Analysis of "Comparative LCA of Biodiesel and Fossil Diesel Fuel" by Ceuterick and Spirinckx

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The paper "Comparison of LCA and external-cost analysis for biodiesel and diesel" by L. DeNocker and C. Spirinckx was presented at the EPA-sponsored International Conference and Exhibition on Life Cycle Assessment on April 25-27, 2000. The paper presented brief summaries of two studies that compared biodiesel with petroleum-based diesel fuel using Life Cycle Assessment (LCA) approaches. One study was based on a traditional LCA approach and was documented in a report issued in April 1997 ("Comparative LCA of Biodiesel and Fossil Diesel Fuel" by D. Ceuterick and C. Spirinckx). A full report on the second study, which used *external costs analysis*, is in the process of being written and is not available. The studies were conducted at VITO, the Flemish Institute for Technological Research and sponsored by the Belgian Office for Scientific, Technical, and Cultural Affairs and the European Commission.

The DeNocker and Spirinckx paper was mentioned in the "Daily Report for Executives" which provided the following summary of the paper's conclusions:

"… biodiesel fuel causes more health and environmental problems because it created more particulate pollution, released more pollutants that promote ozone formation, generated more waste, and caused more eutrophication…"

Further,

"The benefits biodiesel fuel offers in terms of reducing greenhouse gas emissions do not justify its use in light of the other environmental damage it causes…"

These conclusions caused some consternation in the biodiesel community because they appeared to be in opposition to current thinking about biodiesel in the United States. In this document I present a discussion of the paper and related reports to identify the reasons for the discrepancies between this report and widespread opinion which holds that biodiesel provides environmental benefits.

The paper presented in April is quite brief and primarily presents the conclusions of the two studies with very little discussion of methods. Most of the critique presented here is based on the more lengthy report. However, this means the analysis focuses primarily on the traditional Life Cycle Assessment (LCA) since very little information has been published on the external cost approach.

LCA analysis is a relatively recent technique that evaluates all of the environmental impacts associated with a particulate product. It is sometimes known as a "cradle to grave" analysis since the impacts associated with all aspects of the product are included such as raw material extraction and refining, manufacturing, transportation, actual use, and disposal.

LCA analysis is challenging not only because it requires large amounts of information, but also because it attempts to combine disparate quantities in ways that require considerable explanation and interpretation. For example, an LCA study may examine the energy consumption of a product and combine energy inputs as different as electricity produced by a nuclear power plant, heat provided locally by burning natural gas, and the power from a diesel fuel-powered truck which transports the product to market. Some energy sources, such as solar heat, are considered to be available at no cost and with no environmental impact and are therefore often excluded from the analysis. To give meaning to the impacts calculated from the LCA analysis, two approaches are used. One approach is to *normalize* the impact by dividing it by the total impact for an entire region to give a relative significance. The other approach attempts to combine the impacts into a single number by assigning a *valuation* to each impact that can be summed with other unrelated impacts. This approach gives very simple final results but the assignment of the valuations is extremely subjective. Both approaches were used in this study.

Figure 0.1 shows a comparison of the environmental profiles developed for biodiesel and diesel fuel. The fuel with the highest impact is shown as representing 100% and the impact of the other fuel is shown as a percentage of that value. As can be seen, biodiesel had less impact in only two of the nine categories considered, Fossil Fuels and Greenhouse Effect. The biodiesel advantage in the Fossil Fuels category was a

