A Process Model to Estimate Biodiesel and Petro Diesel Requirement and Mass Allocation Rule

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ABSTRACT

The life cycle assessment (LCA) for the production of biodiesel in USA was done by National Renewable Energy Laboratory (NREL) in 1998.W have focused on the benefits related to biodiesel energy's balance, its effect on the effect of biodiesel on overall consumption and mass allocation with petro diesel and other fossil fuels. In the context of this, fuel's "life cycle"—the sequence of steps involved in making and using the fuel from the extraction of all raw materials from the environment to the final end-use of the fuel in an urban bus., as well as for blends of biodiesel with petroleum diesel. The scope of this study Life cycle analysis is a complex science. The level of detail required in such a study forces a high degree of specificity in the scope and application of the products being studied. Here we study life cycle analysis , a computational tool for assessing the requirement and production of biofuels and petro-diesel.

1. INTRODUCTION

Life Cycle analysis (LCA) provide an opportunity to quantify the total energy demands and the overall energy efficiencies of processes and products. Ascertaining the overall energy requirements of biodiesel is key to our understanding of the extent to which biodiesel made from oil is a "renewable energy" source. More the fossil energy required to make a fuel, the less that this fuel is deemed "renewable". Thus, the renewable nature of a fuel can vary across the spectrum of "completely renewable." (i.e., no fossil energy input) to nonrenewable (i.e., fossil energy inputs as much or more than the energy output of the fuel)[2] . Energy efficiency estimates help us to determine how much additional energy must be expended to convert the energy available in raw materials used in the fuel's life cycle to a useful transportation fuel. The basic concepts as well as the results of our analysis of the life cycle energy balances for biodiesel and petroleum diesel are as follows:[1]

1.1 Types of Life Cycle Energy Inputs

In this study, several types of energy flows through each fuel life cycle.

- *Total Primary Energy*. All raw materials extracted from the environment can contain energy. In estimating the total primary energy inputs to each fuel's life cycle, 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 is termed "feedstock energy." 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*. The second major subset of primary energy is "process energy." This is limited to energy inputs in the life cycle exclusive of the energy contained in the feedstock. 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*. Since the renewable nature of biodiesel is of primary concern, we also track the 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 non fossil energy.
- *Fuel Product Energy*. The energy contained in the final fuel product, which is available to do work in an engine, is the "fuel product energy". All other things being equal, fuel product energy is a function of the energy density of each fuel. We consider the energy trapped in soybean oil to be renewable because it is solar energy stored in liquid form through biological processes that are much more rapid than the geologic time frame associated with fossil energy formation. Also, other forms of nonrenewable energy besides fossil fuel exist.The energy "contained" in a raw material is the amount of energy that would be released by the complete combustion of that raw material.[3-7]

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In this paper two types of energy efficiency are considered. The first is the overall "life cycle energy efficiency". The second is what we refer to as the "fossil energy ratio". Each elucidates a different aspect of the life cycle energy balance for the fuels studied.The calculation of the life cycle energy efficiency is simply the ratio of fuel product energy to total primary energy:

Life Cycle Energy Efficiency = Fuel Product Energy/Total Primary Energy

Fossil Energy Ratio = Fuel Energy/Fossil Energy Inputs

If the fossil energy ratio has a value of zero, a fuel is not only completely nonrenewable, but it provides no useable fuel product energy as a result of the fossil energy consumed to make the fuel. If the fossil energy ratio is equal to 1, then this fuel is still nonrenewable. A fossil energy ratio of one means that no loss of energy occurs in the process of converting the fossil energy to a useable fuel. For fossil energy ratios greater than 1, the fuel actually begins to provide a leveraging of the fossil energy required to make the fuel available for transportation. As a fuel approaches being “completely” renewable, its fossil energy ratio approaches “infinity.” In other words, a completely renewable fuel has no requirements for fossil energy.

From a policy perspective, It is important to understand the extent to which a fuel increases the renewability of our energy supply. Another implication of the fossil energy ratio is the question of climate change. Higher fossil energy ratios imply lower net CO2 emissions. This is a secondary aspect of the ratio, as we are explicitly estimating total CO2 emissions from each fuel’s life cycle. Nevertheless, the fossil energy ratio serves as a check on calculation of CO2 life cycle flows.[9]

As Life cycle analysis is a complex science. The level of details required in such a study forces a high degree of specificity in the scope and application of the products being studied.We have also undertaken studies in our laboratory to characterize the performance of linseed derived biodiesel for life cycle analysis. More importantly, our sensitivity studies show that the estimates of energy requirements are very healthy that is, these results show little change in response to changes in key assumptions.

