Lifecycle Summary

In May of 1998, the US Department of Energy (DOE) and US Department of Agriculture (USDA) published the results of the Biodiesel Lifecycle Inventory Study. It compared findings for a comprehensive "cradle to grave" inventory of materials used; energy resources consumed; and air, water and solid waste emissions generated by petroleum diesel fuels and biodiesel in order to compare the total "lifecycle" costs and benefits of each of the fuels. This 3.5-year study followed US Environmental Protection Agency (EPA) and private industry approved protocols for conducting this type of research.

In evaluating the results of the Lifecycle Inventory Study several caveats need to be noted. First, the study was not designed to present conclusions on the appropriate policies to promote the use of biodiesel. Instead, the study was designed to provide policy makers with comparative information that they could use to formulate appropriate policies regarding biodiesel. Second, the study does not provide any economic comparisons or valuations based on current market prices for the two fuels. Third, the study generally assumes that the comparative lifecycle benefits or costs of biodiesel and diesel fuel are *proportional* when biodiesel and diesel fuel are blended into one fuel, as in the popular 20% biodiesel/80% diesel blend known as B20.

With these caveats in mind, the major findings of the study are:

- The total energy efficiency ratio (ie. total fuel energy/total energy used in production, manufacture, transportation, and distribution) for diesel fuel and biodiesel are 83.28% for diesel vs 80.55% for biodiesel. The report notes: "Biodiesel and petroleum diesel have very similar energy efficiencies."

- The total *fossil* energy efficiency ratio (ie. total fuel energy/total fossil energy used in production, manufacture, transportation, and distribution) for diesel fuel and biodiesel shows that *biodiesel is four times as efficient as diesel fuel in utilizing fossil energy* – 3.215 for biodiesel vs 0.8337% for diesel. The study notes: "In terms of effective use of fossil energy resources, biodiesel yields around 3.2 units of fuel product for every unit of fossil energy consumed in the lifecycle. By contrast, petroleum diesel's life cycle yields only 0.83 units of fuel product per unit of fossil energy consumed. Such measures confirm the 'renewable' nature of biodiesel." The report also notes: "On the basis of fossil energy inputs, biodiesel enhances the effective utilization of this finite energy source."

- In urban bus engines, *biodiesel and B20 exhibit similar fuel economy to diesel fuel,* based on a comparison of the volumetric energy density of the two fuels. The study explains, "Generally fuel consumption is proportional to the volumetric energy density of the fuel based on lower or net heating value. ..{D}iesel contains about 131,295 Btu/gal while biodiesel contains approximately 117,093

Btu/gal. The ratio is 0.892. If biodiesel has no impact on engine efficiency, volumetric fuel economy would be approximately 1 0% lower for biodiesel compared to petroleum diesel. However, fuel efficiency and fuel economy of biodiesel tend to be only 2%-3% less than #2 diesel."

- The overall lifecycle emissions of *carbon dioxide* (a major greenhouse gas) from biodiesel are 78% lower than the overall carbon dioxide emissions from petroleum diesel. "The reduction is a direct result of carbon recycling in soybean plants," notes the study.

*The overall lifecycle emissions of *carbon monoxide (* a poisonous gas and a contributing factor in the localized formation of smog and ozone) from biodiesel are 35% lower than overall carbon monoxide emissions from diesel. Biodiesel also reduces bus tailpipe emissions of carbon monoxide by 46%. The study observes, "Biodiesel could, therefore, be an effective tool for mitigating CO in EPA's designated CO non-attainment areas."

*The overall lifecycle emissions of *particulate matter* (recognized as a contributing factor in respiratory disease) from biodiesel are 32% lower than overall particulate matter emissions from diesel. Bus tailpipe emissions of PM1 0 are 68% lower for biodiesel compared to petroleum diesel. The study notes, 'PM10 emitted from mobile sources is a major EPA target because of its role in respiratory disease. Urban areas represent the greatest risk in terms of numbers of people exposed and level of PM 1 0 present. Use of biodiesel in urban buses is potentially a viable option for controlling both life cycle emissions of total particulate matter and tailpipe emission of PM1 O."

The study also finds that biodiesel reduces the total amount of *particulate matter soot* in bus tailpipe exhaust by 83.6%. Soot is the heavy black smoke portion of the exhaust that is essentially 100% carbon that forms as a result of pyrolysis reactions during fuel combustion. The study notes there is on-going research to discover the relationship between exposure to diesel soot and cancerous growths in mice. Beyond the potential public health benefit from substantially reduced soot emissions, the study also notes: [T]here is an aesthetic benefit associated with significantly less visible smoke observed from the tailpipe. For urban bus operators, this translates into improved public relations."

*The overall lifecycle emissions of *sulfur oxides* (major components of acid rain) from biodiesel are 8% lower than overall sulfur oxides emissions from diesel. Biodiesel *completely eliminates* emissions of sulfur oxides from bus tailpipe emissions. The study notes, "Biodiesel can eliminate sulfur oxides emissions because it is sulfur-free."

* The overall lifecycle emissions of *methane* (one of the most potent greenhouse gases) from biodiesel are almost 3.0% lower than overall methane emissions from

diesel. The study notes, "Though the reductions achieved with biodiesel are small, they could be significant when estimated on the basis of its 'CO2 equivalent'-warming potential."

* The overall lifecycle emissions of *nitrogen oxides* (a contributing factor in the localized formation of smog and ozone) from biodiesel are 13% greater than overall nitrogen oxide emissions from diesel. An urban bus that runs on biodiesel has tailpipe emissions that are *only* 8.89% higher than a bus operated on petroleum diesel. The study also notes: "Smaller changes in NOx emissions for BIOO and B20 have been observed in current research programs on new model engines but it is still to early to predict whether all or just a few future engines will display this characteristic." and "... (S)olutions are potentially achievable that meet tougher future (vehicle) standards for NOx without sacrificing the other benefits of this fuel."

* The bus tailpipe emissions of *hydrocarbons* (a contributing factor in the localized formation of smog and ozone) are 37% lower for biodiesel than diesel fuel. However, the overall lifecycle emissions of hydrocarbons from biodiesel are 35% greater than overall hydrocarbon emissions from diesel. The study notes, 'In understanding the implications of higher lifecycle emissions, it is important to remember that emissions of hydrocarbons, as with all of the air pollutants discussed, have localized effects. In other words it makes a difference where these emissions occur. The fact that biodiesel's hydrocarbon emissions at the tailpipe are lower may mean that the biodiesel life cycle has beneficial effects on urban area pollution."

The study also cautions about drawing hard conclusions related to the total life cycle emissions of hydrocarbons from sources other than the engine tailpipe: "We have less confidence in the hydrocarbon air emissions results from this study. ...Our data set includes numbers reported as "unspecified hydrocarbons" and as "non-methane hydrocarbons'(NMHC). Given these kinds of ambiguities in the data, results on hydrocarbon emissions need to be viewed with caution."

* The overall lifecycle production of *wastewater* from biodiesel is 79.0% lower than overall production of wastewater from diesel. The study notes, 'Petroleum diesel generates roughly five times as much wastewater flow as biodiesel.'

The overall lifecycle production of *hazardous solid wastes* from biodiesel is 96% lower than overall production of hazardous solid wastes from diesel. However, the overall life cycle production of *non-hazardous solid wastes* from biodiesel is twice as great as the production of non-hazardous solid wastes from diesel. The study notes: "Given the more severe impact of hazardous versus non-hazardous waste disposal, this is a reasonable trade-off."