)	 Oxygen (O)
 Water (H_2O)	 Carbon Dioxide(CO_2)	 Methane (CH_4)	 Ethanol(C_2H_6O)

Fuel For Thought:

- By distinguishing protons from electrons, and atoms from molecules, students gain a deeper understanding of chemicals/substances. Models are used to show bonds formed from electrons in atoms (to make molecules). Molecules of everyday life aid understanding of biodiesel molecules. (8.P.1.1,8.P.1.2)
- Incorporating models will aid students to connect atoms and molecules with chemical reactions (bond breaking and bond forming)
- Models aid understanding of physical properties of molecules (intermolecular interactions, e.g. Van der Waals forces, H-bonding, and viscosity). (8.P.1.3,8.P.1.4)

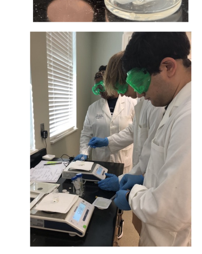
Experiment 2:" Making Biodiesel" Synthesis of 10g biodiesel using ethanol and glyceroxide catalyst

A lab procedural experiment of 10g amount of biodiesel was synthesized using catalyst (potassium glyceroxide) previously generated from the transesterification reaction (Figure 3). This lab is scaled down to be incorporated in a middle school setting to allow students to embark on a procedural journey of curating biodiesel and analyzing the data and any error made along the way.

Step 1: Gather and weigh scintillation vial for mass with stir bar; tare at zero.

20 mL scintillation vial reactor with magnetic stir bar used to make biodiesel in the classroom

Step 2: Pipette 10g of Wesson canola oil into scintillation vial using pipette.



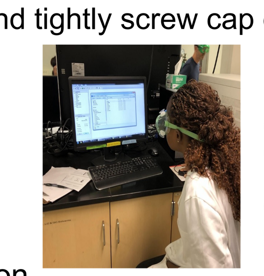
Diego weighing materials to make biodiesel in at the classroom scale (10g)

Step 3: Pipette 2.13g of ethanol into scintillation vial.

Step 4: Pipette 0.71g of catalyst (~30 wt%) into scintillation vial.

Step 5: Add 1-2 drops of phenolphthalein *ethanolic solution* to the mixture. Place and tightly screw cap onto scintillation vial. Shake vigorously.

Step 6: Place vial onto hot plate, or into oven, for 20 min at 75 degrees C.
Note: Vigorously shake every 5 minutes.



Rahina performing quality control of residual ethanol and glycerol in biodiesel

Fuel For Thought:

- Incorporating a procedural process to create a small scale biodiesel reaction.
- Carrying out investigations to determine whether the mixing of two or more substances results in new substances. (PS. 5.1.2)

Experiment 3: Viscosity Race

An experiment designed to measured the viscosity of the four substances commonly used in the production of biodiesel. Substances measured were glycerol, Wesson cooking oil, biodiesel and ethanol. Speed and distance travelled are measured and graphed then compared for analysis.

Step 1: Pour each liquid into NMR tubes ⅙ full and cap, each with a different color cap

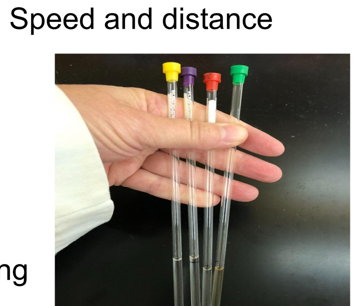
Step 2: Record color of cap per each sample

Step 3: Make predictions of which liquid will come in 1st, 2nd, 3rd, 4th and explain reasoning (intermolecular forces such as H-bonding and Van der Waals)

Step 4: One partner starts stopwatch as the other partner turns all 4 tubes upside down

Step 5: Press "lap" button when each liquid reaches cap

Step 6: Graph results of triplicate experiments including standard deviation in Excel, discuss