The use of biodiesel offers tremendous potential for the strategy for reducing petroleum oil dependence and minimizing fossil fuel consumption. Substituting 100% biodiesel (B100) for petroleum diesel in buses reduces the life cycle consumption of petroleum by 95%. This benefit is proportionate with the blend level of biodiesel used. When a 20% blend of biodiesel and petroleum diesel (B20) is used as a substitute for petroleum diesel in urban buses, the life cycle consumption of petroleum drops by 19%.In our study, biodiesel and petroleum diesel are producing almost identical efficiency of converting a raw energy source (in this case, petroleum and linseed oil) into a fuel product. The difference between these two fuels is in the ability of biodiesel to utilize a renewable energy source.

Biodiesel yields 3.2 units of fuel product energy for every unit of fossil energy consumed in its life cycle. The production of B20 yields 0.98 units of fuel product energy for every unit of fossil energy consumed. In contrast, petroleum diesel’s life cycle yields only 0.83 units of fuel product energy per unit of fossil energy consumed. Such measures confirm the “renewable” nature of biodiesel At the outset, we designed this study to identify and quantify the advantages of biodiesel as a substitute for petroleum diesel. These advantages are substantial; especially in the area of requirement and mass allocation conversion rule .We see these as opportunities for further research to resolve these concerns.

2. PETROLEUM DIESEL LIFE CYCLE ENERGY CONSUMPTION

The total primary energy requirements for the key steps in the production and use of petroleum diesel shown in table 1. The LCI model shows that 1.2007 MJ of primary energy is used to make 1 MJ of petroleum diesel fuel. This corresponds to a life cycle energy efficiency of 83.28%. The distribution of the primary energy requirements for each stage of the petroleum diesel life cycle is shown in Table 3. Ninety-three percent of the primary energy demand is for extracting crude oil from the ground. The stages of petroleum diesel production are ranked from highest to lowest in terms of primary energy demand About 88% of the energy shown for crude oil extraction is associated with the energy value of the crude oil itself. The remaining 7% of the primary energy use the crude oil refinery step for making diesel fuel dominates. Removing the feedstock energy of the crude itself from the primary energy total allows us to analyze the relative contributions of the process energy used in each life cycle. Process energy demand represents 20% of the energy is determined. Using the total primary energy reported in Table 1, Fuel Product ultimately available in the petroleum diesel.

Life Cycle Energy Efficiency = 1 MJ of fuel product. About 90% of the total process energy is in refining (60%) and extraction (29%). The next largest contribution to total process energy is for transporting foreign crude oil to domestic petroleum refiners.[7]

Table 1: Primary Energy Requirements for the Petroleum Diesel Life Cycle

Stage	Primary Energy (MJ per MJ of Fuel)	Percent
Domestic Crude Production	0.5731	47.73%
Foreign Crude Oil Production	0.5400	44.97%
Domestic Crude Transport	0.0033	0.28%
Foreign Crude Transport	0.0131	1.09%
Crude Oil Refining	0.0650	5.41%
Diesel Fuel Transport	0.0063	0.52%
Total	1.2007	100.00%

Foreign crude oil transportation carries with it a fourfold penalty for energy consumption compared to domestic petroleum transport since the overseas transport of foreign oil by tanker increases the factor of four due to transport.

Domestic crude oil extraction is more energy intensive than foreign crude oil production. The United States represent 11% of the total production volume, compared to 3% for foreign oil extraction for the advance oil recovery. Advanced oil recovery uses twice as much primary energy per kilogram of oil compared to conventional extraction. Advanced crude oil extraction requires almost 20 times more process energy for per kilogram of oil out of the ground, than onshore domestic crude oil extraction because the processes employed are energy intensive and the amount of oil recovered is low associated with the linseed oil itself. As with the petroleum life cycle, the stages of the life cycle that are burdened with the feedstock energy overpower all other stages. Had the linseed oil energy been included with the farming operation, then linseed agriculture would have been the dominant consumer of primary energy. This is analogous to placing the crude oil feedstock energy in the extraction stage for petroleum diesel fuel. The next two largest primary energy demands are for linseed crushing and linseed oil conversion. They account for most of the remaining 13% of the total demand.

