ESTIMATING ENERGY EFFICIENCY OF BIODIESEL AS A SUBSTITUTE FOR DIESEL FUEL

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Biodiesel is a renewable diesel fuel substitute that can be made by chemically combining any natural oil or fat with an alcohol such as methanol or ethanol. In Europe, biodiesel is available in both its neat form (100% biodiesel, also known as B100) and in blends with petroleum diesel. Most European biodiesel is made from rapeseed oil. In the United States, initial interest in producing and using biodiesel has focused on the use of soybean oil as the primary feedstock, mainly because this country is the world's largest producer of soybean.

To evaluate energy efficiency of using the fuel we need to define different kinds of energy flows. It can be made by analyzing life cycle of the fuel. Types of life cycle energy inputs are:

- total primary energy - all raw materials extracted from the environment that contain energy. In estimating the total primary energy inputs to each fuel's life cycle, we consider the cumulative energy content of all resources extracted from the environment;

- feedstock energy - energy contained in raw materials that end up directly in the final fuel product. For biodiesel production, feedstock energy includes the energy contained in the soybean oil and methanol feedstocks that are converted to biodiesel. Likewise, the petroleum directly converted to diesel in a refinery contains primary energy that is considered a feedstock energy input for petroleum diesel. Feedstock energy is a subset of the primary energy inputs;

- process energy. It is the energy contained in raw materials extracted from the environment that does not contribute to the energy of the fuel product itself, but is needed in the processing of feedstock energy into its final fuel product form. Process energy consists primarily of coal, natural gas, uranium, and hydroelectric power sources consumed directly or indirectly in the fuel's life cycle;

- fossil energy - primary energy that comes from fossil sources specifically (coal, oil, and natural gas). All three of the previously defined energy flows can be categorized as fossil or nonfossil energy.

- fuel product energy - the energy contained in the final fuel product, which is available to do work in an engine, is what we refer to as the "fuel product energy." All other things being equal, fuel product energy is a function of the energy density of each fuel.

Total energy demand is calculated on each stage of the petroleum diesel and biodiesel life cycles. Biodiesel life cycle include 6 stages: soybean (or rapeseed) agriculture, soybean transport, soybean crushing, soy oil transport, soy oil conversion, biodiesel transport. Diesel fuel life cycle include 4 stages: crude oil extraction, crude oil transportation, crude oil refining, and diesel fuel transportation.

Two types of energy efficiency are represented. The first is the overall "life cycle energy efficiency." The second is the "fossil energy ratio." Each illuminates a different aspect of the life cycle energy balance for the fuels studied.

The calculation of the life cycle energy efficiency is the ratio of fuel product energy to total primary energy:

$$\text{Life Cycle Energy Efficiency} = \frac{\text{Fuel Product Energy}}{\text{Total Primary Energy}} \quad (1)$$

This ratio estimates the total amount of energy that goes into a fuel cycle compared to the energy contained in the fuel product. This efficiency accounts for losses of feedstock energy and additional process energy needed to make the fuel.

The fossil energy ratio tells us something about the degree to which a fuel is or is not renewable. It is defined as the ratio of the final fuel product energy to the amount of fossil energy required to make the fuel:

$$\text{Fossil Energy Ratio} = \frac{\text{Fuel Energy}}{\text{Fossil Energy Inputs}} \quad (2)$$

If the fossil energy ratio has a value of zero, a fuel is completely nonrenewable and provides no usable fuel product energy because of the fossil energy consumed to make the fuel. If the fossil energy ratio is 1, it is still nonrenewable because no energy is lost in the process of converting the fossil energy to a usable fuel. For fossil energy ratios greater than 1, the fuel begins to leverage the fossil energy required to make it available for transportation. As a fuel approaches "complete" renewability, its fossil energy ratio approaches "infinity." That is, a completely renewable fuel has no fossil energy requirements.

From a policy perspective, these are important considerations. Modern policy makers want to understand how much a fuel increases the renewability of energy supply. Another implication of the fossil energy ratio is the question of climate change. Higher fossil energy ratios imply lower net CO_2 emissions. This is a secondary aspect of the ratio, as we are explicitly estimating total CO_2 emissions from each fuel's life cycle.

Compared on the basis of primary energy inputs, biodiesel and petroleum diesel are essentially equivalent. Biodiesel has a life cycle energy efficiency of 80.55%, compared to 83.28% for petroleum diesel. The slightly lower efficiency reflects a slightly higher demand for process energy across the life of cycle for biodiesel. On the basis of fossil energy inputs, biodiesel enhances the effective use of this finite energy resource because it leverages fossil energy inputs by more than three to one. Because 90% of biodiesel feedstock requirements (soybean/rapeseed oil) are renewable, biodiesel's fossil energy ratio is favorable. Biodiesel uses 0.3110 MJ of fossil energy to produce 1 MJ of fuel product; this equates to a fossil energy ratio of 3.215. In other words, the biodiesel life cycle produces more than three times as much energy in its final fuel product as it uses in fossil energy.

Thereby, biodiesel can effectively leverage limited supplies of fossil fuels, can help reduce air pollution and greenhouse gas emissions, can reduce the dependence on foreign petroleum.