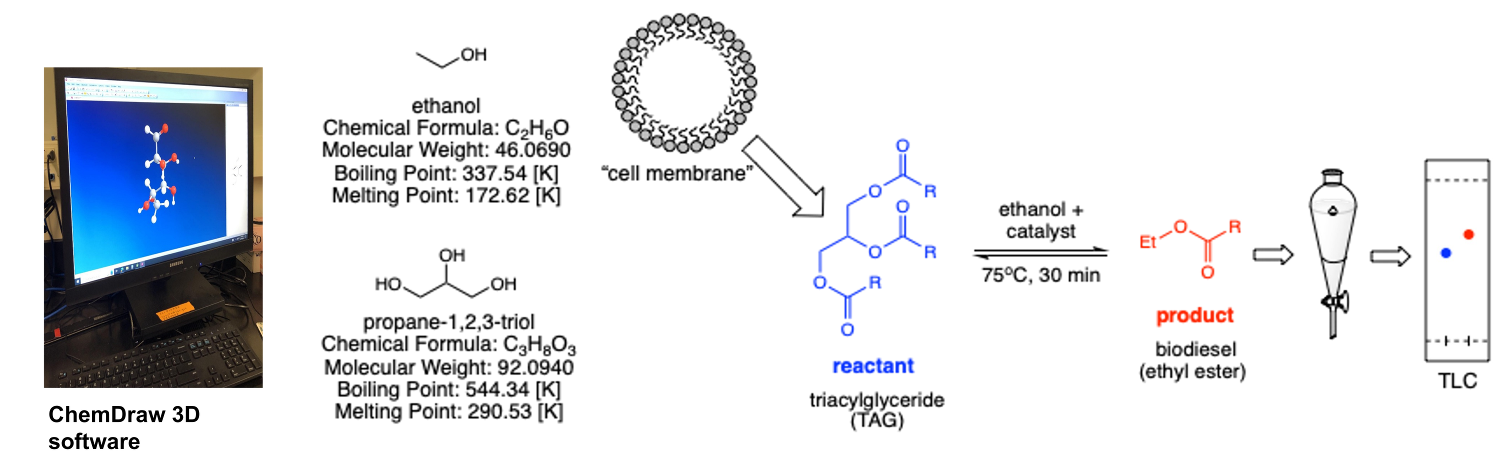
Yellow: glycerol
Purple: cooking oil
Green: biodiesel
Red: ethanol

Fuel For Thought:

- Students learn structure and properties of matter (3.P.2)
- Students observe one of the basic properties (viscosity) of matter (PS.3.1.2)

Results:

Experiment 1: Molecular and Reaction Models using ChemDraw Software



Experiment 2: Making Biodiesel and Performing Quality Control

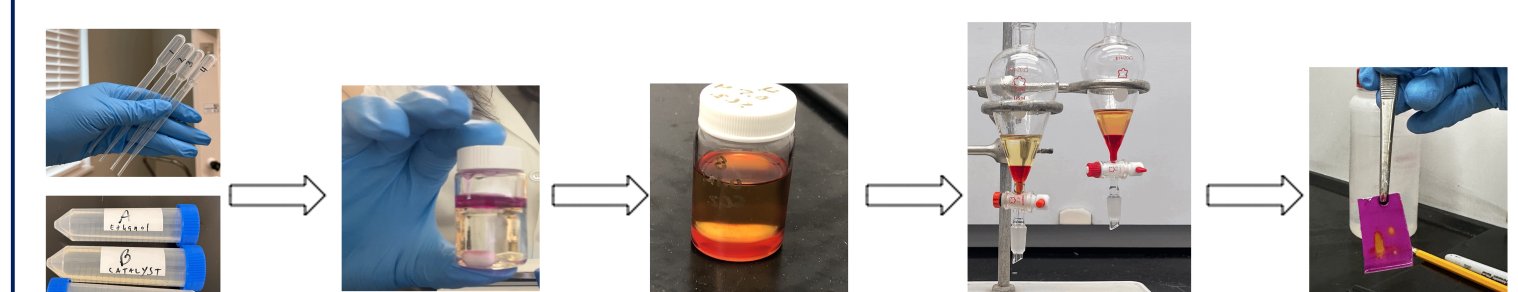


Figure 4: The process of making biodiesel at the classroom scale (10g), showing phase separation and TLC quality control.