Table 2: Fossil Energy Requirements for the Petroleum Diesel Life Cycle

Stage	***Fossil Energy (MJ per MJ of Fuel)***	***Percent***
Domestic Crude Production	0.572809	47.75%
Foreign Crude Oil Production	0.539784	45.00%
Domestic Crude Transport	0.003235	0.27%
Foreign Crude Transport	0.013021	1.09%
Crude Oil Refining	0.064499	5.38%
Diesel Fuel Transport	0.006174	0.51%
Total	1.199522	100.00%

Bio-diesel Life Cycle Energy Consumption

If process energy separates from primary energy, we find that energy demands in the biodiesel life cycle are not dominated by linseed oil conversion (Figure 3). The soybean crushing and soy oil conversion to biodiesel demand the most process energy (34.25 and 34.55%, respectively, of the total demand). Agriculture accounts for most of the remaining process energy consumed in life cycle for biodiesel (almost 25% of total demand). Each transportation step is only 2%-3% of the process energy used in the life cycle.

Table 3: Primary Energy Requirements for Biodiesel Life Cycle

Stage	**Primary Energy (MJ per MJ of Fuel)**	**Percent**
Linseed Agriculture	0.0660	5.32%
Linseed Transport	0.0034	0.27%
Linseed Crushing	0.0803	6.47%
Linseed Transport	0.0072	0.58%
Linseed Conversion	1.0801	87.01%
Biodiesel Transport	0.0044	0.35%
Total	1.2414	100.00%

Table 3 summarize the fossil energy requirements for the biodiesel life cycle. Since 90% of its feedstock requirements are renewable (that is, soybean oil), biodiesel's fossil energy ratio is favorable. Biodiesel uses 0.3110 MJ of fossil energy to produce one 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. Fossil energy demand for the conversion step is almost twice that of its process energy demand, making this stage of the life cycle the largest contributor to fossil energy demand. The use of methanol as a feedstock in the production of biodiesel accounts for this high fossil energy demand. We have counted the feedstock energy of methanol coming into the life cycle at this point, assuming that the methanol is produced from natural gas. This points out an opportunity for further improvement of the fossil energy ratio by substituting natural gas-derived methanol with renewable sources of methanol, ethanol or other alcohols.

3. EFFECT OF BIODIESEL ON LIFE CYCLE ENERGY DEMANDS

Life cycle energy efficiency of biodiesel is 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. Biodiesel leverages fossil energy inputs by more than three to one.

4. STUDY OF MASS ALLOCATION RULE

For biodiesel

Several processes within the biodiesel and the petroleum diesel life cycles produce more than one product. This life cycle study is concerned only with the portion of the environmental flows that is attributable to the biodiesel or petroleum-based diesel LCIs. Therefore, the original LCI flows of a process (emissions, energy and material requirements, etc.) that produce more than one coproduct are split between the various products produced. A mass based allocation is used for the baseline comparison of biodiesel and petroleum-based diesel fuel. The following example shows how a mass allocation works in the case of allocating the soybean conversion into biodiesel environmental flows between multiple coproducts:

First, the overall environmental flows are determined for a specific process, as shown in Table 13 for soybean conversion into biodiesel.

Table 4: Environmental Inflows and Outflows for the Biodiesel Conversion Process

Environmental Flow	***Units***	***Value***
IN: Linseed Oil (degummed)	kg	1.04
Sodium Hydroxide (NaOH, 100%)	kg	0.0023

Methanol (CH3OH)	kg	0.096
Electricity	MJ elec	0.23
Steam	kg	1.03
Water Used (total)	L	0.36
Sodium Methoxide (CH3ONa)	kg	0.024
OUT: Biodiesel (neat, kg)	kg	1.04
Crude Glycerine	kg	0.9
Soapstock	kg	0.00054
Water (chemically polluted)	L	0.38
Waste (total)	kg	0.012

The mass percent of each coproduct produced is calculated, as shown in Table 14:

Table 5: Mass Percent of the Various Conversion Co-Products

Coproducts	*Units*	*Value*	*Mass Percent of Total*
Biodiesel (neat, kg)	kg	1	92%
Crude Glycerine	kg	0.15	8%
Soapstock	kg	0.00054	0% (negligible)
Total:	kg	1.15	100%

The choice of allocation rules can be quite controversial. The assumption of a mass allocation rule applied to multi-product processes was a subject of real debate among the stakeholders. The mass allocation approach was seen as the least problematic approach to use.