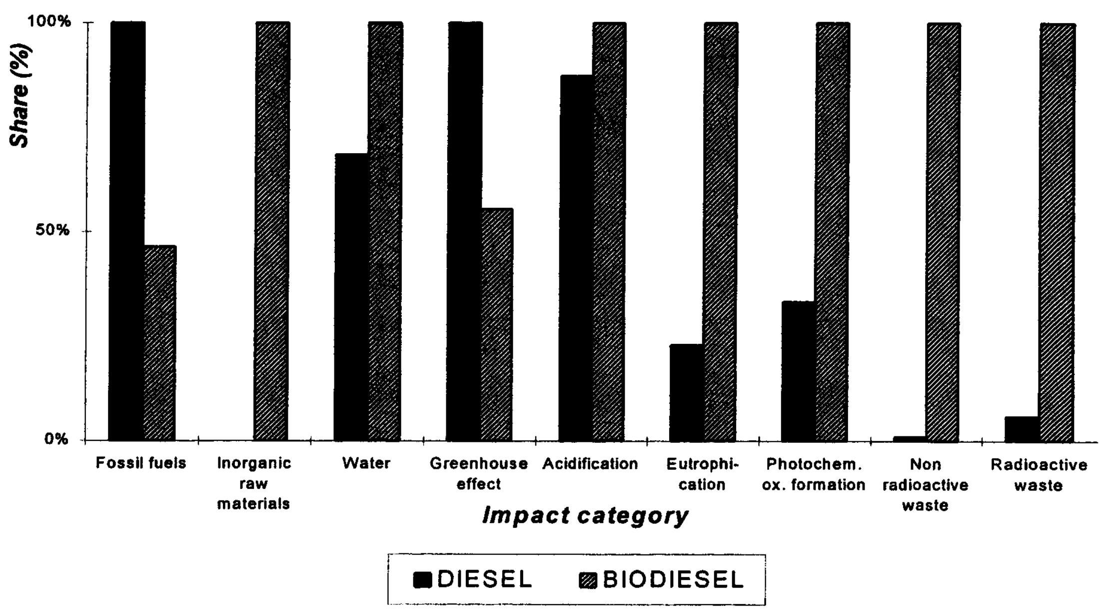

Figure 0.1: Comparison of the two environmental profiles

(Right-hand bars show biodiesel share and left hand bars show diesel share) recognition that biodiesel has a positive energy balance and provides more energy than is contained in the fossil fuels used to produce it. This advantage carries through to the Greenhouse Effect category where biodiesel is only assessed the CO_2 emissions associated with the fossil fuel required to produce it since the CO_2 released when the biodiesel burns was originally extracted from the atmosphere.

Assumptions in LCA Methodology

The traditional LCA methodology requires precise specification of the scenario on which the LCA is based. In this case, the analysis is based on agricultural cultivation of winter rapeseed in Belgium. Any generalization of results beyond this scope must be done very carefully to be sure that conditions are the same. In fact, this appears to be the primary reason the authors have produced results that are different from those found in similar studies conducted in the United States. Although the biodiesel produced from rapeseed in Europe is similar to soybean oil-based biodiesel produced in the U.S., the cultivation of the two crops is very different. The Flemish study assumed that the following amounts of fertilizer must be applied to maintain a steady state nutrient balance in the soil.

N	200 kg/hectare
P_2O_5	70 kg/hectare
K_2O	130 kg/hectare
MgO	80 kg/hectare
CaO	500 kg/hectare

These fertilizer applications rates were said to be based on recommendations from CETIOM and AVEVE, the French and Belgian Farmer's Associations, respectively.

The LCA published by the National Renewable Energy Laboratory (NREL) in May 1998 ("Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus," by Sheehan et al.) noted that soybeans require little, if any, nitrogen fertilizer since they can fix nitrogen from the atmosphere. That study used the following assumptions for fertilizer application on soybeans (based on a 14 state average – Sheehan et al., p. 101):

N	11.1 kg/hectare
P_2O_5	34.8 kg/hectare
K_2O	59.3 kg/hectare

It is clear that the Flemish study assumed much higher levels of fertilizer application than would be common practice for soybean cultivation in the United States. This is especially true for nitrogen, which was assumed to be applied to rapeseed in Belgium at 18 times the average rate at which it is applied to soybeans in the U.S. As will be discussed below, this great disparity in fertilizer application rates is the primary factor for the negative conclusions about the environmental impact of biodiesel in Belgium.

Each of the 9 categories considered for environmental impact in the LCA is discussed below.

Fossil Fuels: The study by Ceuterick and Spirinckx indicated that the fossil fuel consumption to produce biodiesel was only 45% that of diesel fuel. Most of this fossil fuel input for biodiesel is due to the natural gas required for methanol production and fertilizer production. The fraction of fossil fuel required to produce biodiesel will improve further if appropriate fertilizer application rates for soybeans are used.

Inorganic Raw Materials: According to the Flemish study this category consists primarily of the mineral feedstocks for fertilizer production including phosphate rock, sylvinite (for potassium), kieserite (for magnesium), and limestone. If fertilizer application rates were cut back to U.S. levels for soybeans, the impact of this category would be much smaller.

Water: The two major areas cited by Ceuterick and Spirinckx for the higher water consumption associated with biodiesel production were the esterification process with methanol and the production of chemical fertilizers. Most of the water used during esterification is for washing the product to remove soap and catalyst. Some U.S. producers, including Proctor and Gamble, probably the largest, have developed water-less techniques for removing soap. Again, if fertilizer application rates were cut back, the second major source would also be reduced.

Greenhouse Effect: The greenhouse effect calculated for biodiesel was only 55% that for diesel fuel. This biodiesel advantage was primarily attributable to the fact that rapeseed assimilates CO_2 as it grows. This effect should track the fossil fuel impact fairly closely and if the fossil fuel required to produce biodiesel decreases due to lower fertilizer usage, then biodiesel's contribution to the greenhouse effect should decrease proportionately.

Acidification: Ceuterick and Spirinckx state that "acidification is mainly caused by nitrogen and sulphur oxides and ammonia which are released during the growing of the rapeseed." Reducing fertilizer rates would reduce this contribution so that biodiesel's contribution to acidification would be less than diesel fuel's. About a third of the acidification is attributed to the NOx emissions from the tailpipe of the diesel engine which burns the fuels. The authors assumed that diesel fuel only contributed about 70% as much as biodiesel in this category. While this is substantially above the amount that found in the Tier 1 Health Effects study conducted by NBB, the dominant term is still associated with the fertilizer rate.

