Applecross Senior High School

Year 12 ATAR Chemistry
Biodiesel and Ethanol Extended Response Assessment

Background Information
This assessment requires you to research the chemical synthesis and production of ethanol and biodiesel, taking into account sustainability, local resources, economics and environmental impacts (green chemistry).

Preparation for the Assessment

You are advised to read the attached article and view the following video clips and articles in preparation for the test.

1. Alternative Fuel – Ethanol Hits the Wall

   https://www.youtube.com/watch?v=jPdB6_YW1JE

2. Biofuels the Answer or the Problem?

   https://www.youtube.com/watch?v=t_Fw6y4T3Po

3. How Biofuel is Made

   https://www.youtube.com/watch?v=IhpeXuRYJWg

4. Cosmos Article 1
   https://cosmosmagazine.com/climate/are-biofuels-viable-alternative

5. Cosmos Article 2

   https://cosmosmagazine.com/biology/designer-plants-could-seed-cheaper-biofuels

6. The Truth About Ethanol Addressing the Myths

   https://www.youtube.com/watch?v=3MnAqDgXKfc

Details of the Test
This test:
- has a 5% weighting in the assessment schedule
- is an open book test.
- will be 55 minutes in duration.
- You will be permitted to bring in handwritten and electronic notes, a laptop and earphones to view videos during the test.
- You will not be permitted to communicate with anyone or use your mobile phone during the test.

Background

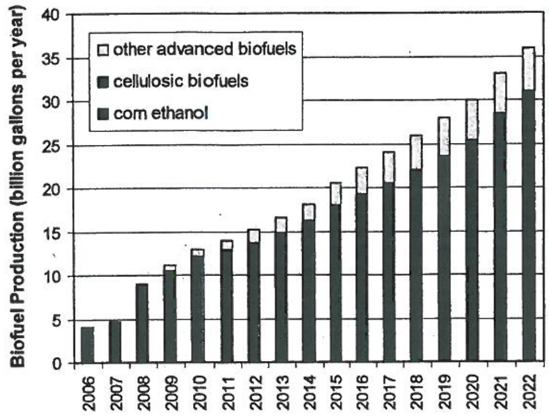
Biofuels are fuels made from recently grown plant or animal matter. Fossil fuels were also originally plant or animal matter, but that material has spent millions of years underground in extreme conditions and so it has changed significantly and its energy value was concentrated. As fossil fuel supplies diminish, renewable energy resources that can be replenished faster than we use them must be found in order for society to continue functioning as we are accustomed. Some folks believe that biofuels, like corn ethanol and biodiesel, could supply this renewable supply of fuel.

There are other negative environmental impacts related to fossil fuel use, in addition to the depletion of a limited resource. Many toxic chemicals contained in fossil fuels are released into the atmosphere upon burning of oil and coal. Biofuels are less toxic than fossil fuels - biodiesel is less toxic than table salt, for example. In addition, carbon released from the sequestered underground reservoirs of fossil fuels goes into the atmosphere as carbon dioxide. Most scientists agree that the human-caused increase in atmospheric carbon dioxide and other greenhouse gases are at least partially influencing global temperature. Thus, fossil fuel use influences global climate destabilization.

Biofuels are touted as a potential solution (at least partially) to the problem of greenhouse gases from fossil fuels. The biofuels still release carbon dioxide into the atmosphere, but since the fuel comes from recently grown plants, it was extracted from the atmosphere through photosynthesis, and will be reused by future crops. By limiting the amount of carbon moving from the underground to the atmosphere, the idea is to reduce the intensity of global warming.

Ethanol and biodiesel are now commonly mixed with petroleum-based fuels for sale as transportation fuels. Ethanol from corn is the most commonly used biofuel made in the U.S. In 2008, over 9 billion gallons of corn ethanol were produced. New technologies are available to make ethanol from cellulosic materials, including wood chips, switch grass, and corn stover, which is the stalk and leaf residue remaining after the corn grain is harvested. Biodiesel is made from soy beans or canola seeds, both of which have high oil contents. Approximately 0.7 BGY of biodiesel was produced in 2008.