Finally, the overall environmental flows are allocated to only the production of biodiesel, as shown in Table 6.

Table 6: Mass Allocated Conversion Results for Biodiesel

Total Process	***Biodiesel Only***	
Environmental Flow	***Units***	***Values Allocation Results***
IN: Linseed Oil (degummed)	kg	1.04 x 0.92 = 0.96
Sodium Hydroxide (NaOH, 100%)	kg	0.0023 x 0.92 = 0.0021
Methanol (CH3OH)	kg	0.096 x 0.92= 0.088
Electricity	MJ	0.23 x 0.92= 0.21
Steam	kg	1.03 x 0.92 = 0.94
Water Used (total)	kg	0.36 x 0.92 = 0.33
Sodium Methoxide (CH3ONa)	kg	0.024 x 0.92 = 0.022

OUT: Biodiesel (neat, kg)	kg	1.04x1.04= 1.081
Crude Glycerine	kg	0.9 x 0 = 0
Soapstock	kg	0.00054 x 0 = 0
Water (chemically polluted)	kg	0.38 x 0.92 = 0.34
Waste (total)	kg	0.012 x 0.92 = 0.011

Similarly, a mass based allocation can be performed for the production of crude glycerine, Table 7. We don't actually carry out the calculations for allocation of life cycle flows to glycerine in our model because our analysis is concerned with those flows allocated only to biodiesel. We show this calculation to demonstrate that the mass balance for all flows is not violated by the application of allocation factors, as long as all coproducts are treated the same way when flows are allocated to them. In this example, in other words, combining the final columns of Table 7 and Table 6 will yield the overall results for biodiesel conversion as shown in Table 8.

The allocated and unallocated mass and energy balances for the two systems considered in this study. These table demonstrate the complexity of the systems we are modeling. A comparison of the allocated and unallocated primary energy inputs for both of these fuels shows that, without allocation, the energy consumption assigned to make each fuel is much higher than the value of the fuel. This is due to the fact that the energy inputs that occur in each life cycle contribute to production of many other products besides petroleum diesel and biodiesel. The application of allocation rules provides an approximate means for assigning energy inputs in the life cycle among all of the products involved.

Table 7: Mass Allocated Conversion Results for Glycerine (not used in this study)

Environmental Flow	***Units***	***Total Process Values***	***Glycerine Only Allocation***	***Glycerine Only Results***
IN: Linsed Oil (degummed)	kg	1.04	x 0.08 =	0.083
Sodium Hydroxide (NaOH, 100%)	kg	0.0023	x 0.08 =	0.000018
Methanol (CH3OH)	kg	0.096	x 0.08 =	0.0076
Electricity	MJ	0.23	x 0.08 =	0.00184
Steam	kg	1.03	x 0.08 =	0.0824
Water Used (total)	kg	0.36	x 0.08 =	0.0288
Sodium Methoxide (CH3ONa)	kg	0.024	x 0.08 =	0.00192
OUT: Biodiesel (neat, kg)	kg	1.04	x 0 =	0
Crude Glycerine	kg	0.9	x 1 =	0.09
Soapstock	kg	0.00054	x 0 =	0
Water (chemically polluted)	kg	0.38	x 0.08 =	0.0304
Waste (total)	kg	0.012	x 0.08 =	0.00096

Table 8: Biodiesel Conversion Process Flows per Coproduct

Environmental Flow	*units*	*Biodiesel Only Results*		*Glycerine Only Results*		*Total Process Values*
IN: Linsee Oil (degummed)	kg	0.96	+	0.083	=	1.79
Sodium Hydroxide (NaOH, 100%)	kg	0.0021	+	0.000018	=	0.0021
Methanol (CH3OH)	kg	0.088	+	0.0076	=	0.096
Electricity	MJ	0.21	+	0.0019	=	0.21
Steam	kg	0.94	+	0.082	=	1.022
Water Used (total)	kg	0.33	+	0.029	=	0.36
Sodium Methoxide (CH3ONa)	kg	0.022	+	0.0019	=	0.024
OUT: Biodiesel (neat, kg)	kg	1.081	+	0	=	1.081
Crude Glycerine	kg	0	+	0.09	=	0.09
Water (chemically polluted)	kg	0.34	+	0.0304	=	0.37
Waste (total)	kg	0.011	+	0.00096	=	0.012

For Petro-diesel

Three separate types of processes for extracting crude oil are modeled in the petroleum extraction system , based on a recent life cycle study of U.S. petroleum production processes (Tyson et al. 1993). The three processes are onshore production, offshore production, and enhanced recovery. Enhanced recovery entails the underground injection of steam (produced by natural gas boilers) and CO2 to force the crude oil to the surface. The shares of total crude oil recovered by each process, for domestic and foreign production, are shown in Table 9.