Eutrophication: Eutrophication refers to the excessive growth of algae in surface water due to nitrate and phosphate fertilizer runoff. The decay of the algae depletes oxygen from the water and renders it unsuitable for other organisms. The impact of this problem should be reduced at least in proportion to the reduction in fertilizer application rates. This factor was identified by Ceuterick and Spirinckx as having the most significant impact using both the normalization and valuation approaches. With U.S. fertilizer rates, it should be a non-issue. A further concern with the approach used by Ceuterick and Spirinckx is that it does not take into account any substitution effects. For example, widespread use of biodiesel will have the greatest impact on the split between corn and soybeans planted each year. If more acres are planted to soybeans to meet biodiesel demand instead of corn, which requires larger amounts of nitrogen, nitrate runoff would be reduced and eutrophication could actually decrease. These effects require complex economic models to predict and were beyond the scope of the Flemish study. However, since eutrophication seems to be the single largest impact of biodiesel production identified by their study, further analysis and inclusion of this effect is certainly justified.

Photochemical oxidants formation: This category comes primarily from volatile organic compounds that are released during the production of biodiesel. A major source of these is the hexane released by solvent-based oil extraction plants. This category was also identified as an area of concern by the NREL study (Sheehan et al.). Recent developments in extraction technology have reportedly reduced these emissions.

Nonradioactive wastes: Non radioactive wastes consists primarily of gypsum which is a by-product of the production of phosphate fertilizer. Lower fertilizer application rates would reduce this impact proportionately. The NREL study (Sheehan et al.) found that biodiesel production generated only 5% as much hazardous waste as diesel fuel.

Radioactive waste: As mentioned earlier, this impact is primarily due to radioactive waste from nuclear power plants. When a product requires more electricity it is charged with a higher level of radioactive waste since a large fraction of the electricity in Europe is produced in nuclear plants (France is over 80%!). Much of the higher electricity input is from fertilizer production, which will be lower in the U.S. In addition, the U.S. derives a lower fraction of its power from nuclear sources than Europe. The contribution of this category would be much lower if it were based on the percentage of U.S. nuclear-derived electricity.

<u>Normalization and Valuation</u>

To normalize their LCA data, the authors divided the fuel-based environmental impact of seven of the nine categories considered by the total nation-wide impact of that category. Insufficient data were available for the other two categories to do the calculation. This process showed that biodiesel production contributed more to eutrophication and photochemical oxidants formation than the other categories. However, this calculation does not show that the contribution is significant or that the entire category describes a serious problem. It is only a technique for comparing the relative contribution of one category against another.

To develop a single number for comparison of biodiesel with diesel fuel, the authors applied weighting factors to 4 of the 9 categories and summed their contributions. The authors were unable to identify weighting factors for the other categories so they were excluded. The greenhouse effect and photochemical oxidants formation were weighted the same, eutrophication was weighted twice as high and acidification was weighted twice that amount. By this comparison, biodiesel was found to have twice the environmental impact of diesel fuel. The authors acknowledged that choosing the weighting factors was arbitrary and is likely to vary from country to country and may depend on political views. They presented an example showing how they could include the fossil fuels category with an appropriate weighting factor and biodiesel would actually have less impact than diesel fuel.

Particulate Emissions

The statements made in media reports that the Flemish study concluded that biodiesel caused more health and environmental problems because it creates more particulate pollution appear to be misinterpretation of what was actually written. In their discussion of the External Cost Analysis, DeNocker and Spirinckx stated that for both diesel fuel and biodiesel, the most important external cost category was from particulate emissions. However, no numbers are given and the contribution of particulates to the external costs shown in Figure 6 of their paper is smaller for biodiesel than for diesel fuel. The authors state that their analysis did not include any differences in the health impact of the particulates from the two fuels. Recent Tier 2 Health Effects data collected by NBB, if included, would increase the apparent advantage of biodiesel in this category.

Conclusions

There is no reason to question the scientific validity of the study. The authors have conducted their study appropriately and reported its findings in a professional manner without apparent bias. However, due to the assumptions made in the LCA analysis, the findings of the study appear to be limited to biodiesel produced from Belgian rapeseed. Extension of these results to the United States with its biodiesel production based on soybeans (or yellow grease) is not appropriate and would give incorrect conclusions.

Since the report by Ceuterick and spirinckx was published, additional information on biodiesel emissions (Tier 1 and Tier 2 Health Effects reports) and Life Cycle Analysis (NREL LCA study, May 1998) has become available. These data, if incorporated into the External Costs Analysis, should show substantial environmental benefits for biodiesel.

The most authoritative reference for LCA data applicable to the U.S. is the NREL study. This study is based on biodiesel produced from soybeans in the United States and showed significant environmental benefits accruing from its use.