U.S. legislation has shaped much of the national history of ethanol production. Bioethanol was first seriously considered as a transportation fuel in the 1970s due to the Arab Oil embargo. In 1990, a $0.54/gal subsidy for the sale of gasoline blends that contain at least 10% ethanol (E10) helped to increase the number of ethanol production facilities. The U.S. Energy Independence and Security Act (EISA) of 2007 mandates that fuel producers use at least 36 billion gallons of biofuel by 2022. This includes 15 BGY of corn ethanol by 2015 and 21 BGY must be cellulosic biofuels. The legislation also



calls for a 20% reduction in oil use by 2010 through improved vehicle fuel economy and a national fuel economy standard of 35 miles per gallon by 2020. The 2022 EISA requirements would replace 15 % of the 2006 U.S. gasoline consumption on an energy basis.

Ethanol

Ethanol is made by the biological fermenting of sugars in the feedstock. If the feedstock does not contain sugars initially, pretreatment steps must precede the fermentation to transform the complex starches (corn) or cellulose into simpler sugar molecules. After the fermentation step, distillation is required to separate the ethanol from water.

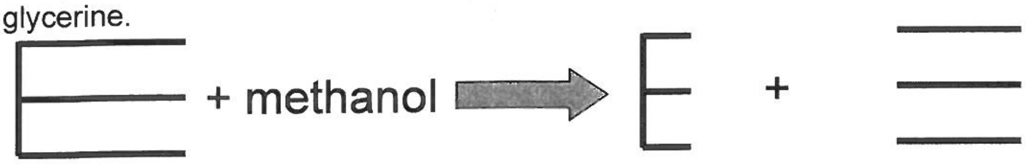
In the United States, the main feedstock for the production of ethanol is currently corn. **Approximately 2.8 gallons of ethanol (10 liters) are produced from one bushel of corn (35 liters)**. While much of the corn turns into ethanol, some of the corn also yields by-products such as DDGS (distillers dried grains with solubles) that can be used to fulfill a portion of the diet of livestock. A bushel of corn produces about 18 pounds of DDGS. Both the corn farming and ethanol production steps are very energy intensive. Diesel fuel and a lot of nitrogen fertilizer are used on the farm. Making the fertilizer requires a lot of energy and natural gas. The ethanol production step requires a lot of heat to keep the fermentation tanks warm and to distill the ethanol. On-site steam production from coal is often used in large-scale ethanol production facilities. Overall, even though the carbon in the fuel is "free" through the photosynthesis reaction, a lot of fossil fuels were also consumed to prepare ethanol for use as a transportation fuel.

Biodiesel

The diesel engine was originally designed to run on peanut oil. Modern diesel engines are designed to run on petroleum (fossil fuel) diesel, but can still run on vegetable oil if the oil's viscosity is low. Warming the oil is required to lower the viscosity, so some alterations must be made to the fuel supply to the engine. The main reason for the use of petroleum diesel is its low cost and slightly higher energy value. Some people are promoting a return to vegetable oil for reasons of renewability and low pollution. By converting the oil to biodiesel, the energy value is increased and viscosity is lowered. This fuel can then be mixed with petroleum diesel (up to 20% mix (B20) can be used safely in any diesel engine) or can be used pure in many vehicles.

Biodiesel can be manufactured safely at a local community scale, while petroleum diesel requires a large refining infrastructure for safety and economy. In terms of energy independence and security for individuals, communities, states and countries, fuels such as biodiesel show promise when compared with the large scale operations of fossil fuel suppliers.

Biodiesel is created by reacting "natural" oils, or triglycerides, with an alcohol (usually methanol) in the presence of a catalyst. There are different methods for carrying out the reaction, but one of the simplest and most common is a base-catalyzed batch reaction of oil with methanol. This reaction is called transesterification. Any type of triglyceride, which includes plant or animal based oils, can be used as the feedstock. The base catalyst, typically lye (sodium hydroxide or potassium hydroxide), is mixed with the alcohol before the reaction is started. The alcohol/catalyst mixture is then added to the oil and the whole mixture is stirred vigorously. The overall reaction can be thought of as a big "E" in which the three fingers are cut off. The "fingers" and the molecules that comprise biodiesel, and the truncated remaining "E" is the glycerine.