Within the enhanced/advanced crude oil extraction category, two processes are typically used with different energy and material requirements: steam injection and CO2 injection. Steam injection is assumed to account for 63% of the enhanced/advanced extraction, and CO2 injection is assumed to account for the remaining 37%.[8]

Table 9: Production of Crude Oil by Technology Type and Origin

Technology Type	**Domestic Crude Oil Production**	**Foreign Crude Oil Production**
Conventional Onshore	69%	77%
Conventional Offshore	20%	20%
Enhanced/Advanced	11%	3%

Diesel Fuel Production

Petroleum refineries produce a number of products from the crude oil they receive. This study is Deal with one specific product, i.e.2 low-sulfur diesel fuel. Therefore, a method of allocating total refinery energy use and total refinery emissions between #2 low-sulfur diesel fuel and the other products needs to be developed.

The simplest allocation procedure (and the baseline case for this study) is to allocate total refinery inputs and releases among the products on a mass output basis. Table 10 outlines how thisconcept, based on the output of all U.S. refineries.

Table 46: Total U.S. Refinery Production

Refinery Flow	***Mass (kg/yr)***	***Mass (%)***
Diesel Oil (< 0.05% Sulfur, kg)	9.12E+10	13.4%
Diesel Oil (> 0.05% Sulfur, kg)	6.91E+10	10.1%
Gasoline	3.00E+11	44.0%
Heavy Fuel Oil	4.21E+10	6.17%
Jet Fuel (kg)	6.79E+10	9.95%
Kerosene (kg)	2.72E+09	0.40%
Misc. Refinery Products (kg)	2.50E+09	0.37%
Petroleum Coke (kg)	4.12E+10	6.04%
Liquefied Petroleum Gas	4.65E+09	0.68%
Asphalt (kg)	2.62E+10	3.83%
Lubricants (kg)	8.87E+09	1.30%
Petrochemical Feedstocks (kg)	2.18E+10	3.19%
Petroleum Waxes (kg)	1.21E+09	0.18%
Naphthas (kg)	2.76E+09	0.41%
Total:	6.83E+11	100%

Based on this table for crude oil refining, 13.4% of the total emissions, raw materials, and energy use required by the refinery are allocated to the production of low-sulfur diesel fuel. This approach ignores issues such as determining the contribution of inputs and releases that are uniquely associated with diesel versus the other refinery products, but it is consistent with the use of U.S. average data on refineries used in this analysis.

5. CONCLUSION

Energy Balance. Biodiesel and petroleum diesel have very similar energy efficiencies. The base case model estimates life cycle energy efficiencies of 80.55% for biodiesel versus 83.28% for petroleum diesel. The lower efficiency for biodiesel reflects slightly higher process energy requirements for converting the energy contained in linseed oil to fuel. In terms of effective use of fossil energy resources, biodiesel yields around 3.2 units of fuel product energy for every unit of fossil energy consumed in the life cycle. By contrast, petroleum diesel's life cycle yields only 0.83 units of fuel product energy per unit of fossil energy consumed. Such measures confirm the "renewable" nature of biodiesel. The life cycle for B20 has a proportionately lower fossil energy ratio (0.98 units of fuel product energy for every unit of fossil energy consumed) and hence ratio reflects the impact of adding petroleum diesel into the blend.

The Model Used to estimate the energy required to convert linseed oil into biodiesel represent a linseed processing plant combined with a transesterification unit.the resultfrom this research suggested a likely improvement of biodiesel FER over time. All other factors are constant for every 100 kg increase in linseed oil yield.

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[8] 8.Source: Shares of each production type were obtained from the Oil & Gas Journal Database, using numbers obtained in 1994. The Enhanced/Advanced category includes all advanced crude oil extraction techniques except water flooding. It is assumed that steam flooding and CO2 injection will represent the largest portion of the Enhanced/Advanced techniques obtained from the Oil & Gas Journal Database.

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