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Response to David Pimentel Biodiesel Life Cycle Analysis
National Biodiesel Board
July 2005

Understanding the Life Cycle or "Well-to-Wheel" Concept

When evaluating a fuel, many people often focus on the fuel's energy use or emissions only when it is burned or utilized in a vehicle engine. Consequently, too little attention is given to the technology or the infrastructure that helped create the fuel and delivered it to market. For example, fuels that show very low pollutant emissions from the vehicle may emit mightily during their production phases. Fuels very suitable for use in combustion engines may be difficult and costly to transport and store.

The effect of biodiesel on overall consumption of petroleum and other fossil fuels can only be understood in the context of biodiesel'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 a diesel vehicle. The chain has five stages: feedstock production, feedstock transportation, fuel production, fuel distribution and, finally, vehicle use.

The effect of biodiesel on overall consumption of petroleum and other fossil fuels can only be understood in the context of this fuel's energy balance, or "life cycle."

Life Cycle Studies

The U.S. Department of Energy and the U.S. Department of Agriculture have performed a life cycle study of the energy balance of biodiesel produced from soybeans in the U.S. This is the most comprehensive, credible and thoroughly peer reviewed study available on biodiesel produced from soybeans. Among its key findings:

- For every one unit of fossil energy used in this entire production cycle, 3.2 unit of energy are gained when the fuel is burned, or a positive energy balance of 320%.

- The energy balance for biodiesel produced from soybeans is so high because the starting component, soybean oil, is already high in energy content. Oils and fats are nature's preferred way to store high density energy.

- This study started with bare soil and took into account all the energy inputs associated with growing and harvesting soybeans: transporting and processing the soybeans into oil and meal, transportation and production of the soybean oil into biodiesel, and transportation of the biodiesel to the end user.

This study can be found at www.nrel.gov/docs/legosti/fy98/24089.pdf.

Additionally, the International Energy Agency recently conducted a review of several biofuel life cycle studies.[1] The results of these studies all indicate that biodiesel has a very good fuel process energy efficiency rating. While these studies apply to biodiesel made from rapeseed and may differ slightly from soybean oil based biodiesel, they establish the fact that biodiesel has a positive energy balance.

Fuel production process efficiency is a measure of how much process fuel is required to grow crops, transport them to production plants, produce biodiesel and deliver it to refueling stations. Studies that estimate better process efficiencies are represented by a lower number in the table below.

	Feedstock	Fuel Process Energy Efficiency (energy in/out)	Net Energy Balance Conversion
GM et al., 2002	Rapeseed	0.33	3.00 to 1
Levington, 2000 Levelton, 1999	Rapeseed	0.40	2.50 to 1
Altener, 1996	Rapeseed-a	0.55	1.82 to 1
Altener, 1996	Rapeseed-b	0.41	2.44 to 1
ETSU, 1996	Rapeseed	0.82	1.22 to 1
Levy, 1993	Rapeseed-a	0.57	1.75 to 1
Levy, 1993	Rapeseed-b	0.52	1.92 to 1

Note: When a range of estimates is reported by a paper, "a" and "b" are shown in the feedstock column to reflects this. The inverse of fuel process production efficiency (1/fuel process production efficiency) is an approximation of the net energy balance.

Response to Pimentel and Patzek Paper

It is the National Biodiesel Board's position that the David Pimentel study, which claimed a negative energy balance for biodiesel, contains some serious flaws. This study cannot be deemed technically credible for the following reasons:

- **In general, the authors do not provide enough details in the paper to determine how they reached their controversial conclusion.** Since this result is the exception to the rule, scientific protocol would dictate that the researchers provide a detailed description of their assumptions and their data sources. However, their entire discussion on making biodiesel from soybean oil was limited to one and a half pages. In contrast, a 1998 study conducted by the U.S. Department of Agriculture and the Department of Energy called the *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus* contained 286 pages of charts, tables, detailed data descriptions, and an in-depth discussion of the assumptions that were used to determine that the net energy balance of biodiesel was 3.2 to one.

- **The study overestimates the energy used to grow soybeans because it uses data from 15 years ago.** The input data listed in table 6 is based on a 1990 study by Ali and McBride. This USDA study reports survey data on the energy used to grow soybeans in 1990. The USDA survey that collects this information is conducted about every 4 years, and the latest data available is 2002. Why did the authors

[1] International Energy Agency, Biofuels for Transport: An International Perspective, 2004.

use data from 15 years ago, when data on the 2002 crop year is readily available? It is important to use the most current data available, since energy use on farms decreases overtime as farmers adopt new methods to reduce energy costs.

- **Soybean production practices are inaccurate.** For example, the researchers' assumption regarding the use of lime (calcium carbonate) does not reflect current farming practices. Lime inputs account for over 36% of the total energy inputs for soybean production in Pimentel and Patzek study. While the use of lime on acidic soils may help improve yields, its use is dependent upon the requirements of the soil and is not a universal input for soybean production. Moreover, in most parts of the country, the use of lime is limited and, if used, is not applied on an annual basis. Therefore energy requirements, at a minimum, must be allocated over multiple years.

- **The study includes labor has an energy input.** Even though the calories consumed by farm workers can be converted to energy equivalents, most researchers do not treat the calories as fossil energy. Labor associated with soybean production has no significant effect on the total number of calories consumed in the United States and calories are not considered to be a scarce resource. Moreover, people must consume food to sustain life, regardless of their occupation. Labor performed by farm workers requires an insignificant amount of fossil energy, and has no direct effect on oil imports or energy security. Including labor as an energy input results in an overestimation of the energy required to produce soybeans.

- **The study overvalues the energy inputs for soybean oil.** Biodiesel production results in three products: the soybean oil used for biodiesel, glycerin, and soybean meal that is used primarily for animal feed. None of the energy used for producing the meal should be included in the energy balance calculations for biodiesel. While soybeans are approximately 80% protein meal and 20% oil, the study allocates 79% of the energy inputs for growing soybeans to the oil. Other studies have allocated a much greater amount of energy to the production of soybean meal, which would lower the amount of energy needed to produce soybean oil.

- **The study does not acknowledge that producing biodiesel also results in the production of glycerin**, a highly valued product used in pharmaceuticals, soaps, and other products. To be accurate, biodiesel's energy balance should have been credited for the glycerin co-product.

- **The study overestimates the energy requirements for secondary inputs, such as steel and cement.** It is unusual for a life cycle study to include the energy used to manufacture construction materials for biodiesel plants and farm equipment. While most researchers recognize that there is energy embodied in these materials, the amount is generally viewed as insignificant. Perhaps the reason this study reports unusually high values for these secondary inputs is that it uses a 1979 study to derive energy estimates for the energy required to manufacture construction materials and farm equipment. The U.S. manufacturing sector has increased energy efficiency dramatically over the past 25 years. There is no comparison between modern production facilities and farm equipment today and those constructed in 1979.

- Pimentel erroneously reports that the USDA/DOE life cycle study concluded that the net energy balance of biodiesel was negative. The Pimentel study misrepresents the 1998 joint study by U.S. researchers from the Department of Energy and U.S. Department of Agriculture. The study actually concluded that biodiesel made from soybean oil resulted in an energy savings of more than 3 to 1. This study can be found at www.nrel.gov/docs/legosti/fy98/24089.pdf. It is the prevailing study cited for biodiesel's positive energy balance, so it is difficult to understand how it could be misrepresented in a peer reviewed journal article.