Triglyceride | Glycerine | Biodiesel (methyl esters)

Simplified conceptualization of transesterification reaction

$$
\begin{array}{llll}
CH_2-O-\overset{\overset{O}{\|}}{C}-R & & & CH_2-OH \\
| & & & | \\
CH_2-O-\overset{\overset{O}{\|}}{C}-R & +\ 3\ CH_3OH \rightarrow & 3\ CH_2-O-\overset{\overset{O}{\|}}{C}-R\quad + & CH-OH \\
| & & & | \\
CH_2-O-\overset{\overset{O}{\|}}{C}-R & & & CH_2-OH
\end{array}
$$

Triglyceride (vegetable oil) | Methanol+Catalyst | Methyl Esters (biodiesel) | Glycerin

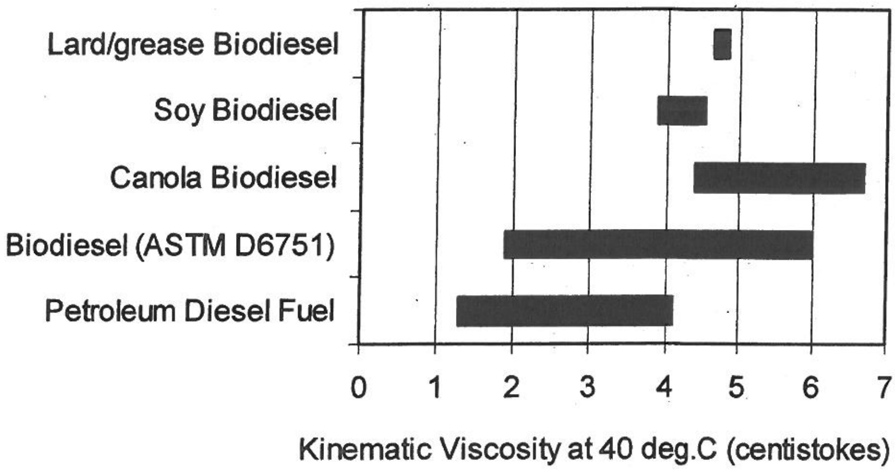
Transesterification of Triglyceride with Alcohol

After the reaction occurs, there will be two products, which separate into phases (like oil and water). The lower density phase (on top) is the biodiesel, and the higher density phase is glycerin. Glycerin can be used in other processes such as making soap or dynamite. In a high-end biodiesel production facility, the biodiesel must be cleaned before it can be sold as fuel.

Properties of Biofuels

The heating (calorific) value is an important physical property of all fuels. The calorific value of diesel is 46 MJ/Kg, kerosene is 47 MJ/Kg, biodiesel is 33–40 MJ/Kg, and canola oil is 36.9 MJ/Kg.[i] In the experiment performed during this lesson, students will use a simple calorimeter to calculate the calorific values of these four fuels.

The viscosity of a fluid can be expressed as a "dynamic viscosity" and a "kinematic viscosity". Dynamic viscosity is measured in "centipoise" while kinematic viscosity takes into account the fluid density and is measured in "centistokes". It is important to note the temperature of the measurements because the viscosity of a liquid will be reduced as the temperature rises. For example, the range of viscosity seen for canolabiodiesel is 4.43 to 6.7 centistokes at 40°C; this drops to around 2.4 centistokes at 100°C.



The maximum viscosity is limited by the design of engine fuel injection systems. The maximum allowable viscosity for No. 2 diesel is 4.1 centistokes at 40°C although most engines are designed to operate on fuels of higher viscosity. ASTM D6751 allows for slightly higher viscosity for biodiesel. Mixing biodiesel with petroleum diesel lowers the overall viscosity.

B100 freezes at higher temperatures than most conventional diesel fuel and this must be taken into account if handling or using B100. Most B100 starts to cloud at between 35°F and 60°F, so heated fuel lines and tanks may be needed even in moderate climates. As B100 begins to gel, the viscosity also begins to rise, and it rises to levels much higher than most diesel fuel, which can cause increased stress on fuel pumps and fuel injection systems. Cold weather properties are the biggest reason many people use biodiesel blends.

Key Terms

- **Biofuel** – fuel made from recently grown plant or animal matter.
- **Biodiesel** – a type of fuel made by a transesterifcation reaction from natural oils that can be used in a diesel engine with minimal or no alterations.
- **Viscosity** – the property of a fluid that resists the force tending to cause the fluid to flow.
- **Glycerin** – a co-product of biodiesel manufacture.
- **Heating value** – the heat energy released through the exothermic oxidation (combustion) reaction when a fuel is combusted.