Experiment 3: Viscosity Race + Error Analysis and Generating Kinetic Data

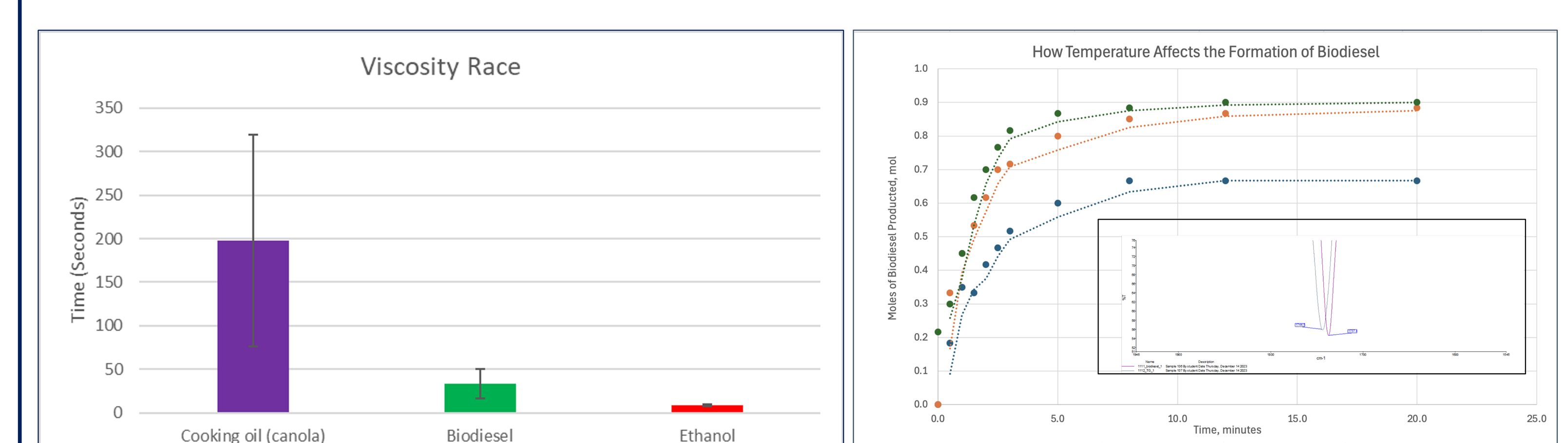
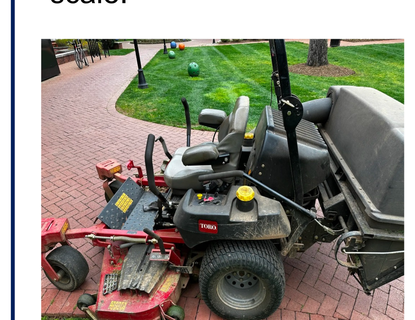


Figure 5: Results from viscosity "race" (left, glycerol not shown - 24 hr) and kinetics experiment (right) of transesterification at three different temperatures as determined by IR (inlay, C=O biodiesel 1737 cm^{-1}, C=O triglyceride 1744 cm^{-1}).

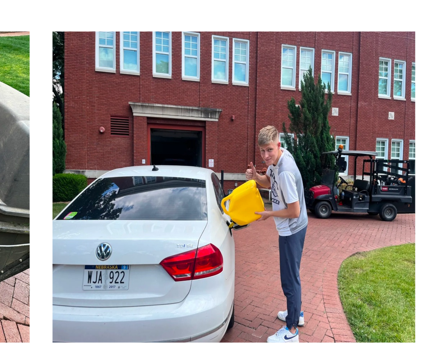
Conclusion

All participants in this project benefited by collaboration through education levels. High school, undergraduate and soon-to-be graduate students gained insight into a shared understanding of science and scientific communication. Dr. Socha and his team helped translate college level chemistry in relatable ways. Elementary and middle school teachers gained hands-on experience working in a chemical lab setting focused on green chemistry.

By observing the scientific and engineering processes used to produce biodiesel at the 20L scale, teachers were able to develop curriculum modules to meet NC Science Standards. When teaching this material in the classroom students will gain knowledge and understanding of abstract concepts by hands-on activities and experiential instruction. They will construct and build molecular models of atoms and compounds (i.e. H_2, H_2O, CH_4, CO_2, glyceride, triglyceride) commonly used in everyday life, make biodiesel, run a viscosity "race", and perform quality control tests on their product. By observing the project website using the QR code below, students will gain additional understanding of the energy input vs. the energy output (in Joules) when making biodiesel on the 20L scale.



Queens campus diesel mower.



Charlie filling up for a chemistry cultural exchange trip!

Queens Sports Complex diesel tractor.

?

"Gus": CMS Safety Program Diesel Bus

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References

1. SDS form (Ethanol and Methanol)
2. https://people.chem.umass.edu/xray/solvent.html
3. Ripins & Evans pKa table CHM 206
4. SDS form (Ethanol and Methanol)

Support

EPA grant number SU840686; *Biodiesel Production from Ethanol and Glycerol: a Living Laboratory for STEM Students,* 1/1/24 - 12/3125.

